TESIS- SF185401

SELEKSI KANAL KUANTUM BAGI TELEPORTASI KUANTUM 2 ARAH DENGAN METODE TENSOR

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QUANTUM CHANNEL SELECTION OF BIDIRECTIONAL QUANTUM TELEPORTATION USING TENSOR METHODS.

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INSTITUT TEKNOLOGI SEPULUH NOPEMBER
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Tesis disusun untuk memenuhi salah satu syarat memperoleh gelar

Magister Sains (M.Si)

di

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Oleh

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SELEKSI KANAL KUANTUM BAGI TELEPORTASI KUANTUM 2 ARAH DENGAN METODE TENSOR

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ABSTRAK

Teleportasi kuantum merupakan proses pengiriman suatu informasi kepada penerima dengan menggunakan prinsip-prinsip kuantum khususnya dalam keterbelitan, secara umum teleportasi kuantum saat ini telah berkembang pesat baik secara teoritis maupun secara ekperimen. Dalam penelitian ini, pengiriman informasi qubit tunggal dilakukan dengan dua arah pengiriman melalui saluran kanal qubit rangkap 4 melalui metode tensor. Selanjutnya diperoleh bahwa tidak semua kanal qubit rangkap 4 dapat mengirimkan informasi secara dua arah dan ada kriteria khusus kanal yang dapat mengirimkan informasi pada teleportasi kuantum dua arah diantaranya adalah untuk pengukuran menggunakan basis Bell kanal teleportasi kuantum dua arah dapat dibentuk dengan menggunakan matriks parameter kanal kuantum $\boldsymbol{R}$, matriks ini merupakan perkalian tensor matriks uniter berukuran 2x2 yang diturunkan dari transformasi hasil Alice dan Bob selanjutnya matriksnya dikalikan dengan hasil perkalian tensor matriks transformasi T^{θ}dan T^{τ}.

Kata Kunci : Teleportasi Kuantum, Teleportasi Kuantum Dua Arah, Matriks Parameter Kanal, Matriks Transformasi, Pengukuran Basis Bell, Metode Tensor.

“Halaman in sengaja dikosongkan”

QUANTUM CHANNEL SELECTION OF BIDIRECTIONAL QUANTUM TELEPORTATION USING TENSOR METHODS

Name : Achmad Fatich al Qodri,S.Si
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ABSTRACT

Quantum teleportation is the process of sending information to the recipient using quantum principles especially in entanglement, in general, quantum teleportation is currently developing rapidly both theoretically and experimentally. In this study, the delivery of single qubit information is carried out in two directions through 4 qubit channel via the tensor method. Furthermore, it was found that not all 4 qubit channel can transmit information in two directions and there are special criteria for channels that can transmit information in two-way quantum teleportation including those for measurement using Bell basis bidirectional quantum teleportation channels can be formed using matrix parameters channels (R), this matrix is direct product of 2x2 unitary matrix derived from the transformation of Alice and Bob results then the matrix is multiplied by the results of the tensor multiplication matrix transformation T^{θ} and T^{τ}

keywords : Quantum Teleportation, Bidirectional Quantum Teleportation, Channel Parameter Matrix, Transformation matrix, measurement, Bell Base, Tensor Method.

“Halaman in sengaja dikosongkan”

KATA PENGANTAR

Segala puji syukur penulis haturkan kehadirat Allah SWt yang telah melimpahkan rahmat serta hidayah-Nya, sehingga dapat menyelesaikan Tesis dengan judul

SELEKSI KANAL KUANTUM BAGI TELEPORTASI KUANTUM 2 ARAH DENGAN METODE TENSOR

Terselesaikannya tesis ini tidak lepas dari bantuan, dukungan dan doa dari banyak pihak yang sangat besar artinya bagi penulis. Penulis mengucapkan terimakasih yang sebesar-besarnya kepada:

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Penulis menyadari bahwa tesis ini masih jauh dari kriteria sempurna. Oleh karena itu, penulis mengharapkan kitik dan saran yang membangun guna kesempurnaan tesis ini. Semoga tesis ini bermanfaat bagi pihak-pihak yang berkepentingan serta dapat menjadi sumbangan bagi almamater tercinta.

Surabaya, Januari 2020

Penulis

DAFTAR ISI

DAFTAR GAMBAR

"Halaman in sengaja dikosongkan"

DAFTAR TABEL

“Halaman in sengaja dikosongkan”

BAB I
PENDAHULUAN

1.1 Latar Belakang

Teleportasi kuantum merupakan proses pengiriman informasi kuantum dari suatu tempat ke tempat lain dengan dibantu komunikasi secara klasik dan memanfaatkan keadaan keterbelitan sebagai cara pengiriman dan penerimaan informasinya. Keterbelitan merupakan fenomena unik yang muncul dari keraguan Albert Einstein, Boris Podolsky, dan Nathan Rosen (EPR) pada kesempurnaan perumusan mekanika kuantum yang tidak memenuhi dua prinsip yaitu elemen realitas dan lokalitas yang dikenal dengan paradoks EPR (Einstein dkk,1935).

Pada tahun 1993, Benneth dkk melakukan penelitian secara teoritik tentang teleportasi kuantum yang selanjutnya mengawali peneliti lain dalam mengembangkan teleportasi kuantum lebih jauh. Benneth dkk, memanfaatkan fenomena partikel dalam keadaan terbelit (Einstein dkk,1935). Dua atau lebih partikel dalam keadaan terbelit digunakan dalam sistem teleportasi kuantum sebagai saluran (kanal) kuantum, keadaan inilah yang selanjutnya disebut sebagai sumber EPR. Dalam teleportasi kuantum ini dimungkinkan pengiriman informasi berupa keadaan kuantum dan pengiriman (misalkan partikel qubit pertama) dari Alice ke Bob. Dengan memanfaatkan dua partikel terbelit sebagai saluran informasi dengan keadaan partikel kedua dimiliki Alice dan partikel ketiga adalah milik Bob., selanjutnya ini memungkinkan keadaan informasi kuantum yang dikirim Alice ke Bob direkonstruksi ulang oleh Bob dengan cara menginteraksikan partikel pertama dengan partikel milik Alice pada saluran informasi. Hasil dari pengukuran Alice selanjutnya dikirimkan ke Bob dengan menggunakan komunikasi secara klasik, sehingga Bob akan memproses semua hasil yang diterima dengan sesuai arahan dari Alice.

Secara Eksperimen, desain teleportasi kuantum telah diawali oleh Beuwmeester dkk. Dalam skala laboratorium, eksperimen dari Beuwmeester ini merujuk pada penelitian Benneth, dan dalam penelitian Bouwmester dkk menghasilkan sumber EPR menggunakan teknik konversi bawah parametrik (*parametric down conversion/PDC*) tipe II. Teknik ini menggunakan foton dari laser yang dilewatkan pada kristal non linier. Setelah foton melewati kristal non linier tersebut, terbentuklah dua foton dalam keadaan terbelit yang dinamakan dengan foton 2 dan foton 3. Selain kedua foton tersebut yang dihasilkan, terdapat dua berkas pantulan foton. Pantulan pertama digunakan sebagai foton 1, yaitu foton yang akan diteleportasikan, sedangkan pantulan kedua digunakan sebagai pemicu (foton 4) yang menandakan foton 1 telah terbentuk(Beuwmeester dkk, 1997).

Teleportasi kuantum saat ini telah mengalami perkembangan yang pesat, pengiriman dalam teleportasi yang awalnya satu qubit informasi digunakan saluran 2 qubit, saat ini telah banyak variasi dalam pengiriman satu qubit informasi bisa digunakan 3 qubit dll. Tidak hanya dibidang teori saja, dalam bidang eksperimen tentang teleportasi kuantum juga mengalami perkembangan pesat. Pada tahun 1997, eksperimen teleportasi kuantum tercatat dengan menggunakan keterbelitan dari foton. Selanjutnya dari sisi jarak pengirimannya pun saat ini telah tercatat pengiriman dengan jarak 100 Km.

Teleportasi kuantum dengan menggunakan pengontrol yang diajukan oleh Karlsson dan Bourennane pada tahun 1993 membawa perkembangan dalam pengiriman informasi dengan teleportasi kuantum yang semakin variatif, dengan adanya pengontrol tentunya beban pengirim dan penerima menjadi lebih ringan.

Pada tahun 2013, Zha dkk mengajukan penelitian dengan menteleportasikan informasi dengan kontrol dan bersifat dupleks (Zha,2013). Alice yang awalnya hanya sebagai pengirim juga bertugas sebagai penerima dari Bob, begitu pula Bob. Zha dkk menggunakan 5 qubit saluran keadaan gugus (Zha,2013) , dan di tahun yang sama diajukan Teleportasi kuantum dengan menggunakan saluran 6 qubit keadaan gugus (Yan dkk,2013), 6 qubit keadaan terbelit umum (Shukla dkk,2013), qubit dan juga 8 qubit saluran (Lie dkk,2013).

Dengan adanya dua arah teleportasi kuantum dengan kontrol maka teleportasi kuantum dua arah tanpa adanya pengontrol juga perlu untuk diteliti. Pada tahun 2014, Fu dkk mengajukan skema dua arah teleportasi kuantum menggunakan saluran 4 qubit keadaan gugus. Namun belum dilakukan penelitian macam-macam saluran yang dapat digunakan dalam pengiriman 1 qubit informasi secara dua arah teleportasi kuantum (Fu,2016).

Dalam penelitian ini digunakan metode tensor untuk mencari macam-macam kanal yang dapat digunakan dalam teleportasi kuantum dua arah dengan 1 qubit informasi dari Alice dan 1 informasi dari Bob dengan menggunakan kanal terbelit kuantum rangkap 4, dimana penelitian ini lebih difokuskan untuk **" Seleksi Kanal Kuantum bagi Teleportasi Kuantum Dua Arah dengan Menggunakan Metode Tensor"**.

1.2 Rumusan Masalah

1. Bagaimana perumusan umum bagi kanal yang diizinkan dalam teleportasi kuantum dua arah melalui pendekatan representasi tensor?

1.3 Tujuan Penelitian

1. Mengetahui kriteria kanal yang dapat digunakan pada teleportasi kuantum dua arah.

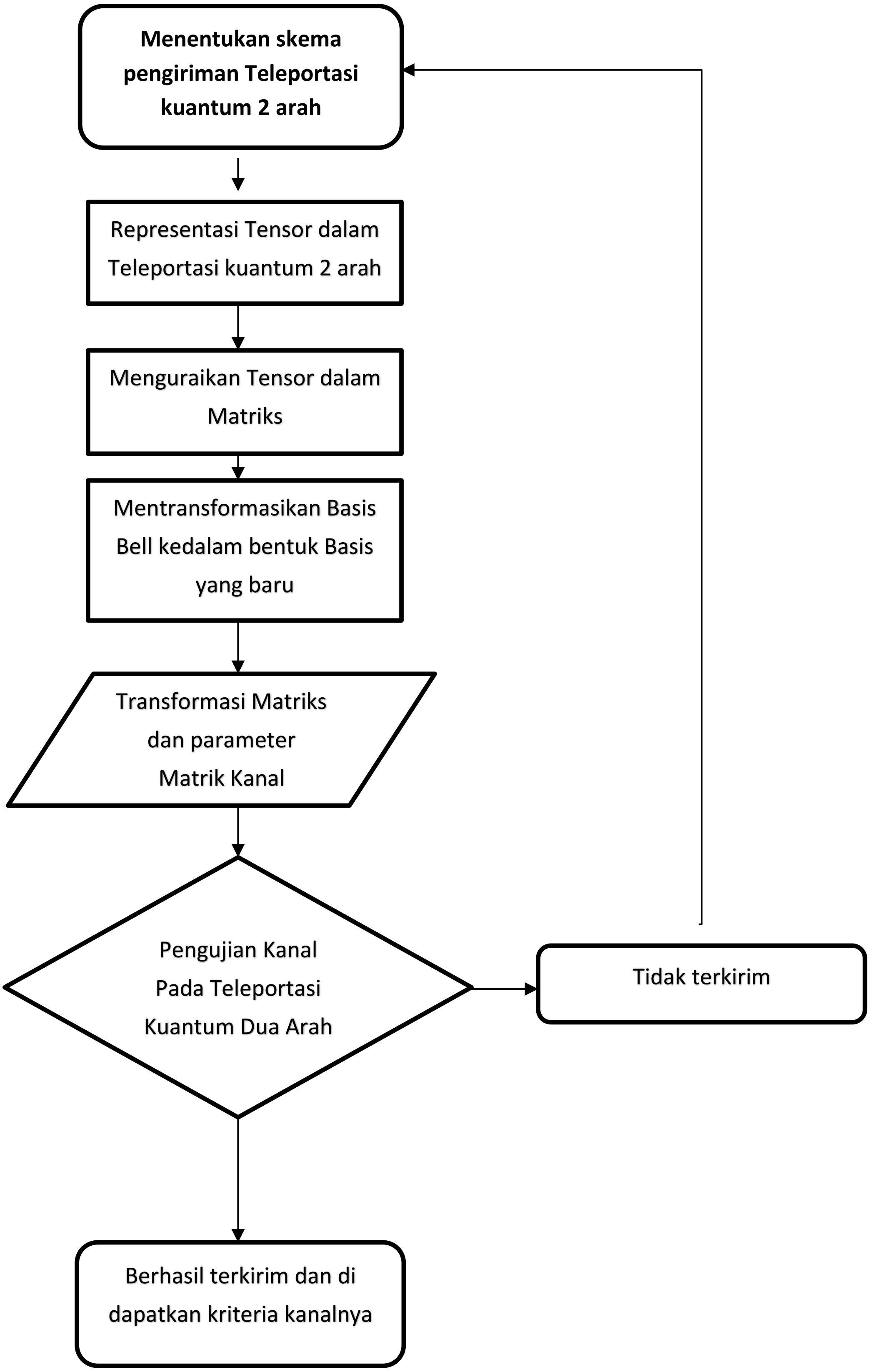
1.4 Manfaat Penelitian

1. Memperoleh gambaran lebih spesifik teleportasi kuantum 2-arah pada qubit yang lebih tinggi.

1.5 Batasan Masalah

1. Teleportasi kuantum dua arah ini hanya menggunakan 1 qubit informasi dari pengirim Alice dan 1 qubit informasi dari pengirim Bob.
2. Saluran yang digunakan adalah saluran yang terbelit dengan qubit rangkap 4 (empat).

1.6 Metodologi Penelitian



BAB II
TINJAUAN PUSTAKA

2.1 Paradoks EPR

Albert Einstein, Boris Podolsky, dan Nathan Rosen mengajukan suatu eksperimen Gedanken untuk menunjukkan bahwa keadaan terbelit melanggar aksioma dari teori relativitas khusus. Misalkan partikel memproduksi pasangan keadaan yang kita sebut sebagai EPR sebagai berikut,

$$|\phi\rangle_4 = \frac{1}{\sqrt{2}}\left(|01\rangle - |10\rangle\right) \tag{2.1}$$

Dengan satu partikel di kirim ke Alice sedangkan satu lagi di kirimkan ke Bob, selanjutnya mereka dipisahkan dengan jarak yang jauh. Alice mengukur partikelnya dan mendapatkan hasil bahwa partikelnya adalah $|0\rangle$ atau $|1\rangle$. Bergantung pada hasil pengamatannya, keadaan EPR digambarkan dengan $|01\rangle(|10\rangle)$, dan Bob akan memastikan hasil pengamatannya $|1\rangle$ $|0\rangle$ dalam hasil pengukurannya. Keadaannya berubah dari,

$$\frac{1}{\sqrt{2}}\left(|01\rangle - |10\rangle\right) \;\rightarrow\; \left(|01\rangle\ atau\ |10\rangle\right) \tag{2.2}$$

Secara sekejap saat mereka dipisahkan dengan jarak yang jauh. Hal ini seakan-akan pengukuran Alice menyebar pada qubit Bob secara sekejap. Dan teori relativitas khusus terlanggar. Inilah yang digunakan oleh mereka untuk menggambarkan kelemahan dari teori mekanika kuantum.

Perhatikan bahwa penyebaran dari Alice kepada Bob dan begitupun sebaliknya tidak terjadi sampai Alice melakukan pengukuran. Sehingga jelas bahwa tak ada energi yang tersebar. Sedangkan untuk informasi Alice tidak mungkin dikontrol oleh Alice dan begitupun sebaliknya. Untuk itu tak mungkin menggunakan pasangan EPR untuk mengirim pesan rahasia dari Alice ke Bob. Jika pengiriman ini terjadi secara sekejap, maka jelas akan melanggar dari teori relativitas khusus. Jika suatu jumlah besar pasangan EPR telah terkirim untuk Alice dan Bob maka selanjutnya Alice dan Bob secara bebas mengukur qubitnya masing-masing. Mereka akan mengamati keadaan acak dari 0 dan 1. Mereka menggaris bawahi untuk hasil ini hanya dapat dihubungkan secara cepat jika telah terjadi komunikasi secara klasik antara mereka. Sehingga ini tidak dapat melebihi kecepatan dari cahaya.

Macam-macam dari keadaan EPR atau yang biasa disebut sebagai keadaan Bell , adalah

$$|\phi\rangle_{mn}^{1} = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)_{mn} \tag{2.3}$$

$$|\phi\rangle_{mn}^{2} = \frac{1}{\sqrt{2}}(|00\rangle - |11\rangle)_{mn} \tag{2.4}$$

$$|\phi\rangle_{mn}^{1} = \frac{1}{\sqrt{2}}(|01\rangle + |10\rangle)_{mn} \tag{2.5}$$

$$|\phi\rangle_{mn}^{1} = \frac{1}{\sqrt{2}}(|01\rangle - |10\rangle)_{mn} \tag{2.6}$$

Merupakan keadaan terbelit maksimal pada 2 qubit dan terjadi dari kombinasi linier dua keadaan superposisi antara keadaan 0 dan 1.

2.2 Teorema tanpa Kloning

Dalam komputasi dan informasi klasik, penyalinan informasi bukanlah merupakan suatu hal yang baru. Hal tersebut sudah menjadi bagian dari kehidupan sehari-hari. Namun bagaimana dengan komputasi dan informasi kuantum, apakah bisa menyalin keadaan kuantum. Tentu untuk menciptakan hal tersebut harus terdapat suatu operator uniter yang mampu mengkloning semua keadaan kuantum. Misalkan operator uniter tersebut adalah U dan untuk setiap keadaan $|\eta\rangle$ maka didefinisikan

$$U|\eta 0\rangle = |\eta\eta\rangle \tag{2.7}$$

Apabila terdapat dua buah keadaan $|\varphi\rangle$ dan $|\phi\rangle$ yang mana keadaan tersebut saling linear independent. Maka sesuai dengan definisi di atas $U|\varphi 0\rangle = |\varphi\varphi\rangle$ dan $U|\phi 0\rangle = |\phi\phi\rangle$. Apabila kombinasi linier dari keadaan $|\varphi\rangle$ dan $|\phi\rangle$ adalah $|\psi\rangle = \frac{1}{\sqrt{2}}(|\varphi\rangle + |\phi\rangle)$ maka dapat dituliskan

$$\begin{aligned} U|\psi 0\rangle &= \frac{1}{\sqrt{2}}(U|\varphi 0\rangle + U|\phi 0\rangle) \\ &= (|\varphi\varphi\rangle + |\phi\phi\rangle) \end{aligned} \tag{2.8}$$

Dikarenakan U adalah operator uniter yang mampu mengkloning semua keadaan kuantum maka,

$$\begin{aligned} U|\psi 0\rangle &= |\psi\psi\rangle \\ &= \frac{1}{2}(|\varphi\varphi\rangle + |\varphi\phi\rangle + |\phi\varphi\rangle + |\phi\phi\rangle) \end{aligned} \tag{2.9}$$

Hasil ini menunjukan kontradiksi hasil dengan perhitungan yang sebelumnya. Sehingga dapat dikatakan bahwa dalam informasi kuantum tidak mampu untuk mengkloning keadaan $|\psi\rangle$. Hal ini kemudian dikenal sebagai teorema tanpa kloning.

2.3 Keadaan Terbelit

Secara umum keadaan 2 qubit dapat dipisahkan menjadi perkalian langsung (*tensor product*) dari dua buah qubit tunggal.

$$|\psi\rangle = |\psi_0\rangle \otimes |\psi_1\rangle \tag{2.10}$$

Dengan $|\psi_0\rangle = c_0|0\rangle + c_1|1\rangle$ dan $|\psi_1\rangle = d_0|0\rangle + d_1|1\rangle$, konstanta pada keadaan tersebut adalah bilangan kompleks.

Keadaan 2 qubit yang tidak dapat dipisahkan sebagai perkalian langsung dari dua buah qubit tunggal disebut keadaan terbelit dan apabila dapat dipisahkan sebagai perkalian langsung dari dua buah qubit tunggal disebut sebagai keadaan tak terbelit (*disentangle state*) atau keadaan yang dapat dipisahkan (*separable state*). Apabila terdapat pernyataan matematis yang tidak konsisten, keadaan tersebut dapat dikatakan sebagai keadaan terbelit. Apabila terdapat keadaan

$$|\psi\rangle = \frac{1}{2}(|00\rangle + |01\rangle + |10\rangle + |11\rangle) \tag{2.11}$$

Berdasarkan pernyataan di atas dapat diketahui

$$c_0d_0 = c_0d_1 = c_1d_0 = c_1d_1 = \frac{1}{2}$$

$$\begin{aligned} c_0d_0 &= c_0d_1 & \qquad c_1d_0 &= c_1d_1 \\ \frac{d_0}{d_1} &= 1 & \qquad \frac{d_0}{d_1} &= 1 \end{aligned}$$

Karena dua persamaan matematis tersebut menunjukkan konsistensi terhadap nilai dari konstanta pada keadaan tersebut maka dapat dikatakan keadaan tersebut adalah keadaan yang terpisah. Apabila terdapat keadaan

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle) \qquad (2.12)$$

$$c_0 d_0 = c_1 d_1 = \frac{1}{\sqrt{2}}, = c_0 d_1 = c_1 d_0 = 0$$

$$c_0 d_0 = c_1 d_1 = \frac{1}{\sqrt{2}} \qquad c_1 d_0 = c_0 d_1$$

$$\frac{c_0}{c_1} = \frac{d_1}{d_0} = \frac{1}{\sqrt{2}} \qquad \frac{c_0}{c_1} = \frac{d_0}{d_1} = 0$$

Karena dua persamaan matematis tersebut menunjukkan ke tidak konsistensi terhadap nilai dari konstanta pada keadaan tersebut, maka dapat dikatakan keadaan tersebut adalah keadaan yang terbelit.

Secara umum vektor keadaan untuk *n* qubit adalah

$$|\psi\rangle = c_0 \underbrace{|0 \cdots 000\rangle}_{n} + c_1 \underbrace{|0 \cdots 001\rangle}_{n} + c_2 \underbrace{|0 \cdots 010\rangle}_{n} + \cdots + c_{2^n} \underbrace{|0 \cdots 000\rangle}_{n} \qquad (2.13)$$

Dengan koefisien komplek $c_0, c_1, c_2, \dots, c_{2^n}$ memenuhi syarat normalisasi

$$\langle\psi|\psi\rangle = |c_0|^2 + |c_1|^2 + |c_2|^2 + \cdots + |c_{2^n}|^2 = 1 \qquad (2.14)$$

Yang mempunyai $2(2^n - 1)$ derajat kebebasan. Untuk vektor keadaan n qubit keadaan, setelah dipisah menjadi perkalian langsung (*tensor product*) dari qubit tunggal adalah

$$|\psi\rangle = |\psi_0\rangle \otimes |\psi_1\rangle \otimes |\psi_2\rangle \otimes \dots \otimes |\psi_{2^n}\rangle \qquad (2.15)$$

Dengan $2n$ derajat kebebasan.

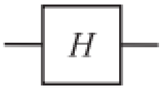
2.4 Gerbang Logika Kuantum

Gerbang logika kuantum adalah piranti yang melangsungkan operasi uniter dari qubit-qubit tertentu dalam selang waktu tertentu. Sedangkan rangkaian atau jaringan kuantum adalah piranti yang terdiri dari gerbang logika kuantum yang mempunyai langkah-langkah komputasi tersinkronisasi dalam waktu. Ukuran dari jaringan merupakan jumlah gerbang yang dimuat di dalamnya.

Gerbang paling umum adalah gerbang Hadamard (H) yang menyelenggarakan operasi uniter pada qubit tunggal $|x\rangle$ menghasilkan output $|\psi\rangle$, menurut hubungan

$$H|x\rangle = |\psi\rangle = \frac{(-1)^x|x\rangle + |1-x\rangle}{\sqrt{2}} \tag{2.16}$$

Dengan nilai x adalah 0 atau 1. Secara simbolik diberikan oleh gambar



Gambar 2.1 Simbol Gerbang Hadamard

Dalam representasi matriks, gerbang Hadamard diberikan oleh

$$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \tag{2.17}$$

Gerbang qubit tunggal lainnya adalah gerbang pergeseran fasa yang didefinisikan

$$R(\phi)|x\rangle = |\psi\rangle = e^{ix\phi}|x\rangle \tag{2.18}$$

Sedangkan representasi matriksnya diberikan oleh

$$R(\phi) = \begin{pmatrix} 1 & 0 \\ 0 & e^{i\phi} \end{pmatrix} \tag{2.19}$$

Gerbang kuantum CNOT (*controlled-NOT*) adalah gerbang qubit dua yang membalik qubit kedua yang disebut qubit target jika qubit pertama yang disebut sebagai qubit kontrol adalah $|1\rangle$, dan mempertahankan qubit kedua jika qubit pertama $|0\rangle$. Secara matematik gerbang CNOT dapat didefinisikan sebagai

$$U_{CNOT}|x\rangle|y\rangle = |x\rangle|y \oplus x\rangle \tag{2.20}$$

Dengan tanda $\oplus$ menyatakan penjumlahan modulus 2. Gerbang CNOT bekerja pada qubit dua standar $|00\rangle, |01\rangle, |10\rangle, |11\rangle$ memberikan

$$U_{CNOT}|00\rangle = |00\rangle$$
$$U_{CNOT}|01\rangle = |01\rangle$$
$$U_{CNOT}|10\rangle = |11\rangle$$
$$U_{CNOT}|11\rangle = |10\rangle$$

Sehingga representasi matriks gerbang CNOT adalah basis qubit dua standar sebagai berikut

$$\begin{aligned} U_{CNOT} &= |00\rangle\langle 00| + |01\rangle\langle 01| + |11\rangle\langle 10| + |10\rangle\langle 11| \\ &= |0\rangle\langle 0|\otimes I + |1\rangle\langle 1|\otimes X \\ &= \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix} \end{aligned} \quad (2.21)$$

Gerbang kuantum SWAP adalah gerbang qubit dua yang membalik posisi qubit kedua dengan posisi qubit pertama, sehingga yang awalnya berada diqubit pertama akan bergeser ke qubit kedua, sedangkan qubit kedua bergeser dengan posisi qubit pertama. Secara matematik gerbang SWAP dapat didefinisikan sebagai

$$U_{SWAP}|x\rangle|y\rangle = |y\rangle|x\rangle \quad (2.22)$$

Dan representasi bentuk matriks dari gerbang kuantum SWAP dapat digambarkan sebagai berikut

$$\begin{aligned} U_{CNOT} &= |00\rangle\langle 00| + |01\rangle\langle 10| + |10\rangle\langle 01| + |11\rangle\langle 11| \\ &= \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \end{aligned} \quad (2.23)$$

2.5 Pengukuran

Teori informasi klasik dirumuskan secara bebas dari pengukuran sistem yang dipertimbangkan. Ini karena pembacaan hasil selalu sama untuk siapa saja dan kapan saja, asalkan sistem memproses informasi yang sama. Ini sangatlah berbeda dengan proses pada informasi kuantum. Pengukuran adalah bagian penting dari teori yang seperti kita lihat dibawah ini.

Dengan membuat pengukuran pada sistem, kita memproyeksikan vektor keadaan untuk satu vektor basis yang didefinisikan pada peralatan pengukuran. Misalkan kita memiliki vektor keadaan $|\psi\rangle = a|0\rangle + b|1\rangle$ dan mengukurnya untuk melihat apakah ini dalam keadaan $|0\rangle$ atau $|1\rangle$. Semisal bergantung pada sistem, suatu spin atas atau spin bawah atau foton dipolarisasi secara horisontal atau vertikal, hasilnya adalah $|0\rangle$ atau $|1\rangle$. Pada kasus pertama keadaan hancur menjadi

$|0\rangle$ sedangkan kasus kedua menjadi $|1\rangle$. Kita temukan setelah banyak pengukuran, probabilitas didapatkannya 0 (1) adalah $|a|^2(|b|^2)$.

Untuk lebih formalnya, kita bangun suatu operator pengukuran M_m yang mana probabilitas untuk mendapatkan m dalam keadaan $|\psi\rangle$ adalah

$$p(m) = \langle\psi|M_m^{+}M_m|\psi\rangle \tag{2.24}$$

Dan seketika setelah pengukuran adalah

$$|m\rangle = \frac{M_m|\psi\rangle}{\sqrt{p(m)}} \tag{2.25}$$

Pada contoh diatas, operator pengukuran tidak lain hanyalah operator proyeksi; $M_0 = |0\rangle\langle 0|$ dan $M_1 = |1\rangle\langle 1|$. Kenyataannya, kita dapatkan

$$p(0) = \langle\psi|M_0^{+}M_0|\psi\rangle = \langle\psi|0\rangle\langle 0|\psi\rangle = |a|^2 \tag{2.26}$$

dan

$$\frac{M_0|\psi\rangle}{\sqrt{p(0)}} = \frac{a}{|a|}|0\rangle \tag{2.27}$$

dan untuk M_1 didapatkan,

$$p(1) = \langle\psi|M_1^{+}M_1|\psi\rangle = \langle\psi|1\rangle\langle 1|\psi\rangle = |b|^2 \tag{2.28}$$

dan

$$\frac{M_1|\psi\rangle}{\sqrt{p(1)}} = \frac{b}{|b|}|1\rangle \tag{2.29}$$

Misalkan diberikan banyak salinan dari keadaan $|\psi\rangle$. Jika di ukur suatu observabel M dalam tiap-tiap salinan , nilai harap dari M diberikan dalam hubungan operator proyeksi, sebagai berikut

$$\begin{aligned} E(M) &= \sum_m m\, p\,(m) = \sum_m m\,\langle\psi|P_m|\psi\rangle \\ &= \langle\psi|\sum_m m\,P_m|\psi\rangle = \langle\psi|M|\psi\rangle \end{aligned} \tag{2.30}$$

dimana telah dibuat kegunaannya pada *Spectral Decomposition* $M = \sum_m mP_m$. standar deviasi diberikan dengan

$$\Delta(M) = \sqrt{\langle(M - \langle M\rangle)^2\rangle} = \sqrt{\langle M^2\rangle - \langle M\rangle^2} \tag{2.31}$$

Selanjutnya dilakukan proses analisis pengukuran dalam sistem dua qubit dalam semua kondisi. Suatu keadaan sembarang dituliskan sebagai,

$$|\psi\rangle = a|00\rangle + b|01\rangle + c|10\rangle + d|11\rangle$$

dengan $|a|^2 + |b|^2 + |c|^2 + |d|^2 = 1$, dimana $a, b, c, d \in \mathbb{C}$. Selanjutnya dilakukan pengukuran pada qubit pertama pada basis $\{|0\rangle, |1\rangle\}$. Keadaannya dapat dituliskan sebagai,

$$\begin{aligned} |\psi\rangle &= a|00\rangle + b|01\rangle + c|10\rangle + d|11\rangle \\ &= |0\rangle \otimes (a|0\rangle + b|1\rangle) + |1\rangle \otimes (c|0\rangle + d|1\rangle) \\ &= u|0\rangle \otimes \left(\frac{a}{u}|0\rangle + \frac{b}{u}|1\rangle\right) + v|1\rangle \otimes \left(\frac{c}{v}|0\rangle + \frac{d}{v}|1\rangle\right) \end{aligned}$$

dimana $u = \sqrt{|a|^2 + |b|^2}$ dan $v = \sqrt{|c|^2 + |d|^2}$. Operator pengukuran yang bekerja pada qubit pertama adalah

$$M_0 = |0\rangle\langle 0| \otimes \boldsymbol{I} \tag{2.32}$$

dan

$$M_1 = |1\rangle\langle 1| \otimes \boldsymbol{I} \tag{2.33}$$

Digunakan perkalian langsung $\otimes \boldsymbol{I}$ karena operator ini bekerja pada 2 qubit ruang Hilbert $\mathbb{C}^4$. Untuk pengukuran pada qubit pertama yaitu 0 dengan probabilitas

$$\langle\psi|M_0|\psi\rangle = u^2 = |a|^2 + |b|^2 \tag{2.34}$$

Selanjutnya diperoleh keadaan proyeksinya adalah

$$\frac{M_0|\psi\rangle}{\sqrt{p(0)}} = |0\rangle \otimes \left(\frac{a}{u}|0\rangle + \frac{b}{u}|1\rangle\right), \tag{2.35}$$

Sedangkan probabilitas keadaan $|1\rangle$ diperoleh dengan $v^2 = |c|^2 + |d|^2$, keadaan proyeksinya adalah

$$\frac{M_1|\psi\rangle}{\sqrt{p(1)}} = |1\rangle \otimes \left(\frac{c}{u}|0\rangle + \frac{d}{u}|1\rangle\right) \tag{2.36}$$

Selanjutnya dengan memperhatikan keadaan setelah pengukuran, maka diperlukan keadaan yang telah dinormalisasi dalam kedua kasus. Pengukuran pada qubit kedua dapat dilakukan dengan cara yang sama. Pengukuran dari sistem qubit-n dapat dilakukan pengulangan pengukuran 1 qubit sebanyak 1 kali.

Dalam contoh dua qubit diatas ruang hilbert untuk sistem dipisahkan dalam penumlahan langsung $\mathcal{H}_0$, dimana qubit pertama adalah pada keadaan $|0\rangle$, dan $|1\rangle$ untuk keadaan $\mathcal{H}_1$ dapat dituliskan $\mathcal{H} = \mathcal{H}_0 + \mathcal{H}_1$. Suatu keadaan dua qubit sembarang $|\psi\rangle$ diuraikan secara unik dalam dua vektor,

$$(|0\rangle\langle 0| \otimes \boldsymbol{I}) \in \mathcal{H}_0$$

dan

$$(|1\rangle\langle 1| \otimes \boldsymbol{I}) \in \mathcal{H}_1$$

Lebih umumnya, suatu pengamatan pada qubit k dalam sistem qubit- n menghasilkan 2^k yang mungkin dengan keluaran $m_i(1 \leq i \leq 2^k)$.

2.6 Teleportasi Kuantum Qubit Tunggal Sembarang

Teleportasi kuantum ini merupakan pengiriman suatu informasi yang tidak diketahui dalam qubit tunggal, pengiriman dilakukan Alice dengan keadaan yang dikirimkan sebagai berikut

$$|\psi\rangle_1 = a|0\rangle + b|1\rangle \tag{2.37}$$

Informasi ini akan dikirimkan kepada Bob menggunakan keadaan terbelit, keadaan terbelit yang digunakan sebagai saluran adalah pasangan EPR, partikel yang terbelit ini dibawa oleh Alice dan Bob. Partikel yang dibawa oleh Alice disebut sebagai partikel 2 dan partikel yang dibawa oleh Bob disebut sebagai partikel 3 sebagai berikut

$$|\varphi\rangle_{23} = \frac{1}{\sqrt{2}}(|01\rangle + |10\rangle) \tag{2.38}$$

Proses pengiriman informasi ini dilakukan dengan cara menghancurkan informasi tersebut. Informasi tersebut akan menjadi satu dengan saluran (kanal). Maka hasil dari gabungan informasi dan kanal secara matematis sebagai berikut

$$|\phi\rangle_{123} = |\psi\rangle_1 \otimes |\varphi\rangle_{23} = \frac{1}{\sqrt{2}}(a|001\rangle + b|101\rangle + a|010\rangle + b|111\rangle) \tag{2.39}$$

Informasi tersebut dapat terkirim setelah Alice melakukan pengukuran terhadap gabungan antara informasi dan saluran tersebut. Pengukuran dilakukan dengan menginteraksikan keadaan gabungan tersebut dengan keadaan lain, yaitu dengan menggunakan basis Bell yang pertama,

$$|\phi\rangle_{12}^{1} = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle) \tag{2.40}$$

Interaksi tersebut menyebabkan informasi dapat terkirim begitu saja, dan keadaan gabungan yang dibawa oleh Alice akan menjadi keadaan yang terbelit.

$$(\langle\phi|_{12}^{1}\otimes \boldsymbol{I})|\phi\rangle_{123}=\langle\phi_{12}^{1}|\phi\rangle_{12}\otimes \boldsymbol{I}|\phi\rangle_{3} \tag{2.41}$$

Setelah dilakukan pengukuran informasi yang diperoleh oleh Bob sebagai berikut

$$|\phi\rangle_3=\tfrac{1}{2}(a|1\rangle+b|0\rangle)_3$$

dimana informasi tersebut tidak seperti informasi yang dikirimkan oleh Alice. Bob akan mendapatkan informasi yang benar setelah menerima informasi mengenai pengukuran yang dilakukan oleh Alice yang dikirim melalui saluran klasik. Oleh karena itu Bob harus menginteraksikan informasi yang diterimanya agar informasi yang diterimanya sesuai, interaksi yang dilakukan oleh Bob berdasarkan pengukuran yang dilakukan oleh Alice.

$$|\phi\rangle_3=2\sigma_x\frac{1}{2}(a|1\rangle+b|0\rangle)_3$$

Setelah Bob melakukan interaksi terhadap informasi yang diterimanya, Bob akan mendapatkan informasi yang sesuai.

$$|\psi\rangle_3=a|0\rangle+b|1\rangle$$

Alice dapat melakukan pengukuran dengan keadaan yang berbeda diantaranya

1. $|\phi\rangle_{12}^{2}=\frac{1}{\sqrt{2}}(|00\rangle-|11\rangle)$
2. $|\phi\rangle_{12}^{3}=\frac{1}{\sqrt{2}}(|01\rangle+|10\rangle)$
3. $|\phi\rangle_{12}^{4}=\frac{1}{\sqrt{2}}(|01\rangle-|10\rangle)$

Informasi yang didapatkan oleh Bob dari pengukuran tersebut sebagai berikut

1. $|\phi\rangle_3=\frac{1}{2}(a|1\rangle-b|0\rangle)_3$
2. $|\phi\rangle_3=\frac{1}{2}(a|0\rangle+b|1\rangle)_3$
3. $|\phi\rangle_3=\frac{1}{2}(a|0\rangle-b|1\rangle)_3$

Bob harus menginteraksikan informasi yang diterimanya berdasarkan pengukuran-pengukuran tersebut, yaitu

1. $|\phi\rangle_3=2\sigma_x\sigma_y\frac{1}{2}(a|1\rangle-b|0\rangle)_3$
2. $|\phi\rangle_3=2\boldsymbol{I}\frac{1}{2}(a|0\rangle+b|1\rangle)_3$

3. $|\phi\rangle_3 = 2\sigma_z \frac{1}{2}(a|0\rangle - b|1\rangle)_3$

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BAB III

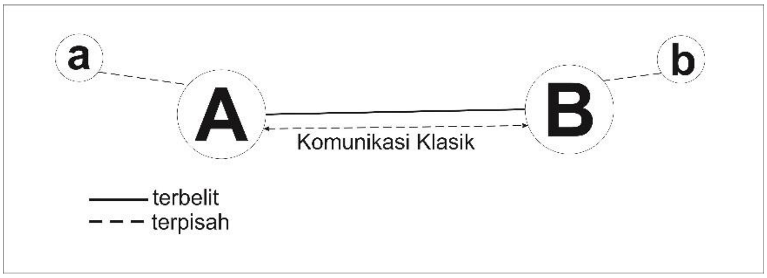
TELEPORTASI KUANTUM DUA ARAH

3.1 Teleportasi Kuantum Dua Arah

Teleportasi kuantum dua arah merupakan pengiriman informasi antara pengirim dan penerima, dimana Alice mengirimkan suatu informasi kepada Bob dan diwaktu yang sama, Bob juga mengirimkan informasi kepada Alice melalui kanal yang sama dan terbelit.

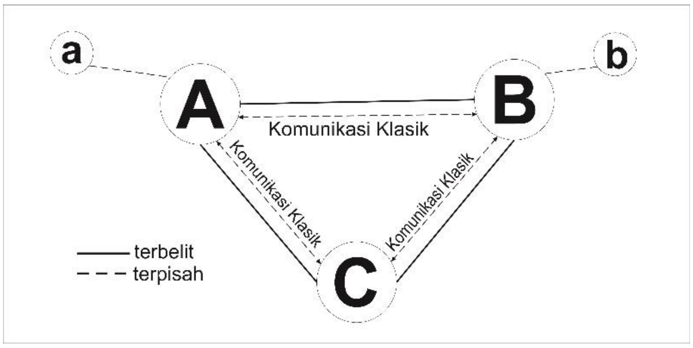
Teleportasi kuantum dua arah dibagi menjadi dua melalui cara pengirimannya, yaitu teleportasi kuantum dua arah tanpa pengontrol dan juga teleportasi dua arah dengan menggunakan pengontrol.

Teleportasi kuantum dua arah tanpa pengontrol merupakan proses pengiriman informasi dari Alice menuju Bob dan begitupun sebaliknya. Dalam pengiriman ini tetap menggunakan komunikasi secara klasik setelah Alice maupun Bob melakukan pengukuran. Komunikasi yang terjadi hanyalah terdiri dari dua Subjek, yaitu Alice dan Bob.



Gambar 3.1 skema teleportasi dua arah tanpa pengontrol

Teleportasi kuantum dua arah menggunakan pengontrol merupakan proses pengiriman infomasi dari Alice menuju ke Pengontrol (Charlie) selanjutnya setelah dikontrol oleh Charlie maka informasi dikirimkan ke Bob, begitupun sebaliknya. Charlie diberi wewenang untuk mengontrol informasi yang dikirim ke penerima, baik dari Alice maupun Bob. Seperti gambar di bawah ini,



Gambar 3.2 Skema Teleportasi Dua Arah dengan Pengontrol

3.2 Representasi Tensor Teleportasi Dua Arah Dengan Informasi (1+1)Melalui Kanal 4 Qubit

Suatu Informasi yang didefinisikan sebagai berikut

$$|\chi\rangle_A = \sum_{i=0}^{1} x_i|i\rangle$$
$$= x_0|0\rangle + x_1|1\rangle \qquad (3.1)$$

merupakan informasi yang dimiliki oleh Alice, dengan nilai $\sum_i |x_i|^2 = 1$. Selanjutnya didefinisikan suatu informasi berikut,

$$|\chi\rangle_B = \sum_{i=0}^{1} y_j|j\rangle$$
$$= y_0|0\rangle + y_1|1\rangle \qquad (3.2)$$

yang merupakan informasi milik Bob dengan nilai $\sum_j \left|y_j\right|^2 = 1$. Selanjutnya Alice dan Bob ingin berbagi informasi yang dilewatkan melalui kanal

$$|\varphi\rangle_{A1,B1,B2,A2} = \sum_{l,m,s,t=0}^{1} R_{lmst}|lmst\rangle$$
$$= R_{0000}|0000\rangle + R_{0001}|0001\rangle + \cdots + R_{1111}|1111\rangle \qquad (3.3)$$

dengan nilai $\sum_{lmst} |R_{lmst}|^2 = 1$.

Selanjutnya dilakukan proses peleburan informasi yang dimiliki Alice, Bob dengan Saluran (kanal) yang digunakan. Keadaan gabungannya dapat dituliskan sebagai berikut.

$$|\psi\rangle_{A,B,A1,B1,B2,A2} = |\chi\rangle_A \otimes |\chi\rangle_B \otimes |\varphi\rangle_{A1,B1,B2,A2} \qquad (3.4)$$
$$= (x_0|0\rangle + x_1|1\rangle) \otimes (y_0|0\rangle + y_1|1\rangle) \otimes (R_{0000}|0000\rangle$$

$$+R_{0001}|0001\rangle + R_{0010}|0010\rangle + R_{0011}|0011\rangle$$
$$+R_{0100}|0100\rangle + R_{0101}|0101\rangle + R_{0110}|0110\rangle$$
$$+R_{0111}|0111\rangle + R_{1000}|1000\rangle + R_{1001}|1001\rangle$$
$$+R_{1010}|1010\rangle + R_{1011}|1011\rangle + R_{1100}|1100\rangle$$
$$+R_{1101}|1101\rangle + R_{1110}|1110\rangle + R_{1111}|1111\rangle)$$

$$= \quad x_0y_0\begin{Bmatrix} (R_{0000}|000000\rangle + R_{0001}|000001\rangle \\ +R_{0010}|000010\rangle + R_{0011}|000011\rangle \\ +R_{0100}|000100\rangle + R_{0101}|000101\rangle \\ +R_{0110}|000110\rangle + R_{0111}|000111\rangle \\ +R_{1000}|001000\rangle + R_{1001}|001001\rangle \\ +R_{1010}|001010\rangle + R_{1011}|001011\rangle \\ +R_{1100}|001100\rangle + R_{1101}|001101\rangle \\ +R_{1110}|001110\rangle + R_{1111}|001111\rangle \end{Bmatrix}$$

$$+x_0y_1\begin{Bmatrix} (R_{0000}|010000\rangle + R_{0001}|010001\rangle \\ +R_{0010}|010010\rangle + R_{0011}|010011\rangle \\ +R_{0100}|010100\rangle + R_{0101}|010101\rangle \\ +R_{0110}|010110\rangle + R_{0111}|010111\rangle \\ +R_{1000}|011000\rangle + R_{1001}|011001\rangle \\ +R_{1010}|011010\rangle + R_{1011}|011011\rangle \\ +R_{1100}|011100\rangle + R_{1101}|011101\rangle \\ +R_{1110}|011110\rangle + R_{1111}|011111\rangle \end{Bmatrix}$$

$$+x_1y_0\begin{Bmatrix} (R_{0000}|100000\rangle + R_{0001}|100001\rangle \\ +R_{0010}|100010\rangle + R_{0011}|100011\rangle \\ +R_{0100}|100100\rangle + R_{0101}|100101\rangle \\ +R_{0110}|100110\rangle + R_{0111}|100111\rangle \\ +R_{1000}|101000\rangle + R_{1001}|101001\rangle \\ +R_{1010}|101010\rangle + R_{1011}|101011\rangle \\ +R_{1100}|101100\rangle + R_{1101}|101101\rangle \\ +R_{1110}|101110\rangle + R_{1111}|101111\rangle \end{Bmatrix}$$

$$+x_1y_1\begin{Bmatrix} (R_{0000}|110000\rangle + R_{0001}|110001\rangle \\ +R_{0010}|110010\rangle + R_{0011}|110011\rangle \\ +R_{0100}|110100\rangle + R_{0101}|110101\rangle \\ +R_{0110}|110110\rangle + R_{0111}|110111\rangle \\ +R_{1000}|111000\rangle + R_{1001}|111001\rangle \\ +R_{1010}|111010\rangle + R_{1011}|111011\rangle \\ +R_{1100}|111100\rangle + R_{1101}|111101\rangle \\ +R_{1110}|111110\rangle + R_{1111}|111111\rangle \end{Bmatrix}$$

Selanjutnya diperkenalkan Operator Swap (P_{23}) yang berfungsi untuk menukar qubit ke-2 dengan qubit ke-3,

$$P_{23} = I \otimes P \otimes I \otimes I \otimes I \tag{3.5}$$

Lalu dilakukan operasi perkalian langsung operator Swap pada persamaan (3.5) dengan persamaan (3.4) sebagai berikut,

$$
\begin{aligned}
|\psi\rangle_{A,A1,B,B1,B2,A2} &= P_{23}|\psi\rangle_{A,B,A1,B1,B2,A2} \\
&= x_0 y_0 \begin{Bmatrix}
(R_{0000}|000000\rangle + R_{0001}|000001\rangle \\
+R_{0010}|000010\rangle + R_{0011}|000011\rangle \\
+R_{0100}|000100\rangle + R_{0101}|000101\rangle \\
+R_{0110}|000110\rangle + R_{0111}|000111\rangle \\
+R_{1000}|010000\rangle + R_{1001}|010001\rangle \\
+R_{1010}|010010\rangle + R_{1011}|001011\rangle \\
+R_{1100}|010100\rangle + R_{1101}|010101\rangle \\
+R_{1110}|010110\rangle + R_{1111}|010111\rangle)
\end{Bmatrix} \\
&\quad + x_0 y_1 \begin{Bmatrix}
(R_{0000}|001000\rangle + R_{0001}|001001\rangle \\
+R_{0010}|001010\rangle + R_{0011}|001011\rangle \\
+R_{0100}|001100\rangle + R_{0101}|001101\rangle \\
+R_{0110}|001110\rangle + R_{0111}|001111\rangle \\
+R_{1000}|011000\rangle + R_{1001}|011001\rangle \\
+R_{1010}|011010\rangle + R_{1011}|011011\rangle \\
+R_{1100}|011100\rangle + R_{1101}|011101\rangle \\
+R_{1110}|011110\rangle + R_{1111}|011111\rangle)
\end{Bmatrix} \\
&\quad + x_1 y_0 \begin{Bmatrix}
(R_{0000}|100000\rangle + R_{0001}|100001\rangle \\
+R_{0010}|100010\rangle + R_{0011}|100011\rangle \\
+R_{0100}|100100\rangle + R_{0101}|100101\rangle \\
+R_{0110}|100110\rangle + R_{0111}|100111\rangle \\
+R_{1000}|110000\rangle + R_{1001}|110001\rangle \\
+R_{1010}|110010\rangle + R_{1011}|110011\rangle \\
+R_{1100}|110100\rangle + R_{1101}|110101\rangle \\
+R_{1110}|110110\rangle + R_{1111}|110111\rangle)
\end{Bmatrix} \\
&\quad + x_1 y_1 \begin{Bmatrix}
(R_{0000}|101000\rangle + R_{0001}|101001\rangle \\
+R_{0010}|101010\rangle + R_{0011}|101011\rangle \\
+R_{0100}|101100\rangle + R_{0101}|101101\rangle \\
+R_{0110}|101110\rangle + R_{0111}|101111\rangle \\
+R_{1000}|111000\rangle + R_{1001}|111001\rangle \\
+R_{1010}|111010\rangle + R_{1011}|111011\rangle \\
+R_{1100}|111100\rangle + R_{1101}|111101\rangle \\
+R_{1110}|111110\rangle + R_{1111}|111111\rangle)
\end{Bmatrix}
\end{aligned} \tag{3.6}
$$

Selanjutnya jika keadaan pada persamaan (3.6) di tuliskan sebagai berikut

$$
\begin{aligned}
|0000\rangle &\equiv \{1\} \quad ; \quad |1000\rangle \equiv \{9\} \\
|0001\rangle &\equiv \{2\} \quad ; \quad |1001\rangle \equiv \{10\} \\
|0010\rangle &\equiv \{3\} \quad ; \quad |1010\rangle \equiv \{11\} \\
|0011\rangle &\equiv \{4\} \quad ; \quad |1011\rangle \equiv \{12\}
\end{aligned} \tag{3.7}
$$

$|0100\rangle \equiv \{5\}$; $|1100\rangle \equiv \{13\}$

$|0101\rangle \equiv \{6\}$; $|1101\rangle \equiv \{14\}$

$|0110\rangle \equiv \{7\}$; $|1110\rangle \equiv \{15\}$

$|0111\rangle \equiv \{8\}$; $|1111\rangle \equiv \{16\}$

Maka persamaan (3.6) dapat dituliskan kembali menjadi

$$|\psi\rangle_{A,A1,B,B1,B2,A2} = \sum_{s,t=0}^{1} x_0 y_0 \left(R_{00st}|\{1\}\rangle + R_{01st}|\{2\}\rangle + R_{10st}|\{5\}\rangle + R_{11st}|\{6\}\rangle\right)|st\rangle$$

$$+ \sum_{s,t=0}^{1} x_0 y_1 \left(R_{00st}|\{3\}\rangle + R_{01st}|\{4\}\rangle + R_{10st}|\{7\}\rangle + R_{11st}|\{8\}\rangle\right)|st\rangle$$

$$+ \sum_{s,t=0}^{1} x_1 y_0 \left(R_{00st}|\{9\}\rangle + R_{01st}|\{10\}\rangle + R_{10st}|\{13\}\rangle + R_{11st}|\{14\}\rangle\right)|st\rangle$$

$$+ \sum_{s,t=0}^{1} x_1 y_1 \left(R_{00st}|\{11\}\rangle + R_{01st}|\{12\}\rangle + R_{10st}|\{15\}\rangle + R_{11st}|\{16\}\rangle\right)|st\rangle$$

$$= x_0 y_0 \sum_{s,t=0}^{1} \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} |\{1\}\rangle \\ |\{2\}\rangle \\ |\{5\}\rangle \\ |\{6\}\rangle \end{pmatrix} |st\rangle$$

$$+ x_0 y_1 \sum_{s,t=0}^{1} \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} |\{3\}\rangle \\ |\{4\}\rangle \\ |\{7\}\rangle \\ |\{8\}\rangle \end{pmatrix} |st\rangle$$

$$+ x_1 y_0 \sum_{s,t=0}^{1} \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} |\{9\}\rangle \\ |\{10\}\rangle \\ |\{13\}\rangle \\ |\{14\}\rangle \end{pmatrix} |st\rangle$$

$$+ x_1 y_1 \sum_{s,t=0}^{1} \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} |\{11\}\rangle \\ |\{12\}\rangle \\ |\{15\}\rangle \\ |\{16\}\rangle \end{pmatrix} |st\rangle \qquad (3.8)$$

Selanjutnya ditinjau keadaan Bell, sebagai berikut

$$|\phi\rangle_{mn}^{1} = \frac{1}{\sqrt{2}}\left(|00\rangle + |11\rangle\right)_{mn} \qquad (3.9)$$

$$|\phi\rangle^2_{mn} = \frac{1}{\sqrt{2}}\,(|00\rangle - |11\rangle)_{mn}$$

$$|\phi\rangle^3_{mn} = \frac{1}{\sqrt{2}}\,(|01\rangle + |10\rangle)_{mn}$$

$$|\phi\rangle^4_{mn} = \frac{1}{\sqrt{2}}\,(|01\rangle - |10\rangle)_{mn}$$

dari keadaan Bell dapat dituliskan basis baru sebagai berikut

$$\begin{aligned}
|00\rangle_{mn} &= \frac{1}{\sqrt{2}}\left(|\phi\rangle^1_{mn} + |\phi\rangle^2_{mn}\right)\\
|01\rangle_{mn} &= \frac{1}{\sqrt{2}}\left(|\phi\rangle^3_{mn} + |\phi\rangle^4_{mn}\right)\\
|10\rangle_{mn} &= \frac{1}{\sqrt{2}}\left(|\phi\rangle^3_{mn} - |\phi\rangle^4_{mn}\right)\\
|11\rangle_{mn} &= \frac{1}{\sqrt{2}}\left(|\phi\rangle^1_{mn} - |\phi\rangle^2_{mn}\right)
\end{aligned} \tag{3.10}$$

dengan indeks mn merupakan indeks dari qubit yang dibentuk. Selanjutnya dengan mensubtitusikan persamaan (3.10) kedalam persamaan (3.8), diperoleh

$$|\psi\rangle_{A,A1,B,B1,B2,A2} =$$

$$\frac{1}{2}x_0y_0\sum_{s,t=0}^{1}(R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix}\left(|\phi\rangle^1_{00}+|\phi\rangle^2_{00}\right)\left(|\phi\rangle^1_{00}+|\phi\rangle^2_{00}\right)\\ \left(|\phi\rangle^1_{00}+|\phi\rangle^2_{00}\right)\left(|\phi\rangle^3_{01}+|\phi\rangle^4_{01}\right)\\ \left(|\phi\rangle^3_{01}+|\phi\rangle^4_{01}\right)\left(|\phi\rangle^1_{00}+|\phi\rangle^2_{00}\right)\\ \left(|\phi\rangle^3_{01}+|\phi\rangle^4_{01}\right)\left(|\phi\rangle^3_{01}+|\phi\rangle^4_{01}\right)\end{pmatrix}|st\rangle$$

$$+\frac{1}{2}x_0y_1\sum_{s,t=0}^{1}(R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix}\left(|\phi\rangle^1_{00}+|\phi\rangle^2_{00}\right)\left(|\phi\rangle^3_{10}-|\phi\rangle^4_{10}\right)\\ \left(|\phi\rangle^1_{00}+|\phi\rangle^2_{00}\right)\left(|\phi\rangle^1_{11}-|\phi\rangle^2_{11}\right)\\ \left(|\phi\rangle^3_{01}+|\phi\rangle^4_{01}\right)\left(|\phi\rangle^3_{10}-|\phi\rangle^4_{10}\right)\\ \left(|\phi\rangle^3_{01}+|\phi\rangle^4_{01}\right)\left(|\phi\rangle^1_{11}-|\phi\rangle^2_{11}\right)\end{pmatrix}|st$$

$$+\frac{1}{2}x_1y_0\sum_{s,t=0}^{1}(R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix}\left(|\phi\rangle^3_{10}-|\phi\rangle^4_{10}\right)\left(|\phi\rangle^1_{00}+|\phi\rangle^2_{00}\right)\\ \left(|\phi\rangle^3_{10}-|\phi\rangle^4_{10}\right)\left(|\phi\rangle^3_{01}+|\phi\rangle^4_{01}\right)\\ \left(|\phi\rangle^1_{11}-|\phi\rangle^2_{11}\right)\left(|\phi\rangle^1_{00}+|\phi\rangle^2_{00}\right)\\ \left(|\phi\rangle^1_{11}-|\phi\rangle^2_{11}\right)\left(|\phi\rangle^3_{01}+|\phi\rangle^4_{01}\right)\end{pmatrix}|st$$

$$+\frac{1}{2}x_1y_1\sum_{s,t=0}^{1}(R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix}(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4})(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4})\\(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4})(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2})\\(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2})(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4})\\(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2})(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2})\end{pmatrix}|st$$

$$=\frac{1}{2}x_0\sum_{s,t=0}^{1}\left\{\begin{matrix}R_{00st}\,(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2})\left\{\left(y_0(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2})\right)+\left(y_1(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4})\right)\right\}\\+R_{01st}(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2})\left\{\left(y_0(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4})\right)+\left(y_1(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2})\right)\right\}\\+R_{10st}(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4})\left\{\left(y_0(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2})\right)+\left(y_1(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4})\right)\right\}\\+R_{11st}(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4})\left\{\left(y_0(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4})\right)+\left(y_1(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2})\right)\right\}\end{matrix}\right\}|st\rangle \quad (3.11)$$

$$+\frac{1}{2}x_1\sum_{s,t=0}^{1}\left\{\begin{matrix}R_{00st}(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4})\left\{\left(y_0(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2})\right)+\left(y_1(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4})\right)\right\}\\+R_{01st}(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4})\left\{\left(y_0(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4})\right)+\left(y_1(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2})\right)\right\}\\+R_{10st}(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2})\left\{\left(y_0(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2})\right)+\left(y_1(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4})\right)\right\}\\+R_{11st}(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2})\left\{\left(y_0(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4})\right)+\left(y_1(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2})\right)\right\}\end{matrix}\right\}|st\rangle$$

Selanjutnya, jika persamaan (3.11) dituliskan menjadi

$|\psi\rangle_{A,A1,B,B1,B2,A2}=$

$$\frac{1}{2}x_0\sum_{s,t=0}^{1}\left\{\begin{matrix}R_{00st}\,(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2})\left\{\begin{matrix}y_0\left(T_{00}^{1}|\phi\rangle_{00}^{1}+T_{00}^{2}|\phi\rangle_{00}^{2}+T_{00}^{3}|\phi\rangle_{00}^{3}+T_{00}^{4}|\phi\rangle_{00}^{4}\right)\\+y_1\left(T_{10}^{1}|\phi\rangle_{10}^{1}+T_{10}^{2}|\phi\rangle_{10}^{2}+T_{10}^{3}|\phi\rangle_{10}^{3}+T_{10}^{4}|\phi\rangle_{10}^{4}\right)\end{matrix}\right\}\\+R_{01st}(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2})\left\{\begin{matrix}y_0\left(T_{01}^{1}|\phi\rangle_{01}^{1}+T_{01}^{2}|\phi\rangle_{01}^{2}+T_{01}^{3}|\phi\rangle_{01}^{3}+T_{01}^{4}|\phi\rangle_{01}^{4}\right)\\+y_1\left(T_{11}^{1}|\phi\rangle_{11}^{1}+T_{11}^{2}|\phi\rangle_{11}^{2}+T_{11}^{3}|\phi\rangle_{11}^{3}+T_{11}^{4}|\phi\rangle_{11}^{4}\right)\end{matrix}\right\}\\+R_{10st}(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4})\left\{\begin{matrix}y_0\left(T_{00}^{1}|\phi\rangle_{00}^{1}+T_{00}^{2}|\phi\rangle_{00}^{2}+T_{00}^{3}|\phi\rangle_{00}^{3}+T_{00}^{4}|\phi\rangle_{00}^{4}\right)\\y_1\left(T_{10}^{1}|\phi\rangle_{10}^{1}+T_{10}^{2}|\phi\rangle_{10}^{2}+T_{10}^{3}|\phi\rangle_{10}^{3}+T_{10}^{4}|\phi\rangle_{10}^{4}\right)\end{matrix}\right\}\\+R_{11st}(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4})\left\{\begin{matrix}y_0\left(T_{01}^{1}|\phi\rangle_{01}^{1}+T_{01}^{2}|\phi\rangle_{01}^{2}+T_{01}^{3}|\phi\rangle_{01}^{3}+T_{01}^{4}|\phi\rangle_{01}^{4}\right)\\+y_1\left(T_{11}^{1}|\phi\rangle_{11}^{1}+T_{11}^{2}|\phi\rangle_{11}^{2}+T_{11}^{3}|\phi\rangle_{11}^{3}+T_{11}^{4}|\phi\rangle_{11}^{4}\right)\end{matrix}\right\}\end{matrix}\right\}$$

$$+\frac{1}{2}x_1\sum_{s,t=0}^{1}\left\{\begin{matrix}R_{00st}(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4})\left\{\begin{matrix}y_0\left(T_{00}^{1}|\phi\rangle_{00}^{1}+T_{00}^{2}|\phi\rangle_{00}^{2}+T_{00}^{3}|\phi\rangle_{00}^{3}+T_{00}^{4}|\phi\rangle_{00}^{4}\right)\\+y_1\left(T_{10}^{1}|\phi\rangle_{10}^{1}+T_{10}^{2}|\phi\rangle_{10}^{2}+T_{10}^{3}|\phi\rangle_{10}^{3}+T_{10}^{4}|\phi\rangle_{10}^{4}\right)\end{matrix}\right\}\\+R_{01st}(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4})\left\{\begin{matrix}y_0\left(T_{01}^{1}|\phi\rangle_{01}^{1}+T_{01}^{2}|\phi\rangle_{01}^{2}+T_{01}^{3}|\phi\rangle_{01}^{3}+T_{01}^{4}|\phi\rangle_{01}^{4}\right)\\+y_1\left(T_{11}^{1}|\phi\rangle_{11}^{1}+T_{11}^{2}|\phi\rangle_{11}^{2}+T_{11}^{3}|\phi\rangle_{11}^{3}+T_{11}^{4}|\phi\rangle_{11}^{4}\right)\end{matrix}\right\}\\+R_{10st}(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2})\left\{\begin{matrix}y_0\left(T_{00}^{1}|\phi\rangle_{00}^{1}+T_{00}^{2}|\phi\rangle_{00}^{2}+T_{00}^{3}|\phi\rangle_{00}^{3}+T_{00}^{4}|\phi\rangle_{00}^{4}\right)\\y_1\left(T_{10}^{1}|\phi\rangle_{10}^{1}+T_{10}^{2}|\phi\rangle_{10}^{2}+T_{10}^{3}|\phi\rangle_{10}^{3}+T_{10}^{4}|\phi\rangle_{10}^{4}\right)\end{matrix}\right\}\\+R_{11st}(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2})\left\{\begin{matrix}y_0\left(T_{01}^{1}|\phi\rangle_{01}^{1}+T_{01}^{2}|\phi\rangle_{01}^{2}+T_{01}^{3}|\phi\rangle_{01}^{3}+T_{01}^{4}|\phi\rangle_{01}^{4}\right)\\+y_1\left(T_{11}^{1}|\phi\rangle_{11}^{1}+T_{11}^{2}|\phi\rangle_{11}^{2}+T_{11}^{3}|\phi\rangle_{11}^{3}+T_{11}^{4}|\phi\rangle_{11}^{4}\right)\end{matrix}\right\}\end{matrix}\right\} \quad (3.12)$$

dengan T_{jm}^{τ} adalah konstanta yang bekerja pada keadaan Bell $|\phi\rangle_{jm}^{\tau}$ untuk $\tau=1,2,3,4$, maka dengan mereduksi persamaan (3.11) dan persamaan (3.12) didapatkan nilai keseluruhan dari konstanta T_{jm}^{τ} adalah

$$\begin{pmatrix} T_{00}^1 & T_{00}^2 & T_{00}^3 & T_{00}^4 \\ T_{01}^1 & T_{01}^2 & T_{01}^3 & T_{01}^4 \\ T_{10}^1 & T_{10}^2 & T_{10}^3 & T_{10}^4 \\ T_{11}^1 & T_{11}^2 & T_{11}^3 & T_{11}^4 \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & -1 & 0 & 0 \end{pmatrix} \tag{3.13}$$

Persamaan (3.12) dapat dituliskan kembali dengan

$$|\psi\rangle_{A,A1,B,B1,B2,A2} =$$

$$\frac{1}{\sqrt{2}}x_0\sum_{j=0}^{1}y_j\sum_{s,t=0}^{1}\left\{\begin{array}{l} R_{00st}\left(\left(|\phi\rangle_{00}^1 + |\phi\rangle_{00}^2\right)\left(T_{j0}^1|\phi\rangle_{j0}^1 + T_{j0}^2|\phi\rangle_{j0}^2 + T_{j0}^3|\phi\rangle_{j0}^3 + T_{j0}^4|\phi\rangle_{j0}^4\right)\right) \\ +R_{01st}\left(\left(|\phi\rangle_{00}^1 + |\phi\rangle_{00}^2\right)\left(T_{j1}^1|\phi\rangle_{j1}^1 + T_{j1}^2|\phi\rangle_{j1}^2 + T_{j1}^3|\phi\rangle_{j1}^3 + T_{j1}^4|\phi\rangle_{j1}^4\right)\right) \\ +R_{10st}\left(\left(|\phi\rangle_{01}^3 + |\phi\rangle_{01}^4\right)\left(T_{j0}^1|\phi\rangle_{j0}^1 + T_{j0}^2|\phi\rangle_{j0}^2 + T_{j0}^3|\phi\rangle_{j0}^3 + T_{j0}^4|\phi\rangle_{j0}^4\right)\right) \\ +R_{11st}\left(\left(|\phi\rangle_{01}^3 + |\phi\rangle_{01}^4\right)\left(T_{j1}^1|\phi\rangle_{j1}^1 + T_{j1}^2|\phi\rangle_{j1}^2 + T_{j1}^3|\phi\rangle_{j1}^3 + T_{j1}^4|\phi\rangle_{j1}^4\right)\right) \end{array}\right\}|st\rangle \tag{3.14}$$

$$+\frac{1}{\sqrt{2}}x_1\sum_{j=0}^{1}y_j\sum_{s,t=0}^{1}\left\{\begin{array}{l} R_{00st}\left(\left(|\phi\rangle_{10}^3 - |\phi\rangle_{10}^4\right)\left(T_{j0}^1|\phi\rangle_{j0}^1 + T_{j0}^2|\phi\rangle_{j0}^2 + T_{j0}^3|\phi\rangle_{j0}^3 + T_{j0}^4|\phi\rangle_{j0}^4\right)\right) \\ +R_{01st}\left(\left(|\phi\rangle_{10}^3 - |\phi\rangle_{10}^4\right)\left(T_{j1}^1|\phi\rangle_{j1}^1 + T_{j1}^2|\phi\rangle_{j1}^2 + T_{j1}^3|\phi\rangle_{j1}^3 + T_{j1}^4|\phi\rangle_{j1}^4\right)\right) \\ +R_{10st}\left(\left(|\phi\rangle_{11}^1 - |\phi\rangle_{11}^2\right)\left(T_{j0}^1|\phi\rangle_{j0}^1 + T_{j0}^2|\phi\rangle_{j0}^2 + T_{j0}^3|\phi\rangle_{j0}^3 + T_{j0}^4|\phi\rangle_{j0}^4\right)\right) \\ +R_{11st}\left(\left(|\phi\rangle_{11}^1 - |\phi\rangle_{11}^2\right)\left(T_{j1}^1|\phi\rangle_{j1}^1 + T_{j1}^2|\phi\rangle_{j1}^2 + T_{j1}^3|\phi\rangle_{j1}^3 + T_{j1}^4|\phi\rangle_{j1}^4\right)\right) \end{array}\right\}|st\rangle$$

Selanjutnya, jika persamaan (3.14) dituliskan sebagai berikut

$$|\psi\rangle_{A,A1,B,B1,B2,A2} =$$

$$\sum_{i=0}^{1}x_i\sum_{j=0}^{1}y_j\sum_{s,t=0}^{1}\left\{\begin{array}{l} R_{00st}\left(\left(T_{i0}^1|\phi\rangle_{i0}^1 + T_{i0}^2|\phi\rangle_{i0}^2 + T_{i0}^3|\phi\rangle_{i0}^3 + T_{i0}^4|\phi\rangle_{i0}^4\right)\left(T_{j0}^1|\phi\rangle_{j0}^1 + T_{j0}^2|\phi\rangle_{j0}^2 + T_{j0}^3|\phi\rangle_{j0}^3 + T_{j0}^4|\phi\rangle_{j0}^4\right)\right) \\ +R_{01st}\left(\left(T_{i0}^1|\phi\rangle_{i0}^1 + T_{i0}^2|\phi\rangle_{i0}^2 + T_{i0}^3|\phi\rangle_{i0}^3 + T_{i0}^4|\phi\rangle_{i0}^4\right)\left(T_{j1}^1|\phi\rangle_{j1}^1 + T_{j1}^2|\phi\rangle_{j1}^2 + T_{j1}^3|\phi\rangle_{j1}^3 + T_{j1}^4|\phi\rangle_{j1}^4\right)\right) \\ +R_{10st}\left(\left(T_{i1}^1|\phi\rangle_{i1}^1 + T_{i1}^2|\phi\rangle_{i1}^2 + T_{i1}^3|\phi\rangle_{i1}^3 + T_{i1}^4|\phi\rangle_{i1}^4\right)\left(T_{j0}^1|\phi\rangle_{j0}^1 + T_{j0}^2|\phi\rangle_{j0}^2 + T_{j0}^3|\phi\rangle_{j0}^3 + T_{j0}^4|\phi\rangle_{j0}^4\right)\right) \\ +R_{11st}\left(\left(T_{i1}^1|\phi\rangle_{i1}^1 + T_{i1}^2|\phi\rangle_{i1}^2 + T_{i1}^3|\phi\rangle_{i1}^3 + T_{i1}^4|\phi\rangle_{i1}^4\right)\left(T_{j1}^1|\phi\rangle_{j1}^1 + T_{j1}^2|\phi\rangle_{j1}^2 + T_{j1}^3|\phi\rangle_{j1}^3 + T_{j1}^4|\phi\rangle_{j1}^4\right)\right) \end{array}\right\}|st\rangle \tag{3.15}$$

maka dengan mereduksi persamaan (3.14) dengan persamaan (3.15) diperoleh nilai keseluruhan dari konstanta T_{il}^{θ}(untuk $\theta = 1,2,3,4$) yang sama dengan konstanta T_{jm}^{τ} pada persamaan (3.13). Selanjutnya persamaan (3.15) dapat dituliskan dengan

$$|\psi\rangle_{A,A1,B,B1,B2,A2} =$$

$$\sum_{i=0}^{1}x_i\sum_{j=0}^{1}y_j\sum_{s,t=0}^{1}\left\{\begin{array}{l} R_{00st}\left(\left(T_{i0}^1|\phi\rangle_{i0}^1 + T_{i0}^2|\phi\rangle_{i0}^2 + T_{i0}^3|\phi\rangle_{i0}^3 + T_{i0}^4|\phi\rangle_{i0}^4\right)\left(T_{j0}^1|\phi\rangle_{j0}^1 + T_{j0}^2|\phi\rangle_{j0}^2 + T_{j0}^3|\phi\rangle_{j0}^3 + T_{j0}^4|\phi\rangle_{j0}^4\right)\right) \\ +R_{01st}\left(\left(T_{i0}^1|\phi\rangle_{i0}^1 + T_{i0}^2|\phi\rangle_{i0}^2 + T_{i0}^3|\phi\rangle_{i0}^3 + T_{i0}^4|\phi\rangle_{i0}^4\right)\left(T_{j1}^1|\phi\rangle_{j1}^1 + T_{j1}^2|\phi\rangle_{j1}^2 + T_{j1}^3|\phi\rangle_{j1}^3 + T_{j1}^4|\phi\rangle_{j1}^4\right)\right) \\ +R_{10st}\left(\left(T_{i1}^1|\phi\rangle_{i1}^1 + T_{i1}^2|\phi\rangle_{i1}^2 + T_{i1}^3|\phi\rangle_{i1}^3 + T_{i1}^4|\phi\rangle_{i1}^4\right)\left(T_{j0}^1|\phi\rangle_{j0}^1 + T_{j0}^2|\phi\rangle_{j0}^2 + T_{j0}^3|\phi\rangle_{j0}^3 + T_{j0}^4|\phi\rangle_{j0}^4\right)\right) \\ +R_{11st}\left(\left(T_{i1}^1|\phi\rangle_{i1}^1 + T_{i1}^2|\phi\rangle_{i1}^2 + T_{i1}^3|\phi\rangle_{i1}^3 + T_{i1}^4|\phi\rangle_{i1}^4\right)\left(T_{j1}^1|\phi\rangle_{j1}^1 + T_{j1}^2|\phi\rangle_{j1}^2 + T_{j1}^3|\phi\rangle_{j1}^3 + T_{j1}^4|\phi\rangle_{j1}^4\right)\right) \end{array}\right\}|st\rangle$$

$$= \sum_{i=0}^{1} x_i \sum_{j=0}^{1} y_j \sum_{s,t=0}^{1} \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix}$$

$$\begin{pmatrix} \left(T_{i0}^{1}|\phi\rangle_{i0}^{1} + T_{i0}^{2}|\phi\rangle_{i0}^{2} + T_{i0}^{3}|\phi\rangle_{i0}^{3} + T_{i0}^{4}|\phi\rangle_{i0}^{4}\right)\left(T_{j0}^{1}|\phi\rangle_{j0}^{1} + T_{j0}^{2}|\phi\rangle_{j0}^{2} + T_{j0}^{3}|\phi\rangle_{j0}^{3} + T_{j0}^{4}|\phi\rangle_{j0}^{4}\right) \\ \left(T_{i0}^{1}|\phi\rangle_{i0}^{1} + T_{i0}^{2}|\phi\rangle_{i0}^{2} + T_{i0}^{3}|\phi\rangle_{i0}^{3} + T_{i0}^{4}|\phi\rangle_{i0}^{4}\right)\left(T_{j1}^{1}|\phi\rangle_{j1}^{1} + T_{j1}^{2}|\phi\rangle_{j1}^{2} + T_{j1}^{3}|\phi\rangle_{j1}^{3} + T_{j1}^{4}|\phi\rangle_{j1}^{4}\right) \\ \left(T_{i1}^{1}|\phi\rangle_{i1}^{1} + T_{i1}^{2}|\phi\rangle_{i1}^{2} + T_{i1}^{3}|\phi\rangle_{i1}^{3} + T_{i1}^{4}|\phi\rangle_{i1}^{4}\right)\left(T_{j0}^{1}|\phi\rangle_{j0}^{1} + T_{j0}^{2}|\phi\rangle_{j0}^{2} + T_{j0}^{3}|\phi\rangle_{j0}^{3} + T_{j0}^{4}|\phi\rangle_{j0}^{4}\right) \\ \left(T_{i1}^{1}|\phi\rangle_{i1}^{1} + T_{i1}^{2}|\phi\rangle_{i1}^{2} + T_{i1}^{3}|\phi\rangle_{i1}^{3} + T_{i1}^{4}|\phi\rangle_{i1}^{4}\right)\left(T_{j1}^{1}|\phi\rangle_{j1}^{1} - T_{j1}^{2}|\phi\rangle_{j1}^{2} + T_{j1}^{3}|\phi\rangle_{j1}^{3} + T_{j1}^{4}|\phi\rangle_{j1}^{4}\right) \end{pmatrix} |st\rangle$$

$$= \sum_{i=0}^{1} x_i \sum_{j=0}^{1} y_j \sum_{s,t=0}^{1} \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix}$$

$$\begin{pmatrix} \left(\sum_{\theta=1}^{4} T_{i0}^{\theta}|\phi\rangle_{i0}^{\theta}\right)\left(\sum_{\tau=1}^{4} T_{j0}^{\tau}|\phi\rangle_{j0}^{\tau}\right) \\ \left(\sum_{\theta=1}^{4} T_{i0}^{\theta}|\phi\rangle_{i0}^{\theta}\right)\left(\sum_{\tau=1}^{4} T_{j1}^{\tau}|\phi\rangle_{j1}^{\tau}\right) \\ \left(\sum_{\theta=1}^{4} T_{i1}^{\theta}|\phi\rangle_{i1}^{\theta}\right)\left(\sum_{\tau=1}^{4} T_{j0}^{\tau}|\phi\rangle_{j0}^{\tau}\right) \\ \left(\sum_{\theta=1}^{4} T_{i1}^{\theta}|\phi\rangle_{i1}^{\theta}\right)\left(\sum_{\tau=1}^{4} T_{j1}^{\tau}|\phi\rangle_{j1}^{\tau}\right) \end{pmatrix} |st\rangle$$

$$= \sum_{i=0}^{1} \sum_{j=0}^{1} \sum_{s,t=0}^{1} \sum_{\theta=1}^{4} \sum_{\tau=1}^{4} x_i\, y_j \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix}$$

$$\begin{pmatrix} \left(T_{i0}^{\theta}|\phi\rangle_{i0}^{\theta}\right)\left(T_{j0}^{\tau}|\phi\rangle_{j0}^{\tau}\right) \\ \left(T_{i0}^{\theta}|\phi\rangle_{i0}^{\theta}\right)\left(T_{j1}^{\tau}|\phi\rangle_{j1}^{\tau}\right) \\ \left(T_{i1}^{\theta}|\phi\rangle_{i1}^{\theta}\right)\left(T_{j0}^{\tau}|\phi\rangle_{j0}^{\tau}\right) \\ \left(T_{i1}^{\theta}|\phi\rangle_{i1}^{\theta}\right)\left(T_{j1}^{\tau}|\phi\rangle_{j1}^{\tau}\right) \end{pmatrix} |st\rangle$$

$$= \sum_{i=0}^{1} \sum_{j=0}^{1} \sum_{m,s,t=0}^{1} \sum_{\theta=1}^{4} \sum_{\tau=1}^{4} x_i\, y_j \begin{pmatrix} R_{0mst} & R_{1mst} \end{pmatrix} \begin{pmatrix} \left(T_{i0}^{\theta}|\phi\rangle_{i0}^{\theta}\right)\left(T_{jm}^{\tau}|\phi\rangle_{jm}^{\tau}\right) \\ \left(T_{i1}^{\theta}|\phi\rangle_{i1}^{\theta}\right)\left(T_{jm}^{\tau}|\phi\rangle_{jm}^{\tau}\right) \end{pmatrix} |st\rangle$$

$$= \sum_{i=0}^{1} \sum_{j=0}^{1} \sum_{l,m,s,t=0}^{1} \sum_{\theta=1}^{4} \sum_{\tau=1}^{4} x_i\, y_j R_{lmst} \left(T_{il}^{\theta}|\phi\rangle_{il}^{\theta}\right)\left(T_{jm}^{\tau}|\phi\rangle_{jm}^{\tau}\right) |st\rangle$$

$$= \sum_{i=0}^{1} \sum_{j=0}^{1} \sum_{l,m,s,t=0}^{1} \sum_{\theta=1}^{4} \sum_{\tau=1}^{4} x_i\, y_j R_{lmst} T_{il}^{\theta} T_{jm}^{\tau} \left(|\phi\rangle_{il}^{\theta}|\phi\rangle_{jm}^{\tau}\right) |st\rangle \qquad (3.16)$$

Selanjutnya apabila dituliskan $|\phi\rangle_{il}^{\theta}=|\theta\rangle_{il}$; $|\phi\rangle_{jm}^{\tau} = |\tau\rangle_{jm}$ dengan $(\theta, \tau \in 1{,}2{,}3{,}4)$, maka persamaan (3.16) dapat dituliskan dengan

$$|\psi\rangle_{A,A1,B,B1,B2,A2} = \sum_{i=0}^{1}\sum_{j=0}^{1}\sum_{l,m,s,t=0}^{1}\sum_{\theta=1}^{4}\sum_{\tau=1}^{4} x_i\, y_j R_{lmst} T_{il}^{\theta} T_{jm}^{\tau} (|\theta\rangle|\tau\rangle)\,|st\rangle$$

$$= \sum_{i=0}^{1}\sum_{j=0}^{1} x_i y_j \sum_{l,m,s,t=0}^{1}\sum_{\theta=1}^{4}\sum_{\tau=1}^{4} R_{lmst} T_{il}^{\theta} T_{jm}^{\tau} |\theta\tau\rangle\,|st\rangle \qquad (3.17)$$

Selanjutnya dengan mengeluarkan nilai $|st\rangle$ pada persamaan (3.17), maka diperoleh

$$|\psi\rangle_{A,A1,B,B1,B2,A2} =$$

$$\sum_{s,t=0}^{1}\sum_{i=0}^{1}\sum_{j=0}^{1} x_i y_j \sum_{\theta,\tau=1}^{4} \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \left(\begin{pmatrix} T_{i0}^{\theta} T_{j0}^{\tau} \\ T_{i0}^{\theta} T_{j1}^{\tau} \\ T_{i1}^{\theta} T_{j0}^{\tau} \\ T_{i1}^{\theta} T_{j1}^{\tau} \end{pmatrix} \right) |\theta\tau\rangle\,|st\rangle$$

$$= \sum_{s,t=0}^{1}\sum_{\theta,\tau=1}^{4} \left\{ \begin{array}{l} x_0 y_0 \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta} T_{00}^{\tau} \\ T_{00}^{\theta} T_{01}^{\tau} \\ T_{01}^{\theta} T_{00}^{\tau} \\ T_{01}^{\theta} T_{01}^{\tau} \end{pmatrix} \\ + x_0 y_1 \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta} T_{10}^{\tau} \\ T_{00}^{\theta} T_{11}^{\tau} \\ T_{01}^{\theta} T_{10}^{\tau} \\ T_{01}^{\theta} T_{11}^{\tau} \end{pmatrix} \\ + x_1 y_0 \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} T_{10}^{\theta} T_{00}^{\tau} \\ T_{10}^{\theta} T_{01}^{\tau} \\ T_{11}^{\theta} T_{00}^{\tau} \\ T_{11}^{\theta} T_{01}^{\tau} \end{pmatrix} \\ + x_1 y_1 \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} T_{10}^{\theta} T_{10}^{\tau} \\ T_{10}^{\theta} T_{11}^{\tau} \\ T_{11}^{\theta} T_{10}^{\tau} \\ T_{11}^{\theta} T_{11}^{\tau} \end{pmatrix} \end{array} \right\} |\theta\tau\rangle|st\rangle$$

$$= \sum_{s,t=0}^{1}\sum_{\theta,\tau=1}^{4} \left(\left(\begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta} T_{00}^{\tau} & T_{00}^{\theta} T_{10}^{\tau} & T_{10}^{\theta} T_{00}^{\tau} & T_{10}^{\theta} T_{10}^{\tau} \\ T_{00}^{\theta} T_{01}^{\tau} & T_{00}^{\theta} T_{11}^{\tau} & T_{10}^{\theta} T_{01}^{\tau} & T_{10}^{\theta} T_{11}^{\tau} \\ T_{01}^{\theta} T_{00}^{\tau} & T_{01}^{\theta} T_{10}^{\tau} & T_{11}^{\theta} T_{00}^{\tau} & T_{11}^{\theta} T_{10}^{\tau} \\ T_{01}^{\theta} T_{01}^{\tau} & T_{01}^{\theta} T_{11}^{\tau} & T_{11}^{\theta} T_{01}^{\tau} & T_{11}^{\theta} T_{11}^{\tau} \end{pmatrix} \right) \begin{pmatrix} x_0 y_0 \\ x_0 y_1 \\ x_1 y_0 \\ x_1 y_1 \end{pmatrix} \right) |\theta\tau\rangle|st\rangle$$

$$
= \sum_{\theta,\tau=1}^{4} \left\{ \begin{aligned}
&\left(\left(\left(R_{0000} \quad R_{0100} \quad R_{1000} \quad R_{1100}\right)\begin{pmatrix} T_{00}^{\theta}T_{00}^{\tau} & T_{00}^{\theta}T_{10}^{\tau} & T_{10}^{\theta}T_{00}^{\tau} & T_{10}^{\theta}T_{10}^{\tau} \\ T_{00}^{\theta}T_{01}^{\tau} & T_{00}^{\theta}T_{11}^{\tau} & T_{10}^{\theta}T_{01}^{\tau} & T_{10}^{\theta}T_{11}^{\tau} \\ T_{01}^{\theta}T_{00}^{\tau} & T_{01}^{\theta}T_{10}^{\tau} & T_{11}^{\theta}T_{00}^{\tau} & T_{11}^{\theta}T_{10}^{\tau} \\ T_{01}^{\theta}T_{01}^{\tau} & T_{01}^{\theta}T_{11}^{\tau} & T_{11}^{\theta}T_{01}^{\tau} & T_{11}^{\theta}T_{11}^{\tau} \end{pmatrix}\right)\begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}\right)|\theta\tau\rangle|00\rangle \\
+&\left(\left(\left(R_{0001} \quad R_{0101} \quad R_{1001} \quad R_{1101}\right)\begin{pmatrix} T_{00}^{\theta}T_{00}^{\tau} & T_{00}^{\theta}T_{10}^{\tau} & T_{10}^{\theta}T_{00}^{\tau} & T_{10}^{\theta}T_{10}^{\tau} \\ T_{00}^{\theta}T_{01}^{\tau} & T_{00}^{\theta}T_{11}^{\tau} & T_{10}^{\theta}T_{01}^{\tau} & T_{10}^{\theta}T_{11}^{\tau} \\ T_{01}^{\theta}T_{00}^{\tau} & T_{01}^{\theta}T_{10}^{\tau} & T_{11}^{\theta}T_{00}^{\tau} & T_{11}^{\theta}T_{10}^{\tau} \\ T_{01}^{\theta}T_{01}^{\tau} & T_{01}^{\theta}T_{11}^{\tau} & T_{11}^{\theta}T_{01}^{\tau} & T_{11}^{\theta}T_{11}^{\tau} \end{pmatrix}\right)\begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}\right)|\theta\tau\rangle|01\rangle \\
+&\left(\left(\left(R_{0010} \quad R_{0110} \quad R_{1010} \quad R_{1110}\right)\begin{pmatrix} T_{00}^{\theta}T_{00}^{\tau} & T_{00}^{\theta}T_{10}^{\tau} & T_{10}^{\theta}T_{00}^{\tau} & T_{10}^{\theta}T_{10}^{\tau} \\ T_{00}^{\theta}T_{01}^{\tau} & T_{00}^{\theta}T_{11}^{\tau} & T_{10}^{\theta}T_{01}^{\tau} & T_{10}^{\theta}T_{11}^{\tau} \\ T_{01}^{\theta}T_{00}^{\tau} & T_{01}^{\theta}T_{10}^{\tau} & T_{11}^{\theta}T_{00}^{\tau} & T_{11}^{\theta}T_{10}^{\tau} \\ T_{01}^{\theta}T_{01}^{\tau} & T_{01}^{\theta}T_{11}^{\tau} & T_{11}^{\theta}T_{01}^{\tau} & T_{11}^{\theta}T_{11}^{\tau} \end{pmatrix}\right)\begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}\right)|\theta\tau\rangle|10\rangle \\
+&\left(\left(\left(R_{0011} \quad R_{0111} \quad R_{1011} \quad R_{1111}\right)\begin{pmatrix} T_{00}^{\theta}T_{00}^{\tau} & T_{00}^{\theta}T_{10}^{\tau} & T_{10}^{\theta}T_{00}^{\tau} & T_{10}^{\theta}T_{10}^{\tau} \\ T_{00}^{\theta}T_{01}^{\tau} & T_{00}^{\theta}T_{11}^{\tau} & T_{10}^{\theta}T_{01}^{\tau} & T_{10}^{\theta}T_{11}^{\tau} \\ T_{01}^{\theta}T_{00}^{\tau} & T_{01}^{\theta}T_{10}^{\tau} & T_{11}^{\theta}T_{00}^{\tau} & T_{11}^{\theta}T_{10}^{\tau} \\ T_{01}^{\theta}T_{01}^{\tau} & T_{01}^{\theta}T_{11}^{\tau} & T_{11}^{\theta}T_{01}^{\tau} & T_{11}^{\theta}T_{11}^{\tau} \end{pmatrix}\right)\begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}\right)|\theta\tau\rangle|11\rangle
\end{aligned} \right\}
$$

$$
= \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left(\begin{pmatrix} R_{0000} & R_{0100} & R_{1000} & R_{1100} \\ R_{0001} & R_{0101} & R_{1001} & R_{1101} \\ R_{0010} & R_{0110} & R_{1010} & R_{1110} \\ R_{0011} & R_{0111} & R_{1011} & R_{1111} \end{pmatrix}\begin{pmatrix} T_{00}^{\theta}T_{00}^{\tau} & T_{00}^{\theta}T_{10}^{\tau} & T_{10}^{\theta}T_{00}^{\tau} & T_{10}^{\theta}T_{10}^{\tau} \\ T_{00}^{\theta}T_{01}^{\tau} & T_{00}^{\theta}T_{11}^{\tau} & T_{10}^{\theta}T_{01}^{\tau} & T_{10}^{\theta}T_{11}^{\tau} \\ T_{01}^{\theta}T_{00}^{\tau} & T_{01}^{\theta}T_{10}^{\tau} & T_{11}^{\theta}T_{00}^{\tau} & T_{11}^{\theta}T_{10}^{\tau} \\ T_{01}^{\theta}T_{01}^{\tau} & T_{01}^{\theta}T_{11}^{\tau} & T_{11}^{\theta}T_{01}^{\tau} & T_{11}^{\theta}T_{11}^{\tau} \end{pmatrix}\right)\begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}
$$

$$
= \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left(\begin{pmatrix} R_{0000} & R_{0100} & R_{1000} & R_{1100} \\ R_{0001} & R_{0101} & R_{1001} & R_{1101} \\ R_{0010} & R_{0110} & R_{1010} & R_{1110} \\ R_{0011} & R_{0111} & R_{1011} & R_{1111} \end{pmatrix}\left(\begin{pmatrix} T_{00}^{\theta} & T_{10}^{\theta} \\ T_{01}^{\theta} & T_{11}^{\theta} \end{pmatrix} \otimes \begin{pmatrix} T_{00}^{\tau} & T_{10}^{\tau} \\ T_{01}^{\tau} & T_{11}^{\tau} \end{pmatrix}\right)\right)\begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix} \tag{3.18}
$$

Selanjutnya dengan menuliskan bentuk matriks T^{θ}dan T^{τ} sebagai berikut

$$
T^{\theta} = \begin{pmatrix} T_{00}^{\theta} & T_{10}^{\theta} \\ T_{01}^{\theta} & T_{11}^{\theta} \end{pmatrix}; dan\ T^{\tau} = \begin{pmatrix} T_{00}^{\tau} & T_{10}^{\tau} \\ T_{01}^{\tau} & T_{11}^{\tau} \end{pmatrix} \tag{3.19}
$$

yang merupakan bentuk matriks dari nilai koefisien T_{il}^{θ} dan T_{jm}^{τ} dengan

$$
\boldsymbol{T^1} = \begin{pmatrix} T_{00}^{1} & T_{10}^{1} \\ T_{01}^{1} & T_{11}^{1} \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \tag{3.20}
$$

$$
\boldsymbol{T^2} = \begin{pmatrix} T_{00}^{2} & T_{10}^{2} \\ T_{01}^{2} & T_{11}^{2} \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}
$$

$$
\boldsymbol{T^3} = \begin{pmatrix} T_{00}^{3} & T_{10}^{3} \\ T_{01}^{3} & T_{11}^{3} \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}
$$

$$
\boldsymbol{T^4} = \begin{pmatrix} T_{00}^{4} & T_{10}^{4} \\ T_{01}^{4} & T_{11}^{4} \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}
$$

selanjutnya dengan mensubtitusikan persamaan (3.19) ke dalam persamaan (3.18) diperoleh,

$$|\psi\rangle_{A,A1,B,B1,B2,A2} =$$

$$\sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left(\left(\begin{pmatrix} R_{0000} & R_{0100} & R_{1000} & R_{1100} \\ R_{0001} & R_{0101} & R_{1001} & R_{1101} \\ R_{0010} & R_{0110} & R_{1010} & R_{1110} \\ R_{0011} & R_{0111} & R_{1011} & R_{1111} \end{pmatrix} (T^{\theta} \otimes T^{\tau}) \right) \begin{pmatrix} x_0 y_0 \\ x_0 y_1 \\ x_1 y_0 \\ x_1 y_1 \end{pmatrix} \right) \tag{3.21}$$

Memperhatikan ulang persamaan (3.17) dengan menuliskan $R_{lmst} T_{il}^{\theta} T_{jm}^{\tau} = \sigma_{iljmst}^{\theta\tau}$,maka dapat dituliskan,

$$|\psi\rangle_{A,A1,B,B1,B2,A2} = \sum_{i=0}^{1} \sum_{j=0}^{1} \sum_{l,m,s,t=0}^{1} \sum_{\theta=1}^{4} \sum_{\tau=1}^{4} x_i \, y_j \sigma_{iljmst}^{\theta\tau} |\theta\tau\rangle \, |st\rangle \tag{3.22}$$

selanjutnya jika $|\theta\tau\rangle$ dan indeks lm nya dijalankan, maka persamaan (3.22) dapat dituliskan sebagai berikut,

$$|\psi\rangle_{A,A1,B,B1,B2,A2} =$$

$$\sum_{s,t=0}^{1} \sum_{i=0}^{1} \sum_{j=0}^{1} x_i y_j \begin{Bmatrix} \left(\sigma_{i0j0st}^{11} + \sigma_{i0j1st}^{11} + \sigma_{i1j0st}^{11} + \sigma_{i1j1st}^{11}\right)|11\rangle + \left(\sigma_{i0j0st}^{12} + \sigma_{i0j1st}^{12} + \sigma_{i1j0st}^{12} + \sigma_{i1j1st}^{12}\right)|12\rangle \\ +\left(\sigma_{i0j0st}^{13} + \sigma_{i0j1st}^{13} + \sigma_{i1j0st}^{13} + \sigma_{i1j1st}^{13}\right)|13\rangle + \left(\sigma_{i0j0st}^{14} + \sigma_{i0j1st}^{14} + \sigma_{i1j0st}^{14} + \sigma_{i1j1st}^{14}\right)|14\rangle \\ +\left(\sigma_{i0j0st}^{21} + \sigma_{i0j1st}^{21} + \sigma_{i1j0st}^{21} + \sigma_{i1j1st}^{21}\right)|21\rangle + \left(\sigma_{i0j0st}^{22} + \sigma_{i0j1st}^{22} + \sigma_{i1j0st}^{22} + \sigma_{i1j1st}^{22}\right)|22\rangle \\ +\left(\sigma_{i0j0st}^{23} + \sigma_{i0j1st}^{23} + \sigma_{i1j0st}^{23} + \sigma_{i1j1st}^{23}\right)|23\rangle + \left(\sigma_{i0j0st}^{24} + \sigma_{i0j1st}^{24} + \sigma_{i1j0st}^{24} + \sigma_{i1j1st}^{24}\right)|24\rangle \\ +\left(\sigma_{i0j0st}^{31} + \sigma_{i0j1st}^{31} + \sigma_{i1j0st}^{31} + \sigma_{i1j1st}^{31}\right)|31\rangle + \left(\sigma_{i0j0st}^{32} + \sigma_{i0j1st}^{32} + \sigma_{i1j0st}^{32} + \sigma_{i1j1st}^{32}\right)|32\rangle \\ +\left(\sigma_{i0j0st}^{33} + \sigma_{i0j1st}^{33} + \sigma_{i1j0st}^{33} + \sigma_{i1j1st}^{33}\right)|33\rangle + \left(\sigma_{i0j0st}^{34} + \sigma_{i0j1st}^{34} + \sigma_{i1j0st}^{34} + \sigma_{i1j1st}^{34}\right)|34\rangle \\ +\left(\sigma_{i0j0st}^{41} + \sigma_{i0j1st}^{41} + \sigma_{i1j0st}^{41} + \sigma_{i1j1st}^{41}\right)|41\rangle + \left(\sigma_{i0j0st}^{42} + \sigma_{i0j1st}^{42} + \sigma_{i1j0st}^{42} + \sigma_{i1j1st}^{42}\right)|42\rangle \\ +\left(\sigma_{i0j0st}^{43} + \sigma_{i0j1st}^{43} + \sigma_{i1j0st}^{43} + \sigma_{i1j1st}^{43}\right)|43\rangle + \left(\sigma_{i0j0st}^{44} + \sigma_{i0j1st}^{44} + \sigma_{i1j0st}^{44} + \sigma_{i1j1st}^{44}\right)|44\rangle \end{Bmatrix} |st\rangle$$

$$= \sum_{s,t=0}^{1} \sum_{i=0}^{1} \sum_{j=0}^{1} x_i y_j \sum_{\theta,\tau=1}^{4} \left(\left(\sigma_{i0j0st}^{\theta\tau} + \sigma_{i0j1st}^{\theta\tau} + \sigma_{i1j0st}^{\theta\tau} + \sigma_{i1j1st}^{\theta\tau}\right) |\theta\tau\rangle \right) |st\rangle \tag{3.23}$$

selanjutnya dengan menuliskan

$$\left(\sigma_{i0j0st}^{\theta\tau} + \sigma_{i0j1st}^{\theta\tau} + \sigma_{i1j0st}^{\theta\tau} + \sigma_{i1j1st}^{\theta\tau}\right) = \sigma_{ijst}^{\theta\tau} \tag{3.24}$$

dan menjalankan indeks ij pada persamaan (3.23), maka dapat dituliskan

$$|\psi\rangle_{A,A1,B,B1,B2,A2} = \sum_{s,t=0}^{1} \sum_{i=0}^{1} \sum_{j=0}^{1} x_i y_j \sum_{\theta,\tau=1}^{4} \left(\left(\sigma_{i0j0st}^{\theta\tau} + \sigma_{i0j1st}^{\theta\tau} + \sigma_{i1j0st}^{\theta\tau} + \sigma_{i1j1st}^{\theta\tau}\right) |\theta\tau\rangle \right) |st\rangle$$

$$= \sum_{s,t=0}^{1} \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left\{ \begin{matrix} x_0 y_0 \left(\left(\sigma_{0000st}^{\theta\tau} + \sigma_{0001st}^{\theta\tau} + \sigma_{0100st}^{\theta\tau} + \sigma_{0101st}^{\theta\tau}\right)\right) \\ +x_0 y_1 \left(\left(\sigma_{0010st}^{\theta\tau} + \sigma_{0011st}^{\theta\tau} + \sigma_{0110st}^{\theta\tau} + \sigma_{0111st}^{\theta\tau}\right)\right) \\ +x_1 y_0 \left(\left(\sigma_{1000st}^{\theta\tau} + \sigma_{1001st}^{\theta\tau} + \sigma_{1100st}^{\theta\tau} + \sigma_{1101st}^{\theta\tau}\right)\right) \\ +x_1 y_1 \left(\left(\sigma_{1010st}^{\theta\tau} + \sigma_{1011st}^{\theta\tau} + \sigma_{1110st}^{\theta\tau} + \sigma_{1111st}^{\theta\tau}\right)\right) \end{matrix} \right\} |st\rangle$$

$$= \sum_{s,t=0}^{1} \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left(x_0 y_0 \sigma_{00st}^{\theta\tau} + x_0 y_1 \sigma_{01st}^{\theta\tau} + x_1 y_0 \sigma_{10st}^{\theta\tau} + x_1 y_1 \sigma_{11st}^{\theta\tau}\right) |st\rangle$$

$$= \sum_{s,t=0}^{1} \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left(\begin{pmatrix} \sigma_{00st}^{\theta\tau} & \sigma_{01st}^{\theta\tau} & \sigma_{10st}^{\theta\tau} & \sigma_{11st}^{\theta\tau} \end{pmatrix} \begin{pmatrix} x_0 y_0 \\ x_0 y_1 \\ x_1 y_0 \\ x_1 y_1 \end{pmatrix} \right) |st\rangle$$

$$= \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left(\begin{pmatrix} \sigma_{0000}^{\theta\tau} & \sigma_{0100}^{\theta\tau} & \sigma_{1000}^{\theta\tau} & \sigma_{1100}^{\theta\tau} \end{pmatrix} \begin{pmatrix} x_0 y_0 \\ x_0 y_1 \\ x_1 y_0 \\ x_1 y_1 \end{pmatrix} \right) |00\rangle$$

$$+ \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left(\begin{pmatrix} \sigma_{0001}^{\theta\tau} & \sigma_{0101}^{\theta\tau} & \sigma_{1001}^{\theta\tau} & \sigma_{1101}^{\theta\tau} \end{pmatrix} \begin{pmatrix} x_0 y_0 \\ x_0 y_1 \\ x_1 y_0 \\ x_1 y_1 \end{pmatrix} \right) |01\rangle$$

$$+ \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left(\begin{pmatrix} \sigma_{0010}^{\theta\tau} & \sigma_{0110}^{\theta\tau} & \sigma_{1010}^{\theta\tau} & \sigma_{1110}^{\theta\tau} \end{pmatrix} \begin{pmatrix} x_0 y_0 \\ x_0 y_1 \\ x_1 y_0 \\ x_1 y_1 \end{pmatrix} \right) |10\rangle$$

$$+ \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left(\begin{pmatrix} \sigma_{0011}^{\theta\tau} & \sigma_{0111}^{\theta\tau} & \sigma_{1011}^{\theta\tau} & \sigma_{1111}^{\theta\tau} \end{pmatrix} \begin{pmatrix} x_0 y_0 \\ x_0 y_1 \\ x_1 y_0 \\ x_1 y_1 \end{pmatrix} \right) |11\rangle$$

$$= \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left(\begin{pmatrix} \sigma_{0000}^{\theta\tau} & \sigma_{0100}^{\theta\tau} & \sigma_{1000}^{\theta\tau} & \sigma_{1100}^{\theta\tau} \\ \sigma_{0001}^{\theta\tau} & \sigma_{0101}^{\theta\tau} & \sigma_{1001}^{\theta\tau} & \sigma_{1101}^{\theta\tau} \\ \sigma_{0010}^{\theta\tau} & \sigma_{0110}^{\theta\tau} & \sigma_{1010}^{\theta\tau} & \sigma_{1110}^{\theta\tau} \\ \sigma_{0011}^{\theta\tau} & \sigma_{0111}^{\theta\tau} & \sigma_{1011}^{\theta\tau} & \sigma_{1111}^{\theta\tau} \end{pmatrix} \begin{pmatrix} x_0 y_0 \\ x_0 y_1 \\ x_1 y_0 \\ x_1 y_1 \end{pmatrix} \right) \tag{3.25}$$

selanjutnya dengan mereduksi persamaan (3.21) ke dalam bentuk persamaan (3.25), diperoleh

$$\left(\begin{pmatrix} R_{0000} & R_{0100} & R_{1000} & R_{1100} \\ R_{0001} & R_{0101} & R_{1001} & R_{1101} \\ R_{0010} & R_{0110} & R_{1010} & R_{1110} \\ R_{0011} & R_{0111} & R_{1011} & R_{1111} \end{pmatrix} (T^{\theta} \otimes T^{\tau})\right) = \begin{pmatrix} \sigma_{0000}^{\theta\tau} & \sigma_{0100}^{\theta\tau} & \sigma_{1000}^{\theta\tau} & \sigma_{1100}^{\theta\tau} \\ \sigma_{0001}^{\theta\tau} & \sigma_{0101}^{\theta\tau} & \sigma_{1001}^{\theta\tau} & \sigma_{1101}^{\theta\tau} \\ \sigma_{0010}^{\theta\tau} & \sigma_{0110}^{\theta\tau} & \sigma_{1010}^{\theta\tau} & \sigma_{1110}^{\theta\tau} \\ \sigma_{0011}^{\theta\tau} & \sigma_{0111}^{\theta\tau} & \sigma_{1011}^{\theta\tau} & \sigma_{1111}^{\theta\tau} \end{pmatrix} \quad (3.26)$$

Selanjutnya, jika dituliskan matriks berikut

$$\begin{pmatrix} R_{0000} & R_{0100} & R_{1000} & R_{1100} \\ R_{0001} & R_{0101} & R_{1001} & R_{1101} \\ R_{0010} & R_{0110} & R_{1010} & R_{1110} \\ R_{0011} & R_{0111} & R_{1011} & R_{1111} \end{pmatrix} = \boldsymbol{R} \quad (3.27)$$

dengan $\boldsymbol{R}$ disebut sebagai matriks parameter kanal, dan untuk

$$\begin{pmatrix} \sigma_{0000}^{\theta\tau} & \sigma_{0100}^{\theta\tau} & \sigma_{1000}^{\theta\tau} & \sigma_{1100}^{\theta\tau} \\ \sigma_{0001}^{\theta\tau} & \sigma_{0101}^{\theta\tau} & \sigma_{1001}^{\theta\tau} & \sigma_{1101}^{\theta\tau} \\ \sigma_{0010}^{\theta\tau} & \sigma_{0110}^{\theta\tau} & \sigma_{1010}^{\theta\tau} & \sigma_{1110}^{\theta\tau} \\ \sigma_{0011}^{\theta\tau} & \sigma_{0111}^{\theta\tau} & \sigma_{1011}^{\theta\tau} & \sigma_{1111}^{\theta\tau} \end{pmatrix} = \boldsymbol{\sigma^{\theta\tau}} \quad (3.28)$$

maka persamaan (3.26) dapat dituliskan menjadi

$$\boldsymbol{R}(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}}) = (\boldsymbol{\sigma})^{\boldsymbol{\theta\tau}} \quad (3.29)$$

selanjutnya untuk mencari nilai dari matriks parameter kanal maka dilakukan perkalian invers dari matriks $(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}})$ dari kanan, sebagai berikut

$$\boldsymbol{R}(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}})(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}})^{-\boldsymbol{1}} = \boldsymbol{\sigma^{\theta\tau}}(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}})^{-\boldsymbol{1}}$$

$$\boldsymbol{R} = \boldsymbol{\sigma^{\theta\tau}}(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}})^{-\boldsymbol{1}} \quad (3.30)$$

selanjutnya saat Alice dan Bob melakukan pengukuran menggunakan basis Bell sebagai berikut,

$$|\psi^{\theta\tau}\rangle_T = (\langle\boldsymbol{\pi\kappa}| \otimes \boldsymbol{I} \otimes \boldsymbol{I})|\boldsymbol{\psi}\rangle_{\boldsymbol{A,A1,B,B1,B2,A2}}$$

$$= (\langle\boldsymbol{\pi\kappa}| \otimes \boldsymbol{I} \otimes \boldsymbol{I}) \sum_{\boldsymbol{i,j,s,t=0}}^{\boldsymbol{1}} \sum_{\boldsymbol{\theta,\tau=1}}^{\boldsymbol{4}} |\boldsymbol{\theta\tau}\rangle\, \boldsymbol{x_i y_j} (\boldsymbol{\sigma})^{\boldsymbol{\theta\tau}} |\boldsymbol{s}\rangle_{\boldsymbol{B2}} |\boldsymbol{t}\rangle_{\boldsymbol{A2}}$$

$$= \sum_{i,j,s,t=0}^{1} \sum_{\theta,\tau=1}^{\boldsymbol{4}} \langle\boldsymbol{\pi\kappa}|\boldsymbol{\theta\tau}\rangle\ \boldsymbol{x_i y_j} (\boldsymbol{\sigma})^{\boldsymbol{\theta\tau}} |\boldsymbol{s}\rangle_{\boldsymbol{B2}} |\boldsymbol{t}\rangle_{\boldsymbol{A2}}$$

$$= \sum_{i,j,s,t=0}^{1} \sum_{\theta,\tau=1}^{\boldsymbol{4}} \langle\boldsymbol{\pi}|\boldsymbol{\theta}\rangle\langle\boldsymbol{\kappa}|\boldsymbol{\tau}\rangle\ \boldsymbol{x_i y_j} (\boldsymbol{\sigma})^{\boldsymbol{\theta\tau}} |\boldsymbol{s}\rangle_{\boldsymbol{B2}} |\boldsymbol{t}\rangle_{\boldsymbol{A2}}$$

dengan π dan κ merupakan basis Bell dan untuk $\langle\boldsymbol{\pi}|\boldsymbol{\theta}\rangle = \boldsymbol{\delta_{\pi\theta}}$ dan $\langle\boldsymbol{\kappa}|\boldsymbol{\tau}\rangle \ = \boldsymbol{\delta_{\kappa\tau}}$ merupakan delta kronecker yang memenuhi ($\delta_{\pi\theta} = 1, jika\, \pi = \theta, dan\, \delta_{\pi\theta} = 0, jika\, \pi \neq \theta$) dan ($\delta_{\kappa\tau} = 1, jika\, \kappa = \tau, dan\, \delta_{\kappa\tau} = 0, jika\, \kappa \neq \tau$), sehingga

$$\begin{aligned}
|\psi^{\theta\tau}\rangle_T &= \sum_{i,j,s,t=0}^{1} \sum_{\theta,\tau=1}^{\boldsymbol{4}} \boldsymbol{\delta_{\pi\theta}\delta_{\kappa\tau}\, x_i y_j (\sigma)^{\theta\tau} |s\rangle_{B2} |t\rangle_{A2}} \\
&= \sum_{i,j,s,t=0}^{1} \boldsymbol{x_i y_j (\sigma)^{\theta\tau} |s\rangle_{B2} |t\rangle_{A2}} \\
&= \sum_{i,j,s,t=0}^{1} \boldsymbol{x_i y_j \left(\sigma^{\theta} \otimes \sigma^{\tau}\right)\left(|s\rangle_{B2} \otimes |t\rangle_{A2}\right)} \\
&= \sum_{i,j,s,t=0}^{1} \boldsymbol{x_i y_j \left(\sigma^{\theta} |s\rangle_{B2}\right) \otimes \left(\sigma^{\tau} |t\rangle_{A2}\right)}
\end{aligned} \tag{3.31}$$

dengan $\boldsymbol{\sigma^{\theta}}$ merupakan matriks yang diturunkan melalui transformasi hasil pengukuran oleh Alice, dan juga untuk $\boldsymbol{\sigma^{\tau}}$ merupakan matriks yang diturunkan melalui transformasi hasil pengukuran Bob, maka untuk mendapatkan matriks parameter kanal dapat juga dituliskan dengan,

$$\begin{aligned}
\boldsymbol{R} &= \boldsymbol{\sigma^{\theta\tau}\left(T^{\theta} \otimes T^{\tau}\right)^{-1}} \\
&= \boldsymbol{\left(\sigma^{\theta} \otimes \sigma^{\tau}\right)\left(T^{\theta} \otimes T^{\tau}\right)^{-1}} \\
&= \boldsymbol{\left(\sigma^{\theta} \otimes \sigma^{\tau}\right)\left(\left(T^{\theta}\right)^{-1} \otimes (T^{\tau})^{-1}\right)}
\end{aligned} \tag{3.32}$$

dengan perkalian tensor matriks $\boldsymbol{T^{\theta}}$ dan $\boldsymbol{T^{\tau}}$ menghasilkan bentuk matriks 4x4 yang uniter, serta $\boldsymbol{\sigma^{\theta}}$ dan $\boldsymbol{\sigma^{\tau}}$ haruslah matriks yang uniter sehingga matriks parameter kanal yang dihasilkan harus merupakan matriks yang uniter agar didapatkan informasi yang saling terkirim antara Alice dan Bob.

3.3 Matriks Uniter

Suatu matriks $\boldsymbol{U}$ dikatakan uniter jika memenuhi,

$$\boldsymbol{UU^{\dagger} = U^{\dagger}U = 1} \tag{3.33}$$

dengan dimisalkan,

$$\boldsymbol{U} = \begin{pmatrix} \boldsymbol{a\, e^{i\alpha}} & \boldsymbol{b\, e^{i\beta}} \\ \boldsymbol{c\, e^{i\gamma}} & \boldsymbol{d\, e^{i\delta}} \end{pmatrix}$$

maka dengan mengoperasikan $\boldsymbol{U}$ pada persamaan (3.32) sebagai berikut,

$$\begin{aligned}\boldsymbol{UU}^{\dagger} &= \begin{pmatrix} \boldsymbol{a\,e^{i\alpha}} & \boldsymbol{b\,e^{i\beta}} \\ \boldsymbol{c\,e^{i\gamma}} & \boldsymbol{d\,e^{i\delta}} \end{pmatrix}\begin{pmatrix} \boldsymbol{a\,e^{-i\alpha}} & \boldsymbol{c\,e^{-i\gamma}} \\ \boldsymbol{b\,e^{-i\beta}} & \boldsymbol{d\,e^{-i\delta}} \end{pmatrix} \\ &= \begin{pmatrix} \boldsymbol{a^2+b^2} & \boldsymbol{ac\,e^{i(\alpha-\gamma)}+bd\,e^{i(\beta-\delta)}} \\ \boldsymbol{ac\,e^{-i(\alpha-\gamma)}+bd\,e^{-i(\beta-\delta)}} & \boldsymbol{c^2+d^2} \end{pmatrix} \\ &= \begin{pmatrix} \boldsymbol{1} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{1} \end{pmatrix}\end{aligned}$$

didapatkan

$$\boldsymbol{a^2+b^2=1}$$

dan

$$\begin{aligned}\boldsymbol{ac\,e^{i(\alpha-\gamma)}+bd\,e^{i(\beta-\delta)}} &= \boldsymbol{0} \\ \boldsymbol{ac\,e^{i(\alpha-\gamma)}} &= \boldsymbol{-bd\,e^{i(\beta-\delta)}} \\ \boldsymbol{ac} &= \boldsymbol{-bd\,e^{-i(\alpha-\gamma)}e^{i(\beta-\delta)}} \\ \boldsymbol{ac} &= \boldsymbol{-bd\,e^{i(\beta+\gamma-\alpha-\delta)}}\end{aligned}$$

Sehingga untuk $\boldsymbol{ac+bd=0}$, maka $\boldsymbol{\beta+\gamma-\alpha-\delta=0}$, atau dapat dituliskan dengan

$$\boldsymbol{\delta=\beta+\gamma-\alpha} \tag{3.34}$$

Selanjutnya jika $a=\cos\theta$; $b=\sin\theta$; $c=\sin\omega$; $d=\cos\omega$, maka diperoleh

$$\begin{aligned}\boldsymbol{ac+bd} &= \boldsymbol{0} \\ \cos\theta\sin\omega+\sin\theta\cos\omega &= 0 \\ \sin(\theta+\omega) &= \sin 0 \\ \theta+\omega &= 0 \\ \theta &= -\omega\end{aligned}$$

Dan jika $a=\cos\theta$; $b=\sin\theta$; $c=-\sin\omega$; $d=\cos\omega$, maka diperoleh

$$\begin{aligned}\boldsymbol{ac+bd} &= \boldsymbol{0} \\ -\cos\theta\sin\omega+\sin\theta\cos\omega &= 0 \\ \sin(\theta-\omega) &= \sin 0 \\ \theta-\omega &= 0 \\ \theta &= \omega\end{aligned}$$

Sehingga untuk $\sin(\theta\pm\omega)=\sin 0$, didapatkan

$$\theta\pm\omega=0$$

$$\theta=\mp\omega \tag{3.35}$$

dan dengan melihat hubungan $\boldsymbol{ac = -bd}$, maka diperoleh

$$a = \pm d = \cos\theta$$

$$b = \mp c = \sin\theta$$

Sehingga bentuk matriks uniter berukuran 2x2 juga dapat dituliskan secara umum dengan,

$$\boldsymbol{U} = \begin{pmatrix} \boldsymbol{\cos\theta\ e^{i\alpha}} & \boldsymbol{\sin\theta\, e^{i\beta}} \\ \boldsymbol{-\sin\theta\, e^{i\gamma}} & \boldsymbol{\cos\theta\, e^{i\delta}} \end{pmatrix}$$

$$= \begin{pmatrix} \boldsymbol{\cos\theta\ e^{i\alpha}} & \boldsymbol{\sin\theta\, e^{i\beta}} \\ \boldsymbol{-\sin\theta\, e^{i\gamma}} & \boldsymbol{\cos\theta\, e^{i(\beta+\gamma-\alpha)}} \end{pmatrix} \tag{3.36}$$

dan dapat ditentukan hanya dengan 4 parameter yaitu $\theta, \alpha, \beta, \gamma$.

Halaman ini sengaja dikosongkan

BAB IV
KRITERIA KANAL UNTUK TELEPORTASI KUANTUM DUA ARAH

4.1 MATRIKS PARAMETER KANAL

Matriks parameter kanal merupakan matriks yang dibentuk dari representasi tensor dari matriks transformasi T^{θ} dan T^{τ} dan juga dengan matriks transformasi dari hasil pengukuran yang dibentuk oleh Alice dan Bob. Matriks parameter kanal ini terdiri dari matriks berukuran 4x4, sebagai berikut

$$\boldsymbol{R} = \begin{pmatrix} R_{0000} & R_{0100} & R_{1000} & R_{1100} \\ R_{0001} & R_{0101} & R_{1001} & R_{1101} \\ R_{0010} & R_{0110} & R_{1010} & R_{1110} \\ R_{0011} & R_{0111} & R_{1011} & R_{1111} \end{pmatrix}$$

dengan $R_{0000}, R_{0001}, \dots, R_{1111}$ merupakan nilai konstanta dari kanal. Nilai dari matriks ini selanjutnya bisa digunakan untuk membentuk kanal kuantumnya, yang dapat dituliskan sebagai berikut

$$|\varphi\rangle_{A1,B1,B2,A2} = \sum_{l,m,s,t=0}^{1} R_{lmst}|lmst\rangle$$

Untuk membentuk matriks parameter kanal berukuran 4x4 pada teleportasi kuantum dua arah dapat dilakukan dengan menggunakan rumusan sebagai berikut.

$$\boldsymbol{R}\left(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}}\right) = \boldsymbol{\sigma^{\theta}} \otimes \boldsymbol{\sigma^{\tau}}$$

Selanjutnya dengan melakukan perkalian $\left(T^{\theta} \otimes T^{\tau}\right)^{-1}$ dari kanan, maka diperoleh persamaan R, sebagai berikut

$$\begin{aligned} \boldsymbol{R} &= \left(\boldsymbol{\sigma^{\theta}} \otimes \boldsymbol{\sigma^{\tau}}\right)\left(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}}\right)^{-1} \\ &= \left(\boldsymbol{\sigma^{\theta}} \otimes \boldsymbol{\sigma^{\tau}}\right)\left(\left(\boldsymbol{T^{\theta}}\right)^{-1} \otimes (\boldsymbol{T^{\tau}})^{-1}\right) \\ &= \left(\boldsymbol{\sigma^{\theta}}\left(\boldsymbol{T^{\theta}}\right)^{-1}\right) \otimes \left(\boldsymbol{\sigma^{\tau}}(\boldsymbol{T^{\tau}})^{-1}\right) \end{aligned}$$

dengan $\boldsymbol{T^{\theta}}$ dan $\boldsymbol{T^{\tau}}$ merupakan matriks parameter yang didapatkan sebagai konsekuensi penggunaan metode tensor seperti yang ditunjukkan dalam persamaan

(3.20). Selanjutnya untuk $\boldsymbol{\sigma^{\theta}}$dan $\boldsymbol{\sigma^{\tau}}$merupakan matriks uniter berukuran 2x2 yang memenuhi,

$$\boldsymbol{U} = \begin{pmatrix} \boldsymbol{\cos\theta\ e^{i\alpha}} & \boldsymbol{\sin\theta\ e^{i\beta}} \\ \boldsymbol{-\sin\theta\ e^{i\gamma}} & \boldsymbol{\cos\theta\ e^{i(\beta+\gamma-\alpha)}} \end{pmatrix}$$

.

4.2 Bentuk Umum Kanal $\boldsymbol{R = U(\upsilon)T^{\theta^{-1}} \otimes U(\kappa)T^{\tau^{-1}}}$

Matriks parameter kanal R dapat di bentuk dengan memenuhi syarat uniter dengan

$$\boldsymbol{R = \sigma^{\theta}\ T^{\theta^{-1}} \otimes \sigma^{\tau} T^{\tau^{-1}}}$$

$$\boldsymbol{= U(\upsilon)T^{\theta^{-1}} \otimes U(\kappa)T^{\tau^{-1}}}$$

dengan $\boldsymbol{U(\upsilon)}$ dan $\boldsymbol{U(\kappa)}$ merupakan matriks uniter secara umum untuk σ^{θ} dan σ^{τ}. Selanjutnya jika didefinisikan $\boldsymbol{U_1 = U(\upsilon)T^{\theta^{-1}}}$ dan $\boldsymbol{U_2 = U(\kappa)T^{\tau^{-1}}}$ maka persamaan di atas dapat dituliskan dengan

$$\boldsymbol{R = U_1 \otimes U_2}$$

Selanjutnya bentuk matriks dari U_1secara umum menjadi,

$$\boldsymbol{U_1} = \left(\begin{pmatrix} \boldsymbol{\cos\theta_1\ e^{i\alpha_1}} & \boldsymbol{\sin\theta_1\ e^{i\beta_1}} \\ \boldsymbol{-\sin\theta_1\ e^{i\gamma_1}} & \boldsymbol{\cos\theta_1\ e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta} & T_{10}^{\theta} \\ T_{01}^{\theta} & T_{11}^{\theta} \end{pmatrix}^{-1} \right)$$

dan bentuk matriks U_1untuk $\theta = 1$, didapatkan

$$U_1 = \left(\begin{pmatrix} \boldsymbol{\cos\theta_1\ e^{i\alpha_1}} & \boldsymbol{\sin\theta_1\ e^{i\beta_1}} \\ \boldsymbol{-\sin\theta_1\ e^{i\gamma_1}} & \boldsymbol{\cos\theta_1\ e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix} \begin{pmatrix} T_{00}^{1} & T_{10}^{1} \\ T_{01}^{1} & T_{11}^{1} \end{pmatrix}^{-1} \right)$$

$$= \left(\begin{pmatrix} \boldsymbol{\cos\theta_1\ e^{i\alpha_1}} & \boldsymbol{\sin\theta_1\ e^{i\beta_1}} \\ \boldsymbol{-\sin\theta_1\ e^{i\gamma_1}} & \boldsymbol{\cos\theta_1\ e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix} \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}^{-1} \right)$$

$$= \left(\frac{1}{\sqrt{2}} \begin{pmatrix} \boldsymbol{\cos\theta_1\ e^{i\alpha_1}} & \boldsymbol{\sin\theta_1\ e^{i\beta_1}} \\ \boldsymbol{-\sin\theta_1\ e^{i\gamma_1}} & \boldsymbol{\cos\theta_1\ e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \right)$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} \boldsymbol{\cos\theta_1\ e^{i\alpha_1}} & \boldsymbol{\sin\theta_1\ e^{i\beta_1}} \\ \boldsymbol{-\sin\theta_1\ e^{i\gamma_1}} & \boldsymbol{\cos\theta_1\ e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix}$$

untuk $\theta = 2$, maka

$$U_1 = \left(\begin{pmatrix} \boldsymbol{cos\,\theta_1\;\, e^{i\alpha_1}} & \boldsymbol{sin\,\theta_1\, e^{i\beta_1}} \\ \boldsymbol{-sin\,\theta_1\, e^{i\gamma_1}} & \boldsymbol{cos\,\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix} \begin{pmatrix} T_{00}^2 & T_{10}^2 \\ T_{01}^2 & T_{11}^2 \end{pmatrix}^{-1} \right)$$

$$= \left(\begin{pmatrix} \boldsymbol{cos\,\theta_1\;\, e^{i\alpha_1}} & \boldsymbol{sin\,\theta_1\, e^{i\beta_1}} \\ \boldsymbol{-sin\,\theta_1\, e^{i\gamma_1}} & \boldsymbol{cos\,\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix} \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}^{-1} \right)$$

$$= \left(\frac{1}{\sqrt{2}} \begin{pmatrix} \boldsymbol{cos\,\theta_1\;\, e^{i\alpha_1}} & \boldsymbol{sin\,\theta_1\, e^{i\beta_1}} \\ \boldsymbol{-sin\,\theta_1\, e^{i\gamma_1}} & \boldsymbol{cos\,\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \right)$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} \boldsymbol{cos\,\theta_1\;\, e^{i\alpha_1}} & \boldsymbol{-sin\,\theta_1\, e^{i\beta_1}} \\ \boldsymbol{-sin\,\theta_1\, e^{i\gamma_1}} & \boldsymbol{-cos\,\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix}$$

untuk $\theta = 3$, maka

$$U_1 = \left(\begin{pmatrix} \boldsymbol{cos\,\theta_1\;\, e^{i\alpha_1}} & \boldsymbol{sin\,\theta_1\, e^{i\beta_1}} \\ \boldsymbol{-sin\,\theta_1\, e^{i\gamma_1}} & \boldsymbol{cos\,\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix} \begin{pmatrix} T_{00}^3 & T_{10}^3 \\ T_{01}^3 & T_{11}^3 \end{pmatrix}^{-1} \right)$$

$$= \left(\begin{pmatrix} \boldsymbol{cos\,\theta_1\;\, e^{i\alpha_1}} & \boldsymbol{sin\,\theta_1\, e^{i\beta_1}} \\ \boldsymbol{-sin\,\theta_1\, e^{i\gamma_1}} & \boldsymbol{cos\,\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix} \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}^{-1} \right)$$

$$= \left(\frac{1}{\sqrt{2}} \begin{pmatrix} \boldsymbol{cos\,\theta_1\;\, e^{i\alpha_1}} & \boldsymbol{sin\,\theta_1\, e^{i\beta_1}} \\ \boldsymbol{-sin\,\theta_1\, e^{i\gamma_1}} & \boldsymbol{cos\,\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix} \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \right)$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} \boldsymbol{sin\,\theta_1\, e^{i\beta_1}} & \boldsymbol{cos\,\theta_1\;\, e^{i\alpha_1}} \\ \boldsymbol{cos\,\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)}} & \boldsymbol{-sin\,\theta_1\, e^{i\gamma_1}} \end{pmatrix}$$

untuk $\theta = 4$, maka

$$U_1 = \left(\begin{pmatrix} \boldsymbol{cos\,\theta_1\;\, e^{i\alpha_1}} & \boldsymbol{sin\,\theta_1\, e^{i\beta_1}} \\ \boldsymbol{-sin\,\theta_1\, e^{i\gamma_1}} & \boldsymbol{cos\,\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix} \begin{pmatrix} T_{00}^4 & T_{10}^4 \\ T_{01}^4 & T_{11}^4 \end{pmatrix}^{-1} \right)$$

$$= \left(\begin{pmatrix} \boldsymbol{cos\,\theta_1\;\, e^{i\alpha_1}} & \boldsymbol{sin\,\theta_1\, e^{i\beta_1}} \\ \boldsymbol{-sin\,\theta_1\, e^{i\gamma_1}} & \boldsymbol{cos\,\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix} \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}^{-1} \right)$$

$$= \left(\frac{1}{\sqrt{2}} \begin{pmatrix} \boldsymbol{cos\,\theta_1\;\, e^{i\alpha_1}} & \boldsymbol{sin\,\theta_1\, e^{i\beta_1}} \\ \boldsymbol{-sin\,\theta_1\, e^{i\gamma_1}} & \boldsymbol{cos\,\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)}} \end{pmatrix} \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \right)$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} -\boldsymbol{sin\ \theta_1\ e^{i\beta_1}} & \boldsymbol{cos\ \theta_1\ \ e^{i\alpha_1}} \\ -\boldsymbol{cos\ \theta_1\ e^{i(\beta_1+\gamma_1-\alpha_1)}} & -\boldsymbol{sin\ \theta_1\ e^{i\gamma_1}} \end{pmatrix}$$

selanjutnya secara umum bentuk matriks U_2dapat dituliskna dengan,

$$\boldsymbol{U_2} = \left(\begin{pmatrix} \boldsymbol{cos\ \theta_2\ e^{i\alpha_2}} & \boldsymbol{sin\ \theta_2\ e^{i\beta_2}} \\ -\boldsymbol{sin\ \theta_2\ e^{i\gamma_2}} & \boldsymbol{cos\ \theta_2\ e^{i(\beta_2+\gamma_2-\alpha_2)}} \end{pmatrix} \begin{pmatrix} \boldsymbol{T_{00}^{\tau}} & \boldsymbol{T_{10}^{\tau}} \\ \boldsymbol{T_{01}^{\tau}} & \boldsymbol{T_{11}^{\tau}} \end{pmatrix}^{\boldsymbol{-1}} \right)$$

dan bentuk matriks U_2untuk $\tau = 1$, didapatkan

$$U_2 = \left(\begin{pmatrix} \boldsymbol{cos\ \theta_2\ e^{i\alpha_2}} & \boldsymbol{sin\ \theta_2\ e^{i\beta_2}} \\ -\boldsymbol{sin\ \theta_2\ e^{i\gamma_2}} & \boldsymbol{cos\ \theta_2\ e^{i(\beta_2+\gamma_2-\alpha_2)}} \end{pmatrix} \begin{pmatrix} T_{00}^{1} & T_{10}^{1} \\ T_{01}^{1} & T_{11}^{1} \end{pmatrix}^{-1} \right)$$

$$= \left(\begin{pmatrix} \boldsymbol{cos\ \theta_2\ e^{i\alpha_2}} & \boldsymbol{sin\ \theta_2\ e^{i\beta_2}} \\ -\boldsymbol{sin\ \theta_2\ e^{i\gamma_2}} & \boldsymbol{cos\ \theta_2\ e^{i(\beta_2+\gamma_2-\alpha_2)}} \end{pmatrix} \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}^{-1} \right)$$

$$= \left(\frac{1}{\sqrt{2}} \begin{pmatrix} \boldsymbol{cos\ \theta_2\ e^{i\alpha_2}} & \boldsymbol{sin\ \theta_2\ e^{i\beta_2}} \\ -\boldsymbol{sin\ \theta_2\ e^{i\gamma_2}} & \boldsymbol{cos\ \theta_2\ e^{i(\beta_2+\gamma_2-\alpha_2)}} \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \right)$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} \boldsymbol{cos\ \theta_2\ e^{i\alpha_2}} & \boldsymbol{sin\ \theta_2\ e^{i\beta_2}} \\ -\boldsymbol{sin\ \theta_2\ e^{i\gamma_2}} & \boldsymbol{cos\ \theta_2\ e^{i(\beta_2+\gamma_2-\alpha_2)}} \end{pmatrix}$$

Untuk $\tau = 2$, maka

$$U_2 = \left(\begin{pmatrix} \boldsymbol{cos\ \theta_2\ e^{i\alpha_2}} & \boldsymbol{sin\ \theta_2\ e^{i\beta_2}} \\ -\boldsymbol{sin\ \theta_2\ e^{i\gamma_2}} & \boldsymbol{cos\ \theta_2\ e^{i(\beta_2+\gamma_2-\alpha_2)}} \end{pmatrix} \begin{pmatrix} T_{00}^{2} & T_{10}^{2} \\ T_{01}^{2} & T_{11}^{2} \end{pmatrix}^{-1} \right)$$

$$= \left(\begin{pmatrix} \boldsymbol{cos\ \theta_2\ e^{i\alpha_2}} & \boldsymbol{sin\ \theta_2\ e^{i\beta_2}} \\ -\boldsymbol{sin\ \theta_2\ e^{i\gamma_2}} & \boldsymbol{cos\ \theta_2\ e^{i(\beta_2+\gamma_2-\alpha_2)}} \end{pmatrix} \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}^{-1} \right)$$

$$= \left(\frac{1}{\sqrt{2}} \begin{pmatrix} \boldsymbol{cos\ \theta_2\ e^{i\alpha_2}} & \boldsymbol{sin\ \theta_2\ e^{i\beta_2}} \\ -\boldsymbol{sin\ \theta_2\ e^{i\gamma_2}} & \boldsymbol{cos\ \theta_2\ e^{i(\beta_2+\gamma_2-\alpha_2)}} \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \right)$$

$$= \frac{1}{\sqrt{2}} \left(\begin{pmatrix} \boldsymbol{cos\ \theta_2\ e^{i\alpha_2}} & -\boldsymbol{sin\ \theta_2\ e^{i\beta_2}} \\ -\boldsymbol{sin\ \theta_2\ e^{i\gamma_2}} & -\boldsymbol{cos\ \theta_2\ e^{i(\beta_2+\gamma_2-\alpha_2)}} \end{pmatrix} \right)$$

Untuk $\tau = 3$, maka

$$U_2 = \left(\begin{pmatrix} \cos\theta_2\, e^{i\alpha_2} & \sin\theta_2\, e^{i\beta_2} \\ -\sin\theta_2\, e^{i\gamma_2} & \cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} \end{pmatrix} \begin{pmatrix} T_{00}^3 & T_{10}^3 \\ T_{01}^3 & T_{11}^3 \end{pmatrix}^{-1} \right)$$

$$= \left(\begin{pmatrix} \cos\theta_2\, e^{i\alpha_2} & \sin\theta_2\, e^{i\beta_2} \\ -\sin\theta_2\, e^{i\gamma_2} & \cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} \end{pmatrix} \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}^{-1} \right)$$

$$= \left(\frac{1}{\sqrt{2}} \begin{pmatrix} \cos\theta_2\, e^{i\alpha_2} & \sin\theta_2\, e^{i\beta_2} \\ -\sin\theta_2\, e^{i\gamma_2} & \cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} \end{pmatrix} \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \right)$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} \sin\theta_2\, e^{i\beta_2} & \cos\theta_2\, e^{i\alpha_2} \\ \cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_2\, e^{i\gamma_2} \end{pmatrix}$$

Untuk $\tau = 4$, maka

$$U_2 = \left(\begin{pmatrix} \cos\theta_2\, e^{i\alpha_2} & \sin\theta_2\, e^{i\beta_2} \\ -\sin\theta_2\, e^{i\gamma_2} & \cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} \end{pmatrix} \begin{pmatrix} T_{00}^4 & T_{10}^4 \\ T_{01}^4 & T_{11}^4 \end{pmatrix}^{-1} \right)$$

$$= \left(\begin{pmatrix} \cos\theta_2\, e^{i\alpha_2} & \sin\theta_2\, e^{i\beta_2} \\ -\sin\theta_2\, e^{i\gamma_2} & \cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} \end{pmatrix} \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}^{-1} \right)$$

$$= \left(\frac{1}{\sqrt{2}} \begin{pmatrix} \cos\theta_2\, e^{i\alpha_2} & \sin\theta_2\, e^{i\beta_2} \\ -\sin\theta_2\, e^{i\gamma_2} & \cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} \end{pmatrix} \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \right)$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} -\sin\theta_2\, e^{i\beta_2} & \cos\theta_2\, e^{i\alpha_2} \\ -\cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_2\, e^{i\gamma_2} \end{pmatrix}$$

Sehingga bentuk matriks parameter kanal secara umum dapat dituliskan dengan

1. Persamaan umum R untuk $\theta = 1$ dan $\tau = 1$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} \cos\theta_1\, e^{i\alpha_1} & \sin\theta_1\, e^{i\beta_1} \\ -\sin\theta_1\, e^{i\gamma_1} & \cos\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)} \end{pmatrix} \otimes \frac{1}{\sqrt{2}} \begin{pmatrix} \cos\theta_2\, e^{i\alpha_2} & \sin\theta_2\, e^{i\beta_2} \\ -\sin\theta_2\, e^{i\gamma_2} & \cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} \cos\theta_1 \cos\theta_2\, e^{i(\alpha_1+\alpha_2)} & \cos\theta_1 \sin\theta_2\, e^{i(\alpha_1+\beta_2)} & \sin\theta_1 \cos\theta_2\, e^{i(\beta_1+\alpha_2)} & \sin\theta_1 \sin\theta_2\, e^{i(\beta_1+\beta_2)} \\ -\cos\theta_1 \sin\theta_2\, e^{i(\alpha_1+\gamma_2)} & \cos\theta_1 \cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_1 \sin\theta_2\, e^{i(\beta_1+\gamma_2)} & \sin\theta_1 \cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} \\ -\sin\theta_1 \cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & -\sin\theta_1 \sin\theta_2\, e^{i(\gamma_1+\beta_2)} & \cos\theta_1 \cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & \cos\theta_1 \sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} \\ \sin\theta_1 \sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & -\sin\theta_1 \cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1 \sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & \cos\theta_1 \cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

2. Persamaan umum R untuk $\theta = 1$ dan $\tau = 2$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} \cos\theta_1 \; e^{i\alpha_1} & \sin\theta_1 \, e^{i\beta_1} \\ -\sin\theta_1 \, e^{i\gamma_1} & \cos\theta_1 \, e^{i(\beta_1+\gamma_1-\alpha_1)} \end{pmatrix} \otimes \frac{1}{\sqrt{2}} \begin{pmatrix} \cos\theta_2 \, e^{i\alpha_2} & -\sin\theta_2 \, e^{i\beta_2} \\ -\sin\theta_2 \, e^{i\gamma_2} & -\cos\theta_2 \, e^{i(\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} \cos\theta_1 \cos\theta_2 \; e^{i(\alpha_1+\alpha_2)} & -\cos\theta_1 \sin\theta_2 \; e^{i(\alpha_1+\beta_2)} & \sin\theta_1 \cos\theta_2 \, e^{i(\beta_1+\alpha_2)} & -\sin\theta_1 \sin\theta_2 \, e^{i(\beta_1+\beta_2)} \\ -\cos\theta_1 \sin\theta_2 \; e^{i(\alpha_1+\gamma_2)} & -\cos\theta_1 \cos\theta_2 \, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_1 \sin\theta_2 \, e^{i(\beta_1+\gamma_2)} & -\sin\theta_1 \cos\theta_2 \, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} \\ -\sin\theta_1 \cos\theta_2 \, e^{i(\gamma_1+\alpha_2)} & \sin\theta_1 \sin\theta_2 \, e^{i(\gamma_1+\beta_2)} & \cos\theta_1 \cos\theta_2 \, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & -\cos\theta_1 \sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} \\ \sin\theta_1 \sin\theta_2 \, e^{i(\gamma_1+\gamma_2)} & \sin\theta_1 \cos\theta_2 \, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1 \sin\theta_2 \, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & -\cos\theta_1 \cos\theta_2 \, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

3. Persamaan umum R untuk $\theta = 1$ dan $\tau = 3$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} \cos\theta_1 \; e^{i\alpha_1} & \sin\theta_1 \, e^{i\beta_1} \\ -\sin\theta_1 \, e^{i\gamma_1} & \cos\theta_1 \, e^{i(\beta_1+\gamma_1-\alpha_1)} \end{pmatrix} \otimes \frac{1}{\sqrt{2}} \begin{pmatrix} \sin\theta_2 \, e^{i\beta_2} & \cos\theta_2 \, e^{i\alpha_2} \\ \cos\theta_2 \, e^{i(\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_2 \, e^{i\gamma_2} \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} \cos\theta_1 \sin\theta_2 \;\; e^{i(\alpha_1+\beta_2)} & \cos\theta_1 \cos\theta_2 \, e^{i(\alpha_1+\alpha_2)} & \sin\theta_1 \sin\theta_2 \, e^{i(\beta_1+\beta_2)} & \sin\theta_1 \cos\theta_2 e^{i(\beta_1+\alpha_2)} \\ \cos\theta_1 \; \cos\theta_2 \, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1 \sin\theta_2 \;\; e^{i(\alpha_1+\gamma_2)} & \sin\theta_1 \cos\theta_2 \, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_1 \sin\theta_2 \, e^{i(\beta_1+\gamma_2)} \\ -\sin\theta_1 \sin\theta_2 \, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1 \cos\theta_2 \, e^{i(\gamma_1+\alpha_2)} & \cos\theta_1 \sin\theta_2 \, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & \cos\theta_1 \cos\theta_2 \, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} \\ -\sin\theta_1 \cos\theta_2 \, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1 \sin\theta_2 \, e^{i(\gamma_1+\gamma_2)} & \cos\theta_1 \cos\theta_2 \, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1 \sin\theta_2 \, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} \end{pmatrix}$$

4. Persamaan umum R untuk $\theta = 1$ dan $\tau = 4$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} \cos\theta_1 \; e^{i\alpha_1} & \sin\theta_1 \, e^{i\beta_1} \\ -\sin\theta_1 \, e^{i\gamma_1} & \cos\theta_1 \, e^{i(\beta_1+\gamma_1-\alpha_1)} \end{pmatrix} \otimes \frac{1}{\sqrt{2}} \begin{pmatrix} -\sin\theta_2 \, e^{i\beta_2} & \cos\theta_2 \, e^{i\alpha_2} \\ -\cos\theta_2 \, e^{i(\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_2 \, e^{i\gamma_2} \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} -\cos\theta_1 \sin\theta_2 \;\; e^{i(\alpha_1+\beta_2)} & \cos\theta_1 \cos\theta_2 \, e^{i(\alpha_1+\alpha_2)} & -\sin\theta_1 \sin\theta_2 \, e^{i(\beta_1+\beta_2)} & \sin\theta_1 \cos\theta_2 e^{i(\beta_1+\alpha_2)} \\ -\cos\theta_1 \; \cos\theta_2 \, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1 \sin\theta_2 \;\; e^{i(\alpha_1+\gamma_2)} & -\sin\theta_1 \cos\theta_2 \, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_1 \sin\theta_2 \, e^{i(\beta_1+\gamma_2)} \\ \sin\theta_1 \sin\theta_2 \, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1 \cos\theta_2 \, e^{i(\gamma_1+\alpha_2)} & -\cos\theta_1 \sin\theta_2 \, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & \cos\theta_1 \cos\theta_2 \, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} \\ \sin\theta_1 \cos\theta_2 \, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1 \sin\theta_2 \, e^{i(\gamma_1+\gamma_2)} & -\cos\theta_1 \cos\theta_2 \, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1 \sin\theta_2 \, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} \end{pmatrix}$$

5. Persamaan umum R untuk $\theta = 2$ dan $\tau = 1$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} \cos\theta_1 \; e^{i\alpha_1} & -\sin\theta_1 \, e^{i\beta_1} \\ -\sin\theta_1 \, e^{i\gamma_1} & -\cos\theta_1 \, e^{i(\beta_1+\gamma_1-\alpha_1)} \end{pmatrix} \otimes \frac{1}{\sqrt{2}} \begin{pmatrix} \cos\theta_2 \, e^{i\alpha_2} & \sin\theta_2 \, e^{i\beta_2} \\ -\sin\theta_2 \, e^{i\gamma_2} & \cos\theta_2 \, e^{i(\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} \cos\theta_1 \cos\theta_2 \; e^{i(\alpha_1+\alpha_2)} & \cos\theta_1 \sin\theta_2 \; e^{i(\alpha_1+\beta_2)} & -\sin\theta_1 \cos\theta_2 \, e^{i(\beta_1+\alpha_2)} & -\sin\theta_1 \sin\theta_2 \, e^{i(\beta_1+\beta_2)} \\ -\cos\theta_1 \sin\theta_2 \; e^{i(\alpha_1+\gamma_2)} & \cos\theta_1 \cos\theta_2 \, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1 \sin\theta_2 \, e^{i(\beta_1+\gamma_2)} & -\sin\theta_1 \cos\theta_2 \, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} \\ -\sin\theta_1 \cos\theta_2 \, e^{i(\gamma_1+\alpha_2)} & -\sin\theta_1 \sin\theta_2 \, e^{i(\gamma_1+\beta_2)} & -\cos\theta_1 \cos\theta_2 \, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & -\cos\theta_1 \sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} \\ \sin\theta_1 \sin\theta_2 \, e^{i(\gamma_1+\gamma_2)} & -\sin\theta_1 \cos\theta_2 \, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \cos\theta_1 \sin\theta_2 \, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & -\cos\theta_1 \cos\theta_2 \, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

6. Persamaan umum R untuk $\theta = 2$ dan $\tau = 2$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}}\begin{pmatrix} \cos\theta_1\ e^{i\alpha_1} & -\sin\theta_1\, e^{i\beta_1} \\ -\sin\theta_1\, e^{i\gamma_1} & -\cos\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)} \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} \cos\theta_2\, e^{i\alpha_2} & -\sin\theta_2\, e^{i\beta_2} \\ -\sin\theta_2\, e^{i\gamma_2} & -\cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} \cos\theta_1\cos\theta_2\ e^{i(\alpha_1+\alpha_2)} & -\cos\theta_1\sin\theta_2\ e^{i(\alpha_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} \\ -\cos\theta_1\sin\theta_2\ e^{i(\alpha_1+\gamma_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} \\ -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & \cos\theta_1\sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} \\ \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

7. Persamaan umum R untuk $\theta = 2$ dan $\tau = 3$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}}\begin{pmatrix} \cos\theta_1\ e^{i\alpha_1} & -\sin\theta_1\, e^{i\beta_1} \\ -\sin\theta_1\, e^{i\gamma_1} & -\cos\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)} \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} \sin\theta_2\, e^{i\beta_2} & \cos\theta_2\, e^{i\alpha_2} \\ \cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_2\, e^{i\gamma_2} \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} \cos\theta_1\sin\theta_2\ e^{i(\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & -\sin\theta_1\cos\theta_2 e^{i(\beta_1+\alpha_2)} \\ \cos\theta_1\ \cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\ e^{i(\alpha_1+\gamma_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} \\ -\sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} \\ -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} \end{pmatrix}$$

8. Persamaan umum R untuk $\theta = 2$ dan $\tau = 4$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}}\begin{pmatrix} \cos\theta_1\ e^{i\alpha_1} & -\sin\theta_1\, e^{i\beta_1} \\ -\sin\theta_1\, e^{i\gamma_1} & -\cos\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)} \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} -\sin\theta_2\, e^{i\beta_2} & \cos\theta_2\, e^{i\alpha_2} \\ -\cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_2\, e^{i\gamma_2} \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} -\cos\theta_1\sin\theta_2\ e^{i(\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & -\sin\theta_1\cos\theta_2 e^{i(\beta_1+\alpha_2)} \\ -\cos\theta_1\ \cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\ e^{i(\alpha_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} \\ \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} \\ \sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} \end{pmatrix}$$

9. Persamaan umum R untuk $\theta = 3$ dan $\tau = 1$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}}\begin{pmatrix} \sin\theta_1\, e^{i\beta_1} & \cos\theta_1\ e^{i\alpha_1} \\ \cos\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)} & -\sin\theta_1\, e^{i\gamma_1} \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} \cos\theta_2\, e^{i\alpha_2} & \sin\theta_2\, e^{i\beta_2} \\ -\sin\theta_2\, e^{i\gamma_2} & \cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & \cos\theta_1\cos\theta_2\ e^{i(\alpha_1+\alpha_2)} & \cos\theta_1\sin\theta_2\ e^{i(\alpha_1+\beta_2)} \\ -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\ e^{i(\alpha_1+\gamma_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} \\ \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & \cos\theta_1\sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} \\ -\cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

10. Persamaan umum R untuk $\theta = 3$ dan $\tau = 2$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} \sin\theta_1\, e^{i\beta_1} & \cos\theta_1\, e^{i\alpha_1} \\ \cos\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)} & -\sin\theta_1\, e^{i\gamma_1} \end{pmatrix} \otimes \frac{1}{\sqrt{2}} \begin{pmatrix} \cos\theta_2\, e^{i\alpha_2} & -\sin\theta_2\, e^{i\beta_2} \\ -\sin\theta_2\, e^{i\gamma_2} & -\cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} \sin\theta_1 \cos\theta_2\, e^{i(\beta_1+\alpha_2)} & -\sin\theta_1 \sin\theta_2\, e^{i(\beta_1+\beta_2)} & \cos\theta_1 \cos\theta_2\, e^{i(\alpha_1+\alpha_2)} & -\cos\theta_1 \sin\theta_2\, e^{i(\alpha_1+\beta_2)} \\ -\sin\theta_1 \sin\theta_2\, e^{i(\beta_1+\gamma_2)} & -\sin\theta_1 \cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1 \sin\theta_2\, e^{i(\alpha_1+\gamma_2)} & -\cos\theta_1 \cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} \\ \cos\theta_1 \cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & -\cos\theta_1 \sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\sin\theta_1 \cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & \sin\theta_1 \sin\theta_2\, e^{i(\gamma_1+\beta_2)} \\ -\cos\theta_1 \sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & -\cos\theta_1 \cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1 \sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & \sin\theta_1 \cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

11. Persamaan umum R untuk $\theta = 3$ dan $\tau = 3$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} \sin\theta_1\, e^{i\beta_1} & \cos\theta_1\, e^{i\alpha_1} \\ \cos\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)} & -\sin\theta_1\, e^{i\gamma_1} \end{pmatrix} \otimes \frac{1}{\sqrt{2}} \begin{pmatrix} \sin\theta_2\, e^{i\beta_2} & \cos\theta_2\, e^{i\alpha_2} \\ \cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_2\, e^{i\gamma_2} \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} \sin\theta_1 \sin\theta_2\, e^{i(\beta_1+\beta_2)} & \sin\theta_1 \cos\theta_2 e^{i(\beta_1+\alpha_2)} & \cos\theta_1 \sin\theta_2\, e^{i(\alpha_1+\beta_2)} & \cos\theta_1 \cos\theta_2\, e^{i(\alpha_1+\alpha_2)} \\ \sin\theta_1 \cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_1 \sin\theta_2\, e^{i(\beta_1+\gamma_2)} & \cos\theta_1 \cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1 \sin\theta_2\, e^{i(\alpha_1+\gamma_2)} \\ \cos\theta_1 \sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & \cos\theta_1 \cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & -\sin\theta_1 \sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1 \cos\theta_2\, e^{i(\gamma_1+\alpha_2)} \\ \cos\theta_1 \cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1 \sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & -\sin\theta_1 \cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1 \sin\theta_2\, e^{i(\gamma_1+\gamma_2)} \end{pmatrix}$$

12. Persamaan umum R untuk $\theta = 3$ dan $\tau = 4$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} \sin\theta_1\, e^{i\beta_1} & \cos\theta_1\, e^{i\alpha_1} \\ \cos\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)} & -\sin\theta_1\, e^{i\gamma_1} \end{pmatrix} \otimes \frac{1}{\sqrt{2}} \begin{pmatrix} -\sin\theta_2\, e^{i\beta_2} & \cos\theta_2\, e^{i\alpha_2} \\ -\cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_2\, e^{i\gamma_2} \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} -\sin\theta_1 \sin\theta_2\, e^{i(\beta_1+\beta_2)} & \sin\theta_1 \cos\theta_2 e^{i(\beta_1+\alpha_2)} & -\cos\theta_1 \sin\theta_2\, e^{i(\alpha_1+\beta_2)} & \cos\theta_1 \cos\theta_2\, e^{i(\alpha_1+\alpha_2)} \\ -\sin\theta_1 \cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_1 \sin\theta_2\, e^{i(\beta_1+\gamma_2)} & -\cos\theta_1 \cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1 \sin\theta_2\, e^{i(\alpha_1+\gamma_2)} \\ -\cos\theta_1 \sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & \cos\theta_1 \cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & \sin\theta_1 \sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1 \cos\theta_2\, e^{i(\gamma_1+\alpha_2)} \\ -\cos\theta_1 \cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1 \sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & \sin\theta_1 \cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1 \sin\theta_2\, e^{i(\gamma_1+\gamma_2)} \end{pmatrix}$$

13. Persamaan umum R untuk $\theta = 4$ dan $\tau = 1$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} -\sin\theta_1\, e^{i\beta_1} & \cos\theta_1\, e^{i\alpha_1} \\ -\cos\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)} & -\sin\theta_1\, e^{i\gamma_1} \end{pmatrix} \otimes \frac{1}{\sqrt{2}} \begin{pmatrix} \cos\theta_2\, e^{i\alpha_2} & \sin\theta_2\, e^{i\beta_2} \\ -\sin\theta_2\, e^{i\gamma_2} & \cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} -\sin\theta_1 \cos\theta_2\, e^{i(\beta_1+\alpha_2)} & -\sin\theta_1 \sin\theta_2\, e^{i(\beta_1+\beta_2)} & \cos\theta_1 \cos\theta_2\, e^{i(\alpha_1+\alpha_2)} & \cos\theta_1 \sin\theta_2\, e^{i(\alpha_1+\beta_2)} \\ \sin\theta_1 \sin\theta_2\, e^{i(\beta_1+\gamma_2)} & -\sin\theta_1 \cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1 \sin\theta_2\, e^{i(\alpha_1+\gamma_2)} & \cos\theta_1 \cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} \\ -\cos\theta_1 \cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & -\cos\theta_1 \sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\sin\theta_1 \cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & -\sin\theta_1 \sin\theta_2\, e^{i(\gamma_1+\beta_2)} \\ \cos\theta_1 \sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & -\cos\theta_1 \cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1 \sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & -\sin\theta_1 \cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

14. Persamaan umum R untuk $\theta = 4$ dan $\tau = 2$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}}\begin{pmatrix} -\sin\theta_1\, e^{i\beta_1} & \cos\theta_1\ e^{i\alpha_1} \\ -\cos\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)} & -\sin\theta_1\, e^{i\gamma_1} \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} \cos\theta_2\, e^{i\alpha_2} & -\sin\theta_2\, e^{i\beta_2} \\ -\sin\theta_2\, e^{i\gamma_2} & -\cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & \cos\theta_1\cos\theta_2\ e^{i(\alpha_1+\alpha_2)} & -\cos\theta_1\sin\theta_2\ e^{i(\alpha_1+\beta_2)} \\ \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\ e^{i(\alpha_1+\gamma_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} \\ -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & \cos\theta_1\sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} \\ \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

15. Persamaan umum R untuk $\theta = 3$ dan $\tau = 3$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}}\begin{pmatrix} -\sin\theta_1\, e^{i\beta_1} & \cos\theta_1\ e^{i\alpha_1} \\ -\cos\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)} & -\sin\theta_1\, e^{i\gamma_1} \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} \sin\theta_2\, e^{i\beta_2} & \cos\theta_2\, e^{i\alpha_2} \\ \cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_2\, e^{i\gamma_2} \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & -\sin\theta_1\cos\theta_2 e^{i(\beta_1+\alpha_2)} & \cos\theta_1\sin\theta_2\ e^{i(\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} \\ -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & \cos\theta_1\ \cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\ e^{i(\alpha_1+\gamma_2)} \\ -\cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} \\ -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} \end{pmatrix}$$

16. Persamaan umum R untuk $\theta = 4$ dan $\tau = 4$

$$\boldsymbol{R = U_1 \otimes U_2}$$

$$= \frac{1}{\sqrt{2}}\begin{pmatrix} -\sin\theta_1\, e^{i\beta_1} & \cos\theta_1\ e^{i\alpha_1} \\ -\cos\theta_1\, e^{i(\beta_1+\gamma_1-\alpha_1)} & -\sin\theta_1\, e^{i\gamma_1} \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} -\sin\theta_2\, e^{i\beta_2} & \cos\theta_2\, e^{i\alpha_2} \\ -\cos\theta_2\, e^{i(\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_2\, e^{i\gamma_2} \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & -\sin\theta_1\cos\theta_2 e^{i(\beta_1+\alpha_2)} & -\cos\theta_1\sin\theta_2\ e^{i(\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} \\ \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & -\cos\theta_1\ \cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\ e^{i(\alpha_1+\gamma_2)} \\ \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} \\ \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} \end{pmatrix}$$

dengan $\theta_1, \alpha_1, \beta_1, \gamma_1$dan $\theta_2, \alpha_2, \beta_2, \gamma_2$ ini merupakan parameter bebasnya.

4.3 Macam Kanal pada Teleportasi Kuantum Dua Arah.

Untuk bermacam-macam matriks uniter 2x2 sebagai berikut

$$\boldsymbol{U} = \begin{pmatrix} \cos\theta\ e^{i\alpha} & \sin\theta\, e^{i\beta} \\ \pm\sin\theta\, e^{i\gamma} & \pm\cos\theta\, e^{i\delta} \end{pmatrix}$$

$$= \begin{pmatrix} \cos\theta\ e^{i\alpha} & \sin\theta\, e^{i\beta} \\ \mp\sin\theta\, e^{i\gamma} & \pm\cos\theta\, e^{i(\beta+\gamma-\alpha)} \end{pmatrix}$$

Untuk nilai $\alpha, \beta, \gamma = 0$ sehingga didapatkan matriks uniter sebagai berikut,

$$\boldsymbol{U} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

- Untuk nilai $\theta = 0$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 0 & \sin 0 \\ -\sin 0 & \cos 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} = \boldsymbol{U_1} = \boldsymbol{I}$$

- Untuk nilai $\theta = 30$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 30 & \sin 30 \\ -\sin 30 & \cos 30 \end{pmatrix} = \frac{1}{2}\begin{pmatrix} \sqrt{3} & 1 \\ -1 & \sqrt{3} \end{pmatrix} = \boldsymbol{U_2}$$

- Untuk nilai $\theta = 45$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 45 & \sin 45 \\ -\sin 45 & \cos 45 \end{pmatrix} = \frac{1}{2}\begin{pmatrix} \sqrt{2} & \sqrt{2} \\ -\sqrt{2} & \sqrt{2} \end{pmatrix} = \frac{\sqrt{2}}{2}\begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix} = \boldsymbol{U_3}$$

- Untuk nilai $\theta = 60$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 60 & \sin 60 \\ -\sin 60 & \cos 60 \end{pmatrix} = \frac{1}{2}\begin{pmatrix} 1 & \sqrt{3} \\ -\sqrt{3} & 1 \end{pmatrix} = \boldsymbol{U_4}$$

- Untuk nilai $\theta = 90$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 90 & \sin 90 \\ -\sin 90 & \cos 90 \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} = \boldsymbol{U_5}$$

- Untuk nilai $\theta = 0$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 0 & \sin 0 \\ \sin 0 & -\cos 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} = \boldsymbol{U_6} = \boldsymbol{\sigma^z}$$

- Untuk nilai $\theta = 30$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 30 & \sin 30 \\ \sin 30 & -\cos 30 \end{pmatrix} = \frac{1}{2}\begin{pmatrix} \sqrt{3} & 1 \\ 1 & -\sqrt{3} \end{pmatrix} = \boldsymbol{U_7}$$

- Untuk nilai $\theta = 45$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 45 & \sin 45 \\ \sin 45 & -\cos 45 \end{pmatrix} = \frac{1}{2}\begin{pmatrix} \sqrt{2} & \sqrt{2} \\ \sqrt{2} & -\sqrt{2} \end{pmatrix} = \frac{\sqrt{2}}{2}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} = \boldsymbol{U_8}$$

- Untuk nilai $\theta = 60$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 60 & \sin 60 \\ \sin 60 & -\cos 60 \end{pmatrix} = \frac{1}{2}\begin{pmatrix} 1 & \sqrt{3} \\ \sqrt{3} & -1 \end{pmatrix} = \boldsymbol{U_9}$$

- Untuk nilai $\theta = 90$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 90 & \sin 90 \\ \sin 90 & -\cos 90 \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} = \boldsymbol{U_{10}} = \boldsymbol{\sigma^x}$$

Macam-macam kanal yang digunakan bisa ditentukan dari bentuk transformasi hasil pengukuran Alice dan Bob. Diantaranya

1) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 1}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$
$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^1})^{-1} \otimes (\boldsymbol{T^1})^{-1})$$
$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$
$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \end{pmatrix}$$
$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0011}\rangle + |\mathbf{0110}\rangle + |\mathbf{1001}\rangle + |\mathbf{1100}\rangle)$$

2) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 2}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$
$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^1})^{-1} \otimes (\boldsymbol{T^2})^{-1})$$
$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$
$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1} \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0011\rangle - |0110\rangle + |1001\rangle - |1100\rangle)$$

3) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^1})^{-1} \otimes (\boldsymbol{T^3})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0010\rangle + |0111\rangle + |1000\rangle + |1101\rangle)$$

4) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^1})^{-1} \otimes (\boldsymbol{T^4})^{-1})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \right) \left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}} \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}} \begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix} \begin{pmatrix} \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ -\mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & -\mathbf{1} & \mathbf{0} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}} \begin{pmatrix} \mathbf{0} & \mathbf{0} & -\mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ -\mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1},\boldsymbol{B1},\boldsymbol{B2},\boldsymbol{A2}} = \frac{\mathbf{1}}{\mathbf{2}}(-|\mathbf{0010}\rangle + |\mathbf{0111}\rangle - |\mathbf{1000}\rangle + |\mathbf{1101}\rangle)$$

5) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = \mathbf{2}$ dan $\boldsymbol{\tau} = \mathbf{1}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-\mathbf{1}} \otimes (\boldsymbol{T^\tau})^{-\mathbf{1}}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^2})^{-\mathbf{1}} \otimes (\boldsymbol{T^1})^{-\mathbf{1}})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \right) \left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}} \begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}} \begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} \end{pmatrix} \right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}} \begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix} \begin{pmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & -\mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & -\mathbf{1} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}} \begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & -\mathbf{1} \\ \mathbf{0} & \mathbf{0} & -\mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1},\boldsymbol{B1},\boldsymbol{B2},\boldsymbol{A2}} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0011}\rangle + |\mathbf{0110}\rangle - |\mathbf{1001}\rangle - |\mathbf{1100}\rangle)$$

6) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 2}$

$$\boldsymbol{R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)}$$

$$\boldsymbol{= (\sigma^x \otimes \sigma^x)((T^2)^{-1} \otimes (T^2)^{-1})}$$

$$\boldsymbol{= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)}$$

$$\boldsymbol{= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}}$$

$$\boldsymbol{= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$\boldsymbol{|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0011\rangle + |0110\rangle - |1001\rangle - |1100\rangle)}$$

7) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)}$$

$$\boldsymbol{= (\sigma^x \otimes \sigma^x)((T^2)^{-1} \otimes (T^3)^{-1})}$$

$$\boldsymbol{= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)}$$

$$\boldsymbol{= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & -1 & 0 \end{pmatrix}}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0011\rangle - |0110\rangle - |1001\rangle + |1100\rangle)$$

8) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa σ^x, maka didapatkan nilai R untuk nilai $\theta = 2$ dan $\tau = 4$

$$R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)$$

$$= (\sigma^x \otimes \sigma^x)((T^2)^{-1} \otimes (T^4)^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|0010\rangle + |0111\rangle + |1000\rangle - |1101\rangle)$$

9) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa σ^x, maka didapatkan nilai R untuk nilai $\theta = 3$ dan $\tau = 1$

$$R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^3})^{-1} \otimes (\boldsymbol{T^1})^{-1})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1},\boldsymbol{B1},\boldsymbol{B2},\boldsymbol{A2}} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0001}\rangle + |\mathbf{0100}\rangle + |\mathbf{1011}\rangle + |\mathbf{1110}\rangle)$$

10) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = \mathbf{3}$ dan $\boldsymbol{\tau} = \mathbf{2}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-\mathbf{1}} \otimes (\boldsymbol{T^\tau})^{-\mathbf{1}}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^3})^{-1} \otimes (\boldsymbol{T^2})^{-1})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & -\mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & -\mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1},\boldsymbol{B1},\boldsymbol{B2},\boldsymbol{A2}} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0001}\rangle - |\mathbf{0100}\rangle + |\mathbf{1011}\rangle - |\mathbf{1110}\rangle)$$

11) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 3}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R = \left(\sigma^\theta \otimes \sigma^\tau\right)\left(\left(T^\theta\right)^{-1} \otimes (T^\tau)^{-1}\right)}$$
$$\boldsymbol{= (\sigma^x \otimes \sigma^x)((T^3)^{-1} \otimes (T^3)^{-1})}$$
$$\boldsymbol{= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)}$$
$$\boldsymbol{= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}}$$
$$\boldsymbol{= \frac{1}{2}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$\boldsymbol{|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0000\rangle + |0101\rangle + |1010\rangle + |1111\rangle)}$$

12) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 3}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R = \left(\sigma^\theta \otimes \sigma^\tau\right)\left(\left(T^\theta\right)^{-1} \otimes (T^\tau)^{-1}\right)}$$
$$\boldsymbol{= (\sigma^x \otimes \sigma^x)((T^3)^{-1} \otimes (T^4)^{-1})}$$
$$\boldsymbol{= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)}$$
$$\boldsymbol{= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}}$$

$$= \frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0000}\rangle + |\mathbf{0101}\rangle - |\mathbf{1010}\rangle + |\mathbf{1111}\rangle)$$

13) Untuk pengukuran Alice berupa $\boldsymbol{\sigma}^{\boldsymbol{x}}$ dan pengukuran Bob berupa $\boldsymbol{\sigma}^{\boldsymbol{x}}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = \mathbf{4}$ dan $\boldsymbol{\tau} = \mathbf{1}$

$$\boldsymbol{R} = (\boldsymbol{\sigma}^{\boldsymbol{\theta}} \otimes \boldsymbol{\sigma}^{\boldsymbol{\tau}})\left(\left(\boldsymbol{T}^{\boldsymbol{\theta}}\right)^{-1} \otimes (\boldsymbol{T}^{\boldsymbol{\tau}})^{-1}\right)$$

$$= (\boldsymbol{\sigma}^{\boldsymbol{x}} \otimes \boldsymbol{\sigma}^{\boldsymbol{x}})((\boldsymbol{T}^{\mathbf{4}})^{-1} \otimes (\boldsymbol{T}^{\mathbf{1}})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0001}\rangle - |\mathbf{0100}\rangle + |\mathbf{1011}\rangle + |\mathbf{1110}\rangle)$$

14) Untuk pengukuran Alice berupa $\boldsymbol{\sigma}^{\boldsymbol{x}}$ dan pengukuran Bob berupa $\boldsymbol{\sigma}^{\boldsymbol{x}}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = \mathbf{4}$ dan $\boldsymbol{\tau} = \mathbf{2}$

$$\boldsymbol{R} = (\boldsymbol{\sigma}^{\boldsymbol{\theta}} \otimes \boldsymbol{\sigma}^{\boldsymbol{\tau}})\left(\left(\boldsymbol{T}^{\boldsymbol{\theta}}\right)^{-1} \otimes (\boldsymbol{T}^{\boldsymbol{\tau}})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^2})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0001}\rangle + |\mathbf{0100}\rangle + |\mathbf{1011}\rangle - |\mathbf{1110}\rangle)$$

15) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^3})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0000}\rangle - |\mathbf{0101}\rangle + |\mathbf{1010}\rangle + |\mathbf{1111}\rangle)$$

16) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)}$$

$$\boldsymbol{= (\sigma^x \otimes \sigma^x)((T^4)^{-1} \otimes (T^4)^{-1})}$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{-1} & \mathbf{0} \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{-1} & \mathbf{0} \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{-1} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{-1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$\boldsymbol{|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0000\rangle - |0101\rangle - |1010\rangle + |1111\rangle)}$$

Kanal yang dibentuk dari transformasi hasil pengukuran Alice dan Bob dapat di tuliskan dalam Tabel berikut,

TABEL4.1 Kanal yang dapat dibentuk dari transformasi hasil pengukuran oleh Alice ($\boldsymbol{\sigma^x}$) dan Bob ($\boldsymbol{\sigma^x}$)

Nilai $\boldsymbol{(T^\theta)^{-1}}$	**Nilai** $\boldsymbol{(T^\tau)^{-1}}$	**Kanal yang terbentuk**
$\boldsymbol{(T^1)^{-1}}$	$\boldsymbol{(T^1)^{-1}}$	$\frac{1}{2}(\|0011\rangle + \|0110\rangle + \|1001\rangle + \|1100\rangle)$
$\boldsymbol{(T^1)^{-1}}$	$\boldsymbol{(T^2)^{-1}}$	$\frac{1}{2}(\|0011\rangle - \|0110\rangle + \|1001\rangle - \|1100\rangle)$
$\boldsymbol{(T^1)^{-1}}$	$\boldsymbol{(T^3)^{-1}}$	$\frac{1}{2}(\|0010\rangle + \|0111\rangle + \|1000\rangle + \|1101\rangle)$

$(\boldsymbol{T^1})^{-1}$	$(\boldsymbol{T^4})^{-1}$	$\frac{1}{2}(-\|0010\rangle + \|0111\rangle - \|1000\rangle + \|1101\rangle)$
$(\boldsymbol{T^2})^{-1}$	$(\boldsymbol{T^1})^{-1}$	$\frac{1}{2}(\|0011\rangle + \|0110\rangle - \|1001\rangle - \|1100\rangle)$
$(\boldsymbol{T^2})^{-1}$	$(\boldsymbol{T^2})^{-1}$	$\frac{1}{2}(\|0011\rangle - \|0110\rangle - \|1001\rangle + \|1100\rangle)$
$(\boldsymbol{T^2})^{-1}$	$(\boldsymbol{T^3})^{-1}$	$\frac{1}{2}(\|0010\rangle + \|0111\rangle - \|1000\rangle - \|1101\rangle)$
$(\boldsymbol{T^2})^{-1}$	$(\boldsymbol{T^4})^{-1}$	$\frac{1}{2}(-\|0010\rangle + \|0111\rangle + \|1000\rangle - \|1101\rangle)$
$(\boldsymbol{T^3})^{-1}$	$(\boldsymbol{T^1})^{-1}$	$\frac{1}{2}(\|0001\rangle + \|0100\rangle + \|1011\rangle + \|1110\rangle)$
$(\boldsymbol{T^3})^{-1}$	$(\boldsymbol{T^2})^{-1}$	$\frac{1}{2}(\|0001\rangle - \|0100\rangle + \|1011\rangle - \|1110\rangle)$
$(\boldsymbol{T^3})^{-1}$	$(\boldsymbol{T^3})^{-1}$	$\frac{1}{2}(\|0000\rangle + \|0101\rangle + \|1010\rangle + \|1111\rangle)$
$(\boldsymbol{T^3})^{-1}$	$(\boldsymbol{T^4})^{-1}$	$\frac{1}{2}(-\|0000\rangle + \|0101\rangle - \|1010\rangle + \|1111\rangle)$
$(\boldsymbol{T^4})^{-1}$	$(\boldsymbol{T^1})^{-1}$	$\frac{1}{2}(-\|0001\rangle - \|0100\rangle + \|1011\rangle + \|1110\rangle)$
$(\boldsymbol{T^4})^{-1}$	$(\boldsymbol{T^2})^{-1}$	$\frac{1}{2}(-\|0001\rangle + \|0100\rangle + \|1011\rangle - \|1110\rangle)$
$(\boldsymbol{T^4})^{-1}$	$(\boldsymbol{T^3})^{-1}$	$\frac{1}{2}(-\|0000\rangle - \|0101\rangle + \|1010\rangle + \|1111\rangle)$
$(\boldsymbol{T^4})^{-1}$	$(\boldsymbol{T^4})^{-1}$	$\frac{1}{2}(\|0000\rangle - \|0101\rangle - \|1010\rangle + \|1111\rangle)$

TABEL4.2 Kanal yang dapat dibentuk dari transformasi hasil pengukuran oleh Alice $(\boldsymbol{\sigma^x})$ dan Bob $(\boldsymbol{I})$

Nilai $(\boldsymbol{T^\theta})^{-1}$	Nilai $(\boldsymbol{T^\tau})^{-1}$	Nilai *R*	Kanal yang terbentuk
$(\boldsymbol{T^1})^{-1}$	$(\boldsymbol{T^1})^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\|0010\rangle + \|0111\rangle + \|1000\rangle + \|1101\rangle)$

$(T^1)^{-1}$	$(T^2)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0010\rangle - \lvert 0111\rangle + \lvert 1000\rangle - \lvert 1101\rangle)$
$(T^1)^{-1}$	$(T^3)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0011\rangle + \lvert 0110\rangle + \lvert 1001\rangle + \lvert 1100\rangle)$
$(T^1)^{-1}$	$(T^4)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(-\lvert 0011\rangle + \lvert 0110\rangle - \lvert 1001\rangle + \lvert 1100\rangle)$
$(T^2)^{-1}$	$(T^1)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0010\rangle + \lvert 0111\rangle - \lvert 1000\rangle - \lvert 1101\rangle)$
$(T^2)^{-1}$	$(T^2)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0010\rangle - \lvert 0111\rangle - \lvert 1000\rangle + \lvert 1101\rangle)$
$(T^2)^{-1}$	$(T^3)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0011\rangle + \lvert 0110\rangle - \lvert 1001\rangle - \lvert 1100\rangle)$
$(T^2)^{-1}$	$(T^4)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(-\lvert 0011\rangle + \lvert 0110\rangle + \lvert 1001\rangle - \lvert 1100\rangle)$
$(T^3)^{-1}$	$(T^1)^{-1}$	$\frac{1}{2}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$	$\frac{1}{2}(\lvert 0000\rangle + \lvert 0101\rangle + \lvert 1010\rangle + \lvert 1111\rangle)$
$(T^3)^{-1}$	$(T^2)^{-1}$	$\frac{1}{2}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$	$\frac{1}{2}(\lvert 0000\rangle - \lvert 0101\rangle + \lvert 1010\rangle - \lvert 1111\rangle)$
$(T^3)^{-1}$	$(T^3)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0001\rangle + \lvert 0100\rangle + \lvert 1011\rangle + \lvert 1110\rangle)$
$(T^3)^{-1}$	$(T^4)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$	$\frac{1}{2}(-\lvert 0001\rangle + \lvert 0100\rangle - \lvert 1011\rangle + \lvert 1110\rangle)$
$(T^4)^{-1}$	$(T^1)^{-1}$	$\frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$	$\frac{1}{2}(-\lvert 0000\rangle - \lvert 0101\rangle + \lvert 1010\rangle + \lvert 1111\rangle)$

$(\boldsymbol{T}^4)^{-1}$	$(\boldsymbol{T}^2)^{-1}$	$\frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$	$\frac{1}{2}(-\lvert 0000\rangle + \lvert 0101\rangle + \lvert 1010\rangle - \lvert 1111\rangle)$
$(\boldsymbol{T}^4)^{-1}$	$(\boldsymbol{T}^3)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$	$\frac{1}{2}(-\lvert 0001\rangle - \lvert 0100\rangle + \lvert 1011\rangle + \lvert 1110\rangle)$
$(\boldsymbol{T}^4)^{-1}$	$(\boldsymbol{T}^4)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0001\rangle - \lvert 0100\rangle - \lvert 1011\rangle + \lvert 1110\rangle)$

TABEL4.3 Kanal yang dapat dibentuk dari transformasi hasil pengukuran oleh Alice $(\boldsymbol{\sigma^x})$ dan Bob $(-\boldsymbol{i\sigma^y} = \boldsymbol{Y})$

Nilai $(T^{\theta})^{-1}$	Nilai $(T^{\tau})^{-1}$	Nilai *R*	Kanal yang terbentuk
$(T^1)^{-1}$	$(T^1)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0011\rangle - \lvert 0110\rangle + \lvert 1001\rangle - \lvert 1100\rangle)$
$(T^1)^{-1}$	$(T^2)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0011\rangle + \lvert 0110\rangle + \lvert 1001\rangle + \lvert 1100\rangle)$
$(T^1)^{-1}$	$(T^3)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(-\lvert 0010\rangle + \lvert 0111\rangle - \lvert 1000\rangle + \lvert 1101\rangle)$
$(T^1)^{-1}$	$(T^4)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0010\rangle + \lvert 0111\rangle + \lvert 1000\rangle + \lvert 1101\rangle)$
$(T^2)^{-1}$	$(T^1)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0011\rangle - \lvert 0110\rangle - \lvert 1001\rangle + \lvert 1100\rangle)$
$(T^2)^{-1}$	$(T^2)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0011\rangle + \lvert 0110\rangle - \lvert 1001\rangle - \lvert 1100\rangle)$
$(T^2)^{-1}$	$(T^3)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(-\lvert 0010\rangle + \lvert 0111\rangle + \lvert 1000\rangle - \lvert 1101\rangle)$
$(T^2)^{-1}$	$(T^4)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0010\rangle + \lvert 0111\rangle - \lvert 1000\rangle - \lvert 1101\rangle)$
$(T^3)^{-1}$	$(T^1)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0001\rangle - \lvert 0100\rangle + \lvert 1011\rangle - \lvert 1110\rangle)$

$(T^3)^{-1}$	$(T^2)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$	$\frac{1}{2}(\|0001\rangle + \|0100\rangle + \|1011\rangle + \|1110\rangle)$
$(T^3)^{-1}$	$(T^3)^{-1}$	$\frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$	$\frac{1}{2}(-\|0000\rangle + \|0101\rangle - \|1010\rangle + \|1111\rangle)$
$(T^3)^{-1}$	$(T^4)^{-1}$	$\frac{1}{2}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$	$\frac{1}{2}(\|0000\rangle + \|0101\rangle + \|1010\rangle + \|1111\rangle)$
$(T^4)^{-1}$	$(T^1)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$	$\frac{1}{2}(-\|0001\rangle + \|0100\rangle + \|1011\rangle - \|1110\rangle)$
$(T^4)^{-1}$	$(T^2)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$	$\frac{1}{2}(-\|0001\rangle - \|0100\rangle + \|1011\rangle + \|1110\rangle)$
$(T^4)^{-1}$	$(T^3)^{-1}$	$\frac{1}{2}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$	$\frac{1}{2}(\|0000\rangle - \|0101\rangle - \|1010\rangle + \|1111\rangle)$
$(T^4)^{-1}$	$(T^4)^{-1}$	$\frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$	$\frac{1}{2}(-\|0000\rangle - \|0101\rangle + \|1010\rangle + \|1111\rangle)$

TABEL4.4 Kanal yang dapat dibentuk dari transformasi hasil pengukuran oleh Alice (σ^x) dan Bob (σ^z)

Nilai $(T^\theta)^{-1}$	Nilai $(T^\tau)^{-1}$	Nilai *R*	Kanal yang terbentuk
$(T^1)^{-1}$	$(T^1)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\|0010\rangle + \|0111\rangle + \|1000\rangle + \|1101\rangle)$
$(T^1)^{-1}$	$(T^2)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\|0010\rangle - \|0111\rangle + \|1000\rangle - \|1101\rangle)$

$(T^1)^{-1}$	$(T^3)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0011\rangle + \lvert 0110\rangle + \lvert 1001\rangle + \lvert 1100\rangle)$
$(T^1)^{-1}$	$(T^4)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(-\lvert 0011\rangle + \lvert 0110\rangle - \lvert 1001\rangle + \lvert 1100\rangle)$
$(T^2)^{-1}$	$(T^1)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0010\rangle + \lvert 0111\rangle - \lvert 1000\rangle - \lvert 1101\rangle)$
$(T^2)^{-1}$	$(T^2)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0010\rangle - \lvert 0111\rangle - \lvert 1000\rangle + \lvert 1101\rangle)$
$(T^2)^{-1}$	$(T^3)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0011\rangle + \lvert 0110\rangle - \lvert 1001\rangle - \lvert 1100\rangle)$
$(T^2)^{-1}$	$(T^4)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$	$\frac{1}{2}(-\lvert 0011\rangle + \lvert 0110\rangle + \lvert 1001\rangle - \lvert 1100\rangle)$
$(T^3)^{-1}$	$(T^1)^{-1}$	$\frac{1}{2}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$	$\frac{1}{2}(\lvert 0000\rangle + \lvert 0101\rangle + \lvert 1010\rangle + \lvert 1111\rangle)$
$(T^3)^{-1}$	$(T^2)^{-1}$	$\frac{1}{2}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$	$\frac{1}{2}(\lvert 0000\rangle - \lvert 0101\rangle + \lvert 1010\rangle - \lvert 1111\rangle)$
$(T^3)^{-1}$	$(T^3)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0001\rangle + \lvert 0100\rangle + \lvert 1011\rangle + \lvert 1110\rangle)$
$(T^3)^{-1}$	$(T^4)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$	$\frac{1}{2}(-\lvert 0001\rangle + \lvert 0100\rangle - \lvert 1011\rangle + \lvert 1110\rangle)$
$(T^4)^{-1}$	$(T^1)^{-1}$	$\frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$	$\frac{1}{2}(-\lvert 0000\rangle - \lvert 0101\rangle + \lvert 1010\rangle + \lvert 1111\rangle)$
$(T^4)^{-1}$	$(T^2)^{-1}$	$\frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$	$\frac{1}{2}(-\lvert 0000\rangle + \lvert 0101\rangle + \lvert 1010\rangle - \lvert 1111\rangle)$

$(\boldsymbol{T}^4)^{-1}$	$(\boldsymbol{T}^3)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$	$\frac{1}{2}(-\lvert 0001\rangle - \lvert 0100\rangle + \lvert 1011\rangle + \lvert 1110\rangle)$
$(\boldsymbol{T}^4)^{-1}$	$(\boldsymbol{T}^4)^{-1}$	$\frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$	$\frac{1}{2}(\lvert 0001\rangle - \lvert 0100\rangle - \lvert 1011\rangle + \lvert 1110\rangle)$

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BAB V
KESIMPULAN

Dalam skema teleportasi kuantum dua arah dengan menggunakan kanal qubit rangkap empat dapat dilakukan untuk qubit informasi tunggal yang dimiliki oleh Alice dan juga qubit tunggal yang dimiliki oleh Bob. Selanjutnya, dilakukan penukaran urutan qubit untuk (A,B,A1,B1) menjadi (A,A1,B,B1) dengan menggunakan operator Swap.

Kriteria kanal yang bisa mengirimkan teleportasi kuantum dua arah dibentuk melalui matriks parameter kanal kuantum $(\boldsymbol{R})$ yang ditentukan dari hasil pengukuran oleh Alice dan Bob dengan

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^{\theta}}\left(\boldsymbol{T^{\theta}}\right)^{-\boldsymbol{1}}\right) \otimes \left(\boldsymbol{\sigma^{\tau}}(\boldsymbol{T^{\tau}})^{-\boldsymbol{1}}\right)$$

dimana $\boldsymbol{\sigma^{\theta}}$ dan $\boldsymbol{\sigma^{\tau}}$ merupakan matriks uniter berukuran 2x2 yang diturunkan melalui transformasi hasil pengukuran Alice dan Bob agar sesuai dengan informasi yang dikirim. Berikut matriks parameter yang dituliskan sebagai

$$\boldsymbol{T^{1}} = \begin{pmatrix} T_{00}^{1} & T_{10}^{1} \\ T_{01}^{1} & T_{11}^{1} \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$\boldsymbol{T^{2}} = \begin{pmatrix} T_{00}^{2} & T_{10}^{2} \\ T_{01}^{2} & T_{11}^{2} \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

$$\boldsymbol{T^{3}} = \begin{pmatrix} T_{00}^{3} & T_{10}^{3} \\ T_{01}^{3} & T_{11}^{3} \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

$$\boldsymbol{T^{4}} = \begin{pmatrix} T_{00}^{4} & T_{10}^{4} \\ T_{01}^{4} & T_{11}^{4} \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

Sehingga secara umum ada 16 bentuk matriks parameter kanal sebagai berikut

1. R untuk $\theta = 1$ dan $\tau = 1$

   $R =$

$$\frac{1}{2}\begin{pmatrix} \cos\theta_1 \cos\theta_2\ e^{i(\alpha_1+\alpha_2)} & \cos\theta_1 \sin\theta_2\ e^{i(\alpha_1+\beta_2)} & \sin\theta_1 \cos\theta_2\ e^{i(\beta_1+\alpha_2)} & \sin\theta_1 \sin\theta_2\ e^{i(\beta_1+\beta_2)} \\ -\cos\theta_1 \sin\theta_2\ e^{i(\alpha_1+\gamma_2)} & \cos\theta_1 \cos\theta_2\ e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_1 \sin\theta_2\ e^{i(\beta_1+\gamma_2)} & \sin\theta_1 \cos\theta_2\ e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} \\ -\sin\theta_1 \cos\theta_2\ e^{i(\gamma_1+\alpha_2)} & -\sin\theta_1 \sin\theta_2\ e^{i(\gamma_1+\beta_2)} & \cos\theta_1 \cos\theta_2\ e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & \cos\theta_1 \sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} \\ \sin\theta_1 \sin\theta_2\ e^{i(\gamma_1+\gamma_2)} & -\sin\theta_1 \cos\theta_2\ e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1 \sin\theta_2\ e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & \cos\theta_1 \cos\theta_2\ e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

2. R untuk $\theta = 1$ dan $\tau = 2$

$$\boldsymbol{R} =$$

$$\frac{1}{2}\begin{pmatrix} \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\beta_2)} & \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} \\ -\cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\gamma_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} \\ -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & -\cos\theta_1\sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} \\ \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

3. R untuk $\theta = 1$ dan $\tau = 3$

$$\boldsymbol{R} =$$

$$\frac{1}{2}\begin{pmatrix} \cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & \sin\theta_1\cos\theta_2 e^{i(\beta_1+\alpha_2)} \\ \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} \\ -\sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} \\ -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} \end{pmatrix}$$

4. R untuk $\theta = 1$ dan $\tau = 4$

$$\boldsymbol{R} =$$

$$\frac{1}{2}\begin{pmatrix} -\cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & \sin\theta_1\cos\theta_2 e^{i(\beta_1+\alpha_2)} \\ -\cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\gamma_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} \\ \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} \\ \sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} \end{pmatrix}$$

5. R untuk $\theta = 2$ dan $\tau = 1$

$$\boldsymbol{R} =$$

$$\frac{1}{2}\begin{pmatrix} \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} \\ -\cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\gamma_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} \\ -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & -\cos\theta_1\sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} \\ \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

6. R untuk $\theta = 2$ dan $\tau = 2$

$$\boldsymbol{R} =$$

$$\frac{1}{2}\begin{pmatrix} \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} \\ -\cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\gamma_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} \\ -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & \cos\theta_1\sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} \\ \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

7. R untuk $\theta = 2$ dan $\tau = 3$

$$\boldsymbol{R} =$$

$$\frac{1}{2}\begin{pmatrix} \cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & -\sin\theta_1\cos\theta_2 e^{i(\beta_1+\alpha_2)} \\ \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\gamma_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} \\ -\sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} \\ -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} \end{pmatrix}$$

8. R untuk $\theta = 2$ dan $\tau = 4$

$$\boldsymbol{R} =$$

$$\frac{1}{2}\begin{pmatrix} -\cos\theta_1\sin\theta_2\; e^{i(\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & -\sin\theta_1\cos\theta_2 e^{i(\beta_1+\alpha_2)} \\ -\cos\theta_1\;\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\; e^{i(\alpha_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} \\ \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} \\ \sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} \end{pmatrix}$$

9. R untuk $\theta = 3$ dan $\tau = 1$

$$\boldsymbol{R} =$$

$$\frac{1}{2}\begin{pmatrix} \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & \cos\theta_1\cos\theta_2\; e^{i(\alpha_1+\alpha_2)} & \cos\theta_1\sin\theta_2\; e^{i(\alpha_1+\beta_2)} \\ -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\; e^{i(\alpha_1+\gamma_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} \\ \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & \cos\theta_1\sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} \\ -\cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

10. R untuk $\theta = 3$ dan $\tau = 2$

$$\boldsymbol{R} =$$

$$\frac{1}{2}\begin{pmatrix} \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & \cos\theta_1\cos\theta_2\; e^{i(\alpha_1+\alpha_2)} & -\cos\theta_1\sin\theta_2\; e^{i(\alpha_1+\beta_2)} \\ -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\; e^{i(\alpha_1+\gamma_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} \\ \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & -\cos\theta_1\sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} \\ -\cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

11. R untuk $\theta = 3$ dan $\tau = 3$

$$\boldsymbol{R} =$$

$$\frac{1}{2}\begin{pmatrix} \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & \sin\theta_1\cos\theta_2 e^{i(\beta_1+\alpha_2)} & \cos\theta_1\sin\theta_2\; e^{i(\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} \\ \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & \cos\theta_1\;\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\; e^{i(\alpha_1+\gamma_2)} \\ \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} \\ \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} \end{pmatrix}$$

12. R untuk $\theta = 3$ dan $\tau = 4$

$$\boldsymbol{R} =$$

$$\frac{1}{2}\begin{pmatrix} -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & \sin\theta_1\cos\theta_2 e^{i(\beta_1+\alpha_2)} & -\cos\theta_1\sin\theta_2\; e^{i(\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} \\ -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & -\cos\theta_1\;\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\; e^{i(\alpha_1+\gamma_2)} \\ -\cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} \\ -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} \end{pmatrix}$$

13. R untuk $\theta = 4$ dan $\tau = 1$

$$\boldsymbol{R} =$$

$$= \frac{1}{2}\begin{pmatrix} -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & \cos\theta_1\cos\theta_2\; e^{i(\alpha_1+\alpha_2)} & \cos\theta_1\sin\theta_2\; e^{i(\alpha_1+\beta_2)} \\ \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\; e^{i(\alpha_1+\gamma_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} \\ -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & -\cos\theta_1\sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} \\ \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

14. R untuk $\theta = 4$ dan $\tau = 2$

$$\boldsymbol{R} =$$

$$\frac{1}{2}\begin{pmatrix} -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\beta_2)} \\ \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\gamma_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} \\ -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & \cos\theta_1\sin\theta_2 e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} \\ \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} \end{pmatrix}$$

15. R untuk $\theta = 3$ dan $\tau = 3$

$$\boldsymbol{R} =$$

$$\frac{1}{2}\begin{pmatrix} -\sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & -\sin\theta_1\cos\theta_2 e^{i(\beta_1+\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} \\ -\sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\gamma_2)} \\ -\cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & -\sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} \\ -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} \end{pmatrix}$$

16. R untuk $\theta = 4$ dan $\tau = 4$

$$\boldsymbol{R} =$$

$$\frac{1}{2}\begin{pmatrix} \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\beta_2)} & -\sin\theta_1\cos\theta_2 e^{i(\beta_1+\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\beta_2)} & \cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\alpha_2)} \\ \sin\theta_1\cos\theta_2\, e^{i(\beta_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\alpha_1+\beta_2+\gamma_2-\alpha_2)} & -\cos\theta_1\sin\theta_2\, e^{i(\alpha_1+\gamma_2)} \\ \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2)} & -\cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\beta_2)} & -\sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\alpha_2)} \\ \cos\theta_1\cos\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\beta_2+\gamma_2-\alpha_2)} & \cos\theta_1\sin\theta_2\, e^{i(\beta_1+\gamma_1-\alpha_1+\gamma_2)} & \sin\theta_1\cos\theta_2\, e^{i(\gamma_1+\beta_2+\gamma_2-\alpha_2)} & \sin\theta_1\sin\theta_2\, e^{i(\gamma_1+\gamma_2)} \end{pmatrix}$$

dengan $\theta_1, \alpha_1, \beta_1, \gamma_1$dan $\theta_2, \alpha_2, \beta_2, \gamma_2$ ini merupakan parameter bebasnya.

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LAMPIRAN A

REPRESENTASI TENSOR TELEPORTASI DUA ARAH MELALUI KANAL 4 QUBIT

Suatu Informasi yang didefinisikan sebagai berikut

$$|\chi\rangle_A = \sum_{i=0}^{1} x_i|i\rangle \quad (L.1)$$

$$= x_0|0\rangle + x_1|1\rangle$$

Dengan nilai $\sum_i |x_i|^2 = 1$. Dan merupakan informasi yang di miliki oleh alice, selanjutnya

$$|\chi\rangle_B = \sum_{j=0}^{1} y_j|j\rangle \quad (L.2)$$

$$= y_0|0\rangle + y_1|1\rangle$$

Dengan nilai $\sum_j |x_j|^2 = 1$. Yang merupakan informasi yang dimiliki oleh Bob. Alice dan bob ingin berbagi informasi yang dilewatkan melalui kanal

$$|\varphi\rangle_{A1,B1,B2,A2} = \sum_{l,m,s,t=0}^{1} R_{lmst}|lmst\rangle \quad (L.3)$$

$$= \begin{Bmatrix} R_{0000}|0000\rangle + R_{0001}|0001\rangle + R_{0010}|0010\rangle + R_{0011}|0011\rangle \\ +R_{0100}|0100\rangle + R_{0101}|0101\rangle + R_{0110}|0110\rangle + R_{0111}|0111\rangle \\ +R_{1000}|1000\rangle + R_{1001}|1001\rangle + R_{1010}|1010\rangle + R_{1011}|1011\rangle \\ +R_{1100}|1100\rangle + R_{1101}|1101\rangle + R_{1110}|1110\rangle + R_{1111}|1111\rangle \end{Bmatrix}$$

Dengan nilai $\sum_{lmst} |R_{lmst}|^2 = 1$. Maka keadaan gabungannya adalah

$$|\psi\rangle_{A,B,A1,B1,B2,A2} = |\chi\rangle_A \otimes |\chi\rangle_B \otimes |\varphi\rangle_{A1,B1,B2,A2}$$

$$\begin{aligned} = \ & (x_0|0\rangle + x_1|1\rangle) \otimes (y_0|0\rangle + y_1|1\rangle) \otimes (R_{0000}|0000\rangle \\ & +R_{0001}|0001\rangle + R_{0010}|0010\rangle + R_{0011}|0011\rangle + R_{0100}|0100\rangle \\ & +R_{0101}|0101\rangle + R_{0110}|0110\rangle + R_{0111}|0111\rangle + R_{1000}|1000\rangle \\ & +R_{1001}|1001\rangle + R_{1010}|1010\rangle + R_{1011}|1011\rangle + R_{1100}|1100\rangle \\ & +R_{1101}|1101\rangle + R_{1110}|1110\rangle + R_{1111}|1111\rangle) \end{aligned}$$

$$= \quad x_0y_0\begin{Bmatrix} (R_{0000}|000000\rangle + R_{0001}|000001\rangle + R_{0010}|000010\rangle \\ +R_{0011}|000011\rangle + R_{0100}|000100\rangle + R_{0101}|000101\rangle \\ +R_{0110}|000110\rangle + R_{0111}|000111\rangle + R_{1000}|001000\rangle \\ +R_{1001}|001001\rangle + R_{1010}|001010\rangle + R_{1011}|001011\rangle \\ +R_{1100}|001100\rangle + R_{1101}|001101\rangle + R_{1110}|001110\rangle \\ +R_{1111}|001111\rangle \end{Bmatrix} \qquad (L.4)$$

$$+x_0y_1\begin{Bmatrix} (R_{0000}|010000\rangle + R_{0001}|010001\rangle + R_{0010}|010010\rangle \\ +R_{0011}|010011\rangle + R_{0100}|010100\rangle + R_{0101}|010101\rangle \\ +R_{0110}|010110\rangle + R_{0111}|010111\rangle + R_{1000}|011000\rangle \\ +R_{1001}|011001\rangle + R_{1010}|011010\rangle + R_{1011}|011011\rangle \\ +R_{1100}|011100\rangle + R_{1101}|011101\rangle + R_{1110}|011110\rangle \\ +R_{1111}|011111\rangle \end{Bmatrix}$$

$$+x_1y_0\begin{Bmatrix} (R_{0000}|100000\rangle + +R_{0001}|100001\rangle + R_{0010}|100010\rangle \\ +R_{0011}|100011\rangle + R_{0100}|100100\rangle + R_{0101}|100101\rangle \\ +R_{0110}|100110\rangle + R_{0111}|100111\rangle + R_{1000}|101000\rangle \\ +R_{1001}|101001\rangle + R_{1010}|101010\rangle + R_{1011}|101011\rangle \\ +R_{1100}|101100\rangle + R_{1101}|101101\rangle + R_{1110}|101110\rangle \\ +R_{1111}|101111\rangle \end{Bmatrix}$$

$$+x_1y_1\begin{Bmatrix} (R_{0000}|110000\rangle + R_{0001}|110001\rangle + R_{0010}|110010\rangle \\ +R_{0011}|110011\rangle + R_{0100}|110100\rangle + R_{0101}|110101\rangle \\ +R_{0110}|110110\rangle + R_{0111}|110111\rangle + R_{1000}|111000\rangle \\ +R_{1001}|111001\rangle + R_{1010}|111010\rangle + R_{1011}|111011\rangle \\ +R_{1100}|111100\rangle + R_{1101}|111101\rangle + R_{1110}|111110\rangle \\ +R_{1111}|111111\rangle\} \end{Bmatrix}$$

Selanjutnya di perkenalkan Operator swap (P) dengan membalik qubit ke 2 dan ke 3 pada persamaan (L.4) dengan

$$P_{23} \quad = \quad I \otimes P \otimes I \otimes I \otimes I \qquad (L.5)$$

Sehingga persamaan (L.4) menjadi

$$|\psi\rangle_{A,A1,B,B1,B2,A2} \quad = \quad P_{23}|\psi\rangle_{A,B,A1,B1,B2,A2}$$

$$= \quad x_0y_0\begin{Bmatrix} (R_{0000}|000000\rangle + R_{0001}|000001\rangle + R_{0010}|000010\rangle \\ +R_{0011}|000011\rangle + R_{0100}|000100\rangle + R_{0101}|000101\rangle \\ +R_{0110}|000110\rangle + R_{0111}|000111\rangle + R_{1000}|010000\rangle \\ +R_{1001}|010001\rangle + R_{1010}|010010\rangle + R_{1011}|010011\rangle \\ +R_{1100}|010100\rangle + R_{1101}|010101\rangle + R_{1110}|010110\rangle \\ +R_{1111}|010111\rangle \end{Bmatrix} \qquad (L.6)$$

$$+x_0y_1\begin{Bmatrix} (R_{0000}|001000\rangle + R_{0001}|001001\rangle + R_{0010}|001010\rangle \\ +R_{0011}|001011\rangle + R_{0100}|001100\rangle + R_{0101}|001101\rangle \\ +R_{0110}|001110\rangle + R_{0111}|001111\rangle + R_{1000}|011000\rangle \\ +R_{1001}|011001\rangle + R_{1010}|011010\rangle + R_{1011}|011011\rangle \\ +R_{1100}|011100\rangle + R_{1101}|011101\rangle + R_{1110}|011110\rangle \\ +R_{1111}|011111\rangle \end{Bmatrix}$$

$$+x_1y_0\begin{Bmatrix}(R_{0000}|100000\rangle+R_{0001}|100001\rangle+R_{0010}|100010\rangle\\+R_{0011}|100011\rangle+R_{0100}|100100\rangle+R_{0101}|100101\rangle\\+R_{0110}|100110\rangle+R_{0111}|100111\rangle+R_{1000}|110000\rangle\\+R_{1001}|110001\rangle+R_{1010}|110010\rangle+R_{1011}|110011\rangle\\+R_{1100}|110100\rangle+R_{1101}|110101\rangle+R_{1110}|110110\rangle\\+R_{1111}|110111\rangle\}\end{Bmatrix}$$

$$+x_1y_1\begin{Bmatrix}(R_{0000}|101000\rangle+R_{0001}|101001\rangle+R_{0010}|101010\rangle\\+R_{0011}|101011\rangle+R_{0100}|101100\rangle+R_{0101}|101101\rangle\\+R_{0110}|101110\rangle+R_{0111}|101111\rangle+R_{1000}|111000\rangle\\+R_{1001}|111001\rangle+R_{1010}|111010\rangle+R_{1011}|111011\rangle\\+R_{1100}|111100\rangle+R_{1101}|111101\rangle+R_{1110}|111110\rangle\\+R_{1111}|111111\rangle\}\end{Bmatrix}$$

Diperkenalkan keadaan Bell sebagai berikut

$$\begin{aligned}|\phi\rangle^1_{mn} &= \frac{1}{\sqrt{2}}(|00\rangle+|11\rangle)_{mn}\\ |\phi\rangle^2_{mn} &= \frac{1}{\sqrt{2}}(|00\rangle-|11\rangle)_{mn}\\ |\phi\rangle^3_{mn} &= \frac{1}{\sqrt{2}}(|01\rangle+|10\rangle)_{mn}\\ |\phi\rangle^4_{mn} &= \frac{1}{\sqrt{2}}(|01\rangle-|10\rangle)_{mn}\end{aligned} \tag{L.7}$$

Selanjutnya dengan menggunakan persamaan (L.7) maka dapat dibentuk basis baru sebagai berikut:

$$\begin{aligned}|00\rangle_{mn} &= \frac{1}{\sqrt{2}}\left(|\phi\rangle^1_{mn}+|\phi\rangle^2_{mn}\right)\\ |01\rangle_{mn} &= \frac{1}{\sqrt{2}}\left(|\phi\rangle^3_{mn}+|\phi\rangle^4_{mn}\right)\\ |10\rangle_{mn} &= \frac{1}{\sqrt{2}}\left(|\phi\rangle^3_{mn}-|\phi\rangle^4_{mn}\right)\\ |11\rangle_{mn} &= \frac{1}{\sqrt{2}}\left(|\phi\rangle^1_{mn}-|\phi\rangle^2_{mn}\right)\end{aligned} \tag{L.8}$$

Maka dari persamaan (L.8), keadaan gabungan perkalian antara keadaan Bell pada qubit 1 dan 3 dengan qubit 2 dan 4 yang ada di persamaan (L.6) dapat dibangun kembali dengan basis berikut:

$$
\begin{aligned}
(|00\rangle|00\rangle)_{iljm} &= \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{1}+|\phi\rangle_{il}^{2}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{1}+|\phi\rangle_{jm}^{2}\right)\right) \\
&= \frac{1}{2}\left\{|\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{1}+|\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{2}+|\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{1}+|\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{2}\right\} \equiv \{1\} \\
(|00\rangle|01\rangle)_{iljm} &= \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{1}+|\phi\rangle_{il}^{2}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{3}+|\phi\rangle_{jm}^{4}\right)\right) \\
&= \frac{1}{2}\left\{|\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{3}+|\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{4}+|\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{3}+|\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{4}\right\} \equiv \{2\} \\
(|00\rangle|10\rangle)_{iljm} &= \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{1}+|\phi\rangle_{il}^{2}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{3}-|\phi\rangle_{jm}^{4}\right)\right) \\
&= \frac{1}{2}\left\{|\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{3}-|\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{4}+|\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{3}-|\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{4}\right\} \equiv \{3\} \\
(|00\rangle|11\rangle)_{iljm} &= \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{1}+|\phi\rangle_{il}^{2}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{1}-|\phi\rangle_{jm}^{2}\right)\right) \\
&= \frac{1}{2}\left\{|\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{1}-|\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{2}+|\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{1}-|\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{2}\right\} \equiv \{4\} \\
(|01\rangle|00\rangle)_{iljm} &= \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{3}+|\phi\rangle_{il}^{4}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{1}+|\phi\rangle_{jm}^{2}\right)\right) \\
&= \frac{1}{2}\left\{|\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{1}+|\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{2}+|\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{1}+|\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{2}\right\} \equiv \{5\} \\
(|01\rangle|01\rangle)_{iljm} &= \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{3}+|\phi\rangle_{il}^{4}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{3}+|\phi\rangle_{jm}^{4}\right)\right) \\
&= \frac{1}{2}\left\{|\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{3}+|\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{4}+|\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{3}+|\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{4}\right\} \equiv \{6\} \\
(|01\rangle|10\rangle)_{iljm} &= \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{3}+|\phi\rangle_{il}^{4}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{3}-|\phi\rangle_{jm}^{4}\right)\right) \\
&= \frac{1}{2}\left\{|\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{3}-|\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{4}+|\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{3}-|\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{4}\right\} \equiv \{7\} \\
(|01\rangle|11\rangle)_{iljm} &= \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{3}+|\phi\rangle_{il}^{4}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{1}-|\phi\rangle_{jm}^{2}\right)\right) \\
&= \frac{1}{2}\left\{|\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{1}-|\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{2}+|\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{1}-|\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{2}\right\} \equiv \{8\} \\
(|10\rangle|00\rangle)_{iljm} &= \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{3}-|\phi\rangle_{il}^{4}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{1}+|\phi\rangle_{jm}^{2}\right)\right) \\
&= \frac{1}{2}\left\{|\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{1}+|\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{2}-|\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{1}-|\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{2}\right\} \equiv \{9\}
\end{aligned}
$$

$$(|10\rangle|01\rangle)_{iljm} = \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{3} - |\phi\rangle_{il}^{4}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{3} + |\phi\rangle_{jm}^{4}\right)\right)$$

$$= \frac{1}{2}\left\{|\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{3} + |\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{4} - |\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{3} - |\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{4}\right\} \equiv \{10\}$$

$$(|10\rangle|10\rangle)_{iljm} = \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{3} - |\phi\rangle_{il}^{4}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{3} - |\phi\rangle_{jm}^{4}\right)\right)$$

$$= \frac{1}{2}\left\{|\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{3} - |\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{4} - |\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{3} + |\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{4}\right\} \equiv \{11\}$$

$$(|10\rangle|11\rangle)_{iljm} = \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{3} - |\phi\rangle_{il}^{4}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{1} - |\phi\rangle_{jm}^{2}\right)\right)$$

$$= \frac{1}{2}\left\{|\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{1} - |\phi\rangle_{il}^{3}|\phi\rangle_{jm}^{2} - |\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{1} + |\phi\rangle_{il}^{4}|\phi\rangle_{jm}^{2}\right\} \equiv \{12\}$$

$$(|11\rangle|00\rangle)_{iljm} = \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{1} - |\phi\rangle_{il}^{2}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{1} + |\phi\rangle_{jm}^{2}\right)\right)$$

$$= \frac{1}{2}\left\{|\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{1} + |\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{2} - |\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{1} - |\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{2}\right\} \equiv \{13\}$$

$$(|11\rangle|01\rangle)_{iljm} = \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{1} - |\phi\rangle_{il}^{2}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{3} + |\phi\rangle_{jm}^{4}\right)\right)$$

$$= \frac{1}{2}\left\{|\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{3} + |\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{4} - |\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{3} - |\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{4}\right\} \equiv \{14\}$$

$$(|11\rangle|10\rangle)_{iljm} = \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{1} - |\phi\rangle_{il}^{2}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{3} - |\phi\rangle_{jm}^{4}\right)\right)$$

$$= \frac{1}{2}\left\{|\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{3} - |\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{4} - |\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{3} + |\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{4}\right\} \equiv \{15\}$$

$$(|11\rangle|11\rangle)_{iljm} = \left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{il}^{1} - |\phi\rangle_{il}^{2}\right)\right)\left(\frac{1}{\sqrt{2}}\left(|\phi\rangle_{jm}^{1} - |\phi\rangle_{jm}^{2}\right)\right)$$

$$= \frac{1}{2}\left\{|\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{1} - |\phi\rangle_{il}^{1}|\phi\rangle_{jm}^{2} - |\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{1} + |\phi\rangle_{il}^{2}|\phi\rangle_{jm}^{2}\right\} \equiv \{16\} \qquad (L.9)$$

Selanjutnya persamaan (L.6) dapat di tuliskan kembali sebagai berikut

$$|\psi\rangle_{A,A1,B,B1,B2,A2} =$$

$$x_0y_0\{(R_{0000}|\{1\}00\rangle + R_{0001}|\{1\}01\rangle + R_{0010}|\{1\}10\rangle + R_{0011}|\{1\}11\rangle$$
$$+R_{0100}|\{2\}00\rangle + R_{0101}|\{2\}01\rangle + R_{0110}|\{2\}10\rangle + R_{0111}|\{2\}11\rangle$$
$$+R_{1000}|\{5\}00\rangle + R_{1001}|\{5\}01\rangle + R_{1010}|\{5\}10\rangle + R_{1011}|\{5\}11\rangle$$
$$+R_{1100}|\{6\}00\rangle + R_{1101}|\{6\}01\rangle + R_{1110}|\{6\}10\rangle + R_{1111}|\{6\}11\rangle\}$$
$$+x_0y_1\{(R_{0000}|\{3\}00\rangle + R_{0001}|\{3\}01\rangle + R_{0010}|\{3\}10\rangle + R_{0011}|\{3\}11\rangle$$
$$+R_{0100}|\{4\}00\rangle + R_{0101}|\{4\}01\rangle + R_{0110}|\{4\}10\rangle + R_{0111}|\{4\}11\rangle$$

$$
\begin{aligned}
&\quad +R_{1000}|\{7\}00\rangle + R_{1001}|\{7\}01\rangle + R_{1010}|\{7\}10\rangle + R_{1011}|\{7\}11\rangle \\
&\quad +R_{1100}|\{8\}00\rangle + R_{1101}|\{8\}01\rangle + R_{1110}|\{8\}10\rangle + R_{1111}|\{8\}11\rangle\} \\
&+x_1y_0\{(R_{0000}|\{9\}00\rangle + R_{0001}|\{9\}01\rangle + R_{0010}|\{9\}10\rangle + R_{0011}|\{9\}11\rangle \\
&\quad +R_{0100}|\{10\}00\rangle + R_{0101}|\{10\}01\rangle + R_{0110}|\{10\}10\rangle + R_{0111}|\{10\}11\rangle \\
&\quad +R_{1000}|\{13\}00\rangle + R_{1001}|\{13\}01\rangle + R_{1010}|\{13\}10\rangle + R_{1011}|\{13\}11\rangle \\
&\quad +R_{1100}|\{14\}00\rangle + R_{1101}|\{14\}01\rangle + R_{1110}|\{14\}10\rangle + R_{1111}|\{14\}11\rangle\} \\
&+x_1y_1\{(R_{0000}|\{11\}00\rangle + R_{0001}|\{11\}01\rangle + R_{0010}|\{11\}10\rangle + R_{0011}|\{11\}11\rangle \\
&\quad +R_{0100}|\{12\}00\rangle + R_{0101}|\{12\}01\rangle + R_{0110}|\{12\}10\rangle + R_{0111}|\{12\}11\rangle \\
&\quad +R_{1000}|\{15\}00\rangle + R_{1001}|\{15\}01\rangle + R_{1010}|\{15\}10\rangle + R_{1011}|\{15\}11\rangle \\
&\quad +R_{1100}|\{16\}00\rangle + R_{1101}|\{16\}01\rangle + R_{1110}|\{16\}10\rangle + R_{1111}|\{16\}11\rangle\} \\
&= \sum_{s,t=0}^{1} x_0y_0\,(R_{00st}|\{1\}st\rangle + R_{01st}|\{2\}st\rangle + R_{10st}|\{5\}st\rangle + R_{11st}|\{6\}st\rangle) \\
&\quad + \sum_{s,t=0}^{1} x_0y_1\,(R_{00st}|\{3\}st\rangle + R_{01st}|\{4\}st\rangle + R_{10st}|\{7\}st\rangle + R_{11st}|\{8\}st\rangle) \\
&\quad + \sum_{s,t=0}^{1} x_1y_0\,(R_{00st}|\{9\}st\rangle + R_{01st}|\{10\}st\rangle + R_{10st}|\{13\}st\rangle \\
&\qquad\qquad + R_{11st}|\{14\}st\rangle) \\
&\quad + \sum_{s,t=0}^{1} x_1y_1\,(R_{00st}|\{11\}st\rangle + R_{01st}|\{12\}st\rangle + R_{10st}|\{15\}st\rangle \\
&\qquad\qquad + R_{11st}|\{16\}st\rangle) \\
&= \sum_{s,t=0}^{1} x_0y_0\,(R_{00st}|\{1\}\rangle + R_{01st}|\{2\}\rangle + R_{10st}|\{5\}\rangle + R_{11st}|\{6\}\rangle)\,|st\rangle \\
&\quad + \sum_{s,t=0}^{1} x_0y_1\,(R_{00st}|\{3\}\rangle + R_{01st}|\{4\}\rangle + R_{10st}|\{7\}\rangle + R_{11st}|\{8\}\rangle)|st\rangle \\
&\quad + \sum_{s,t=0}^{1} x_1y_0\,(R_{00st}|\{9\}\rangle + R_{01st}|\{10\}\rangle + R_{10st}|\{13\}\rangle + R_{11st}|\{14\}\rangle)|st\rangle \\
&\quad + \sum_{s,t=0}^{1} x_1y_1\,(R_{00st}|\{11\}\rangle + R_{01st}|\{12\}\rangle + R_{10st}|\{15\}\rangle + R_{11st}|\{16\}\rangle)|st\rangle \\
&= x_0y_0\sum_{s,t=0}^{1}(R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix}|\{1\}\rangle\\|\{2\}\rangle\\|\{5\}\rangle\\|\{6\}\rangle\end{pmatrix}|st\rangle \qquad (L.10)
\end{aligned}
$$

$$+x_0y_1\sum_{s,t=0}^{1}(R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st})\begin{pmatrix}|\{3\}\rangle\\|\{4\}\rangle\\|\{7\}\rangle\\|\{8\}\rangle\end{pmatrix}|st\rangle$$

$$+x_1y_0\sum_{s,t=0}^{1}(R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st})\begin{pmatrix}|\{9\}\rangle\\|\{10\}\rangle\\|\{13\}\rangle\\|\{14\}\rangle\end{pmatrix}|st\rangle$$

$$+x_1y_1\sum_{s,t=0}^{1}(R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st})\begin{pmatrix}|\{11\}\rangle\\|\{12\}\rangle\\|\{15\}\rangle\\|\{16\}\rangle\end{pmatrix}|st\rangle$$

Selanjutnya dengan mensubtitusikan persamaan (L.9) kedalam persamaan (L.10) didapatkan

$$|\psi\rangle_{A,A1,B,B1,B2,A2} =$$

$$\frac{1}{2}x_0y_0\sum_{s,t=0}^{1}(R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st})\begin{pmatrix}|\phi\rangle_{00}^{1}|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{1}|\phi\rangle_{00}^{2}+|\phi\rangle_{00}^{2}|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}|\phi\rangle_{00}^{2}\\|\phi\rangle_{00}^{1}|\phi\rangle_{01}^{3}+|\phi\rangle_{00}^{1}|\phi\rangle_{01}^{4}+|\phi\rangle_{00}^{2}|\phi\rangle_{01}^{3}+|\phi\rangle_{00}^{2}|\phi\rangle_{01}^{4}\\|\phi\rangle_{01}^{3}|\phi\rangle_{00}^{1}+|\phi\rangle_{01}^{3}|\phi\rangle_{00}^{2}+|\phi\rangle_{01}^{4}|\phi\rangle_{00}^{1}+|\phi\rangle_{01}^{4}|\phi\rangle_{00}^{2}\\|\phi\rangle_{01}^{3}|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{3}|\phi\rangle_{01}^{4}+|\phi\rangle_{01}^{4}|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}|\phi\rangle_{01}^{4}\end{pmatrix}|st\rangle$$

$$+\frac{1}{2}x_0y_1\sum_{s,t=0}^{1}(R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st})\begin{pmatrix}|\phi\rangle_{00}^{1}|\phi\rangle_{10}^{3}-|\phi\rangle_{00}^{1}|\phi\rangle_{10}^{4}+|\phi\rangle_{00}^{2}|\phi\rangle_{10}^{3}-|\phi\rangle_{00}^{2}|\phi\rangle_{10}^{4}\\|\phi\rangle_{00}^{1}|\phi\rangle_{11}^{1}-|\phi\rangle_{00}^{1}|\phi\rangle_{11}^{2}+|\phi\rangle_{00}^{2}|\phi\rangle_{11}^{1}-|\phi\rangle_{00}^{2}|\phi\rangle_{11}^{2}\\|\phi\rangle_{01}^{3}|\phi\rangle_{10}^{3}-|\phi\rangle_{01}^{3}|\phi\rangle_{10}^{4}+|\phi\rangle_{01}^{4}|\phi\rangle_{10}^{3}-|\phi\rangle_{01}^{4}|\phi\rangle_{10}^{4}\\|\phi\rangle_{01}^{3}|\phi\rangle_{11}^{1}-|\phi\rangle_{01}^{3}|\phi\rangle_{11}^{2}+|\phi\rangle_{01}^{4}|\phi\rangle_{11}^{1}-|\phi\rangle_{01}^{4}|\phi\rangle_{11}^{2}\end{pmatrix}|st\rangle$$

$$+\frac{1}{2}x_1y_0\sum_{s,t=0}^{1}(R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st})\begin{pmatrix}|\phi\rangle_{10}^{3}|\phi\rangle_{00}^{1}+|\phi\rangle_{10}^{3}|\phi\rangle_{00}^{2}-|\phi\rangle_{10}^{4}|\phi\rangle_{00}^{1}-|\phi\rangle_{10}^{4}|\phi\rangle_{00}^{2}\\|\phi\rangle_{10}^{3}|\phi\rangle_{01}^{3}+|\phi\rangle_{10}^{3}|\phi\rangle_{01}^{4}-|\phi\rangle_{10}^{4}|\phi\rangle_{01}^{3}-|\phi\rangle_{10}^{4}|\phi\rangle_{01}^{4}\\|\phi\rangle_{11}^{1}|\phi\rangle_{00}^{1}+|\phi\rangle_{11}^{1}|\phi\rangle_{00}^{2}-|\phi\rangle_{11}^{2}|\phi\rangle_{00}^{1}-|\phi\rangle_{11}^{2}|\phi\rangle_{00}^{2}\\|\phi\rangle_{11}^{1}|\phi\rangle_{01}^{3}+|\phi\rangle_{11}^{1}|\phi\rangle_{01}^{4}-|\phi\rangle_{11}^{2}|\phi\rangle_{01}^{3}-|\phi\rangle_{11}^{2}|\phi\rangle_{01}^{4}\end{pmatrix}|st\rangle$$

$$+\frac{1}{2}x_1y_1\sum_{s,t=0}^{1}(R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st})\begin{pmatrix}|\phi\rangle_{10}^{3}|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{3}|\phi\rangle_{10}^{4}-|\phi\rangle_{10}^{4}|\phi\rangle_{10}^{3}+|\phi\rangle_{10}^{4}|\phi\rangle_{10}^{4}\\|\phi\rangle_{10}^{3}|\phi\rangle_{11}^{1}-|\phi\rangle_{10}^{3}|\phi\rangle_{11}^{2}-|\phi\rangle_{10}^{4}|\phi\rangle_{11}^{1}+|\phi\rangle_{10}^{4}|\phi\rangle_{11}^{2}\\|\phi\rangle_{11}^{1}|\phi\rangle_{10}^{3}-|\phi\rangle_{11}^{1}|\phi\rangle_{10}^{4}-|\phi\rangle_{11}^{2}|\phi\rangle_{10}^{3}+|\phi\rangle_{11}^{2}|\phi\rangle_{10}^{4}\\|\phi\rangle_{11}^{1}|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{1}|\phi\rangle_{11}^{2}-|\phi\rangle_{11}^{2}|\phi\rangle_{11}^{1}+|\phi\rangle_{11}^{2}|\phi\rangle_{11}^{2}\end{pmatrix}|st\rangle$$

$$=\frac{1}{2}x_0y_0\sum_{s,t=0}^{1}(R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st})\begin{pmatrix}\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\\\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\\\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\\\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\end{pmatrix}|st\rangle$$

$$+\frac{1}{2}x_0y_1\sum_{s,t=0}^{1}\begin{pmatrix}R_{00st} & R_{01st} & R_{10st} & R_{11st}\end{pmatrix}\begin{pmatrix}\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\\ \left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\\ \left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\\ \left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\end{pmatrix}|st\rangle$$

$$+\frac{1}{2}x_1y_0\sum_{s,t=0}^{1}\begin{pmatrix}R_{00st} & R_{01st} & R_{10st} & R_{11st}\end{pmatrix}\begin{pmatrix}\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\\ \left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\\ \left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\\ \left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\end{pmatrix}|st\rangle$$

$$+\frac{1}{2}x_1y_1\sum_{s,t=0}^{1}\begin{pmatrix}R_{00st} & R_{01st} & R_{10st} & R_{11st}\end{pmatrix}\begin{pmatrix}\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\\ \left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\\ \left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\\ \left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\end{pmatrix}|st\rangle$$

$$=\frac{1}{2}x_0y_0\sum_{s,t=0}^{1}\{R_{00st}\left(\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\right)+R_{01st}\left(\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\right)$$
$$+R_{10st}\left(\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\right)+R_{11st}\left(\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\right)\}|st\rangle$$

$$+\frac{1}{2}x_0y_1\sum_{s,t=0}^{1}\{R_{00st}\left(\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\right)+R_{01st}\left(\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\right)$$
$$+R_{10st}\left(\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\right)+R_{11st}\left(\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\right)\}|st\rangle$$

$$+\frac{1}{2}x_1y_0\sum_{s,t=0}^{1}\{R_{00st}\left(\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\right)+R_{01st}\left(\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\right)$$
$$+R_{10st}\left(\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\right)+R_{11st}\left(\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\right)\}|st\rangle$$

$$+\frac{1}{2}x_1y_1\sum_{s,t=0}^{1}\{R_{00st}\left(\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\right)+R_{01st}\left(\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\right)$$
$$+R_{10st}\left(\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\right)+R_{11st}\left(\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\right)\}|st\rangle$$

$$=\frac{1}{2}x_0\sum_{s,t=0}^{1}\begin{Bmatrix}R_{00st}\left\{\left(y_0\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\right)+\left(y_1\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\right)\right\}\\ +R_{01st}\left\{\left(y_0\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\right)+\left(y_1\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\right)\right\}\\ +R_{10st}\left\{\left(y_0\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\right)+\left(y_1\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\right)\right\}\\ +R_{11st}\left\{\left(y_0\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\right)+\left(y_1\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\right)\right\}\end{Bmatrix}|st\rangle$$

$$+\frac{1}{2}x_1\sum_{s,t=0}^{1}\begin{Bmatrix}R_{00st}\left\{\left(y_0\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\right)+\left(y_1\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\right)\right\}\\ +R_{01st}\left\{\left(y_0\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\right)+\left(y_1\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\right)\right\}\\ +R_{10st}\left\{\left(y_0\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\left(|\phi\rangle_{00}^{1}+|\phi\rangle_{00}^{2}\right)\right)+\left(y_1\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\left(|\phi\rangle_{10}^{3}-|\phi\rangle_{10}^{4}\right)\right)\right\}\\ +R_{11st}\left\{\left(y_0\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\left(|\phi\rangle_{01}^{3}+|\phi\rangle_{01}^{4}\right)\right)+\left(y_1\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\left(|\phi\rangle_{11}^{1}-|\phi\rangle_{11}^{2}\right)\right)\right\}\end{Bmatrix}|st\rangle$$

$$
= \frac{1}{2}x_0 \sum_{s,t=0}^{1} \begin{Bmatrix} R_{00st}\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right)\left\{\left(y_0\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right)\right) + \left(y_1\left(|\phi\rangle_{10}^{3} - |\phi\rangle_{10}^{4}\right)\right)\right\} \\ +R_{01st}\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right)\left\{\left(y_0\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right)\right) + \left(y_1\left(|\phi\rangle_{11}^{1} - |\phi\rangle_{11}^{2}\right)\right)\right\} \\ +R_{10st}\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right)\left\{\left(y_0\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right)\right) + \left(y_1\left(|\phi\rangle_{10}^{3} - |\phi\rangle_{10}^{4}\right)\right)\right\} \\ +R_{11st}\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right)\left\{\left(y_0\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right)\right) + \left(y_1\left(|\phi\rangle_{11}^{1} - |\phi\rangle_{11}^{2}\right)\right)\right\} \end{Bmatrix} |st\rangle
$$

$$
+ \frac{1}{2}x_1 \sum_{s,t=0}^{1} \begin{Bmatrix} R_{00st}\left(|\phi\rangle_{10}^{3} - |\phi\rangle_{10}^{4}\right)\left\{\left(y_0\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right)\right) + \left(y_1\left(|\phi\rangle_{10}^{3} - |\phi\rangle_{10}^{4}\right)\right)\right\} \\ +R_{01st}\left(|\phi\rangle_{10}^{3} - |\phi\rangle_{10}^{4}\right)\left\{\left(y_0\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right)\right) + \left(y_1\left(|\phi\rangle_{11}^{1} - |\phi\rangle_{11}^{2}\right)\right)\right\} \\ +R_{10st}\left(|\phi\rangle_{11}^{1} - |\phi\rangle_{11}^{2}\right)\left\{\left(y_0\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right)\right) + \left(y_1\left(|\phi\rangle_{10}^{3} - |\phi\rangle_{10}^{4}\right)\right)\right\} \\ +R_{11st}\left(|\phi\rangle_{11}^{1} - |\phi\rangle_{11}^{2}\right)\left\{\left(y_0\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right)\right) + \left(y_1\left(|\phi\rangle_{11}^{1} - |\phi\rangle_{11}^{2}\right)\right)\right\} \end{Bmatrix} |st\rangle \qquad \textit{(L.11)}
$$

Jika Persamaan (L.11) di tuliskan menjadi

$$
|\psi\rangle_{A,A1,B,B1,B2,A2} =
$$

$$
\frac{1}{2}x_0 \sum_{s,t=0}^{1} \begin{Bmatrix} R_{00st}\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right)\begin{Bmatrix} y_0\left(T_{00}^{1}|\phi\rangle_{00}^{1} + T_{00}^{2}|\phi\rangle_{00}^{2} + T_{00}^{3}|\phi\rangle_{00}^{3} + T_{00}^{4}|\phi\rangle_{00}^{4}\right) \\ +y_1\left(T_{10}^{1}|\phi\rangle_{10}^{1} + T_{10}^{2}|\phi\rangle_{10}^{2} + T_{10}^{3}|\phi\rangle_{10}^{3} + T_{10}^{4}|\phi\rangle_{10}^{4}\right) \end{Bmatrix} \\ +R_{01st}\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right)\begin{Bmatrix} y_0\left(T_{01}^{1}|\phi\rangle_{01}^{1} + T_{01}^{2}|\phi\rangle_{01}^{2} + T_{01}^{3}|\phi\rangle_{01}^{3} + T_{01}^{4}|\phi\rangle_{01}^{4}\right) \\ +y_1\left(T_{11}^{1}|\phi\rangle_{11}^{1} + T_{11}^{2}|\phi\rangle_{11}^{2} + T_{11}^{3}|\phi\rangle_{11}^{3} + T_{11}^{4}|\phi\rangle_{11}^{4}\right) \end{Bmatrix} \\ +R_{10st}\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right)\begin{Bmatrix} y_0\left(T_{00}^{1}|\phi\rangle_{00}^{1} + T_{00}^{2}|\phi\rangle_{00}^{2} + T_{00}^{3}|\phi\rangle_{00}^{3} + T_{00}^{4}|\phi\rangle_{00}^{4}\right) \\ y_1\left(T_{10}^{1}|\phi\rangle_{10}^{1} + T_{10}^{2}|\phi\rangle_{10}^{2} + T_{10}^{3}|\phi\rangle_{10}^{3} + T_{10}^{4}|\phi\rangle_{10}^{4}\right) \end{Bmatrix} \\ +R_{11st}\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right)\begin{Bmatrix} y_0\left(T_{01}^{1}|\phi\rangle_{01}^{1} + T_{01}^{2}|\phi\rangle_{01}^{2} + T_{01}^{3}|\phi\rangle_{01}^{3} + T_{01}^{4}|\phi\rangle_{01}^{4}\right) \\ +y_1\left(T_{11}^{1}|\phi\rangle_{11}^{1} + T_{11}^{2}|\phi\rangle_{11}^{2} + T_{11}^{3}|\phi\rangle_{11}^{3} + T_{11}^{4}|\phi\rangle_{11}^{4}\right) \end{Bmatrix} \end{Bmatrix} |st\rangle \qquad \textit{L.12)}
$$

$$
+\frac{1}{2}x_1 \sum_{s,t=0}^{1} \begin{Bmatrix} R_{00st}\left(|\phi\rangle_{10}^{3} - |\phi\rangle_{10}^{4}\right)\begin{Bmatrix} y_0\left(T_{00}^{1}|\phi\rangle_{00}^{1} + T_{00}^{2}|\phi\rangle_{00}^{2} + T_{00}^{3}|\phi\rangle_{00}^{3} + T_{00}^{4}|\phi\rangle_{00}^{4}\right) \\ +y_1\left(T_{10}^{1}|\phi\rangle_{10}^{1} + T_{10}^{2}|\phi\rangle_{10}^{2} + T_{10}^{3}|\phi\rangle_{10}^{3} + T_{10}^{4}|\phi\rangle_{10}^{4}\right) \end{Bmatrix} \\ +R_{01st}\left(|\phi\rangle_{10}^{3} - |\phi\rangle_{10}^{4}\right)\begin{Bmatrix} y_0\left(T_{01}^{1}|\phi\rangle_{01}^{1} + T_{01}^{2}|\phi\rangle_{01}^{2} + T_{01}^{3}|\phi\rangle_{01}^{3} + T_{01}^{4}|\phi\rangle_{01}^{4}\right) \\ +y_1\left(T_{11}^{1}|\phi\rangle_{11}^{1} + T_{11}^{2}|\phi\rangle_{11}^{2} + T_{11}^{3}|\phi\rangle_{11}^{3} + T_{11}^{4}|\phi\rangle_{11}^{4}\right) \end{Bmatrix} \\ +R_{10st}\left(|\phi\rangle_{11}^{1} - |\phi\rangle_{11}^{2}\right)\begin{Bmatrix} y_0\left(T_{00}^{1}|\phi\rangle_{00}^{1} + T_{00}^{2}|\phi\rangle_{00}^{2} + T_{00}^{3}|\phi\rangle_{00}^{3} + T_{00}^{4}|\phi\rangle_{00}^{4}\right) \\ y_1\left(T_{10}^{1}|\phi\rangle_{10}^{1} + T_{10}^{2}|\phi\rangle_{10}^{2} + T_{10}^{3}|\phi\rangle_{10}^{3} + T_{10}^{4}|\phi\rangle_{10}^{4}\right) \end{Bmatrix} \\ +R_{11st}\left(|\phi\rangle_{11}^{1} - |\phi\rangle_{11}^{2}\right)\begin{Bmatrix} y_0\left(T_{01}^{1}|\phi\rangle_{01}^{1} + T_{01}^{2}|\phi\rangle_{01}^{2} + T_{01}^{3}|\phi\rangle_{01}^{3} + T_{01}^{4}|\phi\rangle_{01}^{4}\right) \\ +y_1\left(T_{11}^{1}|\phi\rangle_{11}^{1} + T_{11}^{2}|\phi\rangle_{11}^{2} + T_{11}^{3}|\phi\rangle_{11}^{3} + T_{11}^{4}|\phi\rangle_{11}^{4}\right) \end{Bmatrix} \end{Bmatrix} |st\rangle
$$

Lalu jika T_{jm}^{τ} adalah konstanta yang bekerja pada keadaan bell $|\phi\rangle_{jm}^{\tau}$, maka dengan membandingkan persamaan (L.11) dan persamaan (L.12) sebagai berikut

$$
\frac{1}{\sqrt{2}}R_{00st}\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right)\begin{Bmatrix} y_0\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right) \\ +y_1\left(|\phi\rangle_{10}^{3} - |\phi\rangle_{10}^{4}\right) \end{Bmatrix} = R_{00st}\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right)\begin{Bmatrix} \left(y_0\left(T_{00}^{1}|\phi\rangle_{00}^{1} + T_{00}^{2}|\phi\rangle_{00}^{2} + T_{00}^{3}|\phi\rangle_{00}^{3} + T_{00}^{4}|\phi\rangle_{00}^{4}\right)\right) \\ +\left(y_1\left(T_{10}^{1}|\phi\rangle_{10}^{1} + T_{10}^{2}|\phi\rangle_{10}^{2} + T_{10}^{3}|\phi\rangle_{10}^{3} + T_{10}^{4}|\phi\rangle_{10}^{4}\right)\right) \end{Bmatrix}
$$

$$
\frac{1}{\sqrt{2}}\left(y_0\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right)\right) + \left(y_1\left(|\phi\rangle_{10}^{3} - |\phi\rangle_{10}^{4}\right)\right) = \begin{Bmatrix} y_0\left(T_{00}^{1}|\phi\rangle_{00}^{1} + T_{00}^{2}|\phi\rangle_{00}^{2} + T_{00}^{3}|\phi\rangle_{00}^{3} + T_{00}^{4}|\phi\rangle_{00}^{4}\right) \\ +y_1\left(T_{10}^{1}|\phi\rangle_{10}^{1} + T_{10}^{2}|\phi\rangle_{10}^{2} + T_{10}^{3}|\phi\rangle_{10}^{3} + T_{10}^{4}|\phi\rangle_{10}^{4}\right) \end{Bmatrix}
$$

Sehingga nilai konstanta T_{jm}^{τ} adalah

$$T_{00}^{1} = \frac{1}{\sqrt{2}} \quad ; \quad T_{10}^{1} = 0$$

$$T_{00}^{2} = \frac{1}{\sqrt{2}} \quad ; \quad T_{10}^{2} = 0$$

$$T_{00}^{3} = 0 \quad ; \quad T_{10}^{3} = \frac{1}{\sqrt{2}}$$

$$T_{00}^{4} = 0 \quad ; \quad T_{10}^{4} = -\frac{1}{\sqrt{2}}$$

Selanjutnya

$$\frac{1}{\sqrt{2}} R_{01st}\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right)\begin{Bmatrix} y_0\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right) \\ +y_1\left(|\phi\rangle_{11}^{1} - |\phi\rangle_{11}^{2}\right) \end{Bmatrix} = R_{01st}\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right)\begin{Bmatrix} y_0\left(T_{01}^{1}|\phi\rangle_{01}^{1} + T_{01}^{2}|\phi\rangle_{01}^{2} + T_{01}^{3}|\phi\rangle_{01}^{3} + T_{01}^{4}|\phi\rangle_{01}^{4}\right) \\ +y_1\left(T_{11}^{1}|\phi\rangle_{11}^{1} + T_{11}^{2}|\phi\rangle_{11}^{2} + T_{11}^{3}|\phi\rangle_{11}^{3} + T_{11}^{4}|\phi\rangle_{11}^{4}\right) \end{Bmatrix}$$

$$\frac{1}{\sqrt{2}}\left(y_0\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right)\right) + \left(y_1\left(|\phi\rangle_{11}^{1} - |\phi\rangle_{11}^{2}\right)\right) = \begin{Bmatrix} y_0\left(T_{01}^{1}|\phi\rangle_{01}^{1} + T_{01}^{2}|\phi\rangle_{01}^{2} + T_{01}^{3}|\phi\rangle_{01}^{3} + T_{01}^{4}|\phi\rangle_{01}^{4}\right) \\ +y_1\left(T_{11}^{1}|\phi\rangle_{11}^{1} + T_{11}^{2}|\phi\rangle_{11}^{2} + T_{11}^{3}|\phi\rangle_{11}^{3} + T_{11}^{4}|\phi\rangle_{11}^{4}\right) \end{Bmatrix}$$

Sehingga nilai konstanta T_{jm}^{τ} adalah

$$T_{01}^{1} = 0 \quad ; \quad T_{11}^{1} \quad \frac{1}{\sqrt{2}}$$

$$T_{01}^{2} = 0 \quad ; \quad T_{11}^{2} \quad -\frac{1}{\sqrt{2}}$$

$$T_{01}^{3} = \frac{1}{\sqrt{2}} \quad ; \quad T_{11}^{3} \quad 0$$

$$T_{01}^{4} = \frac{1}{\sqrt{2}} \quad ; \quad T_{11}^{4} \quad 0$$

Selanjutnya

$$\frac{1}{\sqrt{2}} R_{10st}\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right)\begin{Bmatrix} y_0\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right) \\ +y_1\left(|\phi\rangle_{10}^{3} - |\phi\rangle_{10}^{4}\right) \end{Bmatrix} = R_{10st}\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right)\begin{Bmatrix} y_0\left(T_{00}^{1}|\phi\rangle_{00}^{1} + T_{00}^{2}|\phi\rangle_{00}^{2} + T_{00}^{3}|\phi\rangle_{00}^{3} + T_{00}^{4}|\phi\rangle_{00}^{4}\right) \\ +y_1\left(T_{10}^{1}|\phi\rangle_{10}^{1} + T_{10}^{2}|\phi\rangle_{10}^{2} + T_{10}^{3}|\phi\rangle_{10}^{3} + T_{10}^{4}|\phi\rangle_{10}^{4}\right) \end{Bmatrix}$$

$$\frac{1}{\sqrt{2}}\left(y_0\left(|\phi\rangle_{00}^{1} + |\phi\rangle_{00}^{2}\right)\right) + \left(y_1\left(|\phi\rangle_{10}^{3} - |\phi\rangle_{10}^{4}\right)\right) = \begin{Bmatrix} y_0\left(T_{00}^{1}|\phi\rangle_{00}^{1} + T_{00}^{2}|\phi\rangle_{00}^{2} + T_{00}^{3}|\phi\rangle_{00}^{3} + T_{00}^{4}|\phi\rangle_{00}^{4}\right) \\ +y_1\left(T_{10}^{1}|\phi\rangle_{10}^{1} + T_{10}^{2}|\phi\rangle_{10}^{2} + T_{10}^{3}|\phi\rangle_{10}^{3} + T_{10}^{4}|\phi\rangle_{10}^{4}\right) \end{Bmatrix}$$

Sehingga nilai konstanta T_{jm}^{τ} adalah

$$T_{00}^{1} = \frac{1}{\sqrt{2}} \quad ; \quad T_{10}^{1} = 0$$

$T_{00}^{2} = \frac{1}{\sqrt{2}}$; $T_{10}^{2} = 0$

$T_{00}^{3} = 0$; $T_{10}^{3} = \frac{1}{\sqrt{2}}$

$T_{00}^{4} = 0$; $T_{10}^{4} = -\frac{1}{\sqrt{2}}$

Selanjutnya

$$\frac{1}{\sqrt{2}} R_{11st}\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right)\begin{Bmatrix} y_0\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right) \\ +y_1\left(|\phi\rangle_{11}^{1} - |\phi\rangle_{11}^{2}\right)\end{Bmatrix} = R_{11st}\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right)\begin{Bmatrix} y_0\left(T_{01}^{1}|\phi\rangle_{01}^{1} + T_{01}^{2}|\phi\rangle_{01}^{2} + T_{01}^{3}|\phi\rangle_{01}^{3} + T_{01}^{4}|\phi\rangle_{01}^{4}\right) \\ +y_1\left(T_{11}^{1}|\phi\rangle_{11}^{1} + T_{11}^{2}|\phi\rangle_{11}^{2} + T_{11}^{3}|\phi\rangle_{11}^{3} + T_{11}^{4}|\phi\rangle_{11}^{4}\right)\end{Bmatrix}$$

$$\frac{1}{\sqrt{2}}\left(y_0\left(|\phi\rangle_{01}^{3} + |\phi\rangle_{01}^{4}\right)\right) + \left(y_1\left(|\phi\rangle_{11}^{1} - |\phi\rangle_{11}^{2}\right)\right) = \begin{Bmatrix} y_0\left(T_{01}^{1}|\phi\rangle_{01}^{1} + T_{01}^{2}|\phi\rangle_{01}^{2} + T_{01}^{3}|\phi\rangle_{01}^{3} + T_{01}^{4}|\phi\rangle_{01}^{4}\right) \\ +y_1\left(T_{11}^{1}|\phi\rangle_{11}^{1} + T_{11}^{2}|\phi\rangle_{11}^{2} + T_{11}^{3}|\phi\rangle_{11}^{3} + T_{11}^{4}|\phi\rangle_{11}^{4}\right)\end{Bmatrix}$$

Sehingga nilai konstanta T_{jm}^{τ} adalah

$T_{01}^{1} = 0$; $T_{11}^{1} = \frac{1}{\sqrt{2}}$

$T_{01}^{2} = 0$; $T_{11}^{2} = -\frac{1}{\sqrt{2}}$

$T_{01}^{3} = \frac{1}{\sqrt{2}}$; $T_{11}^{3} = 0$

$T_{01}^{4} = \frac{1}{\sqrt{2}}$; $T_{11}^{4} = 0$

didapatkan nilai keseluruhan dari konstanta T_{jm}^{τ} adalah

$$\begin{pmatrix} T_{00}^{1} & T_{00}^{2} & T_{00}^{3} & T_{00}^{4} \\ T_{01}^{1} & T_{01}^{2} & T_{01}^{3} & T_{01}^{4} \\ T_{10}^{1} & T_{10}^{2} & T_{10}^{3} & T_{10}^{4} \\ T_{11}^{1} & T_{11}^{2} & T_{11}^{3} & T_{11}^{4} \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & -1 & 0 & 0 \end{pmatrix} \qquad (L.13)\;)$$

Sehingga persamaan (L.12) dapat dituliskan kembali dengan

$|\psi\rangle_{A,A1,B,B1,B2,A2} =$

$$\frac{1}{2}x_0\sum_{j=0}^{1}y_j\sum_{s,t=0}^{1}\left\{\begin{matrix} R_{00st}\left(\left(|\phi\rangle_{00}^1+|\phi\rangle_{00}^2\right)\left(T_{j0}^1|\phi\rangle_{j0}^1+T_{j0}^2|\phi\rangle_{j0}^2+T_{j0}^3|\phi\rangle_{j0}^3+T_{j0}^4|\phi\rangle_{j0}^4\right)\right)\\ +R_{01st}\left(\left(|\phi\rangle_{00}^1+|\phi\rangle_{00}^2\right)\left(T_{j1}^1|\phi\rangle_{j1}^1+T_{j1}^2|\phi\rangle_{j1}^2+T_{j1}^3|\phi\rangle_{j1}^3+T_{j1}^4|\phi\rangle_{j1}^4\right)\right)\\ +R_{10st}\left(\left(|\phi\rangle_{01}^3+|\phi\rangle_{01}^4\right)\left(T_{j0}^1|\phi\rangle_{j0}^1+T_{j0}^2|\phi\rangle_{j0}^2+T_{j0}^3|\phi\rangle_{j0}^3+T_{j0}^4|\phi\rangle_{j0}^4\right)\right)\\ +R_{11st}\left(\left(|\phi\rangle_{01}^3+|\phi\rangle_{01}^4\right)\left(T_{j1}^1|\phi\rangle_{j1}^1+T_{j1}^2|\phi\rangle_{j1}^2+T_{j1}^3|\phi\rangle_{j1}^3+T_{j1}^4|\phi\rangle_{j1}^4\right)\right)\end{matrix}\right\}|st\rangle$$

$$+\frac{1}{2}x_1\sum_{j=0}^{1}y_j\sum_{s,t=0}^{1}\left\{\begin{matrix} R_{00st}\left(\left(|\phi\rangle_{10}^3-|\phi\rangle_{10}^4\right)\left(T_{j0}^1|\phi\rangle_{j0}^1+T_{j0}^2|\phi\rangle_{j0}^2+T_{j0}^3|\phi\rangle_{j0}^3+T_{j0}^4|\phi\rangle_{j0}^4\right)\right)\\ +R_{01st}\left(\left(|\phi\rangle_{10}^3-|\phi\rangle_{10}^4\right)\left(T_{j1}^1|\phi\rangle_{j1}^1+T_{j1}^2|\phi\rangle_{j1}^2+T_{j1}^3|\phi\rangle_{j1}^3+T_{j1}^4|\phi\rangle_{j1}^4\right)\right)\\ +R_{10st}\left(\left(|\phi\rangle_{11}^1-|\phi\rangle_{11}^2\right)\left(T_{j0}^1|\phi\rangle_{j0}^1+T_{j0}^2|\phi\rangle_{j0}^2+T_{j0}^3|\phi\rangle_{j0}^3+T_{j0}^4|\phi\rangle_{j0}^4\right)\right)\\ +R_{11st}\left(\left(|\phi\rangle_{11}^1-|\phi\rangle_{11}^2\right)\left(T_{j1}^1|\phi\rangle_{j1}^1+T_{j1}^2|\phi\rangle_{j1}^2+T_{j1}^3|\phi\rangle_{j1}^3+T_{j1}^4|\phi\rangle_{j1}^4\right)\right)\end{matrix}\right\}|st\rangle$$

Dengan menggunakan cara yang sama maka dapat dituliskan secara keseluruhan menjadi

$$|\psi\rangle_{A,A1,B,B1,B2,A2}=$$

$$\frac{1}{2}\sum_{i,j=0}^{1}x_iy_j\sum_{s,t=0}^{1}\left\{\begin{matrix} R_{00st}\left(\left(T_{i0}^1|\phi\rangle_{i0}^1+T_{i0}^2|\phi\rangle_{i0}^2+T_{i0}^3|\phi\rangle_{i0}^3+T_{i0}^4|\phi\rangle_{i0}^4\right)\left(T_{j0}^1|\phi\rangle_{j0}^1+T_{j0}^2|\phi\rangle_{j0}^2+T_{j0}^3|\phi\rangle_{j0}^3+T_{j0}^4|\phi\rangle_{j0}^4\right)\right)\\ +R_{01st}\left(\left(T_{i0}^1|\phi\rangle_{i0}^1+T_{i0}^2|\phi\rangle_{i0}^2+T_{i0}^3|\phi\rangle_{i0}^3+T_{i0}^4|\phi\rangle_{i0}^4\right)\left(T_{j1}^1|\phi\rangle_{j1}^1+T_{j1}^2|\phi\rangle_{j1}^2+T_{j1}^3|\phi\rangle_{j1}^3+T_{j1}^4|\phi\rangle_{j1}^4\right)\right)\\ +R_{10st}\left(\left(T_{i1}^1|\phi\rangle_{i1}^1+T_{i1}^2|\phi\rangle_{i1}^2+T_{i1}^3|\phi\rangle_{i1}^3+T_{i1}^4|\phi\rangle_{i1}^4\right)\left(T_{j0}^1|\phi\rangle_{j0}^1+T_{j0}^2|\phi\rangle_{j0}^2+T_{j0}^3|\phi\rangle_{j0}^3+T_{j0}^4|\phi\rangle_{j0}^4\right)\right)\\ +R_{11st}\left(\left(T_{i1}^1|\phi\rangle_{i1}^1+T_{i1}^2|\phi\rangle_{i1}^2+T_{i1}^3|\phi\rangle_{i1}^3+T_{i1}^4|\phi\rangle_{i1}^4\right)\left(T_{j1}^1|\phi\rangle_{j1}^1+T_{j1}^2|\phi\rangle_{j1}^2+T_{j1}^3|\phi\rangle_{j1}^3+T_{j1}^4|\phi\rangle_{j1}^4\right)\right)\end{matrix}\right\}|st\rangle$$

(L.14)

Maka didapatkan nilai koefisiennya sama dengan pada persamaan (L.13), selanjutnya dengan menuliskan persamaan (L.14)

$$|\psi\rangle_{A,A1,B,B1,B2,A2}=$$

$$\sum_{i,j=0}^{1}x_iy_j\sum_{s,t=0}^{1}\left\{\begin{matrix} R_{00st}\left(\left(T_{i0}^1|\phi\rangle_{i0}^1+T_{i0}^2|\phi\rangle_{i0}^2+T_{i0}^3|\phi\rangle_{i0}^3+T_{i0}^4|\phi\rangle_{i0}^4\right)\left(T_{j0}^1|\phi\rangle_{j0}^1+T_{j0}^2|\phi\rangle_{j0}^2+T_{j0}^3|\phi\rangle_{j0}^3+T_{j0}^4|\phi\rangle_{j0}^4\right)\right)\\ +R_{01st}\left(\left(T_{i0}^1|\phi\rangle_{i0}^1+T_{i0}^2|\phi\rangle_{i0}^2+T_{i0}^3|\phi\rangle_{i0}^3+T_{i0}^4|\phi\rangle_{i0}^4\right)\left(T_{j1}^1|\phi\rangle_{j1}^1+T_{j1}^2|\phi\rangle_{j1}^2+T_{j1}^3|\phi\rangle_{j1}^3+T_{j1}^4|\phi\rangle_{j1}^4\right)\right)\\ +R_{10st}\left(\left(T_{i1}^1|\phi\rangle_{i1}^1+T_{i1}^2|\phi\rangle_{i1}^2+T_{i1}^3|\phi\rangle_{i1}^3+T_{i1}^4|\phi\rangle_{i1}^4\right)\left(T_{j0}^1|\phi\rangle_{j0}^1+T_{j0}^2|\phi\rangle_{j0}^2+T_{j0}^3|\phi\rangle_{j0}^3+T_{j0}^4|\phi\rangle_{j0}^4\right)\right)\\ +R_{11st}\left(\left(T_{i1}^1|\phi\rangle_{i1}^1+T_{i1}^2|\phi\rangle_{i1}^2+T_{i1}^3|\phi\rangle_{i1}^3+T_{i1}^4|\phi\rangle_{i1}^4\right)\left(T_{j1}^1|\phi\rangle_{j1}^1+T_{j1}^2|\phi\rangle_{j1}^2+T_{j1}^3|\phi\rangle_{j1}^3+T_{j1}^4|\phi\rangle_{j1}^4\right)\right)\end{matrix}\right\}|st\rangle$$

$$=\sum_{i,j=0}^{1}x_iy_j\sum_{s,t=0}^{1}\begin{pmatrix}R_{00st} & R_{01st} & R_{10st} & R_{11st}\end{pmatrix}$$

$$\begin{pmatrix}\left(T_{i0}^1|\phi\rangle_{i0}^1+T_{i0}^2|\phi\rangle_{i0}^2+T_{i0}^3|\phi\rangle_{i0}^3+T_{i0}^4|\phi\rangle_{i0}^4\right)\left(T_{j0}^1|\phi\rangle_{j0}^1+T_{j0}^2|\phi\rangle_{j0}^2+T_{j0}^3|\phi\rangle_{j0}^3+T_{j0}^4|\phi\rangle_{j0}^4\right)\\ \left(T_{i0}^1|\phi\rangle_{i0}^1+T_{i0}^2|\phi\rangle_{i0}^2+T_{i0}^3|\phi\rangle_{i0}^3+T_{i0}^4|\phi\rangle_{i0}^4\right)\left(T_{j1}^1|\phi\rangle_{j1}^1+T_{j1}^2|\phi\rangle_{j1}^2+T_{j1}^3|\phi\rangle_{j1}^3+T_{j1}^4|\phi\rangle_{j1}^4\right)\\ \left(T_{i1}^1|\phi\rangle_{i1}^1+T_{i1}^2|\phi\rangle_{i1}^2+T_{i1}^3|\phi\rangle_{i1}^3+T_{i1}^4|\phi\rangle_{i1}^4\right)\left(T_{j0}^1|\phi\rangle_{j0}^1+T_{j0}^2|\phi\rangle_{j0}^2+T_{j0}^3|\phi\rangle_{j0}^3+T_{j0}^4|\phi\rangle_{j0}^4\right)\\ \left(T_{i1}^1|\phi\rangle_{i1}^1+T_{i1}^2|\phi\rangle_{i1}^2+T_{i1}^3|\phi\rangle_{i1}^3+T_{i1}^4|\phi\rangle_{i1}^4\right)\left(T_{j1}^1|\phi\rangle_{j1}^1-T_{j1}^2|\phi\rangle_{j1}^2+T_{j1}^3|\phi\rangle_{j1}^3+T_{j1}^4|\phi\rangle_{j1}^4\right)\end{pmatrix}|st\rangle$$

$$= \sum_{i,j=0}^{1} x_i y_j \sum_{s,t=0}^{1} \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} \left(\sum_{\theta=1}^{4} T_{i0}^{\theta} |\phi\rangle_{i0}^{\theta}\right)\left(\sum_{\tau=1}^{4} T_{j0}^{\tau} |\phi\rangle_{j0}^{\tau}\right) \\ \left(\sum_{\theta=1}^{4} T_{i0}^{\theta} |\phi\rangle_{i0}^{\theta}\right)\left(\sum_{\tau=1}^{4} T_{j1}^{\tau} |\phi\rangle_{j1}^{\tau}\right) \\ \left(\sum_{\theta=1}^{4} T_{i1}^{\theta} |\phi\rangle_{i1}^{\theta}\right)\left(\sum_{\tau=1}^{4} T_{j0}^{\tau} |\phi\rangle_{j0}^{\tau}\right) \\ \left(\sum_{\theta=1}^{4} T_{i1}^{\theta} |\phi\rangle_{i1}^{\theta}\right)\left(\sum_{\tau=1}^{4} T_{j1}^{\tau} |\phi\rangle_{j1}^{\tau}\right) \end{pmatrix} |st\rangle$$

$$= \sum_{i,j,s,t=0}^{1} \sum_{\theta,\tau=1}^{4} x_i y_j \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} \left(T_{i0}^{\theta} |\phi\rangle_{i0}^{\theta}\right)\left(T_{j0}^{\tau} |\phi\rangle_{j0}^{\tau}\right) \\ \left(T_{i0}^{\theta} |\phi\rangle_{i0}^{\theta}\right)\left(T_{j1}^{\tau} |\phi\rangle_{j1}^{\tau}\right) \\ \left(T_{i1}^{\theta} |\phi\rangle_{i1}^{\theta}\right)\left(T_{j0}^{\tau} |\phi\rangle_{j0}^{\tau}\right) \\ \left(T_{i1}^{\theta} |\phi\rangle_{i1}^{\theta}\right)\left(T_{j1}^{\tau} |\phi\rangle_{j1}^{\tau}\right) \end{pmatrix} |st\rangle$$

$$= \sum_{i=0}^{1} \sum_{j=0}^{1} \sum_{m,s,t=0}^{1} \sum_{\theta=1}^{4} \sum_{\tau=1}^{4} x_i\, y_j \begin{pmatrix} R_{0mst} & R_{1mst} \end{pmatrix} \begin{pmatrix} \left(T_{i0}^{\theta} |\phi\rangle_{i0}^{\theta}\right)\left(T_{jm}^{\tau} |\phi\rangle_{jm}^{\tau}\right) \\ \left(T_{i1}^{\theta} |\phi\rangle_{i1}^{\theta}\right)\left(T_{jm}^{\tau} |\phi\rangle_{jm}^{\tau}\right) \end{pmatrix} |st\rangle$$

$$= \sum_{i=0}^{1} \sum_{j=0}^{1} \sum_{l,m,s,t=0}^{1} \sum_{\theta=1}^{4} \sum_{\tau=1}^{4} x_i\, y_j R_{lmst} \left(T_{il}^{\theta} |\phi\rangle_{il}^{\theta}\right)\left(T_{jm}^{\tau} |\phi\rangle_{jm}^{\tau}\right) |st\rangle$$

$$= \sum_{i=0}^{1} \sum_{j=0}^{1} \sum_{l,m,s,t=0}^{1} \sum_{\theta=1}^{4} \sum_{\tau=1}^{4} x_i\, y_j R_{lmst} T_{il}^{\theta} T_{jm}^{\tau} \left(|\phi\rangle_{il}^{\theta} |\phi\rangle_{jm}^{\tau}\right) |st\rangle \qquad (L.15)$$

Selanjutnya dengan menuliskan $|\phi\rangle_{il}^{\theta} = |\theta\rangle_{il}$; $|\phi\rangle_{jm}^{\tau} = |\tau\rangle_{jm}$ dan $(\theta, \tau \in 1,2,3,4)$ sehingga dapat dituliskan kembali persamaan (L.15) dengan

$$|\psi\rangle_{A,A1,B,B1,B2,A2} =$$

$$\sum_{i=0}^{1} \sum_{j=0}^{1} \sum_{l,m,s,t=0}^{1} \sum_{\theta=1}^{4} \sum_{\tau=1}^{4} x_i\, y_j R_{lmst} T_{il}^{\theta} T_{jm}^{\tau} (|\theta\rangle|\tau\rangle)\, |st\rangle$$

$$= \sum_{i=0}^{1} \sum_{j=0}^{1} x_i y_j \sum_{l,m,s,t=0}^{1} \sum_{\theta=1}^{4} \sum_{\tau=1}^{4} R_{lmst} T_{il}^{\theta} T_{jm}^{\tau} (|\theta\rangle|\tau\rangle)\, |st\rangle$$

$$= \sum_{s,t=0}^{1}\sum_{i,j=0}^{1} x_i y_j \left(\begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} \begin{Bmatrix} T_{i0}^1T_{j0}^1|11\rangle + T_{i0}^1T_{j0}^2|12\rangle + T_{i0}^1T_{j0}^3|13\rangle + T_{i0}^1T_{j0}^4|14\rangle \\ +T_{i0}^2T_{j0}^1|21\rangle + T_{i0}^2T_{j0}^2|22\rangle + T_{i0}^2T_{j0}^3|23\rangle + T_{i0}^2T_{j0}^4|24\rangle \\ +T_{i0}^3T_{j0}^1|31\rangle + T_{i0}^3T_{j0}^2|32\rangle + T_{i0}^3T_{j0}^3|33\rangle + T_{i0}^3T_{j0}^4|34\rangle \\ +T_{i0}^4T_{j0}^1|41\rangle + T_{i0}^4T_{j0}^2|42\rangle + T_{i0}^4T_{j0}^3|43\rangle + T_{i0}^4T_{j0}^4|44\rangle \end{Bmatrix} \\ \begin{Bmatrix} T_{i0}^1T_{j1}^1|11\rangle + T_{i0}^1T_{j1}^2|12\rangle + T_{i0}^1T_{j1}^3|13\rangle + T_{i0}^1T_{j1}^4|14\rangle \\ +T_{i0}^2T_{j1}^1|21\rangle + T_{i0}^2T_{j1}^2|22\rangle + T_{i0}^2T_{j1}^3|23\rangle + T_{i0}^2T_{j1}^4|24\rangle \\ +T_{i0}^3T_{j1}^1|31\rangle + T_{i0}^3T_{j1}^2|32\rangle + T_{i0}^3T_{j1}^3|33\rangle + T_{i0}^3T_{j1}^4|34\rangle \\ +T_{i0}^4T_{j1}^1|41\rangle + T_{i0}^4T_{j1}^2|42\rangle + T_{i0}^4T_{j1}^3|43\rangle + T_{i0}^4T_{j1}^4|44\rangle \end{Bmatrix} \\ \begin{Bmatrix} T_{i1}^1T_{j0}^1|11\rangle + T_{i1}^1T_{j0}^2|12\rangle + T_{i1}^1T_{j0}^3|13\rangle + T_{i1}^1T_{j0}^4|14\rangle \\ +T_{i1}^2T_{j0}^1|21\rangle + T_{i1}^2T_{j0}^2|22\rangle + T_{i1}^2T_{j0}^3|23\rangle + T_{i1}^2T_{j0}^4|24\rangle \\ +T_{i1}^3T_{j0}^1|31\rangle + T_{i1}^3T_{j0}^2|32\rangle + T_{i1}^3T_{j0}^3|33\rangle + T_{i1}^3T_{j0}^4|34\rangle \\ +T_{i1}^4T_{j0}^1|41\rangle + T_{i1}^4T_{j0}^2|42\rangle + T_{i1}^4T_{j0}^3|43\rangle + T_{i1}^4T_{j0}^4|44\rangle \end{Bmatrix} \\ \begin{Bmatrix} T_{i1}^1T_{j1}^1|11\rangle + T_{i1}^1T_{j1}^2|12\rangle + T_{i1}^1T_{j1}^3|13\rangle + T_{i1}^1T_{j1}^4|14\rangle \\ +T_{i1}^2T_{j1}^1|21\rangle + T_{i1}^2T_{j1}^2|22\rangle + T_{i1}^2T_{j1}^3|23\rangle + T_{i1}^2T_{j1}^4|24\rangle \\ +T_{i1}^3T_{j1}^1|31\rangle + T_{i1}^3T_{j1}^2|32\rangle + T_{i1}^3T_{j1}^3|33\rangle + T_{i1}^3T_{j1}^4|34\rangle \\ +T_{i1}^4T_{j1}^1|41\rangle + T_{i1}^4T_{j1}^2|42\rangle + T_{i1}^4T_{j1}^3|43\rangle + T_{i1}^4T_{j1}^4|44\rangle \end{Bmatrix} \end{pmatrix} \right) |st\rangle$$

$$= \sum_{s,t=0}^{1}\sum_{i,j=0}^{1} x_i y_j \begin{Bmatrix} \left(R_{00st}T_{i0}^1T_{j0}^1 + R_{01st}T_{i0}^1T_{j1}^1 + R_{10st}T_{i1}^1T_{j0}^1 + R_{11st}T_{i1}^1T_{j1}^1\right)|11\rangle \\ +\left(R_{00st}T_{i0}^1T_{j0}^2 + R_{01st}T_{i0}^1T_{j1}^2 + R_{10st}T_{i1}^1T_{j0}^2 + R_{11st}T_{i1}^1T_{j1}^2\right)|12\rangle \\ +\left(R_{00st}T_{i0}^1T_{j0}^3 + R_{01st}T_{i0}^1T_{j1}^3 + R_{10st}T_{i1}^1T_{j0}^3 + R_{11st}T_{i1}^1T_{j1}^3\right)|13\rangle \\ +\left(R_{00st}T_{i0}^1T_{j0}^4 + R_{01st}T_{i0}^1T_{j1}^4 + R_{10st}T_{i1}^1T_{j0}^4 + R_{11st}T_{i1}^1T_{j1}^4\right)|14\rangle \\ +\left(R_{00st}T_{i0}^2T_{j0}^1 + R_{01st}T_{i0}^2T_{j1}^1 + R_{10st}T_{i1}^2T_{j0}^1 + R_{11st}T_{i1}^2T_{j1}^1\right)|21\rangle \\ +\left(R_{00st}T_{i0}^2T_{j0}^2 + R_{01st}T_{i0}^2T_{j1}^2 + R_{10st}T_{i1}^2T_{j0}^2 + R_{11st}T_{i1}^2T_{j1}^2\right)|22\rangle \\ +\left(R_{00st}T_{i0}^2T_{j0}^3 + R_{01st}T_{i0}^2T_{j1}^3 + R_{10st}T_{i1}^2T_{j0}^3 + R_{11st}T_{i1}^2T_{j1}^3\right)|23\rangle \\ +\left(R_{00st}T_{i0}^2T_{j0}^4 + R_{01st}T_{i0}^2T_{j1}^4 + R_{10st}T_{i1}^2T_{j0}^4 + R_{11st}T_{i1}^2T_{j1}^4\right)|24\rangle \\ +\left(R_{00st}T_{i0}^3T_{j0}^1 + R_{01st}T_{i0}^3T_{j1}^1 + R_{10st}T_{i1}^3T_{j0}^1 + R_{11st}T_{i1}^3T_{j1}^1\right)|31\rangle \\ +\left(R_{00st}T_{i0}^3T_{j0}^2 + R_{01st}T_{i0}^3T_{j1}^2 + R_{10st}T_{i1}^3T_{j0}^2 + R_{11st}T_{i1}^3T_{j1}^2\right)|32\rangle \\ +\left(R_{00st}T_{i0}^3T_{j0}^3 + R_{01st}T_{i0}^3T_{j1}^3 + R_{10st}T_{i1}^3T_{j0}^3 + R_{11st}T_{i1}^3T_{j1}^3\right)|33\rangle \\ +\left(R_{00st}T_{i0}^3T_{j0}^4 + R_{01st}T_{i0}^3T_{j1}^4 + R_{10st}T_{i1}^3T_{j0}^4 + R_{11st}T_{i1}^3T_{j1}^4\right)|34\rangle \\ +\left(R_{00st}T_{i0}^4T_{j0}^1 + R_{01st}T_{i0}^4T_{j1}^1 + R_{10st}T_{i1}^4T_{j0}^1 + R_{11st}T_{i1}^4T_{j1}^1\right)|41\rangle \\ +\left(R_{00st}T_{i0}^4T_{j0}^2 + R_{01st}T_{i0}^4T_{j1}^2 + R_{10st}T_{i1}^4T_{j0}^2 + R_{11st}T_{i1}^4T_{j1}^2\right)|42\rangle \\ +\left(R_{00st}T_{i0}^4T_{j0}^3 + R_{01st}T_{i0}^4T_{j1}^3 + R_{10st}T_{i1}^4T_{j0}^3 + R_{11st}T_{i1}^4T_{j1}^3\right)|43\rangle \\ +\left(R_{00st}T_{i0}^4T_{j0}^4 + R_{01st}T_{i0}^4T_{j1}^4 + R_{10st}T_{i1}^4T_{j0}^4 + R_{11st}T_{i1}^4T_{j1}^4\right)|44\rangle \end{Bmatrix} |st\rangle \qquad (L.16)$$

dengan menuliskan $R_{lmst}T_{il}^{\theta}T_{jm}^{\tau} = \sigma_{iljmst}^{\theta\tau}$,maka dapat dituliskan Maka persamaan (L.16) dapat dituliskan menjadi

$|\psi\rangle_{A,A1,B,B1,B2,A2} =$

$$\sum_{s,t=0}^{1}\sum_{i=0}^{1}\sum_{j=0}^{1} x_i y_j \begin{Bmatrix} \left(\sigma_{i0j0st}^{11} + \sigma_{i0j1st}^{11} + \sigma_{i1j0st}^{11} + \sigma_{i1j1st}^{11}\right)|11\rangle + \left(\sigma_{i0j0st}^{12} + \sigma_{i0j1st}^{12} + \sigma_{i1j0st}^{12} + \sigma_{i1j1st}^{12}\right)|12\rangle \\ +\left(\sigma_{i0j0st}^{13} + \sigma_{i0j1st}^{13} + \sigma_{i1j0st}^{13} + \sigma_{i1j1st}^{13}\right)|13\rangle + \left(\sigma_{i0j0st}^{14} + \sigma_{i0j1st}^{14} + \sigma_{i1j0st}^{14} + \sigma_{i1j1st}^{14}\right)|14\rangle \\ +\left(\sigma_{i0j0st}^{21} + \sigma_{i0j1st}^{21} + \sigma_{i1j0st}^{21} + \sigma_{i1j1st}^{21}\right)|21\rangle + \left(\sigma_{i0j0st}^{22} + \sigma_{i0j1st}^{22} + \sigma_{i1j0st}^{22} + \sigma_{i1j1st}^{22}\right)|22\rangle \\ +\left(\sigma_{i0j0st}^{23} + \sigma_{i0j1st}^{23} + \sigma_{i1j0st}^{23} + \sigma_{i1j1st}^{23}\right)|23\rangle + \left(\sigma_{i0j0st}^{24} + \sigma_{i0j1st}^{24} + \sigma_{i1j0st}^{24} + \sigma_{i1j1st}^{24}\right)|24\rangle \\ +\left(\sigma_{i0j0st}^{31} + \sigma_{i0j1st}^{31} + \sigma_{i1j0st}^{31} + \sigma_{i1j1st}^{31}\right)|31\rangle + \left(\sigma_{i0j0st}^{32} + \sigma_{i0j1st}^{32} + \sigma_{i1j0st}^{32} + \sigma_{i1j1st}^{32}\right)|32\rangle \\ +\left(\sigma_{i0j0st}^{33} + \sigma_{i0j1st}^{33} + \sigma_{i1j0st}^{33} + \sigma_{i1j1st}^{33}\right)|33\rangle + \left(\sigma_{i0j0st}^{34} + \sigma_{i0j1st}^{34} + \sigma_{i1j0st}^{34} + \sigma_{i1j1st}^{34}\right)|34\rangle \\ +\left(\sigma_{i0j0st}^{41} + \sigma_{i0j1st}^{41} + \sigma_{i1j0st}^{41} + \sigma_{i1j1st}^{41}\right)|41\rangle + \left(\sigma_{i0j0st}^{42} + \sigma_{i0j1st}^{42} + \sigma_{i1j0st}^{42} + \sigma_{i1j1st}^{42}\right)|42\rangle \\ +\left(\sigma_{i0j0st}^{43} + \sigma_{i0j1st}^{43} + \sigma_{i1j0st}^{43} + \sigma_{i1j1st}^{43}\right)|43\rangle + \left(\sigma_{i0j0st}^{44} + \sigma_{i0j1st}^{44} + \sigma_{i1j0st}^{44} + \sigma_{i1j1st}^{44}\right)|44\rangle \end{Bmatrix} |st\rangle$$

$$= \sum_{s,t=0}^{1}\sum_{i=0}^{1}\sum_{j=0}^{1} x_i y_j \sum_{\theta,\tau=1}^{4} \left(\left(\sigma_{i0j0st}^{\theta\tau} + \sigma_{i0j1st}^{\theta\tau} + \sigma_{i1j0st}^{\theta\tau} + \sigma_{i1j1st}^{\theta\tau} \right) |\theta\tau\rangle \right) |st\rangle \qquad (L.17)$$

Selanjutnya dengan menuliskan

$$\left(\sigma_{i0j0st}^{\theta\tau}+\sigma_{i0j1st}^{\theta\tau}+\sigma_{i1j0st}^{\theta\tau}+\sigma_{i1j1st}^{\theta\tau}\right)=\sigma_{ijst}^{\theta\tau} \qquad (L.18)$$

Sehingga persamaan (L.17) dapat dituliskan menjadi

$$|\psi\rangle_{A,A1,B,B1,B2,A2}=\sum_{s,t=0}^{1}\sum_{i=0}^{1}\sum_{j=0}^{1}x_iy_j\sum_{\theta,\tau=1}^{4}\sigma_{ijst}^{\theta\tau}\,|\theta\tau\rangle|st\rangle \qquad \textit{(L.19)}$$

dengan menjalankan indeks ij pada persamaan *(L.17)*, maka dapat dituliskan

$$|\psi\rangle_{A,A1,B,B1,B2,A2}=$$

$$\sum_{s,t=0}^{1}\sum_{i=0}^{1}\sum_{j=0}^{1}x_iy_j\begin{Bmatrix}\left(\sigma_{i0j0st}^{11}+\sigma_{i0j1st}^{11}+\sigma_{i1j0st}^{11}+\sigma_{i1j1st}^{11}\right)|11\rangle+\left(\sigma_{i0j0st}^{12}+\sigma_{i0j1st}^{12}+\sigma_{i1j0st}^{12}+\sigma_{i1j1st}^{12}\right)|12\rangle\\+\left(\sigma_{i0j0st}^{13}+\sigma_{i0j1st}^{13}+\sigma_{i1j0st}^{13}+\sigma_{i1j1st}^{13}\right)|13\rangle+\left(\sigma_{i0j0st}^{14}+\sigma_{i0j1st}^{14}+\sigma_{i1j0st}^{14}+\sigma_{i1j1st}^{14}\right)|14\rangle\\+\left(\sigma_{i0j0st}^{21}+\sigma_{i0j1st}^{21}+\sigma_{i1j0st}^{21}+\sigma_{i1j1st}^{21}\right)|21\rangle+\left(\sigma_{i0j0st}^{22}+\sigma_{i0j1st}^{22}+\sigma_{i1j0st}^{22}+\sigma_{i1j1st}^{22}\right)|22\rangle\\+\left(\sigma_{i0j0st}^{23}+\sigma_{i0j1st}^{23}+\sigma_{i1j0st}^{23}+\sigma_{i1j1st}^{23}\right)|23\rangle+\left(\sigma_{i0j0st}^{24}+\sigma_{i0j1st}^{24}+\sigma_{i1j0st}^{24}+\sigma_{i1j1st}^{24}\right)|24\rangle\\+\left(\sigma_{i0j0st}^{31}+\sigma_{i0j1st}^{31}+\sigma_{i1j0st}^{31}+\sigma_{i1j1st}^{31}\right)|31\rangle+\left(\sigma_{i0j0st}^{32}+\sigma_{i0j1st}^{32}+\sigma_{i1j0st}^{32}+\sigma_{i1j1st}^{32}\right)|32\rangle\\+\left(\sigma_{i0j0st}^{33}+\sigma_{i0j1st}^{33}+\sigma_{i1j0st}^{33}+\sigma_{i1j1st}^{33}\right)|33\rangle+\left(\sigma_{i0j0st}^{34}+\sigma_{i0j1st}^{34}+\sigma_{i1j0st}^{34}+\sigma_{i1j1st}^{34}\right)|34\rangle\\+\left(\sigma_{i0j0st}^{41}+\sigma_{i0j1st}^{41}+\sigma_{i1j0st}^{41}+\sigma_{i1j1st}^{41}\right)|41\rangle+\left(\sigma_{i0j0st}^{42}+\sigma_{i0j1st}^{42}+\sigma_{i1j0st}^{42}+\sigma_{i1j1st}^{42}\right)|42\rangle\\+\left(\sigma_{i0j0st}^{43}+\sigma_{i0j1st}^{43}+\sigma_{i1j0st}^{43}+\sigma_{i1j1st}^{43}\right)|43\rangle+\left(\sigma_{i0j0st}^{44}+\sigma_{i0j1st}^{44}+\sigma_{i1j0st}^{44}+\sigma_{i1j1st}^{44}\right)|44\rangle\end{Bmatrix}|st\rangle$$

$$=\sum_{s,t=0}^{1}\sum_{i=0}^{1}\sum_{j=0}^{1}x_iy_j\sum_{\theta,\tau=1}^{4}\left(\left(\sigma_{i0j0st}^{\theta\tau}+\sigma_{i0j1st}^{\theta\tau}+\sigma_{i1j0st}^{\theta\tau}+\sigma_{i1j1st}^{\theta\tau}\right)|\theta\tau\rangle\right)|st\rangle$$

$$=\sum_{s,t=0}^{1}\sum_{\theta,\tau=1}^{4}|\theta\tau\rangle\begin{pmatrix}x_0y_0\left(\left(\sigma_{0000st}^{\theta\tau}+\sigma_{0001st}^{\theta\tau}+\sigma_{0100st}^{\theta\tau}+\sigma_{0101st}^{\theta\tau}\right)\right)+x_0y_1\left(\left(\sigma_{0010st}^{\theta\tau}+\sigma_{0011st}^{\theta\tau}+\sigma_{0110st}^{\theta\tau}+\sigma_{0111st}^{\theta\tau}\right)\right)\\+x_1y_0\left(\left(\sigma_{1000st}^{\theta\tau}+\sigma_{1001st}^{\theta\tau}+\sigma_{1100st}^{\theta\tau}+\sigma_{1101st}^{\theta\tau}\right)\right)+x_1y_1\left(\left(\sigma_{1010st}^{\theta\tau}+\sigma_{1011st}^{\theta\tau}+\sigma_{1110st}^{\theta\tau}+\sigma_{1111st}^{\theta\tau}\right)\right)\end{pmatrix}|st\rangle$$

$$=\sum_{s,t=0}^{1}\sum_{\theta,\tau=1}^{4}|\theta\tau\rangle\left(x_0y_0\sigma_{00st}^{\theta\tau}+x_0y_1\sigma_{0st}^{\theta\tau}+x_1y_0\sigma_{10st}^{\theta\tau}+x_1y_1\sigma_{11st}^{\theta\tau}\right)|st\rangle$$

$$=\sum_{s,t=0}^{1}\sum_{\theta,\tau=1}^{4}|\theta\tau\rangle\left(\begin{pmatrix}\sigma_{00st}^{\theta\tau} & \sigma_{01st}^{\theta\tau} & \sigma_{10st}^{\theta\tau} & \sigma_{11st}^{\theta\tau}\end{pmatrix}\begin{pmatrix}x_0y_0\\x_0y_1\\x_1y_0\\x_1y_1\end{pmatrix}\right)|st\rangle$$

$$=\sum_{\theta,\tau=1}^{4}|\theta\tau\rangle\left(\begin{pmatrix}\sigma_{0000}^{\theta\tau} & \sigma_{0100}^{\theta\tau} & \sigma_{1000}^{\theta\tau} & \sigma_{1100}^{\theta\tau}\end{pmatrix}\begin{pmatrix}x_0y_0\\x_0y_1\\x_1y_0\\x_1y_1\end{pmatrix}\right)|00\rangle+\sum_{\theta,\tau=1}^{4}|\theta\tau\rangle\left(\begin{pmatrix}\sigma_{0001}^{\theta\tau} & \sigma_{0101}^{\theta\tau} & \sigma_{1001}^{\theta\tau} & \sigma_{1101}^{\theta\tau}\end{pmatrix}\begin{pmatrix}x_0y_0\\x_0y_1\\x_1y_0\\x_1y_1\end{pmatrix}\right)|01\rangle$$

$$+\sum_{\theta,\tau=1}^{4}|\theta\tau\rangle\left(\begin{pmatrix}\sigma_{0010}^{\theta\tau} & \sigma_{0110}^{\theta\tau} & \sigma_{1010}^{\theta\tau} & \sigma_{1110}^{\theta\tau}\end{pmatrix}\begin{pmatrix}x_0y_0\\x_0y_1\\x_1y_0\\x_1y_1\end{pmatrix}\right)|10\rangle+\sum_{\theta,\tau=1}^{4}|\theta\tau\rangle\left(\begin{pmatrix}\sigma_{0011}^{\theta\tau} & \sigma_{0111}^{\theta\tau} & \sigma_{1011}^{\theta\tau} & \sigma_{1111}^{\theta\tau}\end{pmatrix}\begin{pmatrix}x_0y_0\\x_0y_1\\x_1y_0\\x_1y_1\end{pmatrix}\right)|11\rangle$$

$$= \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left(\begin{pmatrix} \sigma_{0000}^{\theta\tau} & \sigma_{0100}^{\theta\tau} & \sigma_{1000}^{\theta\tau} & \sigma_{1100}^{\theta\tau} \\ \sigma_{0001}^{\theta\tau} & \sigma_{0101}^{\theta\tau} & \sigma_{1001}^{\theta\tau} & \sigma_{1101}^{\theta\tau} \\ \sigma_{0010}^{\theta\tau} & \sigma_{0110}^{\theta\tau} & \sigma_{1010}^{\theta\tau} & \sigma_{1110}^{\theta\tau} \\ \sigma_{0011}^{\theta\tau} & \sigma_{0111}^{\theta\tau} & \sigma_{1011}^{\theta\tau} & \sigma_{1111}^{\theta\tau} \end{pmatrix} \begin{pmatrix} x_0 y_0 \\ x_0 y_1 \\ x_1 y_0 \\ x_1 y_1 \end{pmatrix} \right) \qquad (L.20)$$

Selanjutnya, kembali ke persamaan (L.16) dapat dituliskan dengan

$$|\psi\rangle_{A,A1,B,B1,B2,A2} =$$

$$\sum_{s,t=0}^{1}\sum_{i,j=0}^{1} x_i y_j \left\{\begin{aligned}
&(R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{1}T_{j0}^{1}\\ T_{i0}^{1}T_{j1}^{1}\\ T_{i1}^{1}T_{j0}^{1}\\ T_{i1}^{1}T_{j1}^{1}\end{pmatrix}|11\rangle + (R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{1}T_{j0}^{2}\\ T_{i0}^{1}T_{j1}^{2}\\ T_{i1}^{1}T_{j0}^{2}\\ T_{i1}^{1}T_{j1}^{2}\end{pmatrix}|12\rangle\\
&+(R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{1}T_{j0}^{3}\\ T_{i0}^{1}T_{j1}^{3}\\ T_{i1}^{1}T_{j0}^{3}\\ T_{i1}^{1}T_{j1}^{3}\end{pmatrix}|13\rangle + (R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{1}T_{j0}^{4}\\ T_{i0}^{1}T_{j1}^{4}\\ T_{i1}^{1}T_{j0}^{4}\\ T_{i1}^{1}T_{j1}^{4}\end{pmatrix}|14\rangle\\
&+(R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{2}T_{j0}^{1}\\ T_{i0}^{2}T_{j1}^{1}\\ T_{i1}^{2}T_{j0}^{1}\\ T_{i1}^{2}T_{j1}^{1}\end{pmatrix}|21\rangle + (R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{2}T_{j0}^{2}\\ T_{i0}^{2}T_{j1}^{2}\\ T_{i1}^{2}T_{j0}^{2}\\ T_{i1}^{2}T_{j1}^{2}\end{pmatrix}|22\rangle\\
&+(R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{2}T_{j0}^{3}\\ T_{i0}^{2}T_{j1}^{3}\\ T_{i1}^{2}T_{j0}^{3}\\ T_{i1}^{2}T_{j1}^{3}\end{pmatrix}|23\rangle + (R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{2}T_{j0}^{4}\\ T_{i0}^{2}T_{j1}^{4}\\ T_{i1}^{2}T_{j0}^{4}\\ T_{i1}^{2}T_{j1}^{4}\end{pmatrix}|24\rangle\\
&+(R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{3}T_{j0}^{1}\\ T_{i0}^{3}T_{j1}^{1}\\ T_{i1}^{3}T_{j0}^{1}\\ T_{i1}^{3}T_{j1}^{1}\end{pmatrix}|31\rangle + (R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{3}T_{j0}^{2}\\ T_{i0}^{3}T_{j1}^{2}\\ T_{i1}^{3}T_{j0}^{2}\\ T_{i1}^{3}T_{j1}^{2}\end{pmatrix}|32\rangle\\
&+(R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{3}T_{j0}^{3}\\ T_{i0}^{3}T_{j1}^{3}\\ T_{i1}^{3}T_{j0}^{3}\\ T_{i1}^{3}T_{j1}^{3}\end{pmatrix}|33\rangle + (R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{1}T_{j0}^{4}\\ T_{i0}^{1}T_{j1}^{4}\\ T_{i1}^{1}T_{j0}^{4}\\ T_{i1}^{1}T_{j1}^{4}\end{pmatrix}|34\rangle\\
&(R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{4}T_{j0}^{1}\\ T_{i0}^{4}T_{j1}^{1}\\ T_{i1}^{4}T_{j0}^{1}\\ T_{i1}^{4}T_{j1}^{1}\end{pmatrix}|41\rangle + (R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{1}T_{j0}^{2}\\ T_{i0}^{1}T_{j1}^{2}\\ T_{i1}^{1}T_{j0}^{2}\\ T_{i1}^{1}T_{j1}^{2}\end{pmatrix}|42\rangle\\
&+(R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{4}T_{j0}^{3}\\ T_{i0}^{4}T_{j1}^{3}\\ T_{i1}^{4}T_{j0}^{3}\\ T_{i1}^{4}T_{j1}^{3}\end{pmatrix}|43\rangle + (R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\begin{pmatrix} T_{i0}^{4}T_{j0}^{4}\\ T_{i0}^{4}T_{j1}^{4}\\ T_{i1}^{4}T_{j0}^{4}\\ T_{i1}^{4}T_{j1}^{4}\end{pmatrix}|44\rangle
\end{aligned}\right\}|st\rangle$$

$$= \sum_{s,t=0}^{1}\sum_{i=0}^{1}\sum_{j=0}^{1} x_i y_j \sum_{\theta,\tau=1}^{4}(R_{00st}\quad R_{01st}\quad R_{10st}\quad R_{11st})\left(\begin{pmatrix} T_{i0}^{\theta}T_{j0}^{\tau}\\ T_{i0}^{\theta}T_{j1}^{\tau}\\ T_{i1}^{\theta}T_{j0}^{\tau}\\ T_{i1}^{\theta}T_{j1}^{\tau}\end{pmatrix}\right)|\theta\tau\rangle\,|st\rangle$$

$$= \sum_{s,t=0}^{1} \sum_{\theta,\tau=1}^{4} x_0 y_0 (R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st}) \begin{pmatrix} T_{00}^{\theta} T_{00}^{\tau} \\ T_{00}^{\theta} T_{01}^{\tau} \\ T_{01}^{\theta} T_{00}^{\tau} \\ T_{01}^{\theta} T_{01}^{\tau} \end{pmatrix} |\theta\tau\rangle\, |st\rangle$$

$$+ \sum_{s,t=0}^{1} \sum_{\theta,\tau=1}^{4} x_0 y_1 (R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st}) \begin{pmatrix} T_{00}^{\theta} T_{10}^{\tau} \\ T_{00}^{\theta} T_{11}^{\tau} \\ T_{01}^{\theta} T_{10}^{\tau} \\ T_{01}^{\theta} T_{11}^{\tau} \end{pmatrix} |\theta\tau\rangle\, |st\rangle$$

$$+ \sum_{s,t=0}^{1} \sum_{\theta,\tau=1}^{4} x_1 y_0 (R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st}) \begin{pmatrix} T_{10}^{\theta} T_{00}^{\tau} \\ T_{10}^{\theta} T_{01}^{\tau} \\ T_{11}^{\theta} T_{00}^{\tau} \\ T_{11}^{\theta} T_{01}^{\tau} \end{pmatrix} |\theta\tau\rangle\, |st\rangle$$

$$+ \sum_{s,t=0}^{1} \sum_{\theta,\tau=1}^{4} x_1 y_1 (R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st}) \begin{pmatrix} T_{10}^{\theta} T_{10}^{\tau} \\ T_{10}^{\theta} T_{11}^{\tau} \\ T_{11}^{\theta} T_{10}^{\tau} \\ T_{11}^{\theta} T_{11}^{\tau} \end{pmatrix} |\theta\tau\rangle\, |st\rangle$$

$$= \sum_{s,t=0}^{1} \sum_{\theta,\tau=1}^{4} \left\{ \begin{array}{l} x_0 y_0 (R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st}) \begin{pmatrix} T_{00}^{\theta} T_{00}^{\tau} \\ T_{00}^{\theta} T_{01}^{\tau} \\ T_{01}^{\theta} T_{00}^{\tau} \\ T_{01}^{\theta} T_{01}^{\tau} \end{pmatrix} \\ + x_0 y_1 (R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st}) \begin{pmatrix} T_{00}^{\theta} T_{10}^{\tau} \\ T_{00}^{\theta} T_{11}^{\tau} \\ T_{01}^{\theta} T_{10}^{\tau} \\ T_{01}^{\theta} T_{11}^{\tau} \end{pmatrix} \\ + x_1 y_0 (R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st}) \begin{pmatrix} T_{10}^{\theta} T_{00}^{\tau} \\ T_{10}^{\theta} T_{01}^{\tau} \\ T_{11}^{\theta} T_{00}^{\tau} \\ T_{11}^{\theta} T_{01}^{\tau} \end{pmatrix} \\ + x_1 y_1 (R_{00st} \quad R_{01st} \quad R_{10st} \quad R_{11st}) \begin{pmatrix} T_{10}^{\theta} T_{10}^{\tau} \\ T_{10}^{\theta} T_{11}^{\tau} \\ T_{11}^{\theta} T_{10}^{\tau} \\ T_{11}^{\theta} T_{11}^{\tau} \end{pmatrix} \end{array} \right\} |\theta\tau\rangle |st\rangle$$

$$
= \sum_{s,t=0}^{1} \sum_{\theta,\tau=1}^{4} \left\{ \begin{array}{l} \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta} T_{00}^{\tau} \\ T_{00}^{\theta} T_{01}^{\tau} \\ T_{01}^{\theta} T_{00}^{\tau} \\ T_{01}^{\theta} T_{01}^{\tau} \end{pmatrix} x_0 y_0 \\ + \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta} T_{10}^{\tau} \\ T_{00}^{\theta} T_{11}^{\tau} \\ T_{01}^{\theta} T_{10}^{\tau} \\ T_{01}^{\theta} T_{11}^{\tau} \end{pmatrix} x_0 y_1 \\ + \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} T_{10}^{\theta} T_{00}^{\tau} \\ T_{10}^{\theta} T_{01}^{\tau} \\ T_{11}^{\theta} T_{00}^{\tau} \\ T_{11}^{\theta} T_{01}^{\tau} \end{pmatrix} x_1 y_0 \\ + \begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} T_{10}^{\theta} T_{10}^{\tau} \\ T_{10}^{\theta} T_{11}^{\tau} \\ T_{11}^{\theta} T_{10}^{\tau} \\ T_{11}^{\theta} T_{11}^{\tau} \end{pmatrix} x_1 y_1 \end{array} \right\} |\theta\tau\rangle |st\rangle
$$

$$
= \sum_{s,t=0}^{1} \sum_{\theta,\tau=1}^{4} \left(\left(\begin{pmatrix} R_{00st} & R_{01st} & R_{10st} & R_{11st} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta} T_{00}^{\tau} & T_{00}^{\theta} T_{10}^{\tau} & T_{10}^{\theta} T_{00}^{\tau} & T_{10}^{\theta} T_{10}^{\tau} \\ T_{00}^{\theta} T_{01}^{\tau} & T_{00}^{\theta} T_{11}^{\tau} & T_{10}^{\theta} T_{01}^{\tau} & T_{10}^{\theta} T_{11}^{\tau} \\ T_{01}^{\theta} T_{00}^{\tau} & T_{01}^{\theta} T_{10}^{\tau} & T_{11}^{\theta} T_{00}^{\tau} & T_{11}^{\theta} T_{10}^{\tau} \\ T_{01}^{\theta} T_{01}^{\tau} & T_{01}^{\theta} T_{11}^{\tau} & T_{11}^{\theta} T_{01}^{\tau} & T_{11}^{\theta} T_{11}^{\tau} \end{pmatrix} \right) \begin{pmatrix} x_0 y_0 \\ x_0 y_1 \\ x_1 y_0 \\ x_1 y_1 \end{pmatrix} \right) |\theta\tau\rangle |st\rangle
$$

$$
= \sum_{\theta,\tau=1}^{4} \left\{ \begin{array}{l} \left(\left(\begin{pmatrix} R_{0000} & R_{0100} & R_{1000} & R_{1100} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta} T_{00}^{\tau} & T_{00}^{\theta} T_{10}^{\tau} & T_{10}^{\theta} T_{00}^{\tau} & T_{10}^{\theta} T_{10}^{\tau} \\ T_{00}^{\theta} T_{01}^{\tau} & T_{00}^{\theta} T_{11}^{\tau} & T_{10}^{\theta} T_{01}^{\tau} & T_{10}^{\theta} T_{11}^{\tau} \\ T_{01}^{\theta} T_{00}^{\tau} & T_{01}^{\theta} T_{10}^{\tau} & T_{11}^{\theta} T_{00}^{\tau} & T_{11}^{\theta} T_{10}^{\tau} \\ T_{01}^{\theta} T_{01}^{\tau} & T_{01}^{\theta} T_{11}^{\tau} & T_{11}^{\theta} T_{01}^{\tau} & T_{11}^{\theta} T_{11}^{\tau} \end{pmatrix} \right) \begin{pmatrix} x_0 y_0 \\ x_0 y_1 \\ x_1 y_0 \\ x_1 y_1 \end{pmatrix} \right) |\theta\tau\rangle |00\rangle \\ + \left(\left(\begin{pmatrix} R_{0001} & R_{0101} & R_{1001} & R_{1101} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta} T_{00}^{\tau} & T_{00}^{\theta} T_{10}^{\tau} & T_{10}^{\theta} T_{00}^{\tau} & T_{10}^{\theta} T_{10}^{\tau} \\ T_{00}^{\theta} T_{01}^{\tau} & T_{00}^{\theta} T_{11}^{\tau} & T_{10}^{\theta} T_{01}^{\tau} & T_{10}^{\theta} T_{11}^{\tau} \\ T_{01}^{\theta} T_{00}^{\tau} & T_{01}^{\theta} T_{10}^{\tau} & T_{11}^{\theta} T_{00}^{\tau} & T_{11}^{\theta} T_{10}^{\tau} \\ T_{01}^{\theta} T_{01}^{\tau} & T_{01}^{\theta} T_{11}^{\tau} & T_{11}^{\theta} T_{01}^{\tau} & T_{11}^{\theta} T_{11}^{\tau} \end{pmatrix} \right) \begin{pmatrix} x_0 y_0 \\ x_0 y_1 \\ x_1 y_0 \\ x_1 y_1 \end{pmatrix} \right) |\theta\tau\rangle |01\rangle \\ + \left(\left(\begin{pmatrix} R_{0010} & R_{0110} & R_{1010} & R_{1110} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta} T_{00}^{\tau} & T_{00}^{\theta} T_{10}^{\tau} & T_{10}^{\theta} T_{00}^{\tau} & T_{10}^{\theta} T_{10}^{\tau} \\ T_{00}^{\theta} T_{01}^{\tau} & T_{00}^{\theta} T_{11}^{\tau} & T_{10}^{\theta} T_{01}^{\tau} & T_{10}^{\theta} T_{11}^{\tau} \\ T_{01}^{\theta} T_{00}^{\tau} & T_{01}^{\theta} T_{10}^{\tau} & T_{11}^{\theta} T_{00}^{\tau} & T_{11}^{\theta} T_{10}^{\tau} \\ T_{01}^{\theta} T_{01}^{\tau} & T_{01}^{\theta} T_{11}^{\tau} & T_{11}^{\theta} T_{01}^{\tau} & T_{11}^{\theta} T_{11}^{\tau} \end{pmatrix} \right) \begin{pmatrix} x_0 y_0 \\ x_0 y_1 \\ x_1 y_0 \\ x_1 y_1 \end{pmatrix} \right) |\theta\tau\rangle |10\rangle \\ + \left(\left(\begin{pmatrix} R_{0011} & R_{0111} & R_{1011} & R_{1111} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta} T_{00}^{\tau} & T_{00}^{\theta} T_{10}^{\tau} & T_{10}^{\theta} T_{00}^{\tau} & T_{10}^{\theta} T_{10}^{\tau} \\ T_{00}^{\theta} T_{01}^{\tau} & T_{00}^{\theta} T_{11}^{\tau} & T_{10}^{\theta} T_{01}^{\tau} & T_{10}^{\theta} T_{11}^{\tau} \\ T_{01}^{\theta} T_{00}^{\tau} & T_{01}^{\theta} T_{10}^{\tau} & T_{11}^{\theta} T_{00}^{\tau} & T_{11}^{\theta} T_{10}^{\tau} \\ T_{01}^{\theta} T_{01}^{\tau} & T_{01}^{\theta} T_{11}^{\tau} & T_{11}^{\theta} T_{01}^{\tau} & T_{11}^{\theta} T_{11}^{\tau} \end{pmatrix} \right) \begin{pmatrix} x_0 y_0 \\ x_0 y_1 \\ x_1 y_0 \\ x_1 y_1 \end{pmatrix} \right) |\theta\tau\rangle |11\rangle \end{array} \right\}
$$

$$
= \sum_{\theta,\tau=1}^{4} \left\{ \begin{array}{l}
\left(\left(\left(R_{0000} \quad R_{0100} \quad R_{1000} \quad R_{1100} \right) \begin{pmatrix} T^{\theta}_{00}T^{\tau}_{00} & T^{\theta}_{00}T^{\tau}_{10} & T^{\theta}_{10}T^{\tau}_{00} & T^{\theta}_{10}T^{\tau}_{10} \\ T^{\theta}_{00}T^{\tau}_{01} & T^{\theta}_{00}T^{\tau}_{11} & T^{\theta}_{10}T^{\tau}_{01} & T^{\theta}_{10}T^{\tau}_{11} \\ T^{\theta}_{01}T^{\tau}_{00} & T^{\theta}_{01}T^{\tau}_{10} & T^{\theta}_{11}T^{\tau}_{00} & T^{\theta}_{11}T^{\tau}_{10} \\ T^{\theta}_{01}T^{\tau}_{01} & T^{\theta}_{01}T^{\tau}_{11} & T^{\theta}_{11}T^{\tau}_{01} & T^{\theta}_{11}T^{\tau}_{11} \end{pmatrix} \right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix} \right) |\theta\tau\rangle \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} \\
+ \left(\left(\left(R_{0001} \quad R_{0101} \quad R_{1001} \quad R_{1101} \right) \begin{pmatrix} T^{\theta}_{00}T^{\tau}_{00} & T^{\theta}_{00}T^{\tau}_{10} & T^{\theta}_{10}T^{\tau}_{00} & T^{\theta}_{10}T^{\tau}_{10} \\ T^{\theta}_{00}T^{\tau}_{01} & T^{\theta}_{00}T^{\tau}_{11} & T^{\theta}_{10}T^{\tau}_{01} & T^{\theta}_{10}T^{\tau}_{11} \\ T^{\theta}_{01}T^{\tau}_{00} & T^{\theta}_{01}T^{\tau}_{10} & T^{\theta}_{11}T^{\tau}_{00} & T^{\theta}_{11}T^{\tau}_{10} \\ T^{\theta}_{01}T^{\tau}_{01} & T^{\theta}_{01}T^{\tau}_{11} & T^{\theta}_{11}T^{\tau}_{01} & T^{\theta}_{11}T^{\tau}_{11} \end{pmatrix} \right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix} \right) |\theta\tau\rangle \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix} \\
+ \left(\left(\left(R_{0010} \quad R_{0110} \quad R_{1010} \quad R_{1110} \right) \begin{pmatrix} T^{\theta}_{00}T^{\tau}_{00} & T^{\theta}_{00}T^{\tau}_{10} & T^{\theta}_{10}T^{\tau}_{00} & T^{\theta}_{10}T^{\tau}_{10} \\ T^{\theta}_{00}T^{\tau}_{01} & T^{\theta}_{00}T^{\tau}_{11} & T^{\theta}_{10}T^{\tau}_{01} & T^{\theta}_{10}T^{\tau}_{11} \\ T^{\theta}_{01}T^{\tau}_{00} & T^{\theta}_{01}T^{\tau}_{10} & T^{\theta}_{11}T^{\tau}_{00} & T^{\theta}_{11}T^{\tau}_{10} \\ T^{\theta}_{01}T^{\tau}_{01} & T^{\theta}_{01}T^{\tau}_{11} & T^{\theta}_{11}T^{\tau}_{01} & T^{\theta}_{11}T^{\tau}_{11} \end{pmatrix} \right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix} \right) |\theta\tau\rangle \begin{pmatrix} 0 \\ 0 \\ 1 \\ 0 \end{pmatrix} \\
+ \left(\left(\left(R_{0011} \quad R_{0111} \quad R_{1011} \quad R_{1111} \right) \begin{pmatrix} T^{\theta}_{00}T^{\tau}_{00} & T^{\theta}_{00}T^{\tau}_{10} & T^{\theta}_{10}T^{\tau}_{00} & T^{\theta}_{10}T^{\tau}_{10} \\ T^{\theta}_{00}T^{\tau}_{01} & T^{\theta}_{00}T^{\tau}_{11} & T^{\theta}_{10}T^{\tau}_{01} & T^{\theta}_{10}T^{\tau}_{11} \\ T^{\theta}_{01}T^{\tau}_{00} & T^{\theta}_{01}T^{\tau}_{10} & T^{\theta}_{11}T^{\tau}_{00} & T^{\theta}_{11}T^{\tau}_{10} \\ T^{\theta}_{01}T^{\tau}_{01} & T^{\theta}_{01}T^{\tau}_{11} & T^{\theta}_{11}T^{\tau}_{01} & T^{\theta}_{11}T^{\tau}_{11} \end{pmatrix} \right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix} \right) |\theta\tau\rangle \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}
\end{array} \right\}
$$

$$
= \sum_{\theta,\tau=1}^{4} \left\{ \begin{array}{l}
|\theta\tau\rangle \begin{pmatrix} \left(\left(\left(R_{0000} \quad R_{0100} \quad R_{1000} \quad R_{1100} \right) \begin{pmatrix} T^{\theta}_{00}T^{\tau}_{00} & T^{\theta}_{00}T^{\tau}_{10} & T^{\theta}_{10}T^{\tau}_{00} & T^{\theta}_{10}T^{\tau}_{10} \\ T^{\theta}_{00}T^{\tau}_{01} & T^{\theta}_{00}T^{\tau}_{11} & T^{\theta}_{10}T^{\tau}_{01} & T^{\theta}_{10}T^{\tau}_{11} \\ T^{\theta}_{01}T^{\tau}_{00} & T^{\theta}_{01}T^{\tau}_{10} & T^{\theta}_{11}T^{\tau}_{00} & T^{\theta}_{11}T^{\tau}_{10} \\ T^{\theta}_{01}T^{\tau}_{01} & T^{\theta}_{01}T^{\tau}_{11} & T^{\theta}_{11}T^{\tau}_{01} & T^{\theta}_{11}T^{\tau}_{11} \end{pmatrix} \right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix} \right) \\ 0 \\ 0 \\ 0 \end{pmatrix} \\
+|\theta\tau\rangle \begin{pmatrix} 0 \\ \left(\left(\left(R_{0001} \quad R_{0101} \quad R_{1001} \quad R_{1101} \right) \begin{pmatrix} T^{\theta}_{00}T^{\tau}_{00} & T^{\theta}_{00}T^{\tau}_{10} & T^{\theta}_{10}T^{\tau}_{00} & T^{\theta}_{10}T^{\tau}_{10} \\ T^{\theta}_{00}T^{\tau}_{01} & T^{\theta}_{00}T^{\tau}_{11} & T^{\theta}_{10}T^{\tau}_{01} & T^{\theta}_{10}T^{\tau}_{11} \\ T^{\theta}_{01}T^{\tau}_{00} & T^{\theta}_{01}T^{\tau}_{10} & T^{\theta}_{11}T^{\tau}_{00} & T^{\theta}_{11}T^{\tau}_{10} \\ T^{\theta}_{01}T^{\tau}_{01} & T^{\theta}_{01}T^{\tau}_{11} & T^{\theta}_{11}T^{\tau}_{01} & T^{\theta}_{11}T^{\tau}_{11} \end{pmatrix} \right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix} \right) \\ 0 \\ 0 \end{pmatrix} \\
+|\theta\tau\rangle \begin{pmatrix} 0 \\ 0 \\ \left(\left(\left(R_{0010} \quad R_{0110} \quad R_{1010} \quad R_{1110} \right) \begin{pmatrix} T^{\theta}_{00}T^{\tau}_{00} & T^{\theta}_{00}T^{\tau}_{10} & T^{\theta}_{10}T^{\tau}_{00} & T^{\theta}_{10}T^{\tau}_{10} \\ T^{\theta}_{00}T^{\tau}_{01} & T^{\theta}_{00}T^{\tau}_{11} & T^{\theta}_{10}T^{\tau}_{01} & T^{\theta}_{10}T^{\tau}_{11} \\ T^{\theta}_{01}T^{\tau}_{00} & T^{\theta}_{01}T^{\tau}_{10} & T^{\theta}_{11}T^{\tau}_{00} & T^{\theta}_{11}T^{\tau}_{10} \\ T^{\theta}_{01}T^{\tau}_{01} & T^{\theta}_{01}T^{\tau}_{11} & T^{\theta}_{11}T^{\tau}_{01} & T^{\theta}_{11}T^{\tau}_{11} \end{pmatrix} \right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix} \right) \\ 0 \end{pmatrix} \\
+|\theta\tau\rangle \begin{pmatrix} 0 \\ 0 \\ 0 \\ \left(\left(\left(R_{0011} \quad R_{0111} \quad R_{1011} \quad R_{1111} \right) \begin{pmatrix} T^{\theta}_{00}T^{\tau}_{00} & T^{\theta}_{00}T^{\tau}_{10} & T^{\theta}_{10}T^{\tau}_{00} & T^{\theta}_{10}T^{\tau}_{10} \\ T^{\theta}_{00}T^{\tau}_{01} & T^{\theta}_{00}T^{\tau}_{11} & T^{\theta}_{10}T^{\tau}_{01} & T^{\theta}_{10}T^{\tau}_{11} \\ T^{\theta}_{01}T^{\tau}_{00} & T^{\theta}_{01}T^{\tau}_{10} & T^{\theta}_{11}T^{\tau}_{00} & T^{\theta}_{11}T^{\tau}_{10} \\ T^{\theta}_{01}T^{\tau}_{01} & T^{\theta}_{01}T^{\tau}_{11} & T^{\theta}_{11}T^{\tau}_{01} & T^{\theta}_{11}T^{\tau}_{11} \end{pmatrix} \right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix} \right) \end{pmatrix}
\end{array} \right\}
$$

$$
= \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left\{ \begin{array}{l}
\begin{pmatrix} \left(\left(\begin{pmatrix} R_{0000} & R_{0100} & R_{1000} & R_{1100} \end{pmatrix} \begin{pmatrix} T^{\theta}_{00}T^{\tau}_{00} & T^{\theta}_{00}T^{\tau}_{10} & T^{\theta}_{10}T^{\tau}_{00} & T^{\theta}_{10}T^{\tau}_{10} \\ T^{\theta}_{00}T^{\tau}_{01} & T^{\theta}_{00}T^{\tau}_{11} & T^{\theta}_{10}T^{\tau}_{01} & T^{\theta}_{10}T^{\tau}_{11} \\ T^{\theta}_{01}T^{\tau}_{00} & T^{\theta}_{01}T^{\tau}_{10} & T^{\theta}_{11}T^{\tau}_{00} & T^{\theta}_{11}T^{\tau}_{10} \\ T^{\theta}_{01}T^{\tau}_{01} & T^{\theta}_{01}T^{\tau}_{11} & T^{\theta}_{11}T^{\tau}_{01} & T^{\theta}_{11}T^{\tau}_{11} \end{pmatrix} \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}\right)\right) \\ 0 \\ 0 \\ 0 \end{pmatrix} \\
+ \begin{pmatrix} 0 \\ \left(\left(\begin{pmatrix} R_{0001} & R_{0101} & R_{1001} & R_{1101} \end{pmatrix} \begin{pmatrix} T^{\theta}_{00}T^{\tau}_{00} & T^{\theta}_{00}T^{\tau}_{10} & T^{\theta}_{10}T^{\tau}_{00} & T^{\theta}_{10}T^{\tau}_{10} \\ T^{\theta}_{00}T^{\tau}_{01} & T^{\theta}_{00}T^{\tau}_{11} & T^{\theta}_{10}T^{\tau}_{01} & T^{\theta}_{10}T^{\tau}_{11} \\ T^{\theta}_{01}T^{\tau}_{00} & T^{\theta}_{01}T^{\tau}_{10} & T^{\theta}_{11}T^{\tau}_{00} & T^{\theta}_{11}T^{\tau}_{10} \\ T^{\theta}_{01}T^{\tau}_{01} & T^{\theta}_{01}T^{\tau}_{11} & T^{\theta}_{11}T^{\tau}_{01} & T^{\theta}_{11}T^{\tau}_{11} \end{pmatrix} \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}\right)\right) \\ 0 \\ 0 \end{pmatrix} \\
+ \begin{pmatrix} 0 \\ 0 \\ \left(\left(\begin{pmatrix} R_{0010} & R_{0110} & R_{1010} & R_{1110} \end{pmatrix} \begin{pmatrix} T^{\theta}_{00}T^{\tau}_{00} & T^{\theta}_{00}T^{\tau}_{10} & T^{\theta}_{10}T^{\tau}_{00} & T^{\theta}_{10}T^{\tau}_{10} \\ T^{\theta}_{00}T^{\tau}_{01} & T^{\theta}_{00}T^{\tau}_{11} & T^{\theta}_{10}T^{\tau}_{01} & T^{\theta}_{10}T^{\tau}_{11} \\ T^{\theta}_{01}T^{\tau}_{00} & T^{\theta}_{01}T^{\tau}_{10} & T^{\theta}_{11}T^{\tau}_{00} & T^{\theta}_{11}T^{\tau}_{10} \\ T^{\theta}_{01}T^{\tau}_{01} & T^{\theta}_{01}T^{\tau}_{11} & T^{\theta}_{11}T^{\tau}_{01} & T^{\theta}_{11}T^{\tau}_{11} \end{pmatrix} \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}\right)\right) \\ 0 \end{pmatrix} \\
+ \begin{pmatrix} 0 \\ 0 \\ 0 \\ \left(\left(\begin{pmatrix} R_{0011} & R_{0111} & R_{1011} & R_{1111} \end{pmatrix} \begin{pmatrix} T^{\theta}_{00}T^{\tau}_{00} & T^{\theta}_{00}T^{\tau}_{10} & T^{\theta}_{10}T^{\tau}_{00} & T^{\theta}_{10}T^{\tau}_{10} \\ T^{\theta}_{00}T^{\tau}_{01} & T^{\theta}_{00}T^{\tau}_{11} & T^{\theta}_{10}T^{\tau}_{01} & T^{\theta}_{10}T^{\tau}_{11} \\ T^{\theta}_{01}T^{\tau}_{00} & T^{\theta}_{01}T^{\tau}_{10} & T^{\theta}_{11}T^{\tau}_{00} & T^{\theta}_{11}T^{\tau}_{10} \\ T^{\theta}_{01}T^{\tau}_{01} & T^{\theta}_{01}T^{\tau}_{11} & T^{\theta}_{11}T^{\tau}_{01} & T^{\theta}_{11}T^{\tau}_{11} \end{pmatrix} \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}\right)\right) \end{pmatrix}
\end{array} \right\}
$$

$$= \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \begin{pmatrix} \left(\left(\begin{pmatrix} R_{0000} & R_{0100} & R_{1000} & R_{1100} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta}T_{00}^{\tau} & T_{00}^{\theta}T_{10}^{\tau} & T_{10}^{\theta}T_{00}^{\tau} & T_{10}^{\theta}T_{10}^{\tau} \\ T_{00}^{\theta}T_{01}^{\tau} & T_{00}^{\theta}T_{11}^{\tau} & T_{10}^{\theta}T_{01}^{\tau} & T_{10}^{\theta}T_{11}^{\tau} \\ T_{01}^{\theta}T_{00}^{\tau} & T_{01}^{\theta}T_{10}^{\tau} & T_{11}^{\theta}T_{00}^{\tau} & T_{11}^{\theta}T_{10}^{\tau} \\ T_{01}^{\theta}T_{01}^{\tau} & T_{01}^{\theta}T_{11}^{\tau} & T_{11}^{\theta}T_{01}^{\tau} & T_{11}^{\theta}T_{11}^{\tau} \end{pmatrix}\right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}\right) \\ \left(\left(\begin{pmatrix} R_{0001} & R_{0101} & R_{1001} & R_{1101} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta}T_{00}^{\tau} & T_{00}^{\theta}T_{10}^{\tau} & T_{10}^{\theta}T_{00}^{\tau} & T_{10}^{\theta}T_{10}^{\tau} \\ T_{00}^{\theta}T_{01}^{\tau} & T_{00}^{\theta}T_{11}^{\tau} & T_{10}^{\theta}T_{01}^{\tau} & T_{10}^{\theta}T_{11}^{\tau} \\ T_{01}^{\theta}T_{00}^{\tau} & T_{01}^{\theta}T_{10}^{\tau} & T_{11}^{\theta}T_{00}^{\tau} & T_{11}^{\theta}T_{10}^{\tau} \\ T_{01}^{\theta}T_{01}^{\tau} & T_{01}^{\theta}T_{11}^{\tau} & T_{11}^{\theta}T_{01}^{\tau} & T_{11}^{\theta}T_{11}^{\tau} \end{pmatrix}\right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}\right) \\ \left(\left(\begin{pmatrix} R_{0010} & R_{0110} & R_{1010} & R_{1110} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta}T_{00}^{\tau} & T_{00}^{\theta}T_{10}^{\tau} & T_{10}^{\theta}T_{00}^{\tau} & T_{10}^{\theta}T_{10}^{\tau} \\ T_{00}^{\theta}T_{01}^{\tau} & T_{00}^{\theta}T_{11}^{\tau} & T_{10}^{\theta}T_{01}^{\tau} & T_{10}^{\theta}T_{11}^{\tau} \\ T_{01}^{\theta}T_{00}^{\tau} & T_{01}^{\theta}T_{10}^{\tau} & T_{11}^{\theta}T_{00}^{\tau} & T_{11}^{\theta}T_{10}^{\tau} \\ T_{01}^{\theta}T_{01}^{\tau} & T_{01}^{\theta}T_{11}^{\tau} & T_{11}^{\theta}T_{01}^{\tau} & T_{11}^{\theta}T_{11}^{\tau} \end{pmatrix}\right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}\right) \\ \left(\left(\begin{pmatrix} R_{0011} & R_{0111} & R_{1011} & R_{1111} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta}T_{00}^{\tau} & T_{00}^{\theta}T_{10}^{\tau} & T_{10}^{\theta}T_{00}^{\tau} & T_{10}^{\theta}T_{10}^{\tau} \\ T_{00}^{\theta}T_{01}^{\tau} & T_{00}^{\theta}T_{11}^{\tau} & T_{10}^{\theta}T_{01}^{\tau} & T_{10}^{\theta}T_{11}^{\tau} \\ T_{01}^{\theta}T_{00}^{\tau} & T_{01}^{\theta}T_{10}^{\tau} & T_{11}^{\theta}T_{00}^{\tau} & T_{11}^{\theta}T_{10}^{\tau} \\ T_{01}^{\theta}T_{01}^{\tau} & T_{01}^{\theta}T_{11}^{\tau} & T_{11}^{\theta}T_{01}^{\tau} & T_{11}^{\theta}T_{11}^{\tau} \end{pmatrix}\right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}\right) \end{pmatrix}$$

$$= \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left(\begin{pmatrix} R_{0000} & R_{0100} & R_{1000} & R_{1100} \\ R_{0001} & R_{0101} & R_{1001} & R_{1101} \\ R_{0010} & R_{0110} & R_{1010} & R_{1110} \\ R_{0011} & R_{0111} & R_{1011} & R_{1111} \end{pmatrix} \begin{pmatrix} T_{00}^{\theta}T_{00}^{\tau} & T_{00}^{\theta}T_{10}^{\tau} & T_{10}^{\theta}T_{00}^{\tau} & T_{10}^{\theta}T_{10}^{\tau} \\ T_{00}^{\theta}T_{01}^{\tau} & T_{00}^{\theta}T_{11}^{\tau} & T_{10}^{\theta}T_{01}^{\tau} & T_{10}^{\theta}T_{11}^{\tau} \\ T_{01}^{\theta}T_{00}^{\tau} & T_{01}^{\theta}T_{10}^{\tau} & T_{11}^{\theta}T_{00}^{\tau} & T_{11}^{\theta}T_{10}^{\tau} \\ T_{01}^{\theta}T_{01}^{\tau} & T_{01}^{\theta}T_{11}^{\tau} & T_{11}^{\theta}T_{01}^{\tau} & T_{11}^{\theta}T_{11}^{\tau} \end{pmatrix}\right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}$$

$$= \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left(\begin{pmatrix} R_{0000} & R_{0100} & R_{1000} & R_{1100} \\ R_{0001} & R_{0101} & R_{1001} & R_{1101} \\ R_{0010} & R_{0110} & R_{1010} & R_{1110} \\ R_{0011} & R_{0111} & R_{1011} & R_{1111} \end{pmatrix} \left(\begin{pmatrix} T_{00}^{\theta} & T_{10}^{\theta} \\ T_{01}^{\theta} & T_{11}^{\theta} \end{pmatrix} \otimes \begin{pmatrix} T_{00}^{\tau} & T_{10}^{\tau} \\ T_{01}^{\tau} & T_{11}^{\tau} \end{pmatrix}\right)\right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix} \qquad \textit{(L.21)}$$

Selanjutnya dengan menuliskan bentuk matriks T^{θ}dan T^{τ} sebagai berikut

$$T^{\theta} = \begin{pmatrix} T_{00}^{\theta} & T_{10}^{\theta} \\ T_{01}^{\theta} & T_{11}^{\theta} \end{pmatrix}; dan\, T^{\tau} = \begin{pmatrix} T_{00}^{\tau} & T_{10}^{\tau} \\ T_{01}^{\tau} & T_{11}^{\tau} \end{pmatrix} \qquad (L.22)$$

Yang merupakan bentuk matriks dari nilai koefisien T_{il}^{θ} dan T_{jm}^{τ}, selanjutnya dengan mensubtitusikan persamaan (L.22) ke dalam persamaan (L.21) diperoleh,

$$|\psi\rangle_{A,A1,B,B1,B2,A2} = \sum_{\theta,\tau=1}^{4} |\theta\tau\rangle \left(\left(\begin{pmatrix} R_{0000} & R_{0100} & R_{1000} & R_{1100} \\ R_{0001} & R_{0101} & R_{1001} & R_{1101} \\ R_{0010} & R_{0110} & R_{1010} & R_{1110} \\ R_{0011} & R_{0111} & R_{1011} & R_{1111} \end{pmatrix} \left(T^{\theta} \otimes T^{\tau}\right)\right) \begin{pmatrix} x_0y_0 \\ x_0y_1 \\ x_1y_0 \\ x_1y_1 \end{pmatrix}\right) \qquad \textit{(L.23)}$$

Dengan demikian, dengan mereduksi persamaan (L.20) ke dalam bentuk persamaan (L.23) diperoleh

$$\left(\begin{pmatrix} R_{0000} & R_{0100} & R_{1000} & R_{1100} \\ R_{0001} & R_{0101} & R_{1001} & R_{1101} \\ R_{0010} & R_{0110} & R_{1010} & R_{1110} \\ R_{0011} & R_{0111} & R_{1011} & R_{1111} \end{pmatrix}\left(T^{\theta} \otimes T^{\tau}\right)\right) = \begin{pmatrix} \sigma_{0000}^{\theta\tau} & \sigma_{0100}^{\theta\tau} & \sigma_{1000}^{\theta\tau} & \sigma_{1100}^{\theta\tau} \\ \sigma_{0001}^{\theta\tau} & \sigma_{0101}^{\theta\tau} & \sigma_{1001}^{\theta\tau} & \sigma_{1101}^{\theta\tau} \\ \sigma_{0010}^{\theta\tau} & \sigma_{0110}^{\theta\tau} & \sigma_{1010}^{\theta\tau} & \sigma_{1110}^{\theta\tau} \\ \sigma_{0011}^{\theta\tau} & \sigma_{0111}^{\theta\tau} & \sigma_{1011}^{\theta\tau} & \sigma_{1111}^{\theta\tau} \end{pmatrix} \qquad (L.24)$$

Dengan menuliskan

$$\boldsymbol{R} = \begin{pmatrix} R_{0000} & R_{0100} & R_{1000} & R_{1100} \\ R_{0001} & R_{0101} & R_{1001} & R_{1101} \\ R_{0010} & R_{0110} & R_{1010} & R_{1110} \\ R_{0011} & R_{0111} & R_{1011} & R_{1111} \end{pmatrix}$$

(L.25)

sebagai matriks parameter kanal. Selanjutnya untuk

$$\boldsymbol{\sigma^{\theta\tau}} = \begin{pmatrix} \sigma_{0000}^{\theta\tau} & \sigma_{0100}^{\theta\tau} & \sigma_{1000}^{\theta\tau} & \sigma_{1100}^{\theta\tau} \\ \sigma_{0001}^{\theta\tau} & \sigma_{0101}^{\theta\tau} & \sigma_{1001}^{\theta\tau} & \sigma_{1101}^{\theta\tau} \\ \sigma_{0010}^{\theta\tau} & \sigma_{0110}^{\theta\tau} & \sigma_{1010}^{\theta\tau} & \sigma_{1110}^{\theta\tau} \\ \sigma_{0011}^{\theta\tau} & \sigma_{0111}^{\theta\tau} & \sigma_{1011}^{\theta\tau} & \sigma_{1111}^{\theta\tau} \end{pmatrix}$$

(L.26)

Sehingga persamaan (L.24) dapat ditulis menjadi

$$\boldsymbol{R}\left(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}}\right) = (\boldsymbol{\sigma})^{\boldsymbol{\theta\tau}}$$

(L.27)

Selanjutnya untuk mencari nilai dari matriks parameter kanal maka dilakukan perkalian invers dari matriks $\left(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}}\right)$ dari kanan, sebagai berikut

$$\boldsymbol{R}\left(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}}\right)\left(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}}\right)^{-1} = \boldsymbol{\sigma^{\theta\tau}}\left(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}}\right)^{-1}$$

$$\boldsymbol{R} = \boldsymbol{\sigma^{\theta\tau}}\left(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}}\right)^{-1}$$

(L.28)

Selanjutnya saat Alice dan Bob melakukan pengukuran menggunakan basis Bell sebagai berikut,

$$\left|\psi^{\theta\tau}\right\rangle_T = (\langle\boldsymbol{\pi\kappa}| \otimes \boldsymbol{I} \otimes \boldsymbol{I})|\boldsymbol{\psi}\rangle_{\boldsymbol{A,A1,B,B1,B2,A2}}$$

$$= (\langle\boldsymbol{\pi\kappa}| \otimes \boldsymbol{I} \otimes \boldsymbol{I}) \sum_{\boldsymbol{i,j,s,t=0}}^{\boldsymbol{1}} \sum_{\boldsymbol{\theta,\tau=1}}^{\boldsymbol{4}} |\boldsymbol{\theta\tau}\rangle\, \boldsymbol{x_i y_j} (\boldsymbol{\sigma})^{\boldsymbol{\theta\tau}} |\boldsymbol{s}\rangle_{\boldsymbol{B2}} |\boldsymbol{t}\rangle_{\boldsymbol{A2}}$$

$$= \sum_{i,j,s,t=0}^{1} \sum_{\theta,\tau=1}^{\boldsymbol{4}} \langle\boldsymbol{\pi\kappa}|\boldsymbol{\theta\tau}\rangle\ \boldsymbol{x_i y_j} (\boldsymbol{\sigma})^{\boldsymbol{\theta\tau}} |\boldsymbol{s}\rangle_{\boldsymbol{B2}} |\boldsymbol{t}\rangle_{\boldsymbol{A2}}$$

$$= \sum_{i,j,s,t=0}^{1} \sum_{\theta,\tau=1}^{\mathbf{4}} \langle \boldsymbol{\pi}|\boldsymbol{\theta}\rangle\langle \boldsymbol{\kappa}|\boldsymbol{\tau}\rangle \; \boldsymbol{x_i y_j}(\boldsymbol{\sigma})^{\boldsymbol{\theta\tau}}|\boldsymbol{s}\rangle_{\boldsymbol{B2}}|\boldsymbol{t}\rangle_{\boldsymbol{A2}}$$

dengan $\langle \boldsymbol{\pi}|\boldsymbol{\theta}\rangle = \boldsymbol{\delta_{\pi\theta}}$ dan $\langle \boldsymbol{\kappa}|\boldsymbol{\tau}\rangle = \boldsymbol{\delta_{\kappa\tau}}$ merupakan delta kronecker yang memenuhi $(\delta_{\pi\theta} = 1, jika\, \pi = \theta, dan\, \delta_{\pi\theta} = 0, jika\, \pi \neq \theta)$ dan $(\delta_{\kappa\tau} = 1, jika\, \kappa = \tau, dan\, \delta_{\kappa\tau} = 0, jika\, \kappa \neq \tau)$, sehingga

$$|\psi^{\theta\tau}\rangle_T = \sum_{i,j,s,t=0}^{1} \sum_{\theta,\tau=1}^{\mathbf{4}} \boldsymbol{\delta_{\pi\theta}\delta_{\kappa\tau}} \, \boldsymbol{x_i y_j}(\boldsymbol{\sigma})^{\boldsymbol{\theta\tau}}|\boldsymbol{s}\rangle_{\boldsymbol{B2}}|\boldsymbol{t}\rangle_{\boldsymbol{A2}}$$

$$= \sum_{i,j,s,t=0}^{1} \boldsymbol{x_i y_j}(\boldsymbol{\sigma})^{\boldsymbol{\theta\tau}}|\boldsymbol{s}\rangle_{\boldsymbol{B2}}|\boldsymbol{t}\rangle_{\boldsymbol{A2}}$$

$$= \sum_{i,j,s,t=0}^{1} \boldsymbol{x_i y_j}\left(\boldsymbol{\sigma^{\theta}} \otimes \boldsymbol{\sigma^{\tau}}\right)\left(|\boldsymbol{s}\rangle_{\boldsymbol{B2}} \otimes |\boldsymbol{t}\rangle_{\boldsymbol{A2}}\right)$$

$$= \sum_{i,j,s,t=0}^{1} \boldsymbol{x_i y_j}\left(\boldsymbol{\sigma^{\theta}}|\boldsymbol{s}\rangle_{\boldsymbol{B2}}\right) \otimes \left(\boldsymbol{\sigma^{\tau}}|\boldsymbol{t}\rangle_{\boldsymbol{A2}}\right)$$

(L.29)

Dengan $\boldsymbol{\sigma^{\theta}}$ merupakan matriks pembalik hasil pengukuran oleh Alice, dan $\boldsymbol{\sigma^{\tau}}$ merupakan matriks pembalik hasil pengukuran Bob, maka untuk mendapatkan matriks parameter kanal dapat juga dituliskan dengan,

$$\boldsymbol{R} = \boldsymbol{\sigma^{\theta\tau}}\left(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}}\right)^{-\mathbf{1}}$$

$$= \left(\boldsymbol{\sigma^{\theta}} \otimes \boldsymbol{\sigma^{\tau}}\right)\left(\boldsymbol{T^{\theta}} \otimes \boldsymbol{T^{\tau}}\right)^{-\mathbf{1}}$$

$$= \left(\boldsymbol{\sigma^{\theta}} \otimes \boldsymbol{\sigma^{\tau}}\right)\left(\left(\boldsymbol{T^{\theta}}\right)^{-\mathbf{1}} \otimes (\boldsymbol{T^{\tau}})^{-\mathbf{1}}\right)$$

(L.30)

Dengan perkalian tensor matriks $\boldsymbol{T^{\theta}}$ dan $\boldsymbol{T^{\tau}}$menghasilkan bentuk matriks 4x4 yang uniter, serta matriks pembalik hasil pengukuran yang juga haruslah matriks yang uniter maka matriks parameter kanal juga harus merupakan matriks yang uniter. Sehingga didapatkan informasi yang saling terkirim antara Alice dan Bob.

LAMPIRAN B

KANAL DARI MATRIKS UNITER (2x2)

Untuk bermacam-macam matriks uniter 2x2 sebagai berikut

$$\boldsymbol{U} = \begin{pmatrix} \cos\theta \; e^{i\alpha} & \sin\theta \, e^{i\beta} \\ \pm\sin\theta \, e^{i\gamma} & \pm\cos\theta \, e^{i\delta} \end{pmatrix}$$

$$= \begin{pmatrix} \cos\theta \; e^{i\alpha} & \sin\theta \, e^{i\beta} \\ \mp\sin\theta \, e^{i\gamma} & \pm\cos\theta \, e^{i(\beta+\gamma-\alpha)} \end{pmatrix}$$

Untuk nilai $\alpha, \beta, \gamma = 0$ sehingga didapatkan matriks uniter sebagai berikut,

$$\boldsymbol{U} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

- Untuk nilai $\theta = 0$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 0 & \sin 0 \\ -\sin 0 & \cos 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} = \boldsymbol{U_1} = \boldsymbol{I}$$

- Untuk nilai $\theta = 30$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 30 & \sin 30 \\ -\sin 30 & \cos 30 \end{pmatrix} = \frac{1}{2}\begin{pmatrix} \sqrt{3} & 1 \\ -1 & \sqrt{3} \end{pmatrix} = \boldsymbol{U_2}$$

- Untuk nilai $\theta = 45$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 45 & \sin 45 \\ -\sin 45 & \cos 45 \end{pmatrix} = \frac{1}{2}\begin{pmatrix} \sqrt{2} & \sqrt{2} \\ -\sqrt{2} & \sqrt{2} \end{pmatrix} = \frac{\sqrt{2}}{2}\begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix} = \boldsymbol{U_3}$$

- Untuk nilai $\theta = 60$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 60 & \sin 60 \\ -\sin 60 & \cos 60 \end{pmatrix} = \frac{1}{2}\begin{pmatrix} 1 & \sqrt{3} \\ -\sqrt{3} & 1 \end{pmatrix} = \boldsymbol{U_4}$$

- Untuk nilai $\theta = 90$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 90 & \sin 90 \\ -\sin 90 & \cos 90 \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} = \boldsymbol{U_5}$$

- Untuk nilai $\theta = 0$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \cos 0 & \sin 0 \\ \sin 0 & -\cos 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} = \boldsymbol{U_6} = \boldsymbol{\sigma^z}$$

- Untuk nilai $\theta = 30$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \boldsymbol{cos\,30} & \boldsymbol{sin\,30} \\ \boldsymbol{sin\,30} & \boldsymbol{-cos\,30} \end{pmatrix} = \frac{1}{2}\begin{pmatrix} \boldsymbol{\sqrt{3}} & \boldsymbol{1} \\ \boldsymbol{1} & \boldsymbol{-\sqrt{3}} \end{pmatrix} = \boldsymbol{U_7}$$

- Untuk nilai $\theta = 45$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \boldsymbol{cos\,45} & \boldsymbol{sin\,45} \\ \boldsymbol{sin\,45} & \boldsymbol{-cos\,45} \end{pmatrix} = \frac{1}{2}\begin{pmatrix} \boldsymbol{\sqrt{2}} & \boldsymbol{\sqrt{2}} \\ \boldsymbol{\sqrt{2}} & \boldsymbol{-\sqrt{2}} \end{pmatrix} = \frac{\sqrt{2}}{2}\begin{pmatrix} \boldsymbol{1} & \boldsymbol{1} \\ \boldsymbol{1} & \boldsymbol{-1} \end{pmatrix} = \boldsymbol{U_8}$$

- Untuk nilai $\theta = 60$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \boldsymbol{cos\,60} & \boldsymbol{sin\,60} \\ \boldsymbol{sin\,60} & \boldsymbol{-cos\,60} \end{pmatrix} = \frac{1}{2}\begin{pmatrix} \boldsymbol{1} & \boldsymbol{\sqrt{3}} \\ \boldsymbol{\sqrt{3}} & \boldsymbol{-1} \end{pmatrix} = \boldsymbol{U_9}$$

- Untuk nilai $\theta = 90$, maka bentuk matriks uniternya menjadi

$$\boldsymbol{U} = \begin{pmatrix} \boldsymbol{cos\,90} & \boldsymbol{sin\,90} \\ \boldsymbol{sin\,90} & \boldsymbol{-cos\,90} \end{pmatrix} = \begin{pmatrix} \boldsymbol{0} & \boldsymbol{1} \\ \boldsymbol{1} & \boldsymbol{0} \end{pmatrix} = \boldsymbol{U_{10}} = \boldsymbol{\sigma^x}$$

Macam-macam kanal yang dapat dibentuk bisa ditentukan dari nilai hasil pengukurannya

- Transformasi hasil pengukuran Alice berupa berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{I}$
  1) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{U_1 = I}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 1}$

$$\begin{aligned}
\boldsymbol{R} &= \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right) \\
&= (\boldsymbol{\sigma^x} \otimes \boldsymbol{I})((\boldsymbol{T^1})^{-1} \otimes (\boldsymbol{T^1})^{-1}) \\
&= \left(\begin{pmatrix} \boldsymbol{0} & \boldsymbol{1} \\ \boldsymbol{1} & \boldsymbol{0} \end{pmatrix} \otimes \begin{pmatrix} \boldsymbol{1} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{1} \end{pmatrix}\right)\left(\frac{\boldsymbol{1}}{\sqrt{\boldsymbol{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{\boldsymbol{1}}{\sqrt{\boldsymbol{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right) \\
&= \frac{\boldsymbol{1}}{\boldsymbol{2}}\begin{pmatrix} \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{1} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{1} \\ \boldsymbol{1} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{1} & \boldsymbol{0} & \boldsymbol{0} \end{pmatrix}\begin{pmatrix} \boldsymbol{1} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{1} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{1} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{1} \end{pmatrix} \\
&= \frac{\boldsymbol{1}}{\boldsymbol{2}}\begin{pmatrix} \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{1} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{1} \\ \boldsymbol{1} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{1} & \boldsymbol{0} & \boldsymbol{0} \end{pmatrix}
\end{aligned}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|\mathbf{0010}\rangle + |\mathbf{0111}\rangle + |\mathbf{1000}\rangle + |\mathbf{1101}\rangle)$$

2) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{I}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 2}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{I})((\boldsymbol{T^1})^{-1} \otimes (\boldsymbol{T^2})^{-1})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|\mathbf{0010}\rangle - |\mathbf{0111}\rangle + |\mathbf{1000}\rangle - |\mathbf{1101}\rangle)$$

3) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{I}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{I})((\boldsymbol{T^1})^{-1} \otimes (\boldsymbol{T^3})^{-1})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|\mathbf{0011}\rangle + |\mathbf{0110}\rangle + |\mathbf{1001}\rangle + |\mathbf{1100}\rangle)$$

4) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{I}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{I})((\boldsymbol{T^1})^{-1} \otimes (\boldsymbol{T^4})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0011}\rangle + |\mathbf{0110}\rangle - |\mathbf{1001}\rangle + |\mathbf{1100}\rangle)$$

5) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa$\boldsymbol{I}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 1}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{I})((\boldsymbol{T^2})^{-1} \otimes (\boldsymbol{T^1})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0010\rangle + |0111\rangle - |1000\rangle - |1101\rangle)$$

6) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa I, maka didapatkan nilai R untuk nilai $\theta = 2$ dan $\tau = 2$

$$R = \left(\sigma^\theta \otimes \sigma^\tau\right)\left(\left(T^\theta\right)^{-1} \otimes (T^\tau)^{-1}\right)$$

$$= (\sigma^x \otimes I)((T^2)^{-1} \otimes (T^2)^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0010\rangle - |0111\rangle - |1000\rangle + |1101\rangle)$$

7) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa I, maka didapatkan nilai R untuk nilai $\theta = 2$ dan $\tau = 3$

$$R = \left(\sigma^\theta \otimes \sigma^\tau\right)\left(\left(T^\theta\right)^{-1} \otimes (T^\tau)^{-1}\right)$$

$$= (\sigma^x \otimes I)((T^2)^{-1} \otimes (T^3)^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0011\rangle + |0110\rangle - |1001\rangle - |1100\rangle)$$

8) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa I, maka didapatkan nilai R untuk nilai $\theta = 2$ dan $\tau = 4$

$$R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)$$

$$= (\sigma^x \otimes I)((T^2)^{-1} \otimes (T^4)^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|0011\rangle + |0110\rangle + |1001\rangle - |1100\rangle)$$

9) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa I, maka didapatkan nilai R untuk nilai $\theta = 3$ dan $\tau = 1$

$$R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{I})((\boldsymbol{T^3})^{-1} \otimes (\boldsymbol{T^1})^{-1})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0000}\rangle + |\mathbf{0101}\rangle + |\mathbf{1010}\rangle + |\mathbf{1111}\rangle)$$

10) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{I}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = \mathbf{3}$ dan $\boldsymbol{\tau} = \mathbf{2}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{I})((\boldsymbol{T^3})^{-1} \otimes (\boldsymbol{T^2})^{-1})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & -\mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & -\mathbf{1} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0000}\rangle - |\mathbf{0101}\rangle + |\mathbf{1010}\rangle - |\mathbf{1111}\rangle)$$

11) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{I}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 3}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{I})((\boldsymbol{T^3})^{-1} \otimes (\boldsymbol{T^3})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{1}{2}(|\boldsymbol{0001}\rangle + |\boldsymbol{0100}\rangle + |\boldsymbol{1011}\rangle + |\boldsymbol{1110}\rangle)$$

12) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{I}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 3}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{I})((\boldsymbol{T^3})^{-1} \otimes (\boldsymbol{T^4})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0001}\rangle + |\mathbf{0100}\rangle - |\mathbf{1011}\rangle + |\mathbf{1110}\rangle)$$

13) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{I}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = \mathbf{4}$ dan $\boldsymbol{\tau} = \mathbf{1}$

$$\begin{aligned}
\boldsymbol{R} &= (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right) \\
&= (\boldsymbol{\sigma^x} \otimes \boldsymbol{I})((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^1})^{-1}) \\
&= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right) \\
&= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix} \\
&= \frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}
\end{aligned}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0000}\rangle - |\mathbf{0101}\rangle + |\mathbf{1010}\rangle + |\mathbf{1111}\rangle)$$

14) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{I}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = \mathbf{4}$ dan $\boldsymbol{\tau} = \mathbf{2}$

$$\begin{aligned}
\boldsymbol{R} &= (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right) \\
&= (\boldsymbol{\sigma^x} \otimes \boldsymbol{I})((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^2})^{-1}) \\
&= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right) \\
&= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}
\end{aligned}$$

$$= \frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0000}\rangle + |\mathbf{0101}\rangle + |\mathbf{1010}\rangle - |\mathbf{1111}\rangle)$$

15) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{I}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{I})((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^3})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0001}\rangle - |\mathbf{0100}\rangle + |\mathbf{1011}\rangle + |\mathbf{1110}\rangle)$$

16) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{I}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{I})((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^4})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0001\rangle - |0100\rangle - |1011\rangle + |1110\rangle)$$

- Transformasi hasil pengukuran Alice berupa berupa σ^x dan pengukuran Bob berupa σ^x

17) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa σ^x, maka didapatkan nilai R untuk nilai $\theta = 1$ dan $\tau = 1$

$$R = \left(\sigma^{\theta} \otimes \sigma^{\tau}\right)\left(\left(T^{\theta}\right)^{-1} \otimes (T^{\tau})^{-1}\right)$$

$$= (\sigma^x \otimes \sigma^x)((T^1)^{-1} \otimes (T^1)^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0011\rangle + |0110\rangle + |1001\rangle + |1100\rangle)$$

18) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa σ^x, maka didapatkan nilai R untuk nilai $\theta = 1$ dan $\tau = 2$

$$R = \left(\boldsymbol{\sigma}^{\theta} \otimes \boldsymbol{\sigma}^{\tau}\right)\left(\left(T^{\theta}\right)^{-1} \otimes (T^{\tau})^{-1}\right)$$
$$= (\boldsymbol{\sigma}^{x} \otimes \boldsymbol{\sigma}^{x})((T^{1})^{-1} \otimes (T^{2})^{-1})$$
$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$
$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$
$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0011\rangle - |0110\rangle + |1001\rangle - |1100\rangle)$$

19) Untuk pengukuran Alice berupa $\boldsymbol{\sigma}^{x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma}^{x}$, maka didapatkan nilai R untuk nilai $\theta = 1$ dan $\tau = 3$

$$R = \left(\boldsymbol{\sigma}^{\theta} \otimes \boldsymbol{\sigma}^{\tau}\right)\left(\left(T^{\theta}\right)^{-1} \otimes (T^{\tau})^{-1}\right)$$
$$= (\boldsymbol{\sigma}^{x} \otimes \boldsymbol{\sigma}^{x})((T^{1})^{-1} \otimes (T^{3})^{-1})$$
$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$
$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$
$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0010\rangle + |0111\rangle + |1000\rangle + |1101\rangle)$$

20) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^1})^{-1} \otimes (\boldsymbol{T^4})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|0010\rangle + |0111\rangle - |1000\rangle + |1101\rangle)$$

21) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 1}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^2})^{-1} \otimes (\boldsymbol{T^1})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|\mathbf{0011}\rangle + |\mathbf{0110}\rangle - |\mathbf{1001}\rangle - |\mathbf{1100}\rangle)$$

22) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 2}$

$$\begin{aligned}
\boldsymbol{R} &= \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right) \\
&= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^2})^{-1} \otimes (\boldsymbol{T^2})^{-1}) \\
&= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right) \\
&= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \\
&= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}
\end{aligned}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|\mathbf{0011}\rangle + |\mathbf{0110}\rangle - |\mathbf{1001}\rangle - |\mathbf{1100}\rangle)$$

23) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 3}$

$$\begin{aligned}
\boldsymbol{R} &= \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right) \\
&= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^2})^{-1} \otimes (\boldsymbol{T^3})^{-1}) \\
&= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right) \\
&= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & -1 & 0 \end{pmatrix}
\end{aligned}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0011\rangle - |0110\rangle - |1001\rangle + |1100\rangle)$$

24) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa σ^x, maka didapatkan nilai R untuk nilai $\theta = 2$ dan $\tau = 4$

$$R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)$$

$$= (\sigma^x \otimes \sigma^x)((T^2)^{-1} \otimes (T^4)^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|0010\rangle + |0111\rangle + |1000\rangle - |1101\rangle)$$

25) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa σ^x, maka didapatkan nilai R untuk nilai $\theta = 3$ dan $\tau = 1$

$$R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)$$

$$= (\sigma^x \otimes \sigma^x)((T^3)^{-1} \otimes (T^1)^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|\mathbf{0001}\rangle + |\mathbf{0100}\rangle + |\mathbf{1011}\rangle + |\mathbf{1110}\rangle)$$

26) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 3}$ dan $\boldsymbol{\tau = 2}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^3})^{-1} \otimes (\boldsymbol{T^2})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|\mathbf{0001}\rangle - |\mathbf{0100}\rangle + |\mathbf{1011}\rangle - |\mathbf{1110}\rangle)$$

27) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 3}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T}^3)^{-1} \otimes (\boldsymbol{T}^3)^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|\mathbf{0000}\rangle + |\mathbf{0101}\rangle + |\mathbf{1010}\rangle + |\mathbf{1111}\rangle)$$

28) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = \mathbf{3}$ dan $\boldsymbol{\tau} = \mathbf{4}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T}^3)^{-1} \otimes (\boldsymbol{T}^4)^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0000}\rangle + |\mathbf{0101}\rangle - |\mathbf{1010}\rangle + |\mathbf{1111}\rangle)$$

29) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 1}$

$$\boldsymbol{R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)}$$
$$\boldsymbol{= (\sigma^x \otimes \sigma^x)((T^4)^{-1} \otimes (T^1)^{-1})}$$
$$\boldsymbol{= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)}$$
$$\boldsymbol{= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}}$$
$$\boldsymbol{= \frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$\boldsymbol{|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|0001\rangle - |0100\rangle + |1011\rangle + |1110\rangle)}$$

30) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 2}$

$$\boldsymbol{R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)}$$
$$\boldsymbol{= (\sigma^x \otimes \sigma^x)((T^4)^{-1} \otimes (T^2)^{-1})}$$
$$\boldsymbol{= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)}$$
$$\boldsymbol{= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}}$$
$$\boldsymbol{= \frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0001}\rangle + |\mathbf{0100}\rangle + |\mathbf{1011}\rangle - |\mathbf{1110}\rangle)$$

31) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^3})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0000}\rangle - |\mathbf{0101}\rangle + |\mathbf{1010}\rangle + |\mathbf{1111}\rangle)$$

32) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^x}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^x})((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^4})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{-1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1},\boldsymbol{B1},\boldsymbol{B2},\boldsymbol{A2}} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0000}\rangle - |\mathbf{0101}\rangle - |\mathbf{1010}\rangle + |\mathbf{1111}\rangle)$$

- Transformasi hasil pengukuran Alice berupa berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $-\boldsymbol{U_5} = \boldsymbol{Y}$

33) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = \mathbf{1}$ dan $\boldsymbol{\tau} = \mathbf{1}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-\mathbf{1}} \otimes (\boldsymbol{T^\tau})^{-\mathbf{1}}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{Y})((\boldsymbol{T^1})^{-\mathbf{1}} \otimes (\boldsymbol{T^1})^{-\mathbf{1}})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{0} & \mathbf{-1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1},\boldsymbol{B1},\boldsymbol{B2},\boldsymbol{A2}} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0011}\rangle - |\mathbf{0110}\rangle + |\mathbf{1001}\rangle - |\mathbf{1100}\rangle)$$

34) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = \mathbf{1}$ dan $\boldsymbol{\tau} = \mathbf{2}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-\mathbf{1}} \otimes (\boldsymbol{T^\tau})^{-\mathbf{1}}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{Y})((\boldsymbol{T^1})^{-\mathbf{1}} \otimes (\boldsymbol{T^2})^{-\mathbf{1}})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{0} & \mathbf{-1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0011\rangle + |0110\rangle + |1001\rangle + |1100\rangle)$$

35) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{Y})((\boldsymbol{T^1})^{-1} \otimes (\boldsymbol{T^3})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|0010\rangle + |0111\rangle - |1000\rangle + |1101\rangle)$$

36) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{Y})((\boldsymbol{T^1})^{-1} \otimes (\boldsymbol{T^4})^{-1})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{0} & \mathbf{-1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{-1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{-1} & \mathbf{0} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0010}\rangle + |\mathbf{0111}\rangle + |\mathbf{1000}\rangle + |\mathbf{1101}\rangle)$$

37) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 1}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{Y})((\boldsymbol{T^2})^{-1} \otimes (\boldsymbol{T^1})^{-1})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{0} & \mathbf{-1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{-1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{-1} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0011}\rangle - |\mathbf{0110}\rangle - |\mathbf{1001}\rangle + |\mathbf{1100}\rangle)$$

38) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 2}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{Y})((\boldsymbol{T^2})^{-1} \otimes (\boldsymbol{T^2})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0011\rangle + |0110\rangle - |1001\rangle - |1100\rangle)$$

39) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{Y})((\boldsymbol{T^2})^{-1} \otimes (\boldsymbol{T^3})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|0010\rangle + |0111\rangle + |1000\rangle - |1101\rangle)$$

40) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$
$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{Y})((\boldsymbol{T^2})^{-1} \otimes (\boldsymbol{T^4})^{-1})$$
$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$
$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$
$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0010\rangle + |0111\rangle - |1000\rangle - |1101\rangle)$$

41) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 3}$ dan $\boldsymbol{\tau = 1}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$
$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{Y})((\boldsymbol{T^3})^{-1} \otimes (\boldsymbol{T^1})^{-1})$$
$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$
$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0001\rangle - |0100\rangle + |1011\rangle - |1110\rangle)$$

42) Untuk pengukuran Alice berupa $\boldsymbol{\sigma}^x$ dan pengukuran Bob berupa $\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = 3$ dan $\boldsymbol{\tau} = 2$

$$\boldsymbol{R} = (\boldsymbol{\sigma}^{\theta} \otimes \boldsymbol{\sigma}^{\tau})\left(\left(\boldsymbol{T}^{\theta}\right)^{-1} \otimes (\boldsymbol{T}^{\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma}^x \otimes \boldsymbol{Y})((\boldsymbol{T}^3)^{-1} \otimes (\boldsymbol{T}^2)^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0001\rangle + |0100\rangle + |1011\rangle + |1110\rangle)$$

43) Untuk pengukuran Alice berupa $\boldsymbol{\sigma}^x$ dan pengukuran Bob berupa $\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = 3$ dan $\boldsymbol{\tau} = 3$

$$\boldsymbol{R} = (\boldsymbol{\sigma}^{\theta} \otimes \boldsymbol{\sigma}^{\tau})\left(\left(\boldsymbol{T}^{\theta}\right)^{-1} \otimes (\boldsymbol{T}^{\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma}^x \otimes \boldsymbol{Y})((\boldsymbol{T}^3)^{-1} \otimes (\boldsymbol{T}^3)^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0000}\rangle + |\mathbf{0101}\rangle - |\mathbf{1010}\rangle + |\mathbf{1111}\rangle)$$

44) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa$\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 3}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{Y})((\boldsymbol{T^3})^{-1} \otimes (\boldsymbol{T^4})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|\mathbf{0000}\rangle + |\mathbf{0101}\rangle + |\mathbf{1010}\rangle + |\mathbf{1111}\rangle)$$

45) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 1}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{Y})((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^1})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{1}{2}(-|\boldsymbol{0001}\rangle + |\boldsymbol{0100}\rangle + |\boldsymbol{1011}\rangle - |\boldsymbol{1110}\rangle)$$

46) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa$\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 2}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{Y})((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^2})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{1}{2}(-|\boldsymbol{0001}\rangle - |\boldsymbol{0100}\rangle + |\boldsymbol{1011}\rangle + |\boldsymbol{1110}\rangle)$$

47) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R = \left(\sigma^{\theta} \otimes \sigma^{\tau}\right)\left(\left(T^{\theta}\right)^{-1} \otimes (T^{\tau})^{-1}\right)}$$

$$\boldsymbol{= (\sigma^{x} \otimes Y)((T^{4})^{-1} \otimes (T^{3})^{-1})}$$

$$\boldsymbol{= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)}$$

$$\boldsymbol{= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}}$$

$$\boldsymbol{= \frac{1}{2}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$\boldsymbol{|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0000\rangle - |0101\rangle - |1010\rangle + |1111\rangle)}$$

48) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{Y}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R = \left(\sigma^{\theta} \otimes \sigma^{\tau}\right)\left(\left(T^{\theta}\right)^{-1} \otimes (T^{\tau})^{-1}\right)}$$

$$\boldsymbol{= (\sigma^{x} \otimes Y)((T^{4})^{-1} \otimes (T^{4})^{-1})}$$

$$\boldsymbol{= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)}$$

$$\boldsymbol{= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}}$$

$$\boldsymbol{= \frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{\mathbf{1}}{\mathbf{2}}(-|\mathbf{0000}\rangle - |\mathbf{0101}\rangle + |\mathbf{1010}\rangle + |\mathbf{1111}\rangle)$$

- Transformasi hasil pengukuran Alice berupa berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{U_7 = \sigma^z}$

49) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^z}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 1}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-\mathbf{1}} \otimes (\boldsymbol{T^\tau})^{-\mathbf{1}}\right)$$
$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^z})((\boldsymbol{T^1})^{-\mathbf{1}} \otimes (\boldsymbol{T^1})^{-\mathbf{1}})$$
$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$
$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & -\mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \end{pmatrix}$$
$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & -\mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0010}\rangle - |\mathbf{0111}\rangle + |\mathbf{1000}\rangle - |\mathbf{1101}\rangle)$$

50) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^z}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 2}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-\mathbf{1}} \otimes (\boldsymbol{T^\tau})^{-\mathbf{1}}\right)$$
$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^z})((\boldsymbol{T^1})^{-\mathbf{1}} \otimes (\boldsymbol{T^2})^{-\mathbf{1}})$$
$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$
$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & -\mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & -\mathbf{1} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0010}\rangle + |\mathbf{0111}\rangle + |\mathbf{1000}\rangle + |\mathbf{1101}\rangle)$$

51) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^z}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left(\left(\boldsymbol{T^\theta}\right)^{-\mathbf{1}} \otimes (\boldsymbol{T^\tau})^{-\mathbf{1}}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^z})((\boldsymbol{T^1})^{-\mathbf{1}} \otimes (\boldsymbol{T^3})^{-\mathbf{1}})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & -\mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & -\mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ -\mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{\mathbf{1}}{\mathbf{2}}(-|\mathbf{0011}\rangle + |\mathbf{0110}\rangle - |\mathbf{1001}\rangle + |\mathbf{1100}\rangle)$$

52) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^z}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left(\left(\boldsymbol{T^\theta}\right)^{-\mathbf{1}} \otimes (\boldsymbol{T^\tau})^{-\mathbf{1}}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^z})((\boldsymbol{T^1})^{-\mathbf{1}} \otimes (\boldsymbol{T^4})^{-\mathbf{1}})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0011\rangle + |0110\rangle + |1001\rangle + |1100\rangle)$$

53) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa σ^z, maka didapatkan nilai R untuk nilai $\theta = 2$ dan $\tau = 1$

$$R = (\sigma^\theta \otimes \sigma^\tau)\left(\left(T^\theta\right)^{-1} \otimes (T^\tau)^{-1}\right)$$

$$= (\sigma^x \otimes \sigma^z)((T^2)^{-1} \otimes (T^1)^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0010\rangle - |0111\rangle - |1000\rangle + |1101\rangle)$$

54) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa σ^z, maka didapatkan nilai R untuk nilai $\theta = 2$ dan $\tau = 2$

$$R = (\sigma^\theta \otimes \sigma^\tau)\left(\left(T^\theta\right)^{-1} \otimes (T^\tau)^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^z})((\boldsymbol{T^2})^{-1} \otimes (\boldsymbol{T^2})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|\mathbf{0010}\rangle + |\mathbf{0111}\rangle - |\mathbf{1000}\rangle - |\mathbf{1101}\rangle)$$

55) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^z}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^z})((\boldsymbol{T^2})^{-1} \otimes (\boldsymbol{T^3})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0011}\rangle + |\mathbf{0110}\rangle + |\mathbf{1001}\rangle - |\mathbf{1100}\rangle)$$

56) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^z}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)}$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^z})((\boldsymbol{T}^2)^{-1} \otimes (\boldsymbol{T}^4)^{-1})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{-1} & \mathbf{0} \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{-1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1} \\ \mathbf{0} & \mathbf{0} & \mathbf{-1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0011}\rangle + |\mathbf{0110}\rangle - |\mathbf{1001}\rangle - |\mathbf{1100}\rangle)$$

57) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^z}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 3}$ dan $\boldsymbol{\tau = 1}$

$$\boldsymbol{R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)}$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^z})((\boldsymbol{T}^3)^{-1} \otimes (\boldsymbol{T}^1)^{-1})$$

$$= \left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0000}\rangle - |\mathbf{0101}\rangle + |\mathbf{1010}\rangle - |\mathbf{1111}\rangle)$$

58) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^z}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 3}$ dan $\boldsymbol{\tau = 2}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-\mathbf{1}} \otimes (\boldsymbol{T^\tau})^{-\mathbf{1}}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^z})((\boldsymbol{T^3})^{-\mathbf{1}} \otimes (\boldsymbol{T^2})^{-\mathbf{1}})$$

$$= \left(\begin{pmatrix}\mathbf{0} & \mathbf{1}\\ \mathbf{1} & \mathbf{0}\end{pmatrix} \otimes \begin{pmatrix}\mathbf{1} & \mathbf{0}\\ \mathbf{0} & \mathbf{-1}\end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix}\mathbf{0} & \mathbf{1}\\ \mathbf{1} & \mathbf{0}\end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix}\mathbf{1} & \mathbf{0}\\ \mathbf{0} & \mathbf{-1}\end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix}\mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0}\\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1}\\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0}\\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0}\end{pmatrix}\begin{pmatrix}\mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0}\\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1}\\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0}\\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0}\end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix}\mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0}\\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0}\\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0}\\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1}\end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{\mathbf{1}}{\mathbf{2}}(|\mathbf{0000}\rangle + |\mathbf{0101}\rangle + |\mathbf{1010}\rangle + |\mathbf{1111}\rangle)$$

59) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^z}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 3}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-\mathbf{1}} \otimes (\boldsymbol{T^\tau})^{-\mathbf{1}}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^z})((\boldsymbol{T^3})^{-\mathbf{1}} \otimes (\boldsymbol{T^3})^{-\mathbf{1}})$$

$$= \left(\begin{pmatrix}\mathbf{0} & \mathbf{1}\\ \mathbf{1} & \mathbf{0}\end{pmatrix} \otimes \begin{pmatrix}\mathbf{1} & \mathbf{0}\\ \mathbf{0} & \mathbf{-1}\end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix}\mathbf{0} & \mathbf{1}\\ \mathbf{1} & \mathbf{0}\end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix}\mathbf{0} & \mathbf{1}\\ \mathbf{1} & \mathbf{0}\end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}\begin{pmatrix}\mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0}\\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{-1}\\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0}\\ \mathbf{0} & \mathbf{-1} & \mathbf{0} & \mathbf{0}\end{pmatrix}\begin{pmatrix}\mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1}\\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0}\\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0}\\ \mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0}\end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|\mathbf{0001}\rangle + |\mathbf{0100}\rangle - |\mathbf{1011}\rangle + |\mathbf{1110}\rangle)$$

60) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^z}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = \mathbf{3}$ dan $\boldsymbol{\tau} = \mathbf{4}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^z})((\boldsymbol{T^3})^{-1} \otimes (\boldsymbol{T^4})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|\mathbf{0001}\rangle + |\mathbf{0100}\rangle + |\mathbf{1011}\rangle + |\mathbf{1110}\rangle)$$

61) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^z}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = \mathbf{4}$ dan $\boldsymbol{\tau} = \mathbf{1}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^z})((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^1})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|0000\rangle + |0101\rangle + |1010\rangle - |1111\rangle)$$

62) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa σ^z, maka didapatkan nilai R untuk nilai $\theta = 4$ dan $\tau = 2$

$$R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)$$

$$= (\sigma^x \otimes \sigma^z)((T^4)^{-1} \otimes (T^2)^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|0000\rangle + |0101\rangle + |1010\rangle - |1111\rangle)$$

63) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa σ^z, maka didapatkan nilai R untuk nilai $\theta = 4$ dan $\tau = 3$

$$R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^z})((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^3})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(-|0001\rangle - |0100\rangle + |1011\rangle + |1110\rangle)$$

64) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{\sigma^z}$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes \boldsymbol{\sigma^z})((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^4})^{-1})$$

$$= \left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2}\begin{pmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2}(|0001\rangle - |0100\rangle - |1011\rangle + |1110\rangle)$$

- Transformasi hasil pengukuran Alice berupa berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\boldsymbol{U_3} = \frac{\sqrt{2}}{2}(\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})$

65) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 1}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$
$$= \left(\boldsymbol{\sigma^x} \otimes \frac{\sqrt{2}}{2}(\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})\right)((\boldsymbol{T^1})^{-1} \otimes (\boldsymbol{T^1})^{-1})$$
$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$
$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$
$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2\sqrt{2}}(|\mathbf{0010}\rangle + |\mathbf{0011}\rangle + |\mathbf{0110}\rangle - |\mathbf{0111}\rangle + |\mathbf{1000}\rangle + |\mathbf{1001}\rangle + |\mathbf{1100}\rangle - |\mathbf{1101}\rangle)$$

66) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 1}$ dan $\boldsymbol{\tau = 2}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$
$$= (\boldsymbol{\sigma^x} \otimes (\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z}))((\boldsymbol{T^1})^{-1} \otimes (\boldsymbol{T^2})^{-1})$$
$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$
$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

$$= \frac{1}{2\sqrt{2}} \begin{pmatrix} 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & 1 \\ 1 & -1 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2\sqrt{2}}(|0010\rangle + |0011\rangle - |0110\rangle + |0111\rangle + |1000\rangle + |1001\rangle - |1100\rangle + |1101\rangle)$$

67) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\sigma^x + \sigma^z)$, maka didapatkan nilai R untuk nilai $\theta = 1$ dan $\tau = 3$

$$R = \left(\sigma^\theta \otimes \sigma^\tau\right)\left(\left(T^\theta\right)^{-1} \otimes (T^\tau)^{-1}\right)$$
$$= (\sigma^x \otimes (\sigma^x + \sigma^z))((T^1)^{-1} \otimes (T^3)^{-1})$$
$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$
$$= \frac{1}{2\sqrt{2}} \begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix} \begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$
$$= \frac{1}{2\sqrt{2}} \begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & -1 & 1 \\ 1 & 1 & 0 & 0 \\ -1 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2\sqrt{2}}(|0010\rangle - |0011\rangle + |0110\rangle + |0111\rangle + |1000\rangle - |1001\rangle + |1100\rangle + |1101\rangle)$$

68) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\sigma^x + \sigma^z)$, maka didapatkan nilai R untuk nilai $\theta = 1$ dan $\tau = 4$

$$R = \left(\sigma^\theta \otimes \sigma^\tau\right)\left(\left(T^\theta\right)^{-1} \otimes (T^\tau)^{-1}\right)$$
$$= (\sigma^x \otimes (\sigma^x + \sigma^z))((T^1)^{-1} \otimes (T^4)^{-1})$$

$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & -1 & 1 \\ 0 & 0 & 1 & 1 \\ -1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2\sqrt{2}}(-|0010\rangle + |0011\rangle + |0110\rangle + |0111\rangle - |1000\rangle + |1001\rangle + |1100\rangle + |1101\rangle)$$

69) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 1}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes ((\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})))((\boldsymbol{T^2})^{-1} \otimes (\boldsymbol{T^1})^{-1})$$

$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & -1 & -1 \\ 0 & 0 & -1 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2\sqrt{2}}(|0010\rangle + |0011\rangle + |0110\rangle - |0111\rangle - |1000\rangle - |1001\rangle - |1100\rangle + |1101\rangle)$$

70) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 2}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes (\boldsymbol{\sigma_x} + \boldsymbol{\sigma_z}))((\boldsymbol{T^2})^{-1} \otimes (\boldsymbol{T^2})^{-1})$$

$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & -1 & 1 \\ 0 & 0 & -1 & -1 \\ 1 & -1 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{1}{2\sqrt{2}}(|\boldsymbol{0010}\rangle + |\boldsymbol{0011}\rangle - |\boldsymbol{0110}\rangle + |\boldsymbol{0111}\rangle - |\boldsymbol{1000}\rangle - |\boldsymbol{1001}\rangle + |\boldsymbol{1100}\rangle - |\boldsymbol{1101}\rangle)$$

71) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes (\boldsymbol{\sigma_x} + \boldsymbol{\sigma_z}))((\boldsymbol{T^2})^{-1} \otimes (\boldsymbol{T^3})^{-1})$$

$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & -1 & -1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ -1 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{\mathbf{1}}{\mathbf{2\sqrt{2}}}(|\mathbf{0010}\rangle - |\mathbf{0011}\rangle + |\mathbf{0110}\rangle + |\mathbf{0111}\rangle - |\mathbf{1000}\rangle + |\mathbf{1001}\rangle - |\mathbf{1100}\rangle - |\mathbf{1101}\rangle)$$

72) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 2}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes (\boldsymbol{\sigma_x} + \boldsymbol{\sigma_z}))((\boldsymbol{T}^2)^{-1} \otimes (\boldsymbol{T^4})^{-1})$$

$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & 1 & -1 \\ 0 & 0 & -1 & -1 \\ -1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{\mathbf{1}}{\mathbf{2\sqrt{2}}}(-|\mathbf{0010}\rangle + |\mathbf{0011}\rangle + |\mathbf{0110}\rangle + |\mathbf{0111}\rangle + |\mathbf{1000}\rangle - |\mathbf{1001}\rangle - |\mathbf{1100}\rangle - |\mathbf{1101}\rangle)$$

73) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 3}$ dan $\boldsymbol{\tau = 1}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes (\boldsymbol{\sigma_x} + \boldsymbol{\sigma_z}))((\boldsymbol{T}^3)^{-1} \otimes (\boldsymbol{T^1})^{-1})$$

$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{1}{2\sqrt{2}} \begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix} \begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2\sqrt{2}} \begin{pmatrix} 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2\sqrt{2}}(|0000\rangle + |0001\rangle + |0100\rangle - |0101\rangle + |1010\rangle + |1011\rangle + |1110\rangle - |1111\rangle)$$

74) Untuk pengukuran Alice berupa σ^x dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\sigma^x + \sigma^z)$, maka didapatkan nilai R untuk nilai $\theta = 3$ dan $\tau = 2$

$$R = (\sigma^\theta \otimes \sigma^\tau)\left((T^\theta)^{-1} \otimes (T^\tau)^{-1}\right)$$

$$= (\sigma^x \otimes (\sigma_x + \sigma_z))((T^3)^{-1} \otimes (T^2)^{-1})$$

$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$

$$= \frac{1}{2\sqrt{2}} \begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix} \begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2\sqrt{2}} \begin{pmatrix} 1 & -1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & 1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\varphi\rangle_{A1,B1,B2,A2} = \frac{1}{2\sqrt{2}}(|0000\rangle + |0001\rangle - |0100\rangle + |0101\rangle + |1010\rangle + |1011\rangle - |1110\rangle + |1111\rangle)$$

75) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 3}$ dan $\boldsymbol{\tau = 3}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes (\boldsymbol{\sigma_x} + \boldsymbol{\sigma_z}))((\boldsymbol{T}^3)^{-1} \otimes (\boldsymbol{T}^3)^{-1})$$

$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 1 & 1 & 0 & 0 \\ -1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & -1 & 1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1,B1,B2,A2}} = \frac{1}{2\sqrt{2}}(|\mathbf{0000}\rangle - |\mathbf{0001}\rangle + |\mathbf{0100}\rangle + |\mathbf{0101}\rangle + |\mathbf{1010}\rangle - |\mathbf{1011}\rangle + |\mathbf{1110}\rangle + |\mathbf{1111}\rangle)$$

76) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 3}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes (\boldsymbol{\sigma_x} + \boldsymbol{\sigma_z}))((\boldsymbol{T}^3)^{-1} \otimes (\boldsymbol{T}^4)^{-1})$$

$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} -1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & -1 & 1 \\ 0 & 0 & 1 & 1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2\sqrt{2}}(-|0000\rangle + |0001\rangle + |0100\rangle + |0101\rangle - |1010\rangle + |1011\rangle + |1110\rangle + |1111\rangle)$$

77) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})$**,** maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 1}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes (\boldsymbol{\sigma_x} + \boldsymbol{\sigma_z}))((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^1})^{-1})$$

$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\right)$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} -1 & -1 & 0 & 0 \\ -1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2\sqrt{2}}(-|0000\rangle - |0001\rangle - |0100\rangle + |0101\rangle + |1010\rangle + |1011\rangle + |1110\rangle - |1111\rangle)$$

78) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 2}$

$$\boldsymbol{R} = (\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau})\left((\boldsymbol{T^\theta})^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes (\boldsymbol{\sigma_x} + \boldsymbol{\sigma_z}))((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^2})^{-1})$$

$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & -\mathbf{1} \\ \mathbf{1} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & -\mathbf{1} \\ -\mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}\sqrt{\mathbf{2}}}\begin{pmatrix} -\mathbf{1} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ -\mathbf{1} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & -\mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{1} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1},\boldsymbol{B1},\boldsymbol{B2},\boldsymbol{A2}} = \frac{\mathbf{1}}{\mathbf{2}\sqrt{\mathbf{2}}}(-|\mathbf{0000}\rangle - |\mathbf{0001}\rangle + |\mathbf{0100}\rangle - |\mathbf{0101}\rangle + |\mathbf{1010}\rangle + |\mathbf{1011}\rangle - |\mathbf{1110}\rangle + |\mathbf{1111}\rangle)$$

79) Untuk pengukuran Alice berupa $\boldsymbol{\sigma}^{\boldsymbol{x}}$ dan pengukuran Bob berupa $\frac{\sqrt{\mathbf{2}}}{\mathbf{2}}(\boldsymbol{\sigma}^{\boldsymbol{x}} + \boldsymbol{\sigma}^{\boldsymbol{z}})$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta} = \mathbf{4}$ dan $\boldsymbol{\tau} = \mathbf{3}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma}^{\boldsymbol{\theta}} \otimes \boldsymbol{\sigma}^{\boldsymbol{\tau}}\right)\left(\left(\boldsymbol{T}^{\boldsymbol{\theta}}\right)^{-\mathbf{1}} \otimes (\boldsymbol{T}^{\boldsymbol{\tau}})^{-\mathbf{1}}\right)$$

$$= (\boldsymbol{\sigma}^{\boldsymbol{x}} \otimes (\boldsymbol{\sigma}_{\boldsymbol{x}} + \boldsymbol{\sigma}_{\boldsymbol{z}}))((\boldsymbol{T}^{\mathbf{4}})^{-\mathbf{1}} \otimes (\boldsymbol{T}^{\mathbf{3}})^{-\mathbf{1}})$$

$$= \frac{\sqrt{\mathbf{2}}}{\mathbf{2}}\left(\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \begin{pmatrix} \mathbf{1} & \mathbf{1} \\ \mathbf{1} & -\mathbf{1} \end{pmatrix}\right)\left(\frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ -\mathbf{1} & \mathbf{0} \end{pmatrix} \otimes \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix}\right)$$

$$= \frac{\mathbf{1}}{\mathbf{2}\sqrt{\mathbf{2}}}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & -\mathbf{1} \\ \mathbf{1} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \\ -\mathbf{1} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{pmatrix}$$

$$= \frac{\mathbf{1}}{\mathbf{2}\sqrt{\mathbf{2}}}\begin{pmatrix} -\mathbf{1} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{1} & -\mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & -\mathbf{1} & \mathbf{1} \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{\boldsymbol{A1},\boldsymbol{B1},\boldsymbol{B2},\boldsymbol{A2}} = \frac{\mathbf{1}}{\mathbf{2}\sqrt{\mathbf{2}}}(-|\mathbf{0000}\rangle - |\mathbf{0001}\rangle - |\mathbf{0100}\rangle - |\mathbf{0101}\rangle + |\mathbf{1010}\rangle - |\mathbf{1011}\rangle + |\mathbf{1110}\rangle + |\mathbf{1111}\rangle)$$

80) Untuk pengukuran Alice berupa $\boldsymbol{\sigma^x}$ dan pengukuran Bob berupa $\frac{\sqrt{2}}{2}(\boldsymbol{\sigma^x} + \boldsymbol{\sigma^z})$, maka didapatkan nilai $\boldsymbol{R}$ untuk nilai $\boldsymbol{\theta = 4}$ dan $\boldsymbol{\tau = 4}$

$$\boldsymbol{R} = \left(\boldsymbol{\sigma^\theta} \otimes \boldsymbol{\sigma^\tau}\right)\left(\left(\boldsymbol{T^\theta}\right)^{-1} \otimes (\boldsymbol{T^\tau})^{-1}\right)$$

$$= (\boldsymbol{\sigma^x} \otimes (\boldsymbol{\sigma_x} + \boldsymbol{\sigma_z}))((\boldsymbol{T^4})^{-1} \otimes (\boldsymbol{T^4})^{-1})$$

$$= \frac{\sqrt{2}}{2}\left(\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \otimes \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \otimes \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}\right)$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{1}{2\sqrt{2}}\begin{pmatrix} 1 & -1 & 0 & 0 \\ -1 & -1 & 0 & 0 \\ 0 & 0 & -1 & 1 \\ 0 & 0 & 1 & 1 \end{pmatrix}$$

sehingga dari bentuk matriks parameter kanalnya didapatkan bentuk kanalnya adalah

$$|\boldsymbol{\varphi}\rangle_{A1,B1,B2,A2} = \frac{1}{2\sqrt{2}}(|\boldsymbol{0000}\rangle - |\boldsymbol{0001}\rangle - |\boldsymbol{0100}\rangle - |\boldsymbol{0101}\rangle - |\boldsymbol{1010}\rangle + |\boldsymbol{1011}\rangle + |\boldsymbol{1110}\rangle + |\boldsymbol{1111}\rangle)$$

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BIODATA PENULIS

Achmad Fatich al Qodri dilahirkan di Jombang pada tanggal 07 April 1991. Anak pertama dari tiga bersaudara pasangan bapak Fauzi dan Ibu Ida ini lahir dari keluarga yang cukup sederhana. Mulai mengecam pendidikan formal dari TK muslimat 7 di Jombang (1995-1997), MIN Darul Ulum Peterongan Jombang (1997-2003), MTS Plus Darul Ulum Jombang (2003-2006), dan MA Unggulan Darul Ulum Jombang (2006-2009). Prestasi yang diraihnya selama sekolah mampu mengantarkan sosok yang hidup di lingkungan religius dan sederhana ini memperoleh beasiswa prestasi sejak MTS sampai MA. Selama masa di MA, selain menjadi ketua grup riset di sekolah, penulis juga aktif mengikuti dan mencatatkan prestasinya di Olimpiade keterampilan alat peraga IPA pada acara Madrasah Sains Ekspo (MSE) tingkat Nasional di Yogyakarta. Setelah lulus dari MA, penulis melanjutkan pendidikan keahlian untuk Teknisi Komputer Jaringan di ISTIKOM Jombang selama satu tahun dan dilanjutkan dengan menempuh pendidikan di UIN Maulana Malik Ibrahim Malang pada jurusan Fisika dan bidang minat Fisika Teori. Setelah lulus S1 di tahun 2015, penulis mengabdi di MA Unggulan Darul Ulum sebagai Pengajar Fisika dan Ekstra Olimpiade Fisika. Karena haus akan ilmu, maka pada tahun 2016 penulis melanjutkan pendidikan S2 di Fisika Insitut Teknologi Sepuluh Nopember (ITS) Surabaya. Penulis yang tetap mengabdi di Madrasah tempatnya menuntut Ilmu serta melanjutkan S2 ini memaksa untuk tidak menetap di Surabaya, melainkan di Jombang. Saat S2 fisika di ITS ini penulis aktif di Laboratorium Fisika Teori dan Filsafat Alam (LaFTiFA) dan mengikuti kegiatan seminar *Conference on Theoretical Physics and Nonlinear Phenomena* (CTPNP) 2019 di UNM Malang sebagai peserta.