5.5

5.5

| Link | $\alpha_{i-1}$ | $a_{i-1}$ | $\theta_i$ | $d_i$ |
|---|---|---|---|---|
| 1 | 0 | 0 | $\theta_1^*$ | 0 |
| 2 | $-\pi/2$ | 0 | $\theta_2^*$ | 0 |
| 3 | 0 | $a_2$ | $\theta_3^*$ | $d_3$ |
| 4 | $-\pi/2$ | $a_3$ | $\theta_4^*$ | $d_4$ |
| 5 | $\pi/2$ | 0 | $\theta_5^*$ | 0 |
| 6 | $-\pi/2$ | 0 | $\theta_6^*$ | 0 |

$$ {}^0_1T = R_z(\theta_1) = \begin{bmatrix} c_1 & -s_1 & 0 & 0 \\ s_1 & c_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, $$

$$ {}^1_2T = R_x(-\pi/2)\, R_z(\theta_2) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c_2 & -s_2 & 0 & 0 \\ s_2 & c_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^1_2T = \begin{bmatrix} c_2 & -s_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -s_2 & -c_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^2_3T = D_x(a_2)\, R_z(\theta_3)\, D_z(d_3) = \begin{bmatrix} 1 & 0 & 0 & a_2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c_3 & -s_3 & 0 & 0 \\ s_3 & c_3 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^2_3T = \begin{bmatrix} c_3 & -s_3 & 0 & a_2 \\ s_3 & c_3 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

5.5 ~ ${}^{3}_{4}T = R_x(-\pi/2)\, D_x(a_3)\, R_z(\theta_4)\, D_z(d_4)$

$$ {}^{3}_{4}T = \begin{bmatrix} 1 & 0 & 0 & a_3 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c_4 & -s_4 & 0 & 0 \\ s_4 & c_4 & 0 & 0 \\ 0 & 0 & 1 & d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} c_4 & -s_4 & 0 & a_3 \\ 0 & 0 & 1 & d_4 \\ -s_4 & -c_4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{4}_{5}T = R_x(\pi/2) R_x(\theta_5) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c_5 & -s_5 & 0 & 0 \\ s_5 & c_5 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{4}_{5}T = \begin{bmatrix} c_5 & -s_5 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ s_5 & c_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{5}_{6}T = R_x(-\pi/2) R_z(\theta_6) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c_6 & -s_6 & 0 & 0 \\ s_6 & c_6 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{5}_{6}T = \begin{bmatrix} c_6 & -s_6 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -s_6 & -c_6 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$5.5\sim \quad {}^0\omega_0 = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \qquad {}^1\omega_1 = \begin{bmatrix} 0 \\ 0 \\ \dot\theta_1 \end{bmatrix},$$

$${}^2\omega_2 = {}^1_2R^T\,{}^1\omega_1 + \begin{bmatrix} 0 \\ 0 \\ \dot\theta_2 \end{bmatrix} = \begin{bmatrix} c_2 & 0 & -s_2 \\ -s_2 & 0 & -c_2 \\ 0 & 1 & 0 \end{bmatrix}\begin{bmatrix} 0 \\ 0 \\ \dot\theta_1 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot\theta_2 \end{bmatrix} = \begin{bmatrix} -s_2\dot\theta_1 \\ -c_2\dot\theta_1 \\ \dot\theta_2 \end{bmatrix},$$

$${}^3\omega_3 = {}^2_3R^T\,{}^2\omega_2 + \begin{bmatrix} 0 \\ 0 \\ \dot\theta_3 \end{bmatrix} = \begin{bmatrix} c_3 & s_3 & 0 \\ -s_3 & c_3 & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} -s_2\dot\theta_1 \\ -c_2\dot\theta_1 \\ \dot\theta_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot\theta_3 \end{bmatrix} = \begin{bmatrix} -s_2c_3\dot\theta_1 - c_2s_3\dot\theta_1 \\ s_2s_3\dot\theta_1 - c_2c_3\dot\theta_1 \\ \dot\theta_2+\dot\theta_3 \end{bmatrix}$$

$${}^3\omega_3 = \begin{bmatrix} -s_{23}\dot\theta_1 \\ -c_{23}\dot\theta_1 \\ \dot\theta_2+\dot\theta_3 \end{bmatrix}, \quad {}^4\omega_4 = {}^3_4R^T\,{}^3\omega_3 + \begin{bmatrix} 0 \\ 0 \\ \dot\theta_4 \end{bmatrix} = \begin{bmatrix} c_4 & 0 & -s_4 \\ -s_4 & 0 & -c_4 \\ 0 & 1 & 0 \end{bmatrix}\begin{bmatrix} -s_{23}\dot\theta_1 \\ -c_{23}\dot\theta_1 \\ \dot\theta_2+\dot\theta_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot\theta_4 \end{bmatrix}$$

$${}^4\omega_4 = \begin{bmatrix} -s_{23}c_4\dot\theta_1 - s_4\dot\theta_2 - s_4\dot\theta_3 \\ s_{23}s_4\dot\theta_1 - c_4\dot\theta_2 - c_4\dot\theta_3 \\ -c_{23}\dot\theta_1 + \dot\theta_4 \end{bmatrix}, \quad {}^5\omega_5 = {}^4_5R^T\,{}^4\omega_4 + \begin{bmatrix} 0 \\ 0 \\ \dot\theta_5 \end{bmatrix}$$

$${}^5\omega_5 = \begin{bmatrix} c_5 & 0 & s_5 \\ -s_5 & 0 & c_5 \\ 0 & -1 & 0 \end{bmatrix}\begin{bmatrix} -s_{23}c_4\dot\theta_1 - s_4\dot\theta_2 - s_4\dot\theta_3 \\ s_{23}s_4\dot\theta_1 - c_4\dot\theta_2 - c_4\dot\theta_3 \\ -c_{23}\dot\theta_1 + \dot\theta_4 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot\theta_5 \end{bmatrix}$$

$${}^5\omega_5 = \begin{bmatrix} -s_{23}c_4c_5\dot\theta_1 - c_{23}s_5\dot\theta_1 - s_4c_5\dot\theta_2 - s_4c_5\dot\theta_3 + s_5\dot\theta_4 \\ s_{23}c_4s_5\dot\theta_1 - c_{23}c_5\dot\theta_1 + s_4s_5\dot\theta_2 + s_4s_5\dot\theta_3 + c_5\dot\theta_4 \\ -s_{23}s_4\dot\theta_1 + c_4\dot\theta_2 + c_4\dot\theta_3 + \dot\theta_5 \end{bmatrix},$$

$${}^6\omega_6 = {}^5_6R^T\,{}^5\omega_5 + \begin{bmatrix} 0 \\ 0 \\ \dot\theta_6 \end{bmatrix} = \begin{bmatrix} c_6 & 0 & -s_6 \\ -s_6 & 0 & -c_6 \\ 0 & 1 & 0 \end{bmatrix}{}^5\omega_5 + \begin{bmatrix} 0 \\ 0 \\ \dot\theta_6 \end{bmatrix}$$

5.5 v Let ${}^6\omega_6 = \begin{bmatrix} {}^6\omega_x \\ {}^6\omega_y \\ {}^6\omega_z \end{bmatrix}$;

${}^6\omega_x = (-s_{23}c_4c_5c_6 - c_{23}s_5c_6 + s_{23}s_4s_6)\dot{\theta}_1 + (-s_4c_5c_6 - c_4s_6)\dot{\theta}_2 +$
$(-s_4c_5c_6 - c_4s_6)\dot{\theta}_3 + s_5c_6\dot{\theta}_4 - s_6\dot{\theta}_5$

${}^6\omega_y = (s_{23}c_4c_5s_6 + c_{23}s_5s_6 + s_{23}s_4c_6)\dot{\theta}_1 + (s_4c_5s_6 - c_4c_6)\dot{\theta}_2 +$
$(s_4c_5s_6 - c_4c_6)\dot{\theta}_3 - s_5s_6\dot{\theta}_4 - c_6\dot{\theta}_5$

${}^6\omega_z = (s_{23}c_4s_5 - c_{23}c_5)\dot{\theta}_1 + s_4s_5\dot{\theta}_2 + s_4s_5\dot{\theta}_3 + c_5\dot{\theta}_4 + \dot{\theta}_6$

${}^0V_0 = {}^1V_1 = {}^2V_2 = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$ (The base point doesn't move),

${}^3V_3 = {}^2_3R^T\left({}^2V_2 + {}^2\omega_2 \times \begin{bmatrix} a_2 \\ 0 \\ d_3 \end{bmatrix}\right)$ ${}^2\omega_2 \times \begin{bmatrix} a_2 \\ 0 \\ d_3 \end{bmatrix} = \begin{bmatrix} 0 & -\dot{\theta}_2 & -c_2\dot{\theta}_1 \\ \dot{\theta}_2 & 0 & s_2\dot{\theta}_1 \\ c_2\dot{\theta}_1 & -s_2\dot{\theta}_1 & 0 \end{bmatrix}\begin{bmatrix} a_2 \\ 0 \\ d_3 \end{bmatrix}$

${}^3V_3 = \begin{bmatrix} c_3 & s_3 & 0 \\ -s_3 & c_3 & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} -d_3c_2\dot{\theta}_1 \\ a_2\dot{\theta}_2 + d_3s_2\dot{\theta}_1 \\ a_2c_2\dot{\theta}_1 \end{bmatrix} = \begin{bmatrix} (-d_3c_2c_3 + d_3s_2s_3)\dot{\theta}_1 + a_2s_3\dot{\theta}_2 \\ (d_3c_2s_3 + d_3s_2c_3)\dot{\theta}_1 + a_2c_3\dot{\theta}_2 \\ a_2c_2\dot{\theta}_1 \end{bmatrix}$,

${}^4V_4 = {}^3_4R^T\left({}^3V_3 + {}^3\omega_3 \times \begin{bmatrix} a_3 \\ d_4 \\ 0 \end{bmatrix}\right)$ ${}^3\omega_3 \times \begin{bmatrix} a_3 \\ d_4 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 & -\dot{\theta}_2-\dot{\theta}_3 & -c_{23}\dot{\theta}_1 \\ \dot{\theta}_2+\dot{\theta}_3 & 0 & s_{23}\dot{\theta}_1 \\ c_{23}\dot{\theta}_1 & -s_{23}\dot{\theta}_1 & 0 \end{bmatrix}\begin{bmatrix} a_3 \\ d_4 \\ 0 \end{bmatrix}$

${}^4V_4 = \begin{bmatrix} c_4 & 0 & -s_4 \\ -s_4 & 0 & -c_4 \\ 0 & 1 & 0 \end{bmatrix}\left(\begin{bmatrix} (d_3s_2s_3 - d_3c_2c_3)\dot{\theta}_1 + a_2s_3\dot{\theta}_2 \\ (d_3c_2s_3 + d_3s_2c_3)\dot{\theta}_1 + a_2c_3\dot{\theta}_2 \\ a_2c_2\dot{\theta}_1 \end{bmatrix} + \begin{bmatrix} -d_4\dot{\theta}_2 - d_4\dot{\theta}_3 \\ a_3\dot{\theta}_2 + a_3\dot{\theta}_3 \\ a_3c_{23}\dot{\theta}_1 - d_4s_{23}\dot{\theta}_1 \end{bmatrix}\right)$

5.5N

$$
{}^4V_4 = \begin{bmatrix} c_4 & 0 & -s_4 \\ -s_4 & 0 & -c_4 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} (d_3 s_2 s_3 - d_3 c_2 c_3)\dot{\theta}_1 + (a_2 s_3 - d_4)\dot{\theta}_2 - d_4\dot{\theta}_3 \\ (d_3 c_2 s_3 + d_3 s_2 c_3)\dot{\theta}_1 + (a_2 c_3 + a_3)\dot{\theta}_2 + a_3\dot{\theta}_3 \\ (a_2 c_2 + a_3 c_{23} - d_4 s_{23})\dot{\theta}_1 \end{bmatrix}
$$

$$
{}^4V_4 = \begin{bmatrix} (d_3 s_2 s_3 c_4 - d_3 c_2 c_3 c_4 - a_2 c_2 s_4 - a_3 c_{23} s_4 + d_4 s_{23} s_4)\dot{\theta}_1 + (a_2 s_3 c_4 - d_4 c_4)\dot{\theta}_2 - d_4 c_4\dot{\theta}_3 \\ (-d_3 s_2 s_3 s_4 + d_3 c_2 c_3 s_4 - a_2 c_2 c_4 - a_3 c_{23} c_4 + d_4 s_{23} c_4)\dot{\theta}_1 + (-a_2 s_3 s_4 + d_4 s_4)\dot{\theta}_2 + d_4 s_4\dot{\theta}_3 \\ (d_3 c_2 s_3 + d_3 s_2 c_3)\dot{\theta}_1 + (a_2 c_3 + a_3)\dot{\theta}_2 + a_3\dot{\theta}_3 \end{bmatrix}
$$

$${}^5V_5 = {}^4_5R^T\,{}^4V_4 \quad \text{and} \quad {}^6V_6 = {}^5_6R^T\,{}^5V_5 \Rightarrow {}^6V_6 = {}^5_6R^T\,{}^4_5R^T\,{}^4V_4$$

$$
{}^6V_6 = \begin{bmatrix} c_6 & 0 & -s_6 \\ -s_6 & 0 & -c_6 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} c_5 & 0 & s_5 \\ -s_5 & 0 & c_5 \\ 0 & -1 & 0 \end{bmatrix} {}^4V_4 = \begin{bmatrix} c_5 c_6 & s_6 & s_5 c_6 \\ -c_5 s_6 & c_6 & -s_5 s_6 \\ -s_5 & 0 & c_5 \end{bmatrix} {}^4V_4 = \begin{bmatrix} {}^6V_x \\ {}^6V_y \\ {}^6V_z \end{bmatrix}
$$

$$
\begin{aligned}
{}^6V_x = {} & (d_3 s_2 s_3 c_4 c_5 c_6 - d_3 c_2 c_3 c_4 c_5 c_6 - a_2 c_2 s_4 c_5 c_6 - a_3 c_{23} s_4 c_5 c_6 + d_4 s_{23} s_4 c_5 c_6 \\
& - d_3 s_2 s_3 s_4 s_6 + d_3 c_2 c_3 s_4 s_6 - a_2 c_2 c_4 s_6 - a_3 c_{23} c_4 s_6 + d_4 s_{23} c_4 s_6 \\
& + d_3 c_2 s_3 s_5 c_6 + d_3 s_2 c_3 s_5 c_6)\underline{\dot{\theta}_1} + (a_2 s_3 c_4 c_5 c_6 - d_4 c_4 c_5 c_6 - a_2 s_3 s_4 s_6 \\
& + d_4 s_4 s_6 + a_2 c_3 s_5 c_6 + a_3 s_5 c_6)\underline{\dot{\theta}_2} + (-d_4 c_4 c_5 c_6 + d_4 s_4 s_6 + a_3 s_5 c_6)\underline{\dot{\theta}_3}
\end{aligned}
$$

$$
\begin{aligned}
{}^6V_y = {} & (-d_3 s_2 s_3 c_5 s_6 + d_3 c_2 c_3 c_4 c_5 s_6 + a_2 c_2 s_4 c_5 s_6 + a_3 c_{23} s_4 c_5 s_6 - d_4 s_{23} s_4 c_5 s_6 \\
& - d_3 s_2 s_3 s_4 c_6 + d_3 c_2 c_3 s_4 c_6 - a_2 c_2 c_4 c_6 - a_3 c_{23} c_4 c_6 + d_4 s_{23} c_4 c_6 \\
& - d_3 c_2 s_3 s_5 s_6 - d_3 s_2 c_3 s_5 s_6)\underline{\dot{\theta}_1} + (-a_2 s_3 c_4 c_5 s_6 + d_4 c_4 c_5 s_6 - a_2 s_3 s_4 c_6 \\
& + d_4 s_4 c_6 - a_2 c_3 s_5 s_6 - a_3 s_5 s_6)\underline{\dot{\theta}_2} + (d_4 c_4 c_5 s_6 + d_4 s_4 c_6 - a_3 s_5 s_6)\underline{\dot{\theta}_3}
\end{aligned}
$$

$$
\begin{aligned}
{}^6V_z = {} & (-d_3 s_2 s_3 s_5 + d_3 c_2 c_3 c_4 s_5 + a_2 c_2 s_4 s_5 + a_3 c_{23} s_4 s_5 - d_4 s_{23} s_4 s_5 \\
& + d_3 c_2 s_3 c_5 + d_3 s_2 c_3 c_5)\underline{\dot{\theta}_1} + (-a_2 s_3 c_4 s_5 + d_4 c_4 s_5 + a_2 c_3 c_5 + a_3 c_5)\underline{\dot{\theta}_2} \\
& + (d_4 c_4 s_5 + a_3 c_5)\underline{\dot{\theta}_3}
\end{aligned}
$$

in which $\begin{bmatrix} {}^6v \\ {}^6w \end{bmatrix} = {}^6J(\theta)\,\dot{\theta}$

5.5 ~

Let $\begin{bmatrix} {}^6v_x \\ {}^6v_y \\ {}^6v_z \\ {}^6\omega_x \\ {}^6\omega_y \\ {}^6\omega_z \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} & r_{16} \\ r_{21} & r_{22} & r_{23} & r_{24} & r_{25} & r_{26} \\ r_{31} & r_{32} & r_{33} & r_{34} & r_{35} & r_{36} \\ r_{41} & r_{42} & r_{43} & r_{44} & r_{45} & r_{46} \\ r_{51} & r_{52} & r_{53} & r_{54} & r_{55} & r_{56} \\ r_{61} & r_{62} & r_{63} & r_{64} & r_{65} & r_{66} \end{bmatrix} \begin{bmatrix} \dot\theta_1 \\ \dot\theta_2 \\ \dot\theta_3 \\ \dot\theta_4 \\ \dot\theta_5 \\ \dot\theta_6 \end{bmatrix}$

$r_{11} = d_3 s_2 s_3 c_4 c_5 c_6 - d_3 c_2 c_3 c_4 c_5 c_6 - a_2 c_2 s_4 c_5 c_6 - a_3 c_{23} s_4 c_5 c_6$
$+ d_4 s_{23} s_4 c_5 c_6 - d_3 s_2 s_3 s_4 s_6 + d_3 c_2 c_3 s_4 s_6 - a_2 c_2 c_4 s_6 - a_3 c_{23} c_4 s_6$
$+ d_4 s_{23} c_4 s_6 + d_3 c_2 s_3 s_5 c_6 + d_3 s_2 c_3 s_5 c_6$,

$r_{12} = a_2 s_3 c_4 c_5 c_6 - d_4 c_4 c_5 c_6 - a_2 s_3 s_4 s_6 + d_4 s_4 s_6 + a_2 c_3 s_5 s_6 + a_3 s_5 c_6$,

$r_{13} = -d_4 c_4 c_5 c_6 + d_4 s_4 s_6 + a_3 s_5 c_6$, $r_{14} = r_{15} = r_{16} = 0$,

$r_{21} = -d_3 s_2 s_3 c_5 s_6 + d_3 c_2 c_3 c_4 c_5 s_6 + a_2 c_2 s_4 c_5 s_6 + a_3 c_{23} s_4 c_5 s_6$
$- d_4 s_{23} s_4 c_5 s_6 - d_3 s_2 s_3 s_4 c_6 + d_3 c_2 c_3 s_4 c_6 - a_2 c_2 c_4 c_6 - a_3 c_{23} c_4 c_6$
$+ d_4 s_{23} c_4 c_6 - d_3 c_2 s_3 s_5 s_6 - d_3 s_2 c_3 s_5 s_6$,

$r_{22} = -a_2 s_3 c_4 c_5 s_6 + d_4 c_4 c_5 s_6 - a_2 s_3 s_4 c_6 + d_4 s_4 c_6 - a_2 c_3 s_5 s_6 - a_3 s_5 s_6$,

$r_{23} = d_4 c_4 c_5 s_6 + d_4 s_4 c_6 - a_3 s_5 s_6$, $r_{24} = r_{25} = r_{26} = 0$,

$r_{31} = -d_3 s_2 s_3 s_5 + d_3 c_2 c_3 c_4 s_5 + a_2 c_2 s_4 s_5 + a_3 c_{23} s_4 s_5 - d_4 s_{23} s_4 s_5$
$+ d_3 c_2 s_3 c_5 + d_3 s_2 c_3 c_5$,

$r_{32} = -a_2 s_3 c_4 s_5 + d_4 c_4 s_5 + a_2 c_3 c_5 + a_3 c_5$,

$r_{33} = d_4 c_4 s_5 + a_3 c_5$, $r_{34} = r_{35} = r_{36} = 0$,

$r_{41} = -s_{23} c_4 c_5 c_6 - c_{23} s_5 c_6 + s_{23} s_4 s_6$, $r_{42} = -s_4 c_5 c_6 - c_4 s_6$,

$r_{43} = -s_4 c_5 c_6 - c_4 s_6$, $r_{44} = s_5 c_6$, $r_{45} = -s_6$, $r_{46} = 0$,

$r_{51} = s_{23} c_4 c_5 s_6 + c_{23} s_5 s_6 + s_{23} s_4 c_6$, $r_{52} = s_4 c_5 s_6 - c_4 c_6$,

$r_{53} = s_4 c_5 s_6 - c_4 c_6$, $r_{54} = -s_5 s_6$, $r_{55} = -c_6$, $r_{56} = 0$,

$r_{61} = s_{23} c_4 s_5 - c_{23} c_5$, $r_{62} = s_4 s_5$, $r_{63} = s_4 s_5$, $r_{64} = c_5$,

$r_{65} = 0$, $r_{66} = 1$