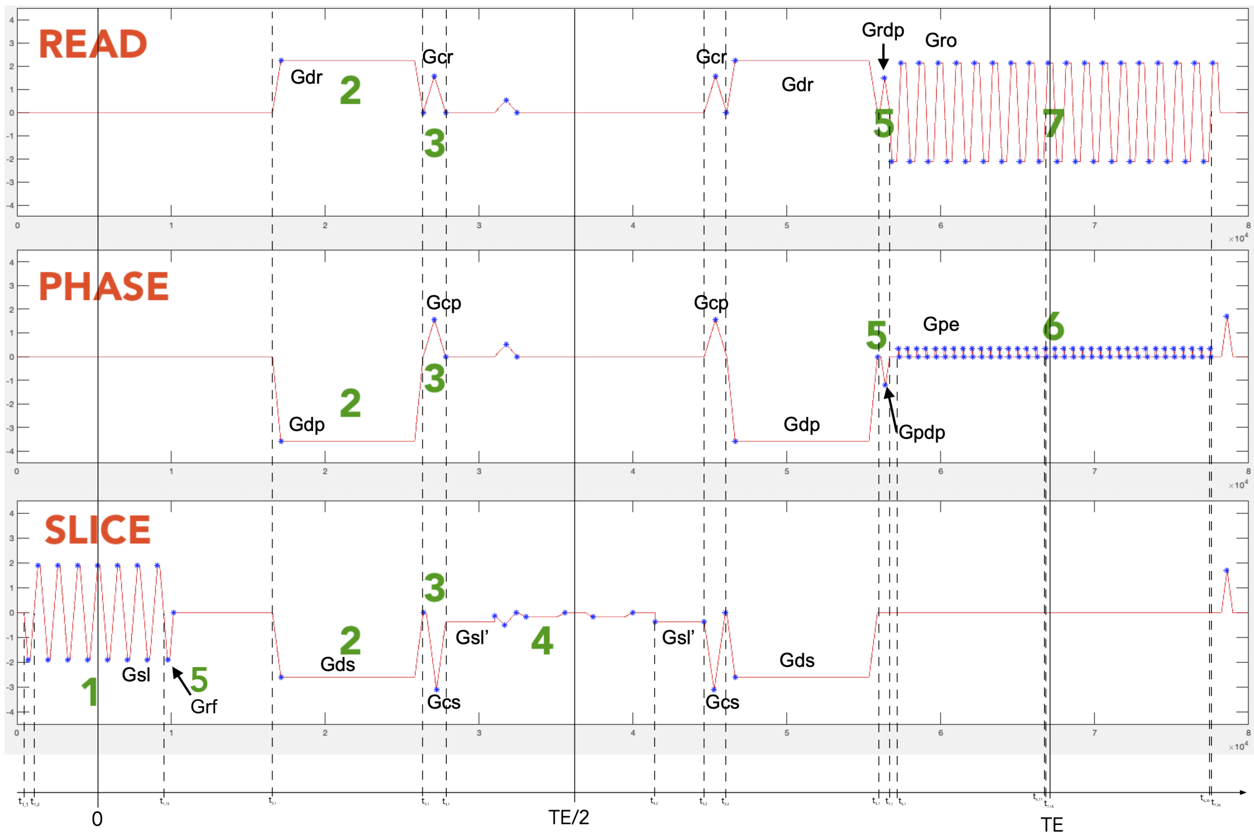
1 Pulse sequence



2 General analytic form

$$
\begin{aligned}
b_{ij} = \gamma^2 \Big[& G_{1i}G_{1j}\tau_{11} + (G_{1i}G_{2j} + G_{2i}G_{1j})\tau_{12} + (G_{1i}G_{3j} + G_{3i}G_{1j})\tau_{13} + \\
& + (G_{1i}G_{4j} + G_{4i}G_{1j})\tau_{14} + (G_{1i}G_{5j} + G_{5i}G_{1j})\tau_{15} + (G_{1i}G_{6mj} + G_{6mi}G_{1j})\tau_{16m} + \\
& + (G_{1i}G_{71j} + G_{71i}G_{1j})\tau_{171} + G_{2i}G_{2j}\tau_{22} + (G_{2i}G_{3j} + G_{3i}G_{2j})\tau_{23} + \\
& + (G_{2i}G_{4j} + G_{4i}G_{2j})\tau_{24} + (G_{2i}G_{5j} + G_{5i}G_{2j})\tau_{25} + (G_{2i}G_{6mj} + G_{6mi}G_{2j})\tau_{26m} + \\
& + (G_{2i}G_{71j} + G_{71i}G_{2j})\tau_{271} + G_{3i}G_{3j}\tau_{33} + (G_{3i}G_{4j} + G_{4i}G_{3j})\tau_{34} + \\
& + (G_{3i}G_{5j} + G_{5i}G_{3j})\tau_{35} + (G_{3i}G_{6mj} + G_{6mi}G_{3j})\tau_{36m} + (G_{3i}G_{71j} + G_{71i}G_{3j})\tau_{371} + \\
& + G_{4i}G_{4j}\tau_{44} + (G_{4i}G_{5j} + G_{5i}G_{4j})\tau_{45} + (G_{4i}G_{6mj} + G_{6mi}G_{4j})\tau_{46m} + \\
& + (G_{4i}G_{71j} + G_{71i}G_{4j})\tau_{471} + G_{5i}G_{5j}\tau_{55} + (G_{5i}G_{6mj} + G_{6mi}G_{5j})\tau_{56m} + (G_{5i}G_{71j} + G_{71i}G_{5j})\tau_{571} \\
& + G_{6mi}G_{6mj}\tau_{6m6m} + (G_{6i}G_{71j} + G_{71i}G_{6j})\tau_{671} + G_{71i}G_{71j}\tau_{7171} + \\
& + (G_{7mi}G_{7(m+1)j} + G_{7(m+1)i}G_{7mj})\tau_{7m7(m+1)} \Big]
\end{aligned}
\tag{1}
$$

3 Diagonal terms

For the read direction we have: $G_1 = 0$; $G_2 = G_{dr}$; $G_3 = G_{cr}$; $G_4 = 0$; $G_5 = G_{rdp}$; $G_6 = 0$; $G_7 = G_{ro}$ which gives the following for the diagonal readout term

$$b_{rr} = \gamma^2 \Big(G_{dr}^2 \tau_{22} + 2G_{dr}G_{cr}\tau_{23} + 2G_{dr}G_{rdp}\tau_{25rp} + 2G_{dr}G_{ro}\tau_{271} + G_{cr}^2\tau_{33} + 2G_{cr}G_{rdp}\tau_{35rp} + \\ + 2G_{cr}G_{ro}\tau_{371} + G_{rdp}^2\tau_{55rp} + 2G_{rdp}G_{ro}\tau_{5rp71} + G_{ro}^2(\tau_{7171} + \tau_{7m7(m+1)}) \Big) \tag{2}$$

taking into account refocused gradient pairs we get:

$$b_{rr} = \gamma^2 \Big(G_{dr}^2 \tau_{22} + 2G_{dr}G_{cr}\tau_{23} + G_{cr}^2\tau_{33} + G_{rdp}^2\tau_{55rp} + 2G_{rdp}G_{ro}\tau_{5rp71} + G_{ro}^2(\tau_{7171} + \tau_{7m7(m+1)}) \Big) \tag{3}$$

For the phase direction we have: $G_1 = 0$; $G_2 = G_{dp}$; $G_3 = G_{cp}$; $G_4 = 0$; $G_5 = G_{pdp}$; $G_6 = G_{pe}$; $G_7 = 0$ which gives the following for the diagonal phase-encoding

$$b_{pp} = \gamma^2 (G_{dp}^2 \tau_{22} + 2G_{dp}G_{cp}\tau_{23} + 2G_{dp}G_{pdp}\tau_{25rp} + 2G_{dp}G_{pe}\tau_{26m} + G_{cp}^2\tau_{33} + 2G_{cp}G_{pdp}\tau_{35rp} \\ + G_{cp}G_{pe}\tau_{36m} + G_{pdp}^2\tau_{55rp} + 2G_{pdp}G_{pe}\tau_{5rp6m} + G_{pe}^2\tau_{6m6m}) \tag{4}$$

taking into account refocused gradient pairs we get:

$$b_{pp} = \gamma^2 (G_{dp}^2 \tau_{22} + 2G_{dp}G_{cp}\tau_{23} + G_{cp}^2\tau_{33} + G_{pdp}^2\tau_{55rp} + 2G_{pdp}G_{pe}\tau_{5rp6m} + G_{pe}^2\tau_{6m6m}) \tag{5}$$

For the slice direction we have: $G_1 = G_{sl}$; $G_2 = G_{ds}$; $G_3 = G_{cs}$; $G_4 = G'_{sl}$; $G_5 = G_{rf}$; $G_6 = 0$; $G_7 = 0$ which gives the following for the diagonal slice-select:

$$b_{ss} = \gamma^2 \bigg(\frac{14}{3} G_{sl}^2 \tau_{11} + G_{sl}G_{ds}\tau_{12} + G_{sl}G_{cs}\tau_{13} + G_{sl}G'_{sl}\tau_{14} + G_{sl}G_{rf}\tau_{15s} + G_{ds}^2\tau_{22} + 2G_{ds}G_{cs}\tau_{23} + \\ + G_{ds}G'_{sl}\tau_{24} + G_{ds}G_{rf}\tau_{25s} + G_{cs}^2\tau_{33} + G_{cs}G'_{sl}\tau_{34} + 2G_{cs}G_{rf}\tau_{35} + G'^2_{sl}\tau_{44} + G'_{sl}G_{rf}\tau_{45s} + \\ + G_{rf}^2\tau_{55s} \bigg) \tag{6}$$

with refocused gradient pairs one arrives to:

$$b_{ss} = \gamma^2 \Big(\frac{14}{3} G_{sl}^2 \tau_{11} + G_{ds}^2\tau_{22} + 2G_{ds}G_{cs}\tau_{23} + G_{ds}G'_{sl}\tau_{24} + G_{ds}G_{rf}\tau_{25s} + G_{cs}^2\tau_{33} + G_{cs}G'_{sl}\tau_{34} + \\ + 2G_{cs}G_{rf}\tau_{35s} + \frac{1}{4}G'^2_{sl}\tau_{44} + G'_{sl}G_{rf}\tau_{45s} + \frac{1}{4}G_{rf}^2\tau_{55s} \Big) \tag{7}$$

4 Off-diagonal terms

Summarizing all gradients together in one place:

$G_{1r} = 0$	$G_{1p} = 0$	$G_{1s} = G_{sl}$
$G_{2r} = G_{dr}$	$G_{2p} = G_{dp}$	$G_{2s} = G_{ds}$
$G_{3r} = G_{cr}$	$G_{3p} = G_{cp}$	$G_{3s} = G_{cs}$
$G_{4r} = 0$	$G_{4p} = 0$	$G_{4s} = G'_{sl}$
$G_{5r} = G_{rdp}$	$G_{5p} = G_{pdp}$	$G_{5s} = G_{rf}$
$G_{6r} = 0$	$G_{6p} = G_{pe}$	$G_{6s} = 0$
$G_{7r} = G_{ro}$	$G_{7p} = 0$	$G_{7s} = 0$

Then starting from the read-out/phase term plugging the gradients G_r and G_p into equation Eq. 1:

$$b_{rp} = b_{pr} = \gamma^2 \Big(G_{dr}G_{dp}\tau_{22} + (G_{dr}G_{cp} + G_{cr}G_{dp})\tau_{23} + (G_{dr}G_{pdp} + G_{rdp}G_{dp})\tau_{25rp} + G_{dr}G_{pe}\tau_{26m} + \\ + G_{ro}G_{dp}\tau_{271} + G_{cr}G_{cp}\tau_{33} + (G_{cr}G_{pdp} + G_{rdp}G_{cp})\tau_{35rp} + G_{cr}G_{pe}\tau_{36m} + G_{ro}G_{cp}\tau_{371} + \\ + G_{rdp}G_{pdp}\tau_{55rp} + G_{rdp}G_{pe}\tau_{5rp6m} + G_{ro}G_{pdp}\tau_{5rp71} + G_{pe}G_{ro}\tau_{6m71} \Big) \tag{8}$$

taking into account refocused gradient pairs we get:

$$
\begin{aligned}
b_{rp} = b_{pr} = \gamma^2 \Big(& G_{dr} G_{dp} \tau_{22} + (G_{dr} G_{cp} + G_{cr} G_{dp}) \tau_{23} + G_{cr} G_{cp} \tau_{33} + G_{rdp} G_{pdp} \tau_{55rp} + G_{rdp} G_{pe} \tau_{5rp6m} + \\
& + G_{ro} G_{pdp} \tau_{5rp71} + G_{pe} G_{ro} \tau_{6m71} \Big)
\end{aligned} \tag{9}
$$

the read-out/slice select term gives:

$$
\begin{aligned}
b_{rs} = b_{sr} = \gamma^2 \Big(& G_{dr} G_{sl} \tau_{12} + G_{cr} G_{sl} \tau_{13} + G_{rdp} G_{sl} \tau_{15s} + G_{ro} G_{sl} \tau_{171} + G_{dr} G_{ds} \tau_{22} + \\
& + (G_{dr} G_{cs} + G_{cr} G_{ds}) \tau_{23} + \frac{1}{2} G_{dr} G'_{sl} \tau_{24} + (\frac{1}{2} G_{dr} G_{rf} + G_{rdp} G_{ds}) \tau_{25s} + G_{ds} G_{ro} \tau_{271} + \\
& + G_{cr} G_{cs} \tau_{33} + \frac{1}{2} G_{cr} G'_{sl} \tau_{34} + (G_{cr} G_{rf} + \frac{1}{2} G_{rdp} G_{cs}) \tau_{35s} + G_{rdp} G'_{sl} \tau_{45s} + \\
& + G_{ro} G'_{sl} \tau_{471} + \frac{1}{2} G_{rdp} G_{rf} \tau_{55rp} + + \frac{1}{2} G_{ro} G_{rf} \tau_{5s71} \Big)
\end{aligned} \tag{10}
$$

again by taking into account refocused gradient pairs the expression simplifies to:

$$
\begin{aligned}
b_{rs} = b_{sr} = \gamma^2 \Big(& (G_{dr} G_{cs} + G_{cr} G_{ds}) \tau_{23} + \frac{1}{2} G_{dr} G'_{sl} \tau_{24} + \frac{1}{2} (G_{dr} G_{rf}) \tau_{25s} + G_{cr} G_{cs} \tau_{33} \\
& + \frac{1}{2} G_{cr} G'_{sl} \tau_{34} + \frac{1}{2} G_{cr} G_{rf} \tau_{35s} + \frac{1}{2} G_{rdp} G_{rf} \tau_{55rp} + \frac{1}{2} G_{ro} G_{rf} \tau_{5s71} \Big)
\end{aligned} \tag{11}
$$

and the last term the phase/slice select:

$$
\begin{aligned}
b_{sp} = b_{ps} = \gamma^2 \Big(& G_{sl} G_{dp} \tau_{12} + G_{sl} G_{cp} \tau_{13} + G_{sl} G_{pdp} \tau_{15rp} + G_{sl} G_{pe} \tau_{16m} + G_{dp} G_{ds} \tau_{22} + \\
& + (G_{ds} G_{cp} + G_{ds} G_{cp}) \tau_{23} + \frac{1}{2} G_{dp} G'_{sl} \tau_{24} + (\frac{1}{2} G_{dp} G_{rf} \tau_{25s} + G_{ds} G_{pdp} \tau_{25rp}) + G_{pe} G_{ds} \tau_{26m} + \\
& + G_{cp} G_{cs} \tau_{33} + \frac{1}{2} G_{cp} G'_{sl} \tau_{34} + (\frac{1}{2} G_{cp} G_{rf} + G_{pdp} G_{cs}) \tau_{35s} + G_{pe} G_{cs} \tau_{36m} + G_{pdp} G'_{sl} \tau_{45s} + \\
& + G_{pe} G'_{sl} \tau_{46m} + \frac{1}{2} G_{pdp} G_{rf} \tau_{55rp} + \frac{1}{2} G_{pe} G_{rf} \tau_{5s6m} \Big)
\end{aligned} \tag{12}
$$

with refocused gradient pairs gives final expression:

$$
\begin{aligned}
b_{sp} = b_{ps} = \gamma^2 \Big(& G_{dp} G_{ds} \tau_{22} + (G_{ds} G_{cp} + G_{ds} G_{cp}) \tau_{23} + \frac{1}{2} G_{dp} G'_{sl} \tau_{24} + \frac{1}{2} G_{dp} G_{rf} \tau_{25s} + G_{cp} G_{cs} \tau_{33} + \\
& + \frac{1}{2} G_{cp} G'_{sl} \tau_{34} + \frac{1}{2} G_{cp} G_{rf} \tau_{35s} + \frac{1}{2} G_{pdp} G_{rf} \tau_{55rp} + \frac{1}{2} G_{pe} G_{rf} \tau_{5s6m} \Big)
\end{aligned} \tag{13}
$$

5 Timing multipliers

$$\tau_{11} = \delta_1^3 \tag{14}$$

$$\tau_{22} = \delta_2^2\left(\Delta_2 - \frac{1}{3}\delta_2\right) + \frac{1}{30}\epsilon_2^3 - \frac{1}{6}\delta_2\epsilon_2^2, \qquad \Delta_2 = t_{22} - t_{21} \tag{15}$$

$$\tau_{23} = \delta_2\delta_3\Delta_3, \qquad \Delta_3 = t_{32} - t_{31} \tag{16}$$

$$\tau_{24} = \delta_2\delta_4\Delta_4, \qquad \Delta_4 = t_{42} - t_{41} \tag{17}$$

$$\tau_{25rp} = \frac{1}{2}\delta_{5rp}\delta_2\Delta_2, \qquad \Delta_2 = t_{22} - t_{21} \tag{18}$$

$$\tau_{25s} = \frac{1}{2}\delta_{5s}\delta_2\Delta_2, \qquad \Delta_2 = t_{22} - t_{21} \tag{19}$$

$$\tau_{33} = \delta_3^2\left(\Delta_3 - \frac{1}{3}\delta_3\right) + \frac{1}{30}\epsilon_3^3 - \frac{1}{6}\delta_3\epsilon_3^2, \qquad \Delta_3 = t_{32} - t_{31} \tag{20}$$

$$\tau_{34} = \delta_3\delta_4\Delta_4, \qquad \Delta_4 = t_{42} - t_{41} \tag{21}$$

$$\tau_{35rp} = \frac{1}{2}\delta_{5rp}\delta_3\Delta_3, \qquad \Delta_3 = t_{32} - t_{31} \tag{22}$$

$$\tau_{35s} = \frac{1}{2}\delta_{5s}\delta_3\Delta_3, \qquad \Delta_3 = t_{32} - t_{31} \tag{23}$$

$$\tau_{44} = \delta_4^2\left(\Delta_4 - \frac{1}{3}\delta_4\right) + \frac{1}{30}\epsilon_4^3 - \frac{1}{6}\delta_4\epsilon_4^2, \qquad \Delta_4 = t_{42} - t_{41} \tag{24}$$

$$\tau_{45rp} = \frac{1}{2}\delta_{5rp}\delta_4\Delta_4, \qquad \Delta_4 = t_{42} - t_{41} \tag{25}$$

$$\tau_{45s} = \frac{1}{2}\delta_{5s}\delta_4\Delta_4, \qquad \Delta_4 = t_{42} - t_{41} \tag{26}$$

$$\tau_{55rp} = \delta_{5rp}^2\left(\Delta_{5rp} - \frac{1}{3}\delta_{5rp}\right) + \frac{1}{30}\epsilon_{5rp}^3 - \frac{1}{6}\delta_{5rp}\epsilon_{5rp}^2, \qquad \Delta_{5rp} = \mathrm{TE} - t_{5rp} \tag{27}$$

$$\tau_{55s} = \delta_{5s}^2\left(\Delta_{5s} - \frac{1}{3}\delta_{5s}\right) + \frac{1}{30}\epsilon_{5s}^3 - \frac{1}{6}\delta_{5s}\epsilon_{5s}^2, \qquad \Delta_{5s} = \mathrm{TE} - t_{5s} \tag{28}$$

$$\tau_{5rp6m} = \epsilon_{5rp}\delta_{5rp}\sum_{m=1}^{\mathrm{res}/2}\left(\Delta_{6m} - \epsilon_6\right), \qquad \Delta_{6m} = \mathrm{TE} - t_{6i} \tag{29}$$

$$\tau_{5s6m} = -\epsilon_{5s}\delta_{rf}\sum_{m=1}^{\mathrm{res}/2}\left(\Delta_{6m} - \epsilon_6\right), \qquad \Delta_{6m} = \mathrm{TE} - t_{6i} \tag{30}$$

$$\tau_{5rp71} = \delta_5\left[\delta_7\left(\Delta_{75} - \frac{1}{4}\delta_7\right) + \frac{1}{12}\epsilon_7^2 - \frac{1}{2}\delta_7\epsilon_7\right], \qquad \Delta_{75} = \Delta_{71} = \mathrm{TE} - t_{71} \tag{31}$$

$$\tau_{5s71} = \delta_5\left[\delta_7\left(\Delta_{75} - \frac{1}{4}\delta_7\right) + \frac{1}{12}\epsilon_7^2 - \frac{1}{2}\delta_7\epsilon_7\right], \qquad \Delta_{75} = \Delta_{71} = \mathrm{TE} - t_{71} \tag{32}$$

$$\tau_{6m6m} = \epsilon_6^2 \sum_{m=1}^{\mathrm{res}/2} \left[(2m-1)\Delta_{6m} - (m\frac{67}{30} - 1)\epsilon_6 \right], \qquad \Delta_{6m} = \mathrm{TE} - t_{6i} \tag{33}$$

$$\tau_{6m71} = \frac{1}{4}\epsilon_6 \left(\delta_7 \Delta_{71} - \frac{1}{60}\epsilon_7^2 \right), \qquad \Delta_{71} = \Delta_{75} = \mathrm{TE} - t_{71} \tag{34}$$

$$\tau_{7171} = \frac{1}{4} \left[\delta_7^2 \left(\Delta_{71} - \frac{1}{3}\delta_7 \right) + \frac{1}{30}\epsilon_7^3 - \frac{1}{2}\delta_7^2 \epsilon_7 \right], \qquad \Delta_{71} = \Delta_{75} = \mathrm{TE} - t_{71} \tag{35}$$

$$\tau_{7m7(m+1)} = \left(\frac{\mathrm{res}}{2} - 1 \right) \left[\frac{1}{12}\delta_7^3 + \frac{1}{60}\epsilon_7 + \frac{1}{4}\delta_7^2 \epsilon_7 - \frac{1}{12}\delta_7 \epsilon_7^2 \right], \qquad \mathrm{res} = 34 \tag{36}$$