A. Constraints (Logical Coordinates)

\[
G_{\text{max}} = \frac{45}{\sqrt{3}} \frac{mT}{m} \quad S_{\text{max}} = \frac{200}{\sqrt{3}} \frac{mT}{mms}
\]

\[
\bar{G}(t_0; t_1) = \begin{bmatrix}
0 \\
0 \\
\text{Readout prewinder} \\
\text{Phase encode} \\
\text{Slice select refocus}
\end{bmatrix} = \begin{bmatrix}
0 \\
0 \\
\frac{mT}{12} \\
\frac{mT}{13}
\end{bmatrix}
\]

\[
\bar{M}_0(t_1; t_2) = \begin{bmatrix}
\text{Readout prewinder} \\
\text{Phase encode} \\
\text{Slice select refocus}
\end{bmatrix} = \begin{bmatrix}
-18 \\
12 \\
-13
\end{bmatrix} \frac{mT_{\text{max}}}{m}
\]

\[
\bar{G}(t_2; t_3) = \begin{bmatrix}
0 \\
0 \\
\text{Readout gradient} \\
\text{Phase encode} \\
\text{Slice select refocus}
\end{bmatrix} = \begin{bmatrix}
12 \\
0 \\
0 \\
-18 \\
-13
\end{bmatrix} \frac{mT_{\text{max}}}{m}
\]

\[
\bar{M}_0(t_3; t_4) = \begin{bmatrix}
\text{Readout prewinder} \\
\text{Phase encode prewinder} \\
\text{Slice select refinder}
\end{bmatrix} = \begin{bmatrix}
-18 \\
12 \\
-13
\end{bmatrix} \frac{mT_{\text{max}}}{m}
\]

B. Rotation Matrix

\[
R = \begin{bmatrix}
\cos(45^\circ) & 0 & \sin(45^\circ) \\
0 & 1 & 0 \\
-\sin(45^\circ) & 0 & \cos(45^\circ)
\end{bmatrix}
\]

C. Timing

D. $\sqrt{3}$ Derated Constraints (Logical Coordinates)

\[
G_{\text{max}} = \frac{45}{\sqrt{3}} \frac{mT}{m} \quad S_{\text{max}} = \frac{200}{\sqrt{3}} \frac{mT}{mms}
\]

E. Max Hardware Constraints (Logical Coordinates)

\[
G_{\text{max}} = 45 \frac{mT}{m} \quad S_{\text{max}} = 200 \frac{mT}{mms}
\]

F. Max Hardware Constraints (Physical Coordinates)

\[
G_{\text{max}} = 45 \frac{mT}{m} \quad S_{\text{max}} = 200 \frac{mT}{mms}
\]

\[
\bar{G}(t_0; t_1) = R \begin{bmatrix}
0 \\
0 \\
15.6 \\
15.6
\end{bmatrix} \frac{mT}{m} \quad \bar{M}_0(t_1; t_2) = R \begin{bmatrix}
-18 \\
12 \\
-13 \\
-22
\end{bmatrix} \frac{mT_{\text{max}}}{m}
\]

\[
\bar{G}(t_2; t_3) = R \begin{bmatrix}
12 \\
0 \\
8.5 \\
-8.5
\end{bmatrix} \frac{mT}{m} \quad \bar{M}_0(t_3; t_4) = R \begin{bmatrix}
-18 \\
12 \\
-13 \\
-22.0
\end{bmatrix} \frac{mT_{\text{max}}}{m}
\]

Supporting Information Figure S1: An overview of the methods for handling slice obliquity in GrOpt. “Logical coordinates” refer to the readout, phase encode, slice select directions. “Physical coordinates” refer to the fixed x, y, z directions of the scanner gradient system. A. Shows the specific (example) constraints used to create a 2D bSSFP sequence. B. Example rotation matrix that transforms from logical coordinates to physical coordinates (in this case a 45° rotation around the y-axis). C. Pulse sequence timing diagram used to define the constraint intervals. D. Gradient waveforms generated with $G_{\text{max}}$ and $S_{\text{max}}$ derated by a “rotationally invariant” factor of $\sqrt{3}$, which permits all rotations to remain within the full $G_{\text{max}}$ and $S_{\text{max}}$. E. An example where the full $G_{\text{max}}$ and $S_{\text{max}}$ were used, which produces a feasible waveform in logical coordinates, but after rotation $G_{\text{max}}$ is exceeded (red arrow), making the waveform infeasible. F. An example where the full $G_{\text{max}}$ and $S_{\text{max}}$ were used, and the waveform was solved directly in the physical coordinate system by applying the rotation matrix to the constraints. This allows for the full hardware limits to be used. The TRs for D., E., and F. are 6.30ms (feasible), 5.50ms (infeasible) and 5.70ms (feasible).