

Constrained Optimized Water Suppression (COWS)



The basic use of the MATLAB executable implementation of COWS

COWS is an algorithm designed to optimally eliminate the longitudinal magnetization of water (or any other signal). It operates like most water suppression modules, through repeated pulses of varying flip angle and delay to dephase the magnetization over as large of a range of T_1 s and B_1 s as possible. Please reference the associated manuscript when using this software. COWS is flexible in that it can accommodate any number of RF pulses and delays between these pulses. Typically, longer duration and more pulses will obtain better water suppression. For any questions, bugs, critiques or suggestions please email me at kl2968@columbia.edu.

To run COWS, you must have the input file named "COWSInput.mat" in the same directory as the executable and then simply run the executable. A sample "COWSInput.mat" is provided, but this file will likely need to be adjusted to suit your needs. COWS requires the MATLAB Compiler Runtime (MR). COWS was written in MATLAB and compiled with the 2013b runtime environment. I cannot guarantee forwards or backwards compatibility, but if it does not work with your version please contact me and we will work to resolve it. Upon completion, COWS will create a .mat file named "COWSOutput.mat" in the directory it was run. COWSOutput.mat contains three variables: thetas (the flip angles in radians for each of the water suppression pulses), delays (the delays between the subsequent water pulses in microseconds, μ s; the final delay is the time between the last water suppression pulse and the flip time of the excitation pulse) and MzMat, which is the matrix containing the residual longitudinal magnetization for all combinations of input T_1 and B_1 . MzMat can be useful for visualization, whereas thetas and delays is what would be input into the sequence. Depending on the amount of T_1 and B_1 values chosen COWS can take very long (several hours) to run.

Mandatory inputs for COWSInput.mat

The basic use of COWS just requires the following variables to be set in COWSInput.mat: minimumDelays, T1range, and B1range. Minimum delays are the minimum delays between pulses in seconds. These delays should be long enough to incorporate the actual RF pulses, plus any gradients for crushers in between. These can

also be elongated to incorporate things like outer volume suppression or inversion pulses. The values used in the manuscript for the 12 pulse scheme were:

```
>>minimumDelays = [28E-3*ones(1,11) 21E-3];
```

T₁ range is the range of T₁ values (in seconds) of the water desired to be killed (in seconds). B₁ range is similar the range of B₁ overdrive factors (i.e., how much the physical applied B₁ varies from the nominal prescribed B₁). The values used in the manuscript were

```
>>T1range = [0.50:0.005:5.00];
```

```
>>B1range = [0.75:0.005:1.25];
```

These are the only three *required* input variables, however I would also recommend to use the variables moduleDuration and TR, as outlined in section 2 (advanced use of COWS).

2. Optional Inputs for COWSInput.mat

Parameters that can be specified in the struct specifiedParameters but are not necessary because they either have default values or aren't applicable to all experiments. Substantial improvement in water suppression efficacy or tailoring to specific sequences can be obtained with these optional inputs.

Module duration

The module duration is the total duration of the water suppression module (i.e., from the first water suppression pulse to the excitation pulse of the MRS sequence), in seconds. To change this value to your desired duration

```
>>specifiedParameters.moduleDuration = 0.626;
```

T1 Gaussian Width

T1GaussianWidth is the width of the Gaussian weighting kernel in the T₁ dimension (seconds). The default value is 3 seconds. If you wanted it to be 2 seconds you would set

```
>>specifiedParameters.T1GaussianWidth = 2;
```

B1 Gaussian Width

B1GaussianWidth is the width of the Gaussian weighting kernel in the B₁ dimension (unitless). The default value 0.1. If you wanted it to be 0.2 you would set

```
>>specifiedParameters.B1GaussianWidth = 0.1;
```

Maximum Flip Angle

maxFlipAngle is the maximum flip angle of the COWS water scheme. The default is $\pi/2$ but if you wanted to reduce it to $\pi/4$ (to reduce SAR, for example) then you would set

```
>>specifiedParameters.maxFlipAngle = pi/4;
```

Maximum Delays Between Pulses

maximumDelays is the maximum delay between subsequent pulses. Its default is 0.3 seconds, but if you would like to change this value to 0.2 seconds you would set

```
>>specifiedParameters.maximumDelays = 0.2;
```

Repetition Time

TR is the repetition time of your sequence in seconds. This affects the steady-state magnetization and hence the suppression scheme. If this is not input, it is assumed that magnetization is fully recovered between TRs. If your TR was 2 seconds you would set

```
>>specifiedParameters.TR = 2;
```

Excitation Angle

excAngle is the excitation angle used in the localization portion of your experiment. The default is $\pi/2$ as this is what's used in standard PRESS, STEAM, sLASER, etc, but for MRSI a reduced flip angle may be used. Once again this will impact the steady-state magnetization of the water signal, so inputting it to be consistent with the experiments will improve water suppression. For example, if you used a sequence which had an excitation flip angle of $\pi/4$

```
>>specifiedParameters.excAngle = pi/4;
```

Number of Discarded Acquisitions

ddaq is the number of discarded acquisitions, i.e., the number of pulse sequence iterations it takes to reach steady-state magnetization. The default is 1, but you could

increase this number (which would increase computation time) if you think it takes more than 1 ddaq to reach steady state, or reduce it to 0 which would improve performance. To change this value to 0 you would set

```
>>specifiedParameters.ddaq = 0;
```

Number of iterations

numberOfIterations is the variable which represents the number of iterations in solving the numerical problem. The default is 200 but can be reduced to improve performance.

rfWaveform & rfDuration

If you would like to do a full Bloch simulation to adjust the final delay (as was done in the manuscript) then you must input the variables rfWaveform and rfDuration. rfWaveform is the shape of your RF pulse that is used for the water suppression module (unitless) and rfDuration is the duration of the water suppression pulses (seconds). The amplitude of rfWaveform is irrelevant as its ultimately determined by the COWS algorithm, so just the shape matters. Note that this can increase the computation time by a large amount (a few hours or so using the default T1range and B1range). For example, if you wanted to use the physical shape of your RF pulse (yourPhysicalPulseShape) with a duration of 17.92 ms water suppression pulses you would set

```
>>specifiedParameters.rfWaveform = yourPhysicalPulseShape;
```

```
>>specifiedParameters.rfDuration = 17.92E-3;
```