How to use data from WBT

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1 Introduction

This document describes how to use the data from the WBT in sweep mode to estimate TS(f) and target position for single targets, and Sv(f) for volume backscattering.

2 Nomenclature

2.1 Constants

f_s	$= 2$ MHz	- Original sampling rate.
$R_{wbt,tx}$	$= 25\ \Omega$	- Internal resistance in WBT during transmission.
$R_{wbt,rx}$	$= 1000\ \Omega$	- Internal resistance in WBT during reception.
Z_{trd}	$= 75\ \Omega$	- Complex transducer impedance. Approximated by constant real resistance.

2.2 Information in raw data files

$y_{tx}(n)$	- Complex WBT transmit signal obtained after WBT filtering and decimation.
$h_{wbt}(n)$	- Complex WBT receiving filter.
$G(f)$	- Transducer gain values.
Ψ_{nom}	- Transducer equivalent beam angle evaluated at the nominal design frequency for the transduce
c	- Water sound speed.
$\alpha(f)$	- Absorption coefficients.
τ	- Pulse duration.
p_{tx}	- Transmit power.
$y_{rx,i}(n)$	- Received complex sample data from each transducer quadrant, i.

2.3 Derived information

L_{filter}		- The length of the WBT receiving filter in samples.
D	$= L_{filter}/4$	- Sampling decimation factor.
$f_{s,dec}$	$= f_s/D$	- Decimated sampling frequency.

3 Prior information

BLOCK DIAGRAM

4 Pulse compression - matched filtering

The initial step is to perform pulse compression using e.g. the transmit signal with maximum amplitude of 1 as a matching filter on the sample data from each quadrant. The pulse compressed signals from each quadrant i normalized with the two-norm of the matching filter are given as

$$y_{c,i}(n) = \frac{y_{rx,i}(n) * y_{tx}^{*}(-n)}{||y_{tx}||^2} \tag{1}$$

For estimating TS and Sv we will need the average summed signal from all quadrants

$$y_c = \frac{1}{4}\sum_{i=1}^{4} y_{c,i}(n) \tag{2}$$

5 Sp and Sv

The WBT measures voltage over a 1 KΩ load. Received "power" in a matched load is given as

$$p_{rx} = 4\left(\frac{|y_c|}{2\sqrt{2}}\right)^2 \left(\frac{|R_{wbt,rx} + Z_{trd}|}{R_{wbt,rx}}\right)^2 \frac{1}{|Z_{trd}|} \tag{3}$$

Then we can estimate Sp as

$$Sp = 10\log(p_{rx}) + 40\log(r) + 2\alpha r - 10\log\left(\frac{p_{tx}\lambda_{fc}^2}{16\pi^2}\right) - 2G_{fc} \tag{4}$$

where λ_{fc} and G_{fc} are evaluated at the sweep center frequency and r is a vector of range values corresponding to the samples.

For Sv we will also need the effective pulse duration τ_{eff} and the equivalent beam angle evaluated at the center frequency.

First we need to calculate the auto correlation function of the transmit signal

$$y_{tx,auto}(n) = \frac{y_{tx}(n) * y_{tx}^{*}(-n)}{||y_{tx}||^2} \tag{5}$$

Then we estimate the effective pulse duration

$$p_{tx,auto}(n) = |y_{tx,auto}(n)|^2 \tag{6}$$

$$\tau_{eff} = \frac{\sum p_{tx,auto}(n)}{\max(p_{tx,auto})f_{s,dec}} \tag{7}$$

$$\tag{8}$$

and the equivalent beam angle evaluated at the center frequency

$$\Psi_{fc} = \Psi_{fnom} + 20\log\frac{fnom}{fc}; \tag{9}$$

where ψ_{fnom} is equivalent beam angle at the nominal design frequency for the transducer.

Then we can estimate Sv as

$$Sv = 10\log(p_{rx}) + 20\log(r) + 2\alpha r - 10\log\left(\frac{p_{tx}\lambda_{fc}^2 c}{32\pi^2}\right) - 2G_{fc} - 10\log\tau_{eff} - \Psi_{fc} \tag{10}$$

6 TS(f)

We assume the target has been detected and the target signal $y_{c,target}$ has been extracted from y_c.

Usually the extracted target signal is shorter than the entire length of the auto correlation function of the transmit signal. In order to compensate correctly we need to extract the same samples from the auto correlation of the transmit signal as from the received signal relative to the peak signal sample. The reduced auto correlation signal of the transmit signal is labeled $y_{tx,auto,red}$.

Then we calculate the FFT's of the target signal and the reduced auto correlation signal.

$$FFT_{target} = fft(y_{c,target}, nfft) \tag{11}$$

$$FFT_{y,tx,auto,red} = fft(y_{tx,auto,red}, nfft) \tag{12}$$

These FFT's represent the frequency band $0 - f_{s,dec}$ with a resolution of $\frac{f_{s,dec}}{nfft}$ and should be transferred to the actual frequency band through simple repetitions of the FFT's and extraction of the original frequency band.

The normalized FFT of the target is given as

$$FFT_{target,norm} = \frac{FFT_{target}}{FFT_{y,tx,auto,red}} \tag{13}$$

Received "power" in a matched load is given as

$$p_{rx,FFT,target} = 4\left(\frac{|FFT_{target,norm}|}{2\sqrt{2}}\right)^2 \left(\frac{|R_{wbt,rx} + Z_{trd}|}{R_{wbt,rx}}\right)^2 \frac{1}{|Z_{trd}|} \tag{14}$$

and we can now estimate TS(f) as

$$TS(f) = 10\log(p_{rx,FFT,target}(f)) + 40\log(r_{target}) + 2\alpha(f) r_{target} - 10\log\left(\frac{p_{tx}\lambda^2}{16\pi^2}\right) - 2G_f \tag{15}$$

where r_{target} is the estimated range to the target based on e.g. the distance between peak of matched transmit signal and peak of matched target signal, and $G(f)$ are estimated gain values at the FFT evaluation frequencies.

7 Sv(f)

In order to estimate Sv(f) we will use a sliding window for the FFT. However, the duration of this sliding window can be so long that the difference in range dependent compensation from the beginning of the window to the end can be significant, in particular for short range measurements where the r^2 function is steep. Thus, we will compensate for r^2 before the FFT windowing. Absorption compensation is both range dependent and frequency dependent, but since absorption compensation is insignificant for our operating frequency band at shorter ranges and the difference in absorption compensation between the beginning and the end of the sliding window is insignificant at longer ranges, we will compensate for absorption after the FFT window.

Thus, we begin by compensating for r^2 for power which becomes r for amplitude

$$y_{spread}(n) = y_c(n)r \tag{16}$$

Then we apply a normalized sliding hanning window, $w(i)$ to the range compensated compressed sample data and calculate the FFT. The duration, t_w, of the sliding window is chosen as a compromise between spatial resolution and frequency resolution but it is recommended to be at least twice the pulse duration and should result in a number of samples, N_w which is a power of 2 for FFT computational reasons.

The normalized hanning window is given as

$$w(i) = \frac{\mathrm{hann}(i)}{\left(\frac{||\mathrm{hann}||}{\sqrt{N_w}}\right)} \tag{17}$$

The FFT of the volume is given as

$$FFT_{volume}(n) = fft\left(w(i)\left(y_{spread}(i+n)\left[u(i+\frac{N_w}{2}) - u(i-\frac{N_w}{2})\right]\right), nfft\right) \tag{18}$$

where $u(n)$ is the step function and

$$nfft = N_w \tag{19}$$

The FFT of the auto correlation function of the transmit signal also needs to be evaluated at the same frequencies

$$FFT_{y,tx,auto} = fft(y_{tx,auto}, nfft) \tag{20}$$

The normalized FFT of the volume is given as

$$FFT_{volume,norm}(n) = \frac{FFT_{volume}(n)}{FFT_{y,tx,auto}} \tag{21}$$

Received "power" in a matched load is given as

$$p_{rx,FFT,volume}(n,f) = 4\left(\frac{|FFT_{volume,norm}(n)|}{2\sqrt{2}}\right)^2\left(\frac{|R_{wbt,rx}+Z_{trd}|}{R_{wbt,rx}}\right)^2\frac{1}{|Z_{trd}|} \tag{22}$$

We can now estimate Sv(n,f) as

$$Sv(n,f) = 10\log(p_{rx,FFT,volume}(n,f)) + 2\alpha(f)r - 10\log\left(\frac{p_{tx}\lambda^2 c}{32\pi^2}\right) - 2G_f - 10\log(t_w) - \Psi_f \tag{23}$$