Radar Transmitter Leakage Cancellation

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***Abstract*—The transmitted signal could leak into the receiving chain in many stages which saturates the receiver components. In this paper, a cancellation method using a second transmitting channel is studied. Simulations are implemented to show the feasibility.**

***Index Terms*—FMCW, radar, leakage, cancellation, software defined radio**

I. Introduction

For FMCW radar, the transmitted signal could leak into the receiving chain in many stages. For example, if using different antennas for transmitting and receiving, the transmitted signal could couples directly into the receiving antenna and saturates the receiver components. Considering the situation of analog to digital converter(ADC) saturation, it degrades the radar SNR and becomes a key obstacle preventing observing weak signals. In the traditional FMCW radar, there is usually a dechirp mixer for pulse compression. The dechirp mixer compares the received signal and transmitted signal, outputs a base band time domain signal including targets range information. It is possible to avoid the ADC saturation by adding a high-pass filter after the dechirp mixer. However, this is different if implement FMCW radar by a software defined radio(SDR), because SDR usually is a direct-conversion receiver. It records the down-converted received signal without the dechirp mixer. Since it is feasible to use two transmitting channels and it is convenient to change the waveform of the transmitted signal, a cancellation method is used to mitigate the problem.

The ADC saturation is caused by strong interference signals and the limited ADC dynamic range. The receiver's amplifier should make the amplitude of signal of interest(SOI) fulfilling as much ADC dynamic range as possible for best SNR. However, if there is a strong interference signal coupling with SOI and both are fed into the receiver, then the SOI will fail to utilize entire dynamic range, because amplifiers set the amplitude of interference to meet the ADC maximum detectable voltage level. Also, the interference, which is the leakage signal here, could be tens of decades stronger then the SOI of echos from targets in far range. This means the SOI is represented by much less digital bits then it should be. Moreover, there is a signal floor in transmitted chirp due to coherent harmonics such as intermodulations. This coherent harmonics floor could dominant radar sensitivity and buries SOI because the signal floor is not random and cannot be reduced by doing averaging.

As shown in figure 1, the cancellation method is to use a second transmitting channel generating a cancellation signal and combining it with the received signal to reduce the leakage. The key point is to derive and generate the proper cancellation signal by using a transmitted template signal and the estimated leakage signal channel. The cancellation signal is a linear combination of delayed and weighted version of the transmitted template signal, and the channel vector length determines the how far the leakage channel covers. It is possible to use analytically method to obtain the leakage channel if the transmitted template signal is known and the size of it is small. There are other methods to get channel weights such as LMS algorithm [1], [2]. After getting the cancellation signal, subtract it from the original received signal and feed the remaining signal to the receiver RF front end such as LNA.

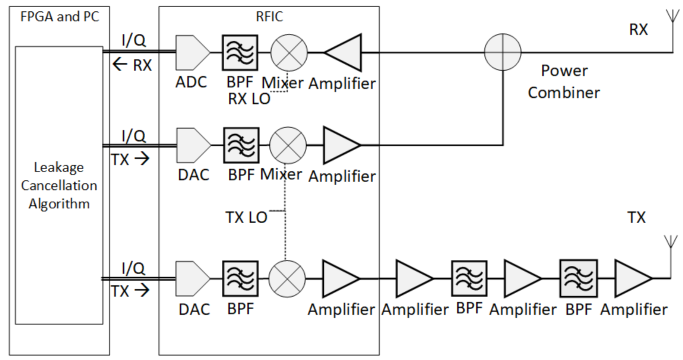

Fig. 1. Radar Block Diagram

II. Theory

A. Pulse Compression

The transmitted template input signal at base band is a linear up-chirp:

$$x_t = cos(2\pi(f_0 t + 0.5Kt^2)) \tag{1}$$

where K is the chirp rate, $K = fs/tc$, $fs = 56MHz$, $tc = N/fs$, $N = 400000$, $f_0 = -28MHz$ is starting frequency of the chirp.

The range information can be extracted by comparing transmitted and received signals by a pulse compression technique such as the stretch processing. Assuming the transmitted signal is the chirp signal, and the received signal is a summation of the chirps with different delays, i.e. the leakage is delayed by 10 taps, and two echos as SOI are delayed by 30 and 100 taps correspondingly. The targets echos are 100dB and 140dB lower than leakage signal power.

$$S = FFT\{y \times x_t^*\} \tag{2}$$

where the symbol $*$ denotes complex-conjugate, y is received signal, and S is the pulse compression result containing range information.

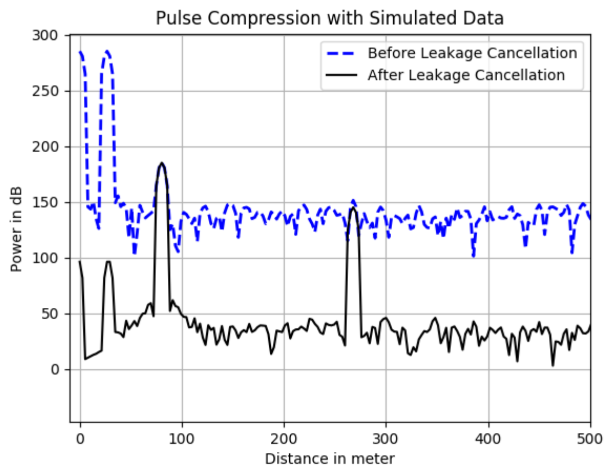

Fig. 2. Leakage Cancellation Simulation

B. Channel Estimation and Leakage Cancellation

Estimated channel c(i) can be derived from the input sequence x(i), additive white noise v(i) and the available measurements y(i). Here is an example of a signal with N complex valued samples, and the channel vector length is set to M.

$$\begin{bmatrix} y(1) \\ \vdots \\ y(N) \end{bmatrix} = \underbrace{\begin{bmatrix} x(1) & & \\ x(2) & x(1) & \\ x(3) & x(2) & \dots \\ \vdots & \vdots & \vdots \\ x(N) & x(N-1) & \dots \end{bmatrix}}_{\text{X:(N)}\times\text{M}} \begin{bmatrix} c(1) \\ \vdots \\ c(M) \end{bmatrix} + \begin{bmatrix} v(1) \\ \vdots \\ v(N) \end{bmatrix} \tag{3}$$

The best weight matrix which is the channel vector can be calculated as [3]

$$c = R_X^{-1} R_{yX} \tag{4}$$

where covariance matrix is

$$R_X = E[X^H X] \tag{5}$$

and cross-covariance matrix of y,X is

$$R_{yX} = E[X^H y] \tag{6}$$

where H is Hermitian transpose for matrix. So the leakage cancellation method can be done in the following steps.
Step 1: The channel vector can be obtained analytically if X and y are given.

$$c = R_X^{-1} R_{yX} \tag{7}$$

Step 2: Then the cancellation signal can be calculated.

$$x_{canc} = Xc \tag{8}$$

Step3: The final signal after leakage cancellation is

$$y_{canc} = y - x_{canc} \tag{9}$$

The dimension of matrix X, M, determines how far the cancellation signal covers because the cancellation signal $x_{canc} = Xc$ is a linear combination of the delayed input signals which is weighted by channel vector c. Each element in channel vector, $c(i)$, determines how strong the corresponding leakage signal is at a certain distance, this distance is how far the leakage signal travels from the transmitter to receiver, and the distance is represented by delay taps here in matrix X.

Assuming the leakages are within 10 taps or delays, then the corresponding distance that leakage signals travel is less or equal to

$$d = N_{taps} \times \frac{cF}{2K} = 10 \times \frac{c}{2f_s} = 26.8meter \tag{10}$$

where K is chirp rate, $K = fs/tc$, $F = fs/N$, $fs = 56MHz$, $N = 400000$, $tc = N/fs$ In the above figure 2, the leakage is alleviated and two small point targets in far range become visible after cancellation.

III. Simulation with Measured Signal

In real world, the transmitted signal is not an ideal chirp which must be distorted because of active and passive RF components in the transmit signal chain, for example, power amplifier could add third-order and higher order harmonic tones [4], transmission lines have more attenuation at higher frequency. Also, the received signal is simulated as echos from point targets. All in all, it is necessary to see how this method performs when using real signals.

A signal is recorded by adding a loop back transmission line and an attenuator between transmitter and receiver ports before antennas. Use this signal as template signal for pulse compression. The received signal is the real measured signal by radar system in field. The measurement was taken on August 22, 2018, a reflector was placed 44 meters away from radar, the physical separation distance between transmit and receive antenna was about 3 meters and the total cable length is 8 meters between transceiver and antennas. In the figure, a strongest peak is the leakage signal. And the second peak at about 44 meters away from radar is the corner reflector.

In the figure 3, there is roughly 150 - 100 = 50 dB cancellation for the transmit-to-receive antenna leakage. The targets at further range are remained.

Note that the remaining signal SNR is not changed here because this cancellation was done after ADC in computer code. The signal held the strong leakage signal was recorded by ADC, so the noise floor was fixed by ADC dynamic range and the strongest signal, the leakage, which sets a reference of maximum dynamic range level. But if cancellation is done before ADC and LNA, the residual signal y_{canc} can be further amplified by LNA in RF front end, then the ADC dynamic range can be fulfilled only for SOI, and hence the SNR can be improved. In order to verify the real performance of the proposed leakage cancellation method, a two-transmit-channel

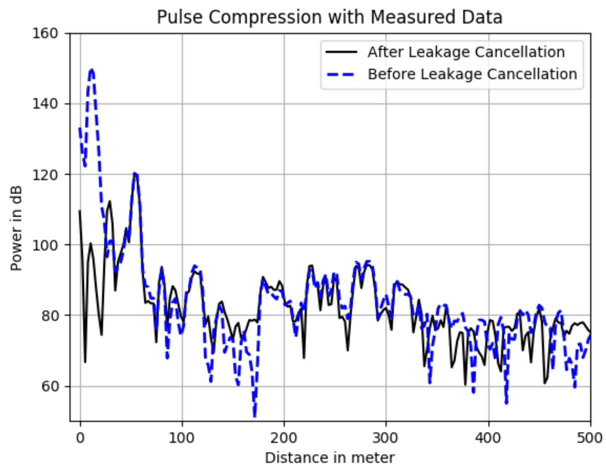

Fig. 3. Leakage Cancellation with Measured Signal

radar system is under developing. Note that this method should work with other leakage mitigation methods such as physically separate transmit and receive antennas.

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