Software defined radio for noise and passive RADAR processing

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Noise RADAR uses the spectrum spreading capability of phase modulation to imprint a known pattern on the carrier. By correlating the surveillance antenna measurement – aimed at targets and directed away from the emitter – with the reference signal transmitted by the emitter or the copy of the pseudo-random sequence, time delay and target motion induced Doppler shift are computed to map the range-Doppler distribution of targets. Rather than using a dedicated emitter, existing non-cooperative emitters can be advantageously used in the passive RADAR approach of similar concepts. Fourier-transform based correlation is demonstrated using GNURadio.

Keywords: noise RADAR, passive RADAR, correlation

1 Introduction

RADAR systems include fundamental limitations related to the physical meaning of the quantities processed: one such limitation is the range resolution ΔR related to the inverse of the bandwidth B of the transmitted signal: $\Delta R = c_0/(2B)$ with c_0 the velocity of light in vacuum. Classical means of spreading the spectrum around the carrier include emitting a short pulse whose bandwidth is inverse of the pulse duration (pulse RADAR) ; sweeping the frequency range and measuring the scattering coefficient at each frequency to recover the time domain response by inverse Fourier transform (Frequency Stepped Continuous Wave – FSCW, as classically implemented in network analyzers) ; monitoring the beat signal between a linearly swept frequency source and the returned signal delayed by the range to the target (Frequency Modulated Continuous Wave – FMCW) ; or binary phase shift keying the phase of the carrier in a pseudo-random pattern switching state at a rate of B bits/s. The latter, implemented in noise RADARs, is well known from software defined radio implementation of Global Navigation Satellite System (GNSS) decoder implementation, or any Code Division Multiple Access (CDMA) protocol in general.

At first, a dedicated broadband signal achieved by feeding the Intermediate Frequency (IF) input of a mixer with a pseudo-random sequence fed at rate B Mb/s (as generated for example using an FPGA) and the Local Oscillator (LO) input of the mixer with a carrier f will generate on the RadioFrequency (RF) output a signal centered on f and spanning a bandwidth B. This signal is emitted and, in a bistatic configuration, a separate receiver antenna collects all signals, both the Direct Signal Interference (DSI) propagating directly from emitter to receiver, as well as echoes reflected on targets. Assuming the pseudo-random pattern is known, correlating the received signal with the pseudo-random sequence exhibits correlation peaks with time-resolution $1/B$.

Since the radiofrequency spectrum is a scarce resource heavily regulated, rather than emitting a dedicated signal, existing RF sources can be advantageously used to such purpose in the biststatic passive RADAR approach. As examples of throughly investigated sources, the 8-MHz wide Digital Video Broadcast-Terrestrial (DVB-T) signal provides a theoretical $c_0/(2B) \simeq 20$ m range resolution, while the 80 MHz IEEE 802.11 WiFi signal provides 2 m range resolution. However, these signals are not random enough and display some structure preventing the correlation from exhibiting sharp target peaks since they are hidden in the auto-correlation signal structure. Getting rid of such artifacts is requires DSI removal, the topic of multiple investigations aimed at identifying short delay components of the reference signal in the measured signal and subtracting these artifacts until the targets appear in the correlation of the cleaned measurement with the reference.

2 Experimental setup

Identifying delayed copies of a reference signal in a measurement is best achieved with the matched filter implemented as the correlation of the reference r and measurement m signals. The time domain correlation is defined as $xcorr(\tau) = \int r(t)m(t+\tau)dt \underbrace{\Longrightarrow}_{\text{discrete time}} xcorr(n) = \sum_k r_k \cdot m_{k+n}$. Practical implementation however usually exploit the convolution theorem stating that the Fourier transform FT of the convolution $conv(\tau) = \int r(t)m(\tau - t)dt$ is the product of the Fourier transforms: $FT(conv) = FT(r) \cdot FT(m)$.

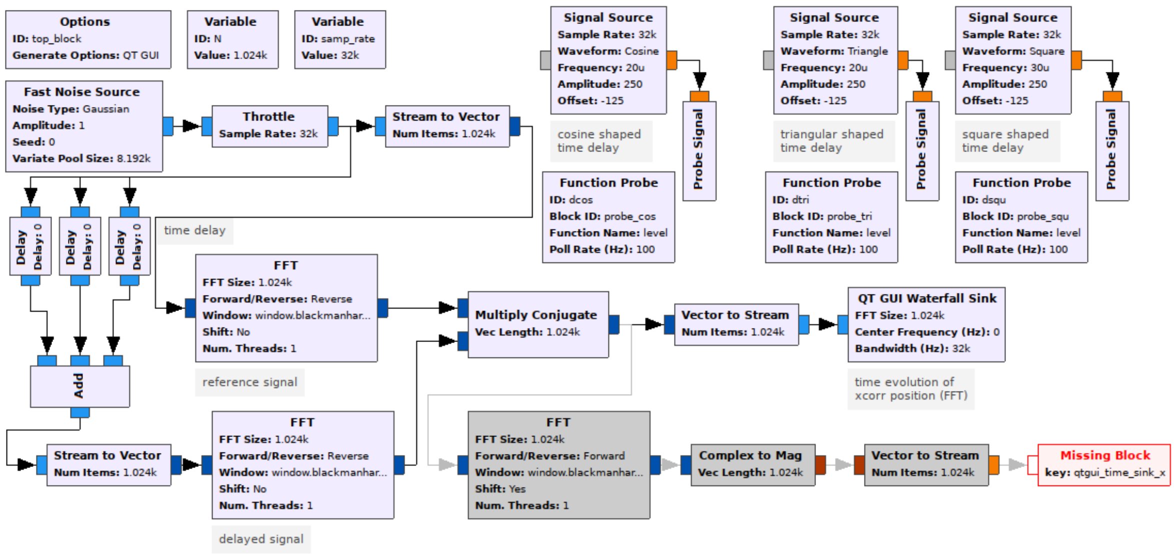

Figure 1: Real time computation of the correlation through the Fourier transform implemented in GNURadio: three delayed reference signal copies are generated using three different signal generators.

Since the convolution and correlation are only differentiated by the direction of time in the second term, and since flipping the sign of the argument of a complex number is a matter of taking its complex conjugate, we conclude that $FT(xcorr) = FT(r) \cdot FT^*(m)$ with * the complex conjugate.

We demonstrate the implementation of this principle in Fig. 1 in which three time delayed copies of the reference signal are summed – representing three targets delayed by a square, triangle and sine shaped delay functions – and separated by the correlation. The three targets are well separated despite the poor timing capability of the Throttle block only aimed at roughly controlling the data-rate.

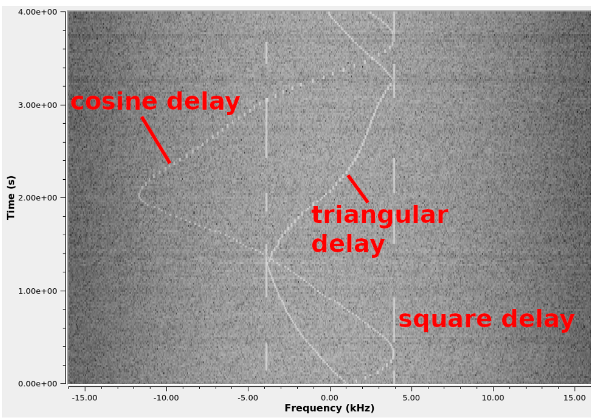

Figure 2: GNURadio Companion output with three targets delayed by square, sine and square wave time-delay functions visible on the waterfall. The data-rate constrained by the Throttle block is not constant, hence the shape deformation of the curves due to the varying speed.

3 Results

The result of running the flowchart of Fig. 1 in GNURadio companion is displayed in Fig. 2.

This simulated flowchart has been implemented and demonstrated functional with two synchronized DVB-T receivers, one aimed at a non-cooperative emitter and one aimed at targets [1, 2].

4 Conclusion

GNURadio not only allows prototyping new discrete-time digital signal processing concepts such as correlating two signals to demonstrate passive RADAR principles, it also allows extending the basic concepts to practical demonstrations. In the current case, the correlation demonstration was extended to a passive RADAR receiver by replacing the pseudo-random generator used as reference signal and the time delayed copies used as measurement channels with two DVB-T (`osmosdr` block) sources feeding the flowchart with experimental signals for demonstrating the bistatic passive RADAR concept.

References

[1] J.-M Friedt, *RADAR passif par intercorrélation de signaux acquis par deux récepteurs de télévision numérique terrestre*, GNU/Linux Magazine France **212** pp.36- (Feb. 2018)

[2] J.-M Friedt *& al.*, *(Yet another) passive RADAR using DVB-T receiver and SDR*, FOSDEM 2018 at `https://fosdem.org/2018/schedule/event/passiveradar/`