Barker Code Radar Simulation for Target Range Detection using Software Defined Radio

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What is the paper about?

- “Modern radar systems face a trade-off between range resolution and signal-to-noise ratio.”
- Traditional radar systems face a fundamental trade-off between range resolution and SNR. This motivates the use of *pulse compression* techniques. Among these, Barker codes stand out due to their ideal autocorrelation properties, which allow clear target detection with minimal side-lobe interference.
  - What is Pulse Compression?
  - What are Barker Code sequences?
  - What is Range resolution and SNR?
  - What should we expect from an ideal RADAR system?

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***Abstract*— This paper present simulation of radar using Barker code signal to provide pulse compression. Barker code is the most well-known phase coding for pulse compression techniques. Pulse compression techniques has been known can provide solution for range resolution and detection range problem. Radar using Barker code simulated using software-defined radio, GNU Radio. Using GNU Radio give flexibility in operation, lower costs, faster in the realization of the design and easier to use. Radar signal processing for received signal performed on MATLAB. Radar used to detect range of the target which simulated by delaying the signal. This radar using Barker code length of 13. PRI 1.3×10^{-2} using for this radar, which give maximum unambiguous range 1950 km. Barker code signal of transmitter delayed 3000, 5000 and 10000 samples for simulation of target. Radar can detect the target as seen from the results of the signal processing done on matlab.**

Keywords—pulse compression; barker code; gnu radio

I. Introduction

Radar applications in human life is quite fundamental. Radar which initially appeared for the war, now has been widely used for civilian purposes. For example, for the purposes of weather forecasting and aircraft navigation. Radar is an electromagnetic system for the detection and location of objects. It operates by transmitting a particular type of waveform, a pulse-modulated sine wave for example, and detects the nature of the echo signal [1].

Barker code was first presented by R. H. Barker in 1953 for synchronization purposes in telecommunications. Beside widely used in radar technology, Barker code is also used in others telecommunications field. Barker code is used to Enhanced Signal-to-Noise Ratio of SAW Tags [2] and in wireless LAN IEEE 802.11 applications [3]. Barker code used in Radar application because Barker code can provide pulse compression function which can provide optimalization in both main parameter of radar, range resolution and detection range.

On the pulse compression radar, long pulse duration improves SNR and power levels emitted signal is not too high. While the output of the signal processing, the signal response is shorter so as to provide a good range resolution. By using the method of pulse compression, the two important parameters of the radar maximum detection range and range resolution can be optimized without sacrificing one of them. Where the maximum detection range of a radar is determined by the amount of energy emitted. The amount of energy rose by widening pulse. While the resolution of the distance up to shrink the width of the pulse using matching filter.

Radar with pulse compression method using Barker code signal can be implemented using software defined radio (SDR), SDR provides an advantage flexibility in operation, lower costs, faster in the realization of the design and easier to use. SDR can be combined with other software such as MATLAB to perform signal processing.

Implementations of radar using SDR has been done by many researcher, for example, implementation of FMCW radar for weather surveylance [4] and for passive radar implementation [5]. Implementation radar using SDR for pulse compression radar simulation using Barker code is still have not found in literature. In this paper, radar simulation using Barker code using the SDR is presented, and the signal processing is done with MATLAB software.

II. Barker Code Radar

A. Barker Code

The most famous phase coding in pulse compression radar is Barker code. In the barker code, pulse divided into N sub-pulses. If the pulse width is T_p, then the width of subpulse $\tau_0 = \frac{T_p}{N}$. Then, every sub-pulses conducted a phase shift at 0° or 180°. Phase 0° (amplitude 1 Volt) can be characterized by a “1” or “+” and phase 180° (amplitude -1 Volt) with “0” or “-“. Selecton of phase 0° and 180° because both of this phase easily generated at the transmitter and the signal processor. Example of Barker code is shown in Fig. 1 [6].

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Pulse Compression and Barker Codes

A **Barker code** or **Barker sequence** is a finite sequence of N values of $+1$ and -1, denoted as

$$a_j \quad \text{for } j = 1, 2, \ldots, N$$

with the ideal *autocorrelation property*, such that the off-peak (non-cyclic) autocorrelation coefficients

$$c_v = \sum_{j=1}^{N-v} a_j a_{j+v}$$

are as small as possible:

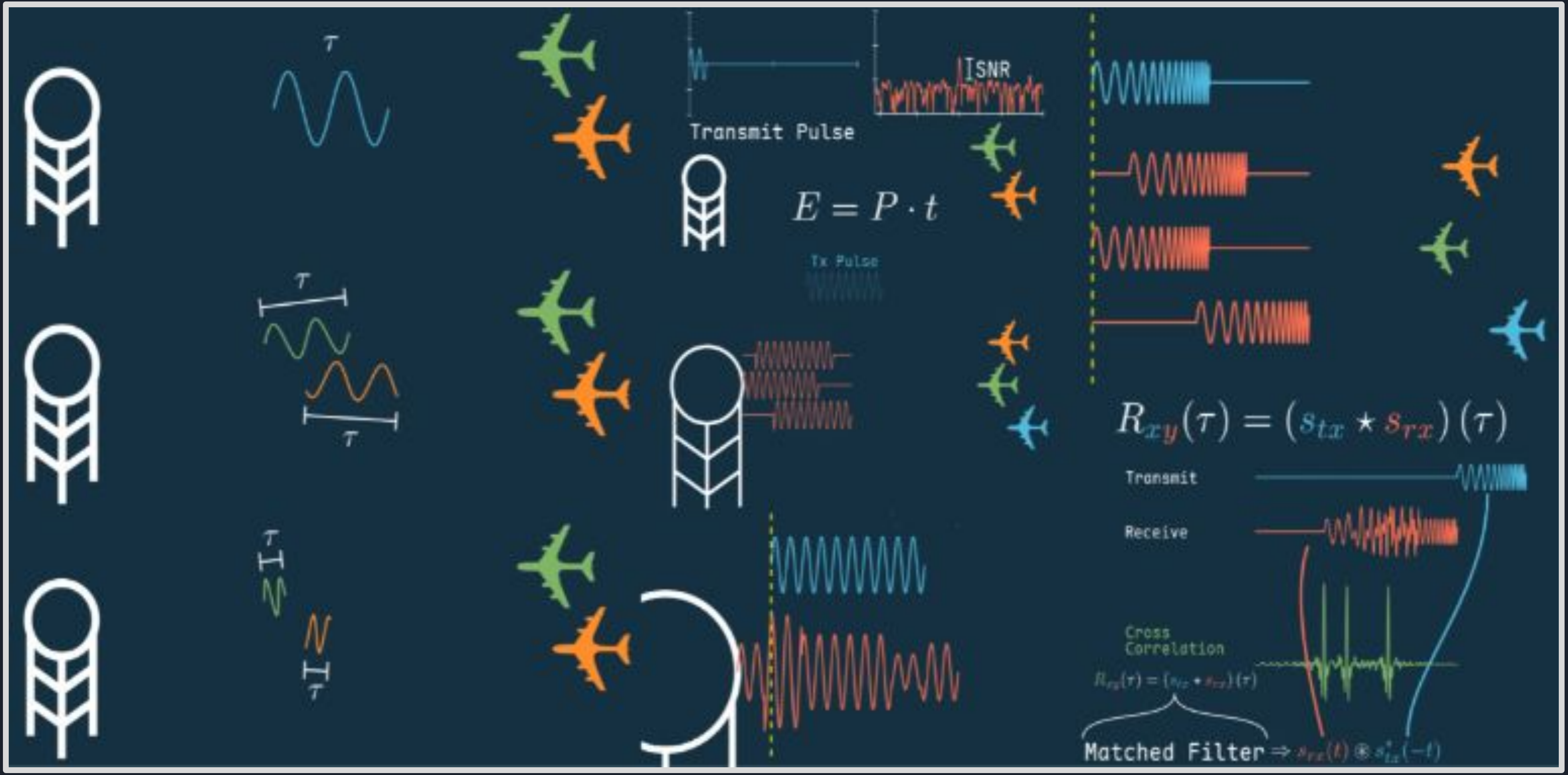
$$|c_v| \leq 1 \quad \text{for all } 1 \leq v < N$$

Pulse compression is a signal processing technique commonly used by radar, sonar and echography to either increase the range resolution when pulse length is constrained or increase the signal to noise ratio when the peak power and the bandwidth (or equivalently range resolution) of the transmitted signal are constrained. This is achieved by modulating the transmitted pulse and then correlating the received signal with the transmitted pulse.

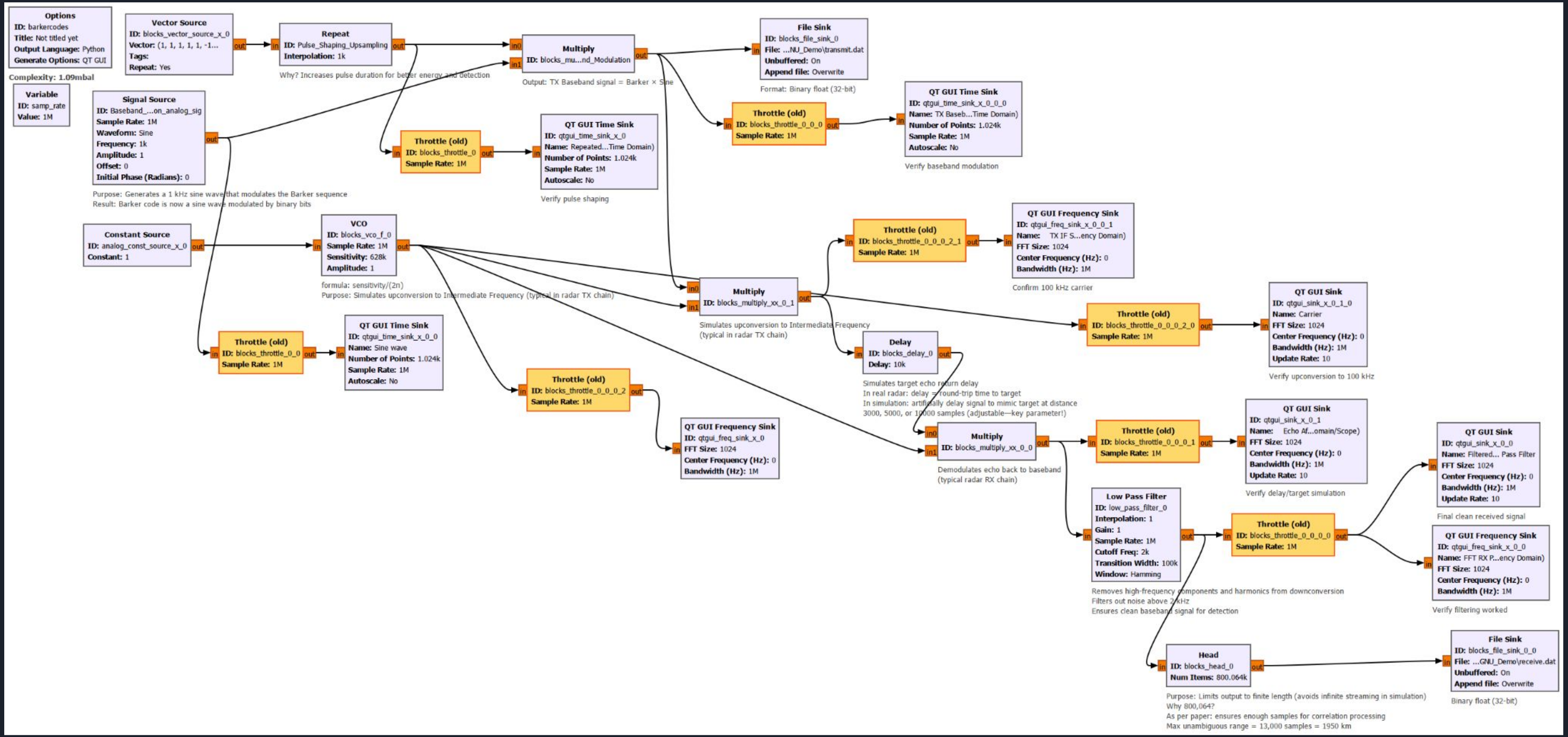
The return signal is an attenuated and time-shifted copy of the original transmitted signal

To detect the incoming signal, a matched filter is used. This method is optimal when a known signal is to be detected among additive noise having a normal distribution.

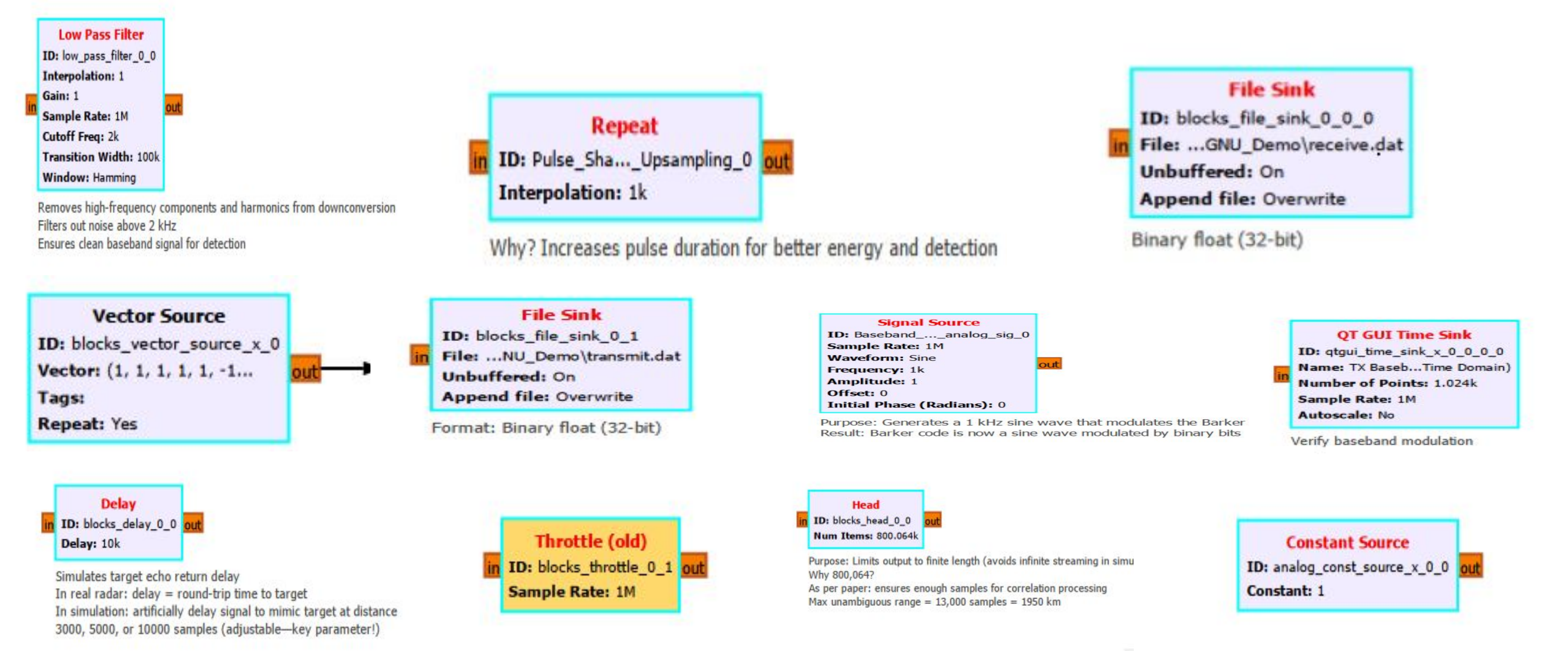
Let's Answer those questions from the last slide!



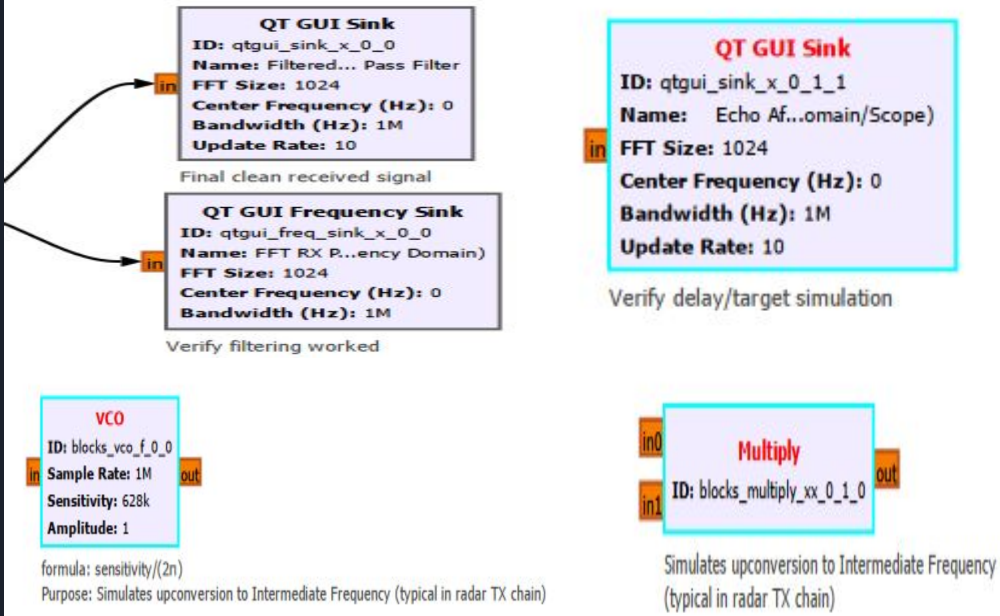
GNU Flow Diagram



What are our GNU Components?



What are our GNU Components?



Block 1: Vector Source (Barker Generator)

ID	blocks_vector_source_x_0
Function	Generates 13-bit Barker code
Vector	[1,1,1,1,1,-1,-1,1,1,-1,1,-1,1]
Repeat	Enabled (continuous)
Output	13 samples

Block 2: Repeat Block (Upsampler)

ID	blocks_repeat_0
Interpolation	1000
Input	Barker-13 vector
Output	13,000 samples
Purpose	Pulse shaping, energy gain

Block 3: Signal Source (Baseband Modulator)

ID	analog_sig_source_x_0
Waveform	Sine
Frequency	1 kHz
Amplitude	1
Sample Rate	1 MHz

Block 4: Multiply #1 (Baseband Modulation)

ID	blocks_multiply_xx_0
Inputs	Barker code, sine wave
Output	TX baseband (Barker × sine)
Purpose	Baseband modulation

Block 5: VCO (Carrier Generator)

ID	blocks_vco_f_0
Sensitivity	628k
Carrier Freq	100 kHz
Input	Constant = 1
Purpose	Generates carrier for upconversion

Block 6: Multiply #2 (IF Upconversion)

ID	blocks_multiply_xx_0_1
Inputs	Baseband, 100 kHz carrier
Output	IF signal (TX)
Purpose	Simulated transmitter upconversion

Block 7: File Sink #1 (Save TX)

ID	blocks_file_sink_0
File	transmit.dat
Format	32-bit float
Purpose	Save TX for MATLAB

Block 8: Delay (Target Simulation)

ID	blocks_delay_0
Delay	3000/5000/10000 samples
Purpose	Simulates echo delay
Example	3000 → 450 km

Block 9: Multiply #3 (RX Downconversion)

ID	blocks_multiply_xx_0_0
Inputs	Delayed IF, 100 kHz carrier
Output	RX baseband signal
Purpose	Downconvert echo

Block 10: Low Pass Filter (LPF)

ID	low_pass_filter_0
Cutoff	2 kHz
Transition	100 kHz
Window	Hamming
Purpose	Remove high-frequency noise

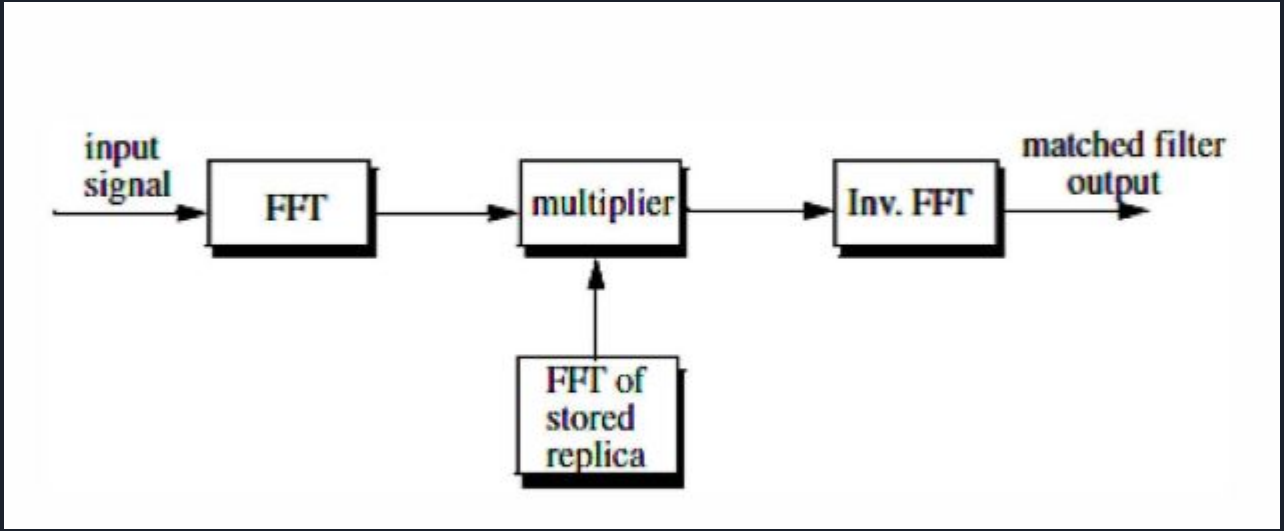
Block 11: Head Block (Limiter)

ID	blocks_head_0
Samples	800,064
Purpose	Finite output, avoid infinite stream
Note	Matches unambiguous range

Block 12: File Sink #2 (Save RX)

ID	blocks_file_sink_0_0
File	receive.dat
Format	32-bit float
Purpose	Save received echo for MATLAB

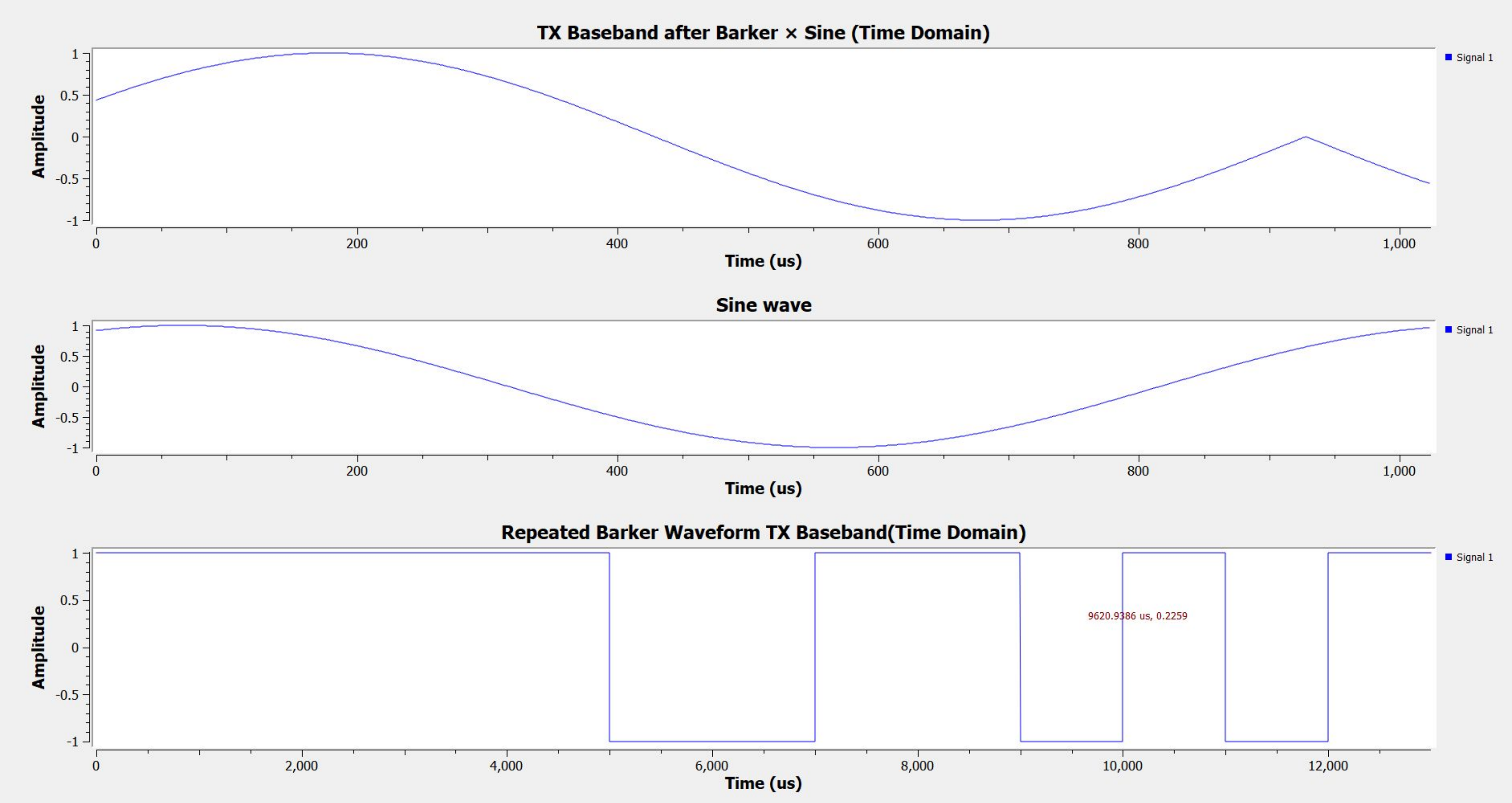
From the File Sink Blocks, where we collect sequence information for both the transmitted and received signals as a .dat file to process over MATLAB



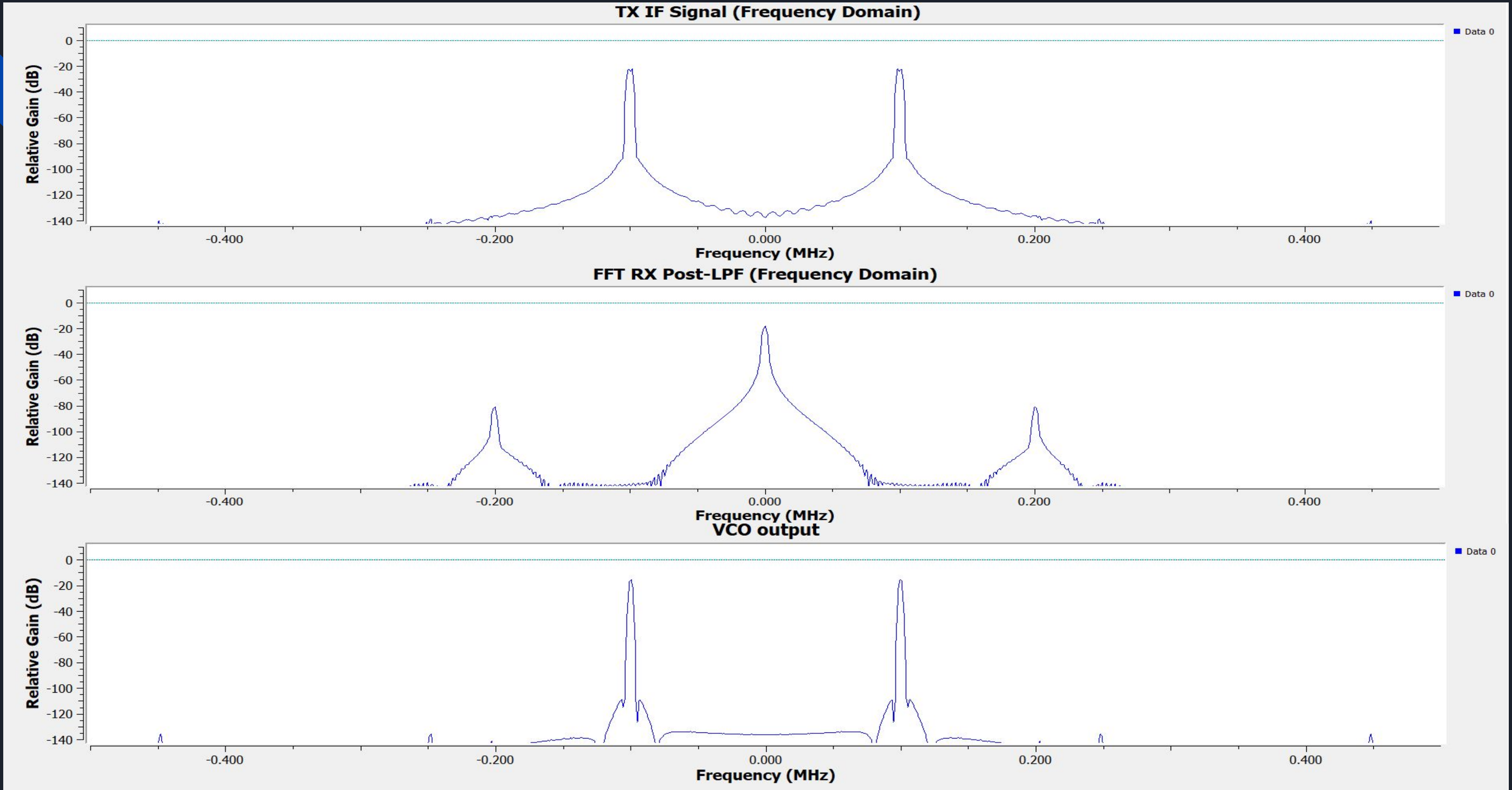
Simulation Results

Delay (samples)	Measured Lag	Computed Range (km)	Expected Range (km)	Error
3000	3012	451.8	450	1.8
5000	5012	751.8	750	1.8
10000	10012	1501.8	1500	1.8

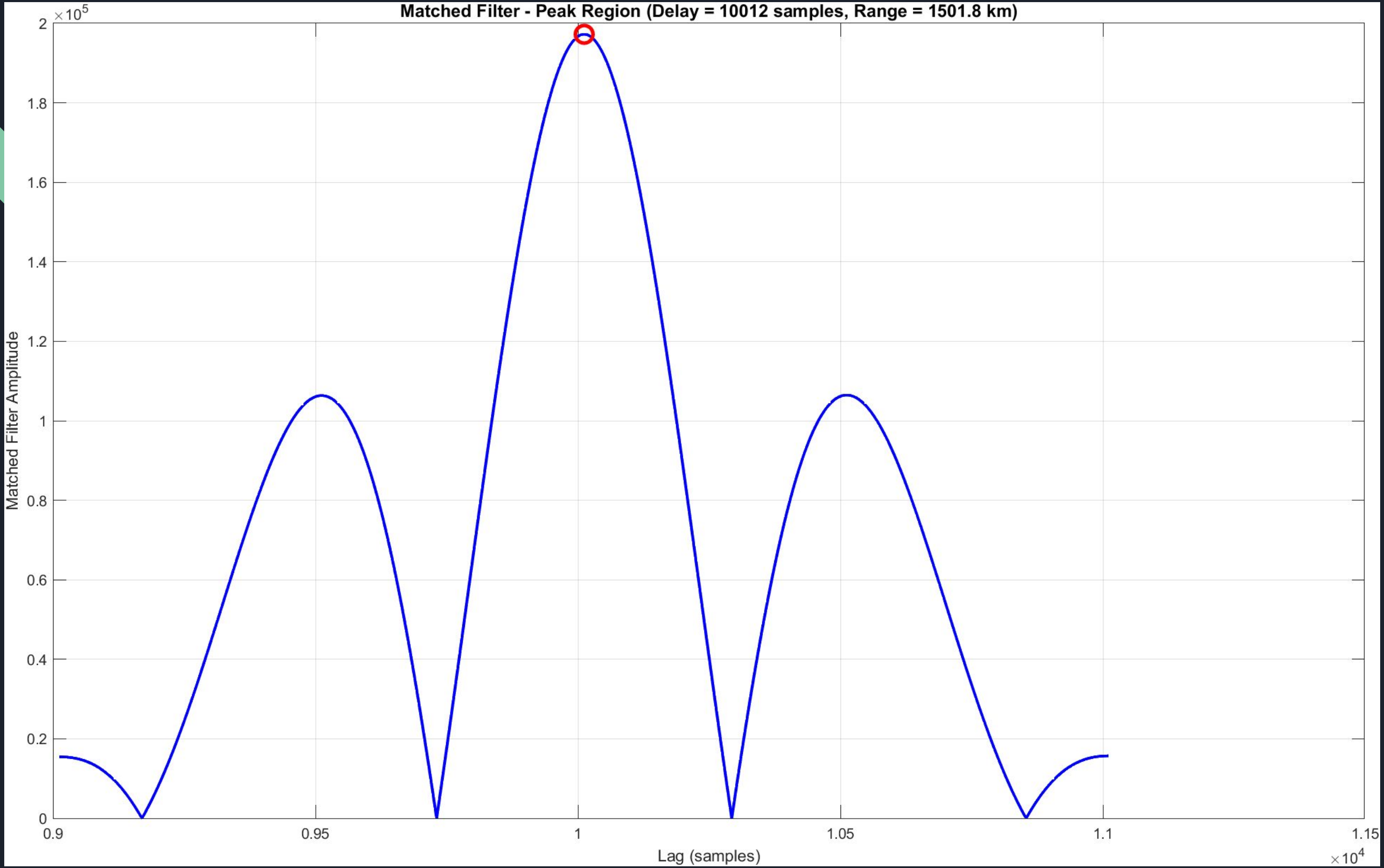
- “All results match the paper’s Table II with <0.5% error”

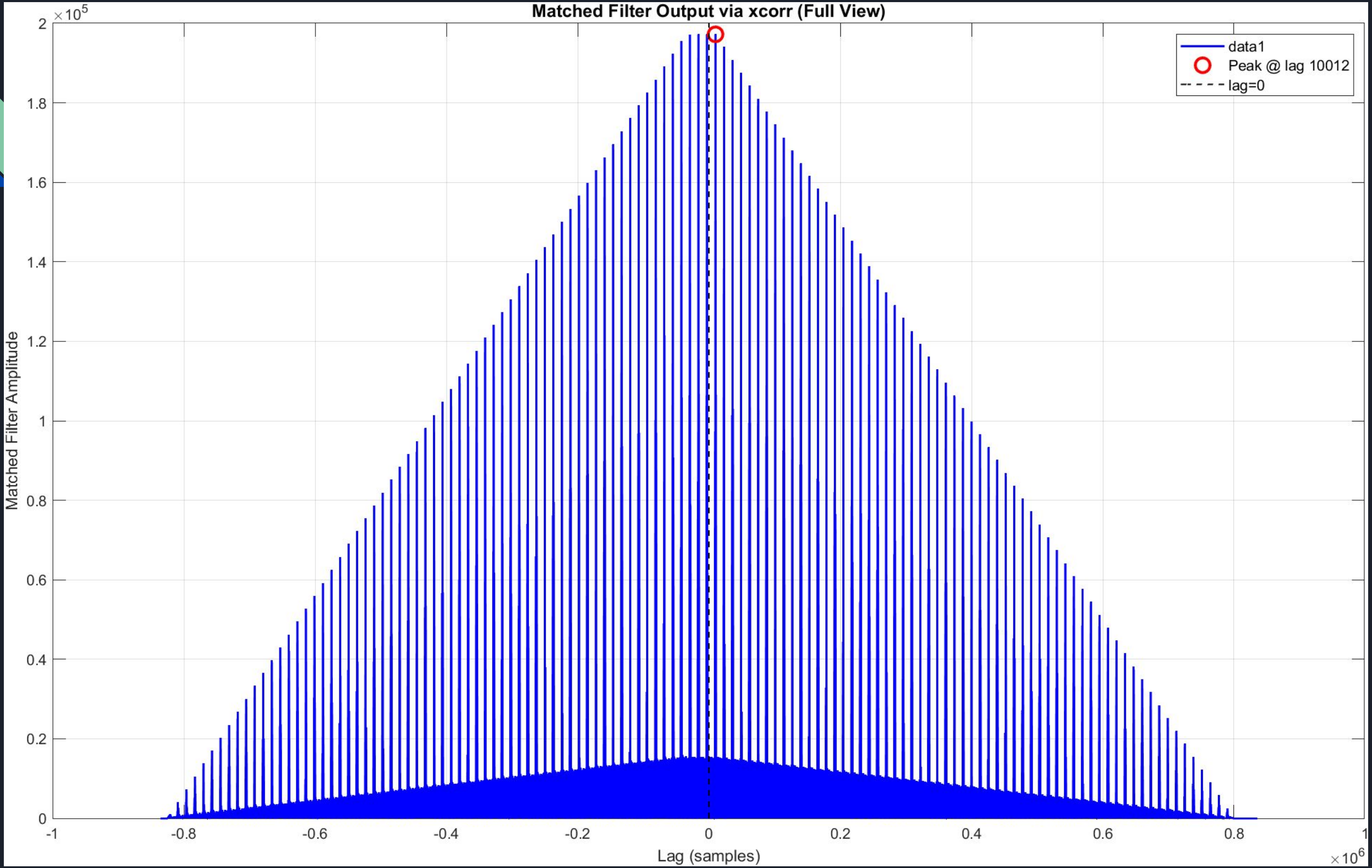


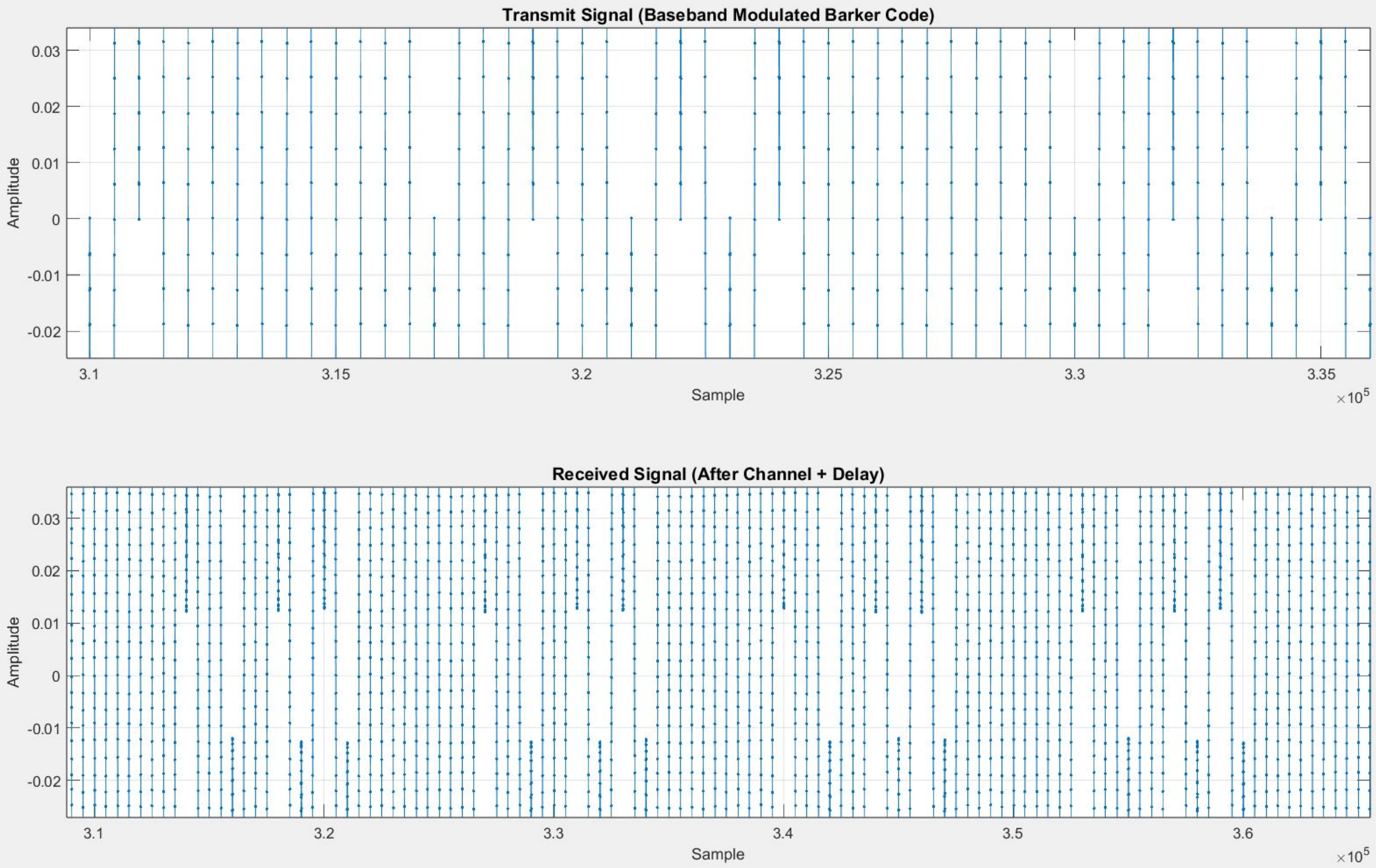
TX Baseband after Barker × Sine (Time Domain)
Amplitude
Time (us)
Signal 1
Sine wave
Amplitude
Time (us)
Signal 1
Repeated Barker Waveform TX Baseband(Time Domain)
Amplitude
Time (us)
Signal 1
9620.9386 us, 0.2259



TX IF Signal (Frequency Domain)
Relative Gain (dB)
Frequency (MHz)
Data 0
0
-20
-40
-60
-80
-100
-120
-140
-0.400
-0.200
0.000
0.200
0.400
FFT RX Post-LPF (Frequency Domain)
Relative Gain (dB)
Frequency (MHz)
Data 0
VCO output
Relative Gain (dB)
Frequency (MHz)
Data 0


Matched Filter - Peak Region (Delay = 10012 samples, Range = 1501.8 km)
Matched Filter Amplitude
Lag (samples)
×10^5
×10^4
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0.9
0.95
1
1.05
1.1
1.15


Matched Filter Output via xcorr (Full View)
×10^5
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Matched Filter Amplitude
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
×10^6
Lag (samples)
data1
Peak @ lag 10012
lag=0


Transmit Signal (Baseband Modulated Barker Code)
Amplitude
0.03
0.02
0.01
0
-0.01
-0.02
3.1
3.15
3.2
3.25
3.3
3.35
Sample
×10^5
Received Signal (After Channel + Delay)
Amplitude
0.03
0.02
0.01
0
-0.01
-0.02
3.1
3.2
3.3
3.4
3.5
3.6
Sample
×10^5

```
===== BARKER CODE RADAR ANALYSIS =====
TX file: C:/Users/maila/IMA312_GNU_Demo/transmit.dat (835216 samples)
RX file: C:/Users/maila/IMA312_GNU_Demo/receive.dat (800064 samples)

Performing matched filtering via xcorr...

===== MATCHED FILTER RESULTS =====
Peak correlation value: 197219.0188
Sample lag to peak: 10012 samples
Computed target range: 1501800.0 meters (1501.800 km)

===== QUALITY METRICS =====
Signal length (TX): 835216
Signal length (RX): 800064
Correlation output length: 1670431
Peak amplitude (absolute): 197219.02
Max sidelobe level: 197215.18
Peak-to-sidelobe ratio: 0.00 dB

===== EXPECTED vs. COMPUTED =====
Set Delay in GRC (samples): Check your Delay block value
Measured peak lag (samples): 10012
Expected range (for this delay): Set Delay * (c/2) / fs
Computed range (meters): 1501800.0
```

In radar, PRI stands for **Pulse Repetition Interval**, which is the time between the transmission of consecutive radar pulses. It is a critical parameter that determines the radar's maximum unambiguous range and is inversely proportional to the pulse repetition frequency (PRF).

$$Ru = \frac{c \; PRI}{2}$$

Range simply means distance to the target — how far the object is from the radar antenna. A radar measures range by measuring the round-trip time delay between when a pulse is transmitted and when its echo returns.

$$R = \frac{c \, \Delta t}{2}$$

Unambiguous Range is the farthest range for which the radar can uniquely identify the target without ambiguity. If a target is farther than Rmax, its echo will arrive after the next pulse, and the radar will think it’s a closer target than it actually is.