

Cheap X-Band Radar based on RTL-SDR and TV Downconverters

and other approaches

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I. INTRODUCTION

THE IEEE Aerospace and Electronics Society is hosting a "COTS-based" radar competition at the 2020 IEEE International RADAR Conference in Washington DC. The goal of this competition is to create ways for people to "see" radar interacting with the environment. Inexpensive Software Defined Radios operate at relatively low frequencies compared to the size and range of target found at the IEEE radar competition. Higher frequencies provide better performance, but are more expensive and more difficult for an amateur to assemble.

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A. The Challenge

There are some requirements we must meet for the competition and some that are optional. The device shall meet the following specification:

- [1] Minimum Value Radars must cost less than USD\$700
- [2] State of the COTS Art Radars must cost less than USD\$3k
- [3] The system can only be constructed from Commercial-off-the-shelf (COTS) components. This does not exclude custom PCBs or antennas and using built-in laptop sound cards / ADCs. The use of commercially-available COTS Radars is also not prohibited, though the system should innovate on the antenna, control, or software.
- [4] The system must comply with FCC Part 15.
- [5] The system should measure parameters, such as location, speed, and separation distance for a small number of targets (a mix of calibration spheres and corner reflectors) from behind a 8 meter by up to 20 meter room. Some targets will be static and some will be moving.
- [6] The testing space will only provide a single 110V US electrical outlet.

Several inexpensive, COTS-based Radars are already available. The most familiar is the Candar from MIT Lincoln Labs. The Candar is a ISM-band (2.4GHz) radar built on an ARM Arduino (Arduino Zero), Minicircuits RF components, and Coffee can directional antennas.¹This is the same radar used for teaching at SRC, including the radar processing live-script.

Other S Band radars include 8 channel arrays.²

II. AN INEXPENSIVE APPROACH

From my work with the Candar, I have identified several challenges to tackle. First, the Candar is susceptible to interference from WIFI, Bluetooth, and other ISM-band emitters. The Candar is relatively expensive, around \$600, due to the high cost the Minicircuits RF components it is constructed from. Although this cost is low for a Radar you can build yourself, its cost is a barrier to hobbyists and students looking to explore. The Candar only determines range or doppler, not both, at any time by using either Doppler processing CW radar or stretch processing FMCW radar and without quadrature sampling implemented. Because it only has a single receive antenna, the Candar is not able to estimate angle-of-arrival. Finally, the Candar's resolution is limited by its frequency.

An improved system would be able to compute range-doppler plots and estimate angle-of-arrival. This system would be built from commodity components to further reduce cost. I propose a radar built from the RTL-SDR. This SDR can cost less than USD \$5 and a readily available to hobbyists. Since 2012, the RTL-SDR has been a favorite of radio hobbyists due to its extremely low cost, and has inspired a number of interesting projects. Previous work has been done by Juha Vieriento build passive radar using the RTL-SDR that features angle-of-arrival estimation.³ There has been a bunch of work on coherent sampling with the RTL-SDR.^{4 5}

¹Candar <https://ocw.mit.edu/resources/res-ll-003-build-a-small-radar-system-capable-of-sensing-range-doppler-and-synthetic-aperture-radar-imaging-january-iap-2011/>

²An indoor S-band radar receive array testbed <https://ieeexplore.ieee.org/document/5494528>

³Passive Radar using RTL-SDR <https://hackaday.com/2015/06/05/building-your-own-sdr-based-passive-radar-on-a-shoestring/>

⁴Thesis https://aaltoodoc.aalto.fi/bitstream/handle/123456789/37163/master_Laakso_Mikko_2019.pdf?sequence=1&isAllowed=y

⁵Phase Corrective Direction Finder <https://www.rtl-sdr.com/an-rtl-sdr-phase-correlative-direction-finder/>

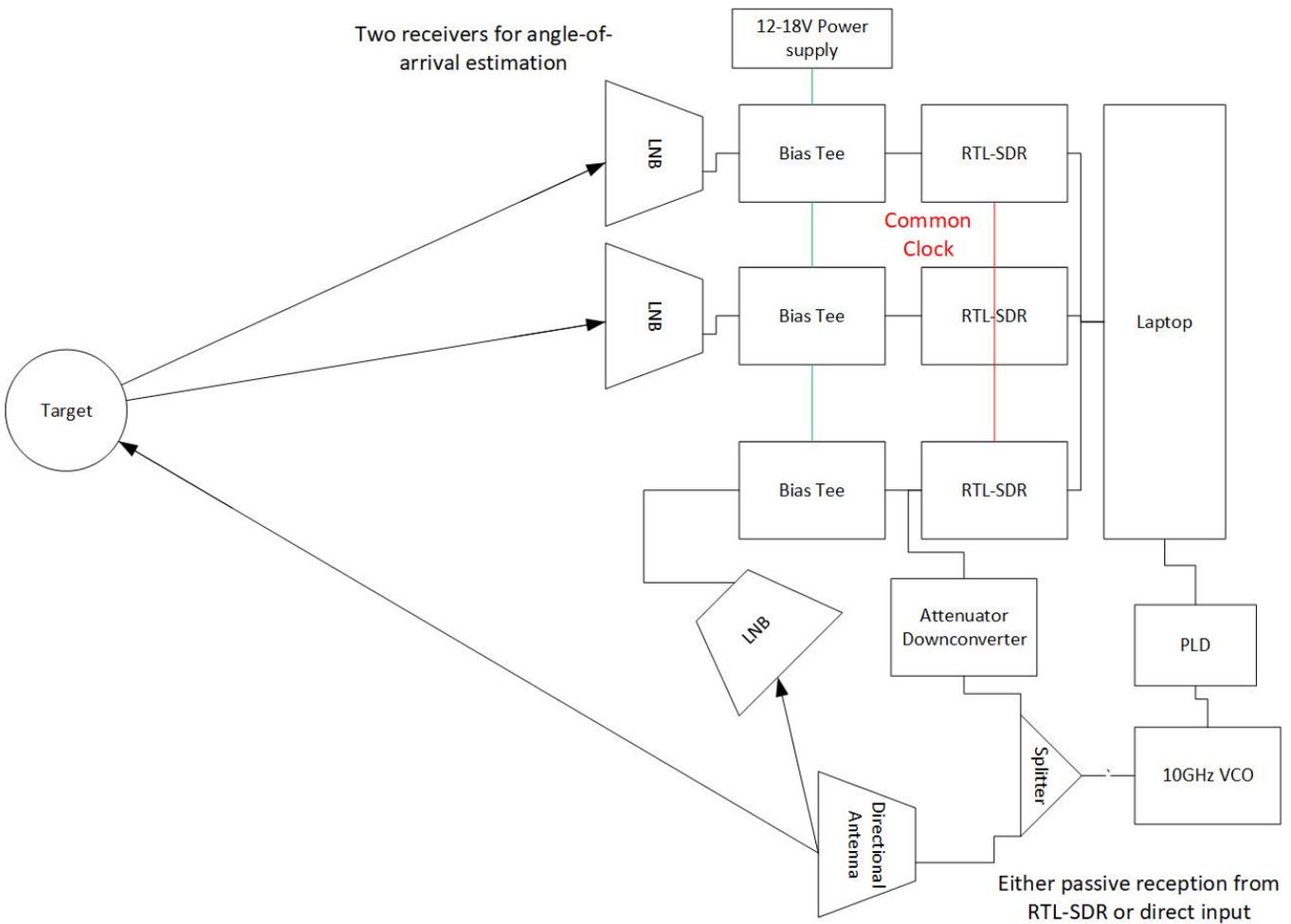


Figure 1: Super Cheap, X-Band, SDR Radar

Item	Quantity	Cost
LNB	3 or 4	\$15
RTL-SDR	3 or 4	\$15
Bias Tee	3 or 4	\$15
Transmitter	1	\$150
	Total	\leq \$400

A. Software-defined Receiver

Vieriento employed multiple RTL-SDRs with a shared clock for the passive radar receiver. While this approach is the most inexpensive, the reliability of the more than three clocks chained together is doubtful. It would be better to use a device designed for coherent sampling, such as the KerberosSDR - 4 Channel Coherent RTL-SDR ⁶.

B. Low-Noise Block Downconverters

LNBS are used in satellite television as the receiver at the front of a dish. These devices are designed to operate in the C (5.4 GHz) and K_u (12-18 GHz) bands and are inexpensive (down to USD \$6) due to their design and economies of scale. There have been a number of experiments in successfully utilizing the RTL-SDR with an LNB. ^{7 8 9 10}

Because the band the LNB is designed for a slightly different frequency than our application, we will have to do some testing to verify that the RF bandpass filter does not attenuate or distort the signal too much.

⁶<https://othernet.is/products/kerberosdr-4x-coherent-rtl-sdr>

⁷Single LNB <https://ok2zaw.blogspot.com/2019/02/10ghz-lnb.html>

⁸Multiple LNBS <https://ok2zaw.blogspot.com/2018/07/10ghz-openweb-rx-at-ol7m-qth-during.html>

⁹Avenger Universal LNB <https://www.rtl-sdr.com/receiving-a-10ghz-beacon-with-rtl-sdr-and-an-avenger-lnbf/>

¹⁰10GHz Moon Beacon <https://www.rtl-sdr.com/receiving-10-ghz-reflected-moon-beacon-rtl-sdr/>

The LNB needs to be powered to function. Normally, this is done by injecting DC into the coax input. Different LNBs take differing voltages, though they usually range from 12-18 volts. DC injection can be done through a Bias Tee, which can either be purchased for around USD\$20¹¹ or built custom. The RTL-SDR V3 also comes with its own built-in DC Injector.

For extra cost, there are kits that include an LNB and Bias-Tee circuit designed to be used with the RTL-SDR.¹²

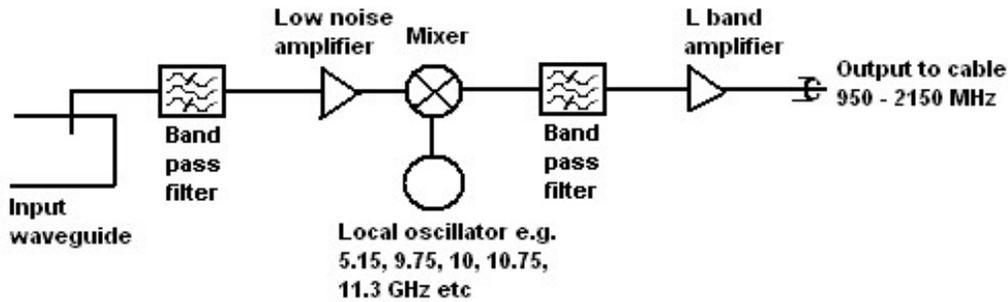


Figure 2: LNB diagram



Figure 3: Bias Tee

C. FCC Compliance

There is an FCC Part 15 band at 10500–10550 MHz restricted to "Intentional radiators used as field disturbance sensors."¹³ Because the FCC restricts the 3-meter Electric field strength to 2500 millivolts per meter at 3 meters, the maximum transmitted power of the radar is limited to 1.5 Watts. To ensure compliance, power would have to be limited to 1 Watt.¹⁴

D. Alternative Downconverters

If the X-band or LNBs do not work out, there are other approaches using COTS parts.

1) *Minicircuits Downconverter*: The Candar makes use of mixers to bring the 2.4 GHz VCO and received signals to the baseband with and bandwidth less than the $\frac{F_s}{2} = 22\text{kHz}$ Arduino ADC sampling maximum. Because the RTL-SDR has a minimum frequency of 500kHz in direct sampling mode,¹⁵ a different Minicircuits mixer may need to be selected, as the one used for the Candar has a limited range of linearity and may not function correctly.

2) *SUP-24000 Downconverter*: The SUP-24000 is another device designed for satellite communications. In this case, it is an upconverter that can be simply modified to be a 2.4GHz downconverter.¹⁶ The mixer costs around USB\$5 on Amazon.

E. Other Alternative Designs

I'd also like to propose some other alternative designs.

1) *L-Band Radar using RTL-SDR*: With a maximum frequency of 1.7GHz, the RTL-SDR could directly receive RF to form a radar. The underlying processing would be the same as the above proposed system. This would still require a secondary transmitter.

¹¹Bias Tee <https://www.amazon.com/Biaser-10MHz-6GHz-Radio-Noise-Amplifier/dp/B07H3P19LH>

¹²LNB SDR Kit <https://www.passion-radio.com/satellite/converter-432-936.html>

¹³FCC 15.245 <https://www.law.cornell.edu/cfr/text/47/15.245>

¹⁴Field Strength Calculation <https://www.giangrandi.org/electronics/anttool/tx-field.shtml>

¹⁵RTL-SDR V3 Datasheet <https://www.rtl-sdr.com/wp-content/uploads/2018/02/RTL-SDR-Blog-V3-Datasheet.pdf>

¹⁶SUP-24000

2) *S-Band Radar using Lime SDR*: The LimeSDR has 4x4 MIMO with a frequency range from 500kHz to 3.8 GHz and costs USD \$299.¹⁷ This SDR could be a radar on its own with the addition of directional antennas.

3) *Harmonic Transmitter using USB to VGA converters*: By the same people who originally developed the rtl-sdr (Osmocom) comes the USB to VGA converted Tx only SDR based on the Fresco FL2000 chip. This converter chip is able to turn H-Sync and V-Sync off and stream bits to the DAC. The maximum fundamental frequency demonstrated is 1.7GHz, with harmonics able to spoof GPS, 3G, LTE, and more.¹⁸ The main challenge with using this transmitter for L-band radar would be the filtering required to get a good signal and the amplification required to get a strong enough reflection to be detected by the sdr receiver. It would also be interesting to combine the R820T2 and FL2000 together with a synchronized clock to form a highly-inexpensive L-band SDR Transceiver.



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¹⁷LimeSDR <https://www.everythingrf.com/News/details/5052-Lime-Microsystems-Introduces-10-GHz-SDR-for-299>

¹⁸USB to VGA SDR Transmitter <https://www.rtl-sdr.com/osmo-fl2k-a-tx-only-sdr-hacked-from-commodity-5-usb-to-vga-adapters-demos-available-for-transmitting-wbfn>