Stupid Cheap Multi-modal / Passive Radar based on RTL-SDR

and other approaches

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Abstract

The abstract goes here.

Index Terms

IEEE, IEEEtran, journal, LaTeX, paper, template.

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.

January 30, 2020

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.

The competition also requires:

[1]The submission of a 4 page concept paper in author’s format by 30 JAN 2020

[2]Sensing results submitted by 29 APR 2020 at 10:00 AM

[3]The BOM must include the price and source for each component. Laptops used do not count, but parts added to laptops (FPGA, specialized cards) must be included.

The scene will be available during the 2020 IEEE International Radar Conference on April 27th through May 1st 2020 in Washington DC, USA. The competition is judged based on how inexpensive, novel, and innovative their systems are and how well participants are able to sense, accurately depict, and describe what is behind the curtain. The hosts are interested in demonstrating the magic of Radar. [1]

There exists several inexpensive, COTS-based Radar that exist. The most familiar is the Candar from MIT Linclon 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.[2]This is the same radar used for teaching at SRC, including the radar processing live-script.

Other S Band radars include 8 channel arrays.[3].

[1]Radar Competition homepage http://ieee-aess.org/radar-challenge

[2]Candar 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/

[3]An indoor S-band radar receive array testbed https://ieeexplore.ieee.org/document/5494528

II. An inexpensive Approach

The goal of the Minimum Value Radar Category is to build a radar for less that $700; I endeavor to build one for far cheaper than that.

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 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 hobbiests and students looking to explore. The Candar only determines range or doppler, not both, at any time by using either stretch processing FMCW radar or Doppler processing CW radar. 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 Vierinento build passive radar using the RTL-SDR that features angle-of-arrival estimation.[4] There has been a bunch of work on coherent sampling with the RTL-SDR. [5] [6]

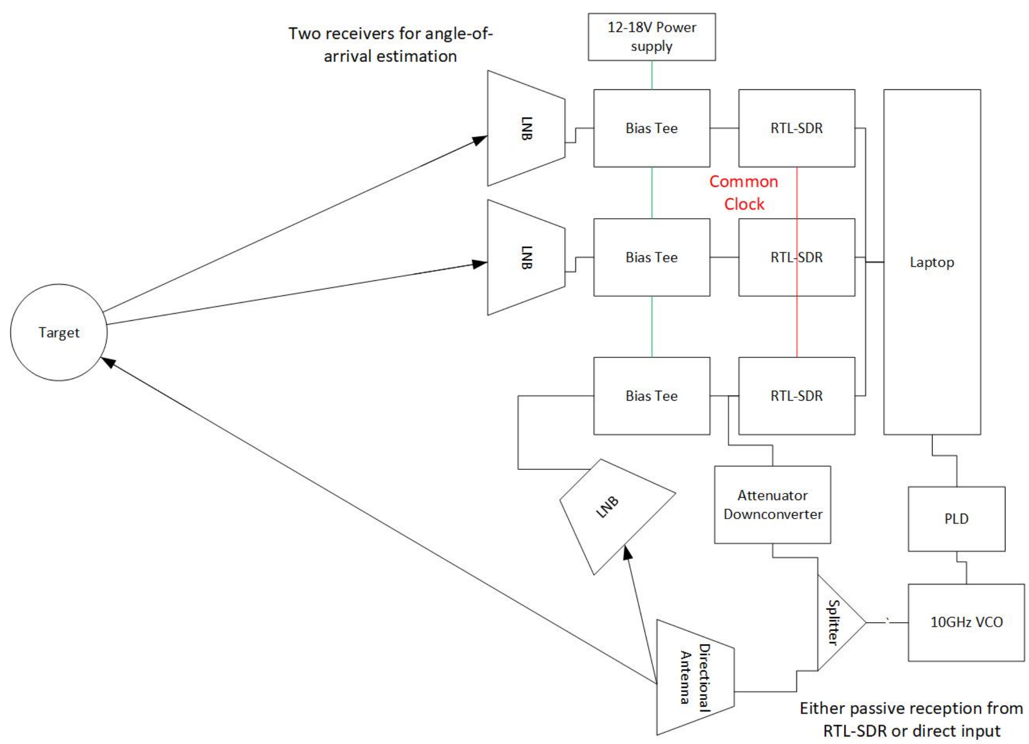

Figure 1. Super Cheap, X-Band, SDR Radar

The total cost of this design is pretty low.

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

Vierinento employed multiple RTL-SDRs with a shared clock for the passive radar receiver. While this approach is the most inexpensive, I'm unsure of the relaibility of the more than three clocks chained together. While we could follow this approach, it would be better to use a device designed for coherent sampling.

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

[5]Thesis https://aaltodoc.aalto.fi/bitstream/handle/123456789/37163/master_Laakso_Mikko_2019.pdf?sequence=1&isAllowed=y

[6]Phase Corrective Direction Finder https://www.rtl-sdr.com/an-rtl-sdr-phase-correlative-direction-finder/

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.

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$20 [11] or built custom. The RTL-SDR V3 also comes with its own built-in DC Injector.

For extra cost, you can purchase kits that include an LNB and Bias-Tee circuit designed to be used with the RTL-SDR. [12]

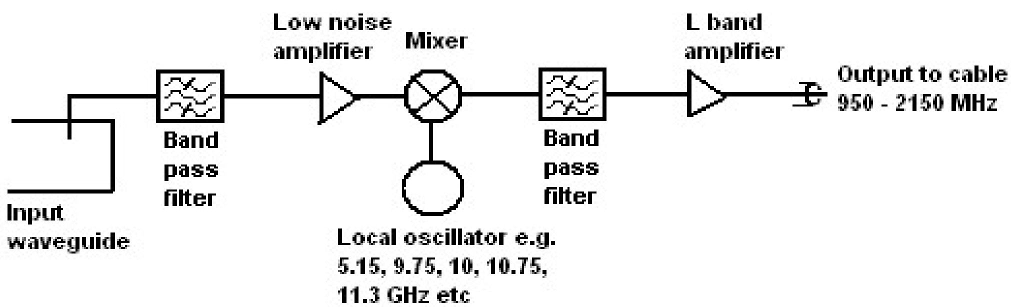

Figure 2. LNB diagram

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, it would be good to limit the power to 1 Watt. [14]

D. Alternative Downconverters

If the X-band or LNBs do not work out, we could try a couple 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 that the $\frac{F_s}{2} = 22$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 .

[7] Single LNB https://ok2zaw.blogspot.com/2019/02/10ghz-lnb.html
[8] Multiple LNBs https://ok2zaw.blogspot.com/2018/07/10ghz-openweb-rx-at-ol7m-qth-during.html
[9] Avenger Universal LNB https://www.rtl-sdr.com/receiving-a-10ghz-beacon-with-rtl-sdr-and-an-avenger-lnbf/
[10] 10GHz Moon Beacon https://www.rtl-sdr.com/receiving-10-ghz-reflected-moon-beacon-rtl-sdr/
[11] Bias Tee https://www.amazon.com/Biaser-10MHz-6GHz-Radio-Noise-Amplifier/dp/B07H3P19LH
[12] LNB SDR Kit https://www.passion-radio.com/satellite/converter-432-936.html
[13] FCC 15.245 https://www.law.cornell.edu/cfr/text/47/15.245
[14] Field Strenght Calculation https://www.giangrandi.org/electronics/anttool/tx-field.shtml
[15] RTL-SDR V3 Datasheet https://www.rtl-sdr.com/wp-content/uploads/2018/02/RTL-SDR-Blog-V3-Datasheet.pdf

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.

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 reciever. 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.

III. Preliminary Design Review

In this section, we analyze the design in terms of expected performance and how it would meet competition requirements.

IV. Performance Expectations

V. Conclusion

The conclusion goes here.

Appendix A

References

[1] H. Kopka and P. W. Daly, *A Guide to LaTeX*, 3rd ed. Harlow, England: Addison-Wesley, 1999.

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[16] SUP-24000
[17] LimeSDR https://www.everythingrf.com/News/details/5052-Lime-Microsystems-Introduces-10-GHz-SDR-for-299
[18] USB 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-wbfm-