EEC 134AB

Application Note

Radar System Design for RF

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Group: Diode Hard 3

Fundamental Design of Radar:

The radar design we decided to go with for the quarter 2 design is one that is fundamentally based of the radar design of quarter 1. The radar design for quarter 1 was already centered around 2.4 GHz with around a frequency span of 100 MHz. The radar design needed the basic components necessary for any FMCW radar design: A way to modulate the signal, a way to split the modulated signal into a transmitter and to act as a local oscillator, a mixer to combine the local oscillator and RF signal into an IF signal, and finally an ADC in order to send the signal to be digitally processed in some form or fashion. These design aspects were present in the quarter 1 system which can be shown here:

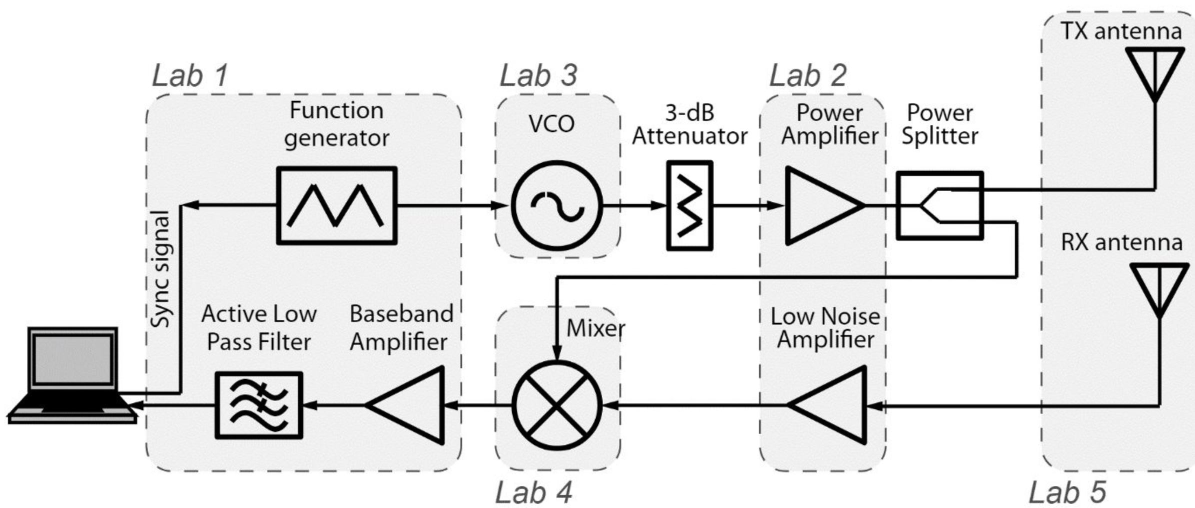


Fig 1. Radar System Design Quarter 1

In our system we decided to keep most of the same components that the quarter 1 system used for these tasks. The combination of a microcontroller with an external DAC and VCO was used as a way to modulate our signal. A simple power splitter was used to split the signal into the mixer and the transmitting antenna. A simple level 10 mixer was used to mix the local oscillator signal and the received signal. An ADC from a computer was used to digitally process the information found in the IF signal in order to find the range of objects detected at a distance. The additions to the fundamental system shown here that were implemented in quarter 1 such as attenuators, amplifiers, and filters were also transferred over to our quarter 2 system in some way with some other additions also present from our own design choice.

<u>Antenna Choice:</u>

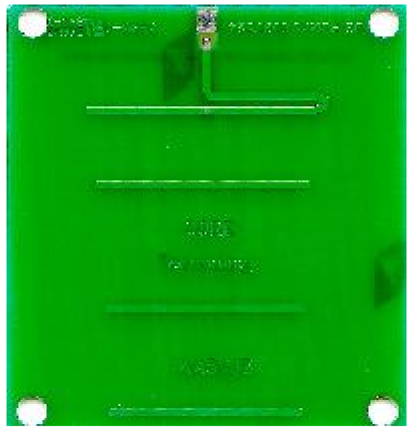


Fig 2. Yagi Antenna

In quarter 1 we used coffee can antennas as both the transmitting and the receiving antennas for the radar. In this quarter we decided to use an antenna that featured more directionality as well as had more gain while weighing less than the cumbersome coffee cans. The antenna that we decided to go with ended up being the Yagi antenna. The Yagi antenna featured a design that centered its frequency around 2.4 GHz and had a lightweight package as well as easy to solder connections for the system. The design and data sheet can be shown here:

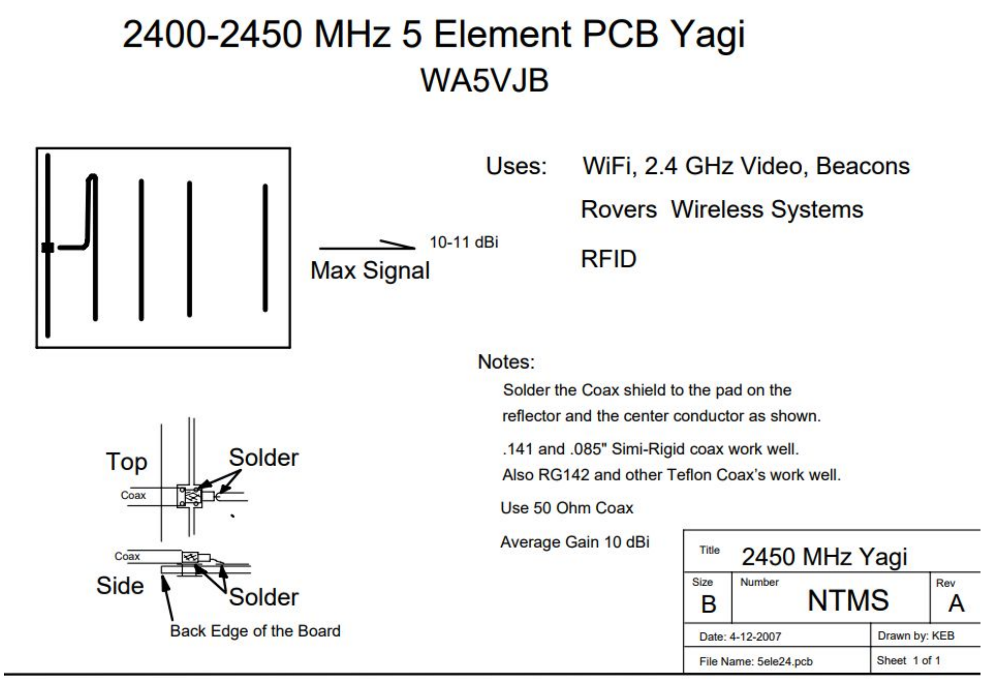


Fig 3. Yagi Antenna datasheet preview

The reason for going for the Yagi antenna in particular was due to the fact that Yagi antennas are designed to have large directionally in order to make use of most of the power used for transmitting found within the inputted signal. The Yagi antenna also has a good amount of gain which means there is less need for amplifiers before it, which saves a lot on power consumption already.

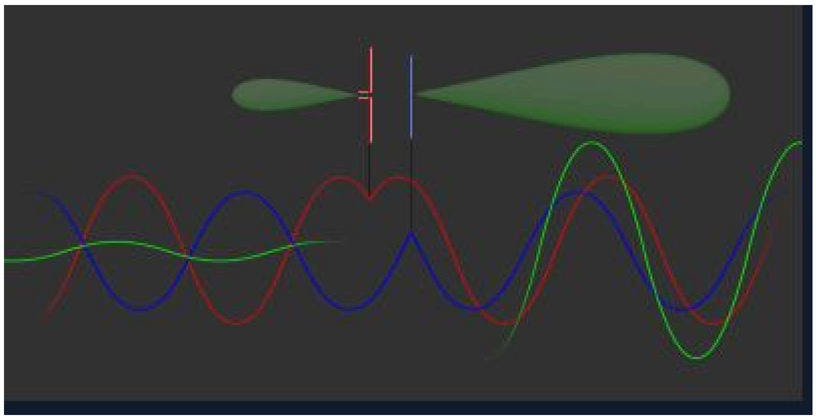
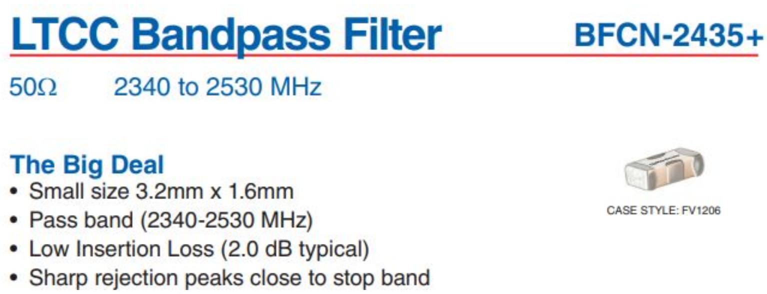


Fig 4. Directionality of a Yagi Antenna

<u>RF Component Selection:</u>

1.) Band-pass filter


LTCC Bandpass Filter **BFCN-2435+**

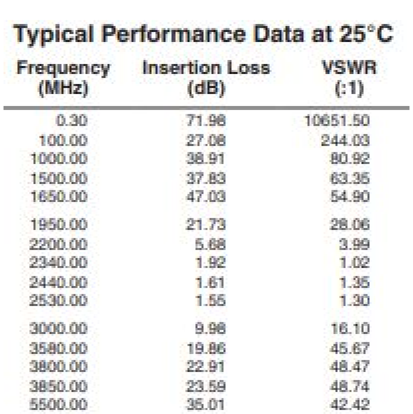
50Ω 2340 to 2530 MHz

The Big Deal
- Small size 3.2mm x 1.6mm
- Pass band (2340-2530 MHz)
- Low Insertion Loss (2.0 dB typical)
- Sharp rejection peaks close to stop band

CASE STYLE: FV1206

Fig 5. BFCN-2435+ BP Filter

Fig 6. Insertion loss characteristic of BP filter


Typical Performance Data at 25°C

Frequency (MHz)	Insertion Loss (dB)	VSWR (:1)
0.30	71.98	10651.50
100.00	27.08	244.03
1000.00	38.91	80.92
1500.00	37.83	63.35
1650.00	47.03	54.90
1950.00	21.73	28.06
2200.00	5.68	3.99
2340.00	1.92	1.02
2440.00	1.61	1.35
2530.00	1.55	1.30
3000.00	9.98	16.10
3580.00	19.86	45.67
3800.00	22.91	48.47
3850.00	23.59	48.74
5500.00	35.01	42.42

The band-pass filter chosen for the radar design was the BFCN-2435+ filter. This filter is what ultimately decides what to choose as our frequency range as anything that is outside and near the stopbands gets attenuated to a huge degree, typically 20 to 25dB+ of attenuation in fact. The BF filter has a low insertion loss that is usually a little bit under 2dB for the range of 2300-2500 MHz; therefore, our VCO will be tuned to around this frequency span centered around 2.4 GHz. Having this band-pass filter placed after our receiver antenna will also stop signals from the local oscillator port of a mixer from reaching the receiver antenna and transmitting out into the air. The band-pass filter though is mainly for filtering our unwanted signals coming into our radar that is not within our span as to not interfere with our mixer and created unwanted spurious signals.

2.) VCO

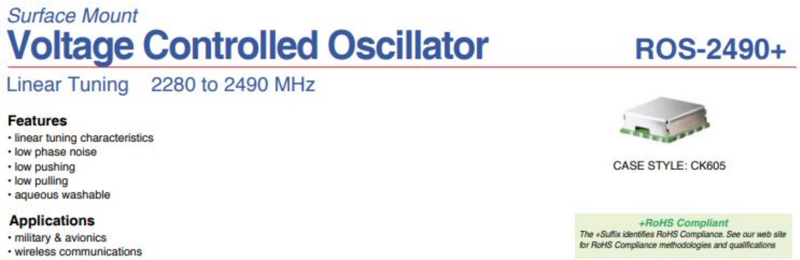


Fig 7. The ROS-2490+ VCO

Fig 8. VTune specs

V TUNE	TUNE SENS (MHz/V)	FREQUENCY (MHz)			POWER OUTPUT (dBm)		
		-55°C	+25°C	+85°C	-55°C	+25°C	+85°C
0.00	32.97	2227.6	2218.2	2210.9	7.44	7.64	7.69
0.50	30.02	2243.7	2234.7	2227.5	7.46	7.64	7.75
1.00	30.15	2259.1	2249.7	2242.6	7.59	7.75	7.84
1.50	31.28	2274.2	2264.8	2257.4	7.62	7.83	7.93
2.00	32.55	2290.2	2280.4	2272.7	7.58	7.83	7.98
2.50	34.34	2306.6	2296.7	2288.7	7.67	7.88	7.99
3.00	35.17	2324.0	2313.8	2305.4	7.75	7.92	8.08
3.50	36.22	2342.1	2331.4	2322.9	7.83	8.04	8.13
4.00	36.73	2360.5	2349.5	2340.5	7.80	8.05	8.18
4.50	36.53	2379.1	2367.9	2358.6	7.81	8.08	8.21
5.00	36.25	2397.4	2386.2	2376.7	7.81	8.02	8.18
5.50	34.86	2415.8	2404.3	2394.4	7.87	8.01	8.11
6.00	33.94	2433.0	2421.7	2411.9	8.05	8.15	8.13
6.50	33.05	2450.3	2438.7	2428.7	8.32	8.36	8.30
7.00	32.48	2466.7	2455.2	2445.1	8.47	8.62	8.49
7.50	31.19	2482.9	2471.5	2461.0	8.51	8.66	8.63
8.00	30.27	2498.8	2487.1	2476.7	8.56	8.79	8.74
8.50	29.64	2513.8	2502.2	2491.8	8.89	8.89	8.82
9.00	29.18	2528.9	2517.0	2506.5	9.09	9.01	8.91
10.00	28.61	2557.9	2545.9	2534.9	9.47	9.37	9.26

The VCO chosen must be able to work with the Teensy 3.1/3.2/3.5/3.6 Microcontroller and the MCP4921 external DAC in order to generate a modulating signal. The VCO chosen for this was the ROS 2490+ from Mini-Circuits. This VCO had a tuning range from 2218.2 to 2545.9 MHz which was in line with our centered 2.4 GHz design. Using a tuning voltage going from 4.00 – 10.00 V in order to match the settings of our band-pass filter allows us to have a modulating signal that fits well into our design specifications with an average power output of around ~8 dBm. The frequency range of this configuration is 2349.5 – 2545.9 MHz. In order to achieve this frequency, the triangle teensy code from quarter one was edited in order output from a range of 2.00 – 5.00V and an external noninverting amplifier circuit was designed for a gain of 2, or 3dB, in order to amplify the DACs output to the correct output for our VCO tuning range. This meant the power supply needed to be increased to feed 10V into our system unfortunately.

3.) Splitter

Fig 9. The SP-2U1+ Splitter

The splitter chosen was the SP-2U1+ splitter due to its operating frequency of 2300-2500 MHz which fits nicely into our center frequency of 2.4 GHz for our radar. The splitter features a standard 3dB loss while splitting the signal into two channels while only having a conversion loss of around 0.5dB around our center frequency which totals to around 3.5dB of loss in total. This low insertion loss allows us to choose a smaller amplifier for our transmitting antenna input section while not causing too many complications for the input of our mixer in the other channel it splits into.

4.) Mixer

Fig 10. The MCA1-42LH+ Mixer

Fig 11. Conversion Loss Specs

Frequency (MHz) RF	Frequency (MHz) LO	Conversion Loss (dB) LO +10dBm
1000.10	1030.10	6.55
1200.10	1230.10	5.97
1500.10	1530.10	5.49
2000.10	2030.10	6.09
2200.10	2230.10	6.10
2500.00	2530.00	5.83
3000.10	3030.10	5.23
3500.10	3530.10	5.48
4000.10	4030.10	6.81
4200.10	4230.10	7.86

The mixer chosen was the MCA1-42LH+ mixer from MiniCircuits for our radar design. This mixer is a level 10 mixer with very low conversion loss around the operating frequency of our system from ~2300-2500. This low conversion loss of 6dB gives us less amplification to worry about in the baseband part of our design which reduces the amount of noise that might get amplified at that stage. The 10dBm requirement for the LO port is easily achievable in our design since the power output of our VCO is already near this requirement. Even with the loss from the splitter, an amplifier before the mixer or before the splitter makes this requirement easily attainable without needing to add too much more power consumption in the process.

5.) LNA(s)

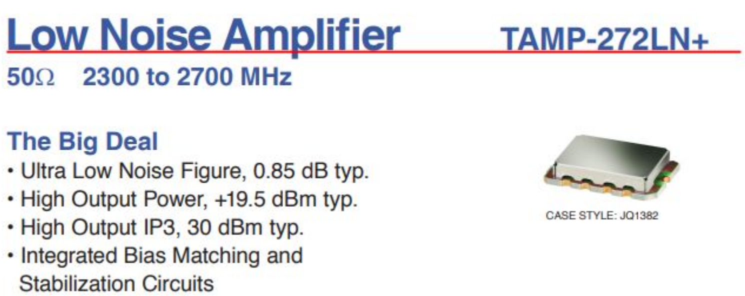


Fig 11. TAMP-272LN+ Low Noise Amplifier(s)

Fig 12. LNA Gain specs

FREQUENCY (MHz)	GAIN (dB)
2300.00	14.54
2320.00	14.49
2340.00	14.43
2360.00	14.38
2380.00	14.33
2400.00	14.28
2420.00	14.23
2440.00	14.18
2460.00	14.13
2480.00	14.07
2500.00	14.02
2520.00	13.97
2540.00	13.92
2560.00	13.86
2580.00	13.81
2600.00	13.75
2620.00	13.70
2640.00	13.64
2680.00	13.54
2700.00	13.48

The LNA(s) chosen for this design was the TAMP-272LN+ LNA that operates well under a span of 2300 to 2700 MHz in general. This operating frequency fits nicely with the operating frequency of our BP filter and our VCO so a good input gain of ~14dB will be achieved at all times while not having too much noise figure added in the process. The LNA(s) will be placed in the areas were amplification is necessary such as before the splitter in order to amplify the circuit to meet the LO specification of the Level 10 mixer and in order to also give the transmitting antenna enough power output to reach the distances required by the competition. Two more LNAs will be necessary at the input of our mixer's RF port in order to boost up the signal that comes from the RF input of our radar which will be very low at reception. This ensures that our mixer's IF signal has enough power to be able to be detected within our baseband since mixers in general tend to be passive elements in radar design.

6.) Attenuator

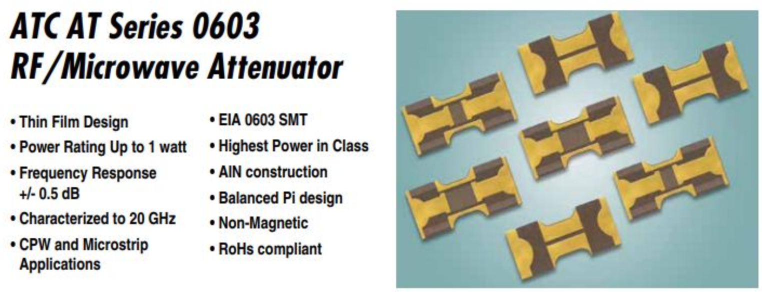


Fig 13. 1284-1848-2-ND 5dB Attenuator

The attenuator chosen for our RF design is Digi-Key's 5dB attenuator from the American Technical Ceramics manufacturer. This 5dB attenuator was chosen due to its operating frequency of DC to 20 GHz which is well within the range of our radar specs. The attenuator was chosen in order to lower the power output of our VCO's 8dBm output level. Having our VCO's power output lowered and then amplified by the LNA present before the splitter allowed us to meet the power specifications of our LO level 10 mixer and the output requirements chosen for our antenna at transmitting. The attenuator at the input of the LNA will cause the noise figure to rise slightly unfortunately.

Conclusion:

When designing the RF portion of your radar system, its best to keep certain things in mind: Have a fundamental system to work with that will ideally get the job done. Make sure you understand the input specification of each of your components. Some components, like mixers or LNA's, have certain power inputs that won't break the component but will cause it to behave non-linearly such as when reaching near the 1-dB compression point or 3-dB spurious signal area of a component. Try to design your system without adding too much non-linearity to it in order to get good system performance. Make sure to keep in mind conversion/insertion loss within components since no components are lossless. Even when matching the circuits well, there will still be some reflections so try to design your system to have a bit more power than you really need it to in order to account for this. Finally, the use of band-pass filters in the RF block of design is useful in order to not only keep out unwanted signals, but to also isolate signals so they don't go to unwanted locations in your design. A good example is the band pass filter we placed at the output of our Rx antenna stage. This allows our Rx antenna to only act as a receiver and not a transmitter due to leaking signals that come from the RF port which tend to be mixed signals that are hopefully outside your BP filter's frequency span. Adding another BP filter in-between the VCO and the mixer is also a good idea in hindsight. As long as your system is designed around your operating frequency with a reasonable frequency span and you match the design specs of each component, the radar should work well in the RF stage and the only complication at that point is how well you want it to work with what distances one has in mind prior to the design realization.