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ECE 432 - MICROWAVE CIRCUIT DESIGN II

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Project II: FSK Reciever

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1 *Abstract*

–This paper describes the process of designing, building, and testing a FSK receiver. The FSK receiver design described consists of: a LNA, a Wilkinson splitter, 2.4 and 2.6 GHz BP filters, as well as 2.4 and 2.6 GHz diode detectors. This paper will describe: ADS simulation results, layout, PCB fabrication, and testing in detail first at the component level, then at the system level. This paper does not cover the design or implementation of an antenna, instead the LNA will be driven directly from a signal source.

Objectives

The objective of this project is to design, build, and test a FSK signal detection circuit with the following specifications:

- Frequency Range: 2.4 to 2.6 GHz
- Reliably distinguish between 2.4 and 2.6 GHz signals
- Incorporate 3 dB power divider to split 2.4 and 2.6 GHz
- Amplifier gain: >10 dB
- Amplifier (S11): <-10 dB
- 2.4 and 2.6 GHz BP filters (S21): >-4 dB
- Incorporate diode detectors to convert high frequency signals to DC
- All stages of the design must be properly matched

2 Theory

The concept for this FSK design is: If a 2.4 GHz signal is detected at the output a digital "0" has been transmitted, and if a 2.6 GHz signal is detected a digital "1" has been transmitted [1]. The received low power signal (directly from a signal generator) is amplified by the LNA, then split into two identical copies using the Wilkinson power divider. These identical signals then are passed or rejected by the narrow band 2.4 and 2.6 GHz filters. The resulting signal is then extracted and converted to DC using the 2.4 and 2.6 GHz diode detectors.

2.1 Amplifier

When designing an FSK reciever isolation, power input, gain and power efficiency, all must be taken into account. Because the device is designed to be a low power reciever, typical input signals are less than -15 dBm. This means the expected input power will be less than 1 mW.

For the LNA we used the PSA4-5043+ ultra low noise MMIC amplifier from mini-circuits. According to mini-circuits the PSA4-5043+ is internally matched for 50 Ω and offers a gain >10 dB at the design frequencies. With no need for external biasing, or impedance matching, the only considerations were: Layout, AC/DC coupling capacitors, and a bias-tee for the DC power supply.

2.2 Wilkinson Splitter

The Wilkinson splitter implements a $\frac{\lambda}{4}$ transmission line with a higher transmission line impedance. This re-positions the initial impedance of 50Ω on the smith chart to a new position normalized to $\sqrt{2} \cdot 50$ and places the new impedance at exactly $\sqrt{2}$ on the smith chart. This splits the signal in half. The circuit is matched by exploiting the fact that $\frac{2}{\sqrt{2}} = \sqrt{2}$ and that $2 \cdot 50 = 100$, the signal impedance is then cut in half on the other side of the circuit so that any reflected signal sees the exact same 50Ω input as before. The Wilkinson splitter is very flexible in design implementation and will remain fairly isolated even a after $\frac{\omega}{2}$ deviation.

It was noted early on that the circuit description for the Wilkinson splitter required a different transmission line length for each frequency to ensure correct matching. This was disregarded due to adequate matching (isolation went down by 2dB) and still correct power splitting, if the circuit was simply designed to respond to 2.5GHz. This removed some design constraints from the circuit(such as asymmetrical component printing for the two different loads) from the project.

2.3 Narrow Band-pass Filters

Several designs were taken into consideration for the 2.4 and 2.6 GHz band pass filters. Size, roll off, and attenuation were all factors. With the need for fairly narrow band width filters(100 MHz) and steep roll off for separation of frequencies a third order maximally flat BP filter was chosen. A hairpin configuration was chosen to keep the circuit as small as possible. It was also noted that with this configuration a steeper roll off could be attained with less attenuation.

2.4 Diode Detectors

The purpose of the diode detector is to rectify the RF power in the pass band into a DC voltage. The RF impedance matching network is vital to achieving the best performance from a diode detector circuit. By minimizing the amount of input reflections in the circuit, the majority of the power can be passed through. However, the diode due to various factors (Namely C_j and R_j in Figure 1) is a non linear device. The presence of C_j and R_j cause signal power loss that is frequency dependent. For maximum output all of the of the incoming RF voltage should appear across R_j.

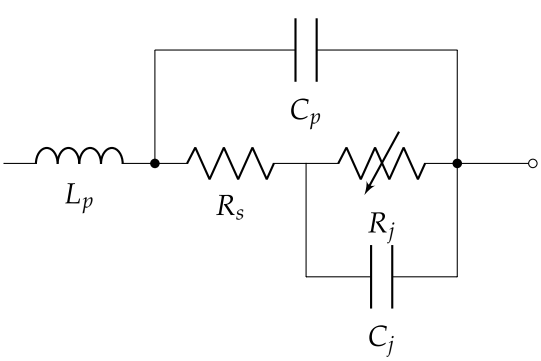

Figure 1: Model of the diode

3 Design, Simulation, and Test Results

3.1 Low Noise Amplifier

The layout recommendations from mini-circuits [2] were followed to create the following layout design and manufactured PCB shown in Figures (2) and (3).

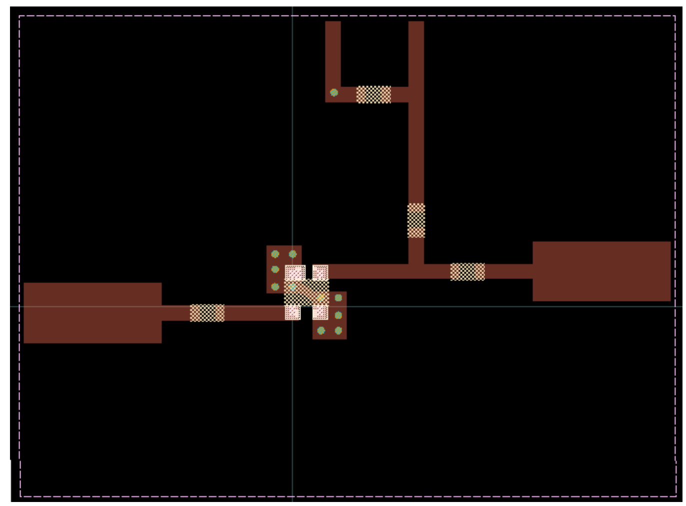

Figure 2: *ADS layout of LNA using mini-circuits PSA4-5043+.*

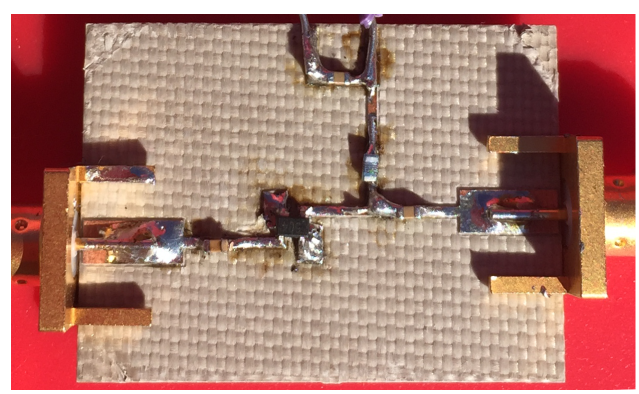

Figure 3: *Manufactured LNA circuit using mini-circuits PSA4-5043+.*

The S-parameters of the manufactured LNA were measured on the VNA and compared with the S2P model from mini-circuits with the results shown in Figure (4) and summarized in Table (1).

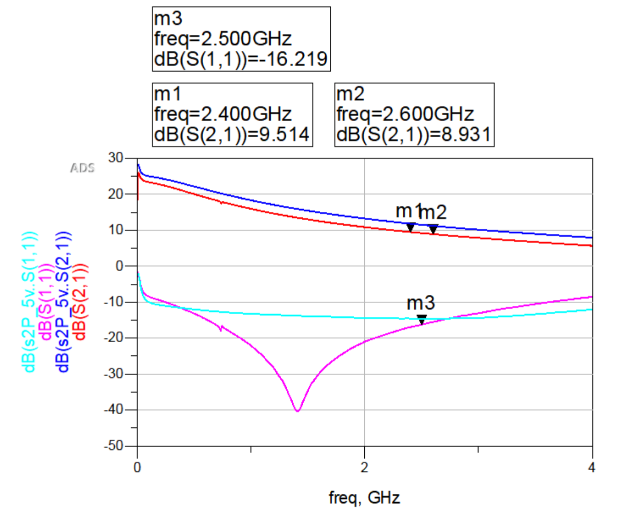

Figure 4: *Measured vs. Simulated S21 and S11 of LNA circuit.*

	Simulated (dB)		Measured (dB)	
f (GHz)	2.4	2.6	2.4	2.6
S11	-14.55	-14.59	-16.95	-15.53
S22	11.85	11.23	9.51	8.93

Table 1: *Measured vs. Simulated S11 and S21 of LNA circuit.*

The return loss of the manufactured circuit was measured was slightly better than the return loss from the simulations. The gain, however, was slightly below the simulations and the design specification of >10 dB. Taking the manufacturers ideal measurement conditions into consideration we expected a small drop in gain due to parasitic losses. Given the time, a two-stage amplifier using the PSA4-5043+ may have been a better choice. While raising the noise floor, the gain could have been increased to be well within the design specifications.

3.2 Wilkinson Splitter

The circuit optimized for 2.5 GHz circuit met the design specifications in simulation, so we created a layout, manufactured a circuit board, then soldered the components and connectors. The manufactured circuit isshown in Figure (5).

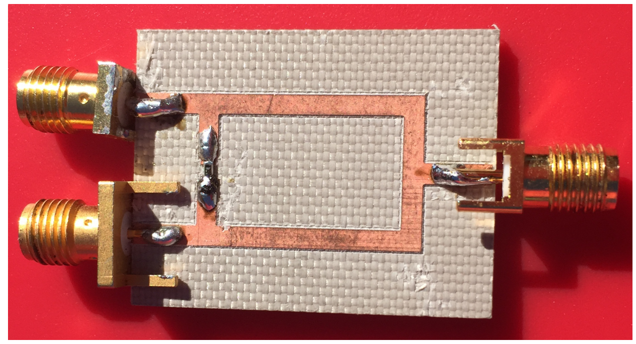

Figure 5: *Manufactured Wilkinson splitter circuit.*

The simulated results are shown in Figure (6).

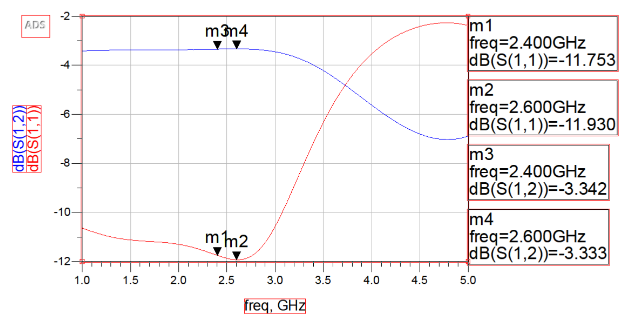

Figure 6: *Simulated results of Wilkinson splitter.*

Unfortunately the S2P file that we saved from the VNA was corrupted but the results were nearly the same with S11 <-10 dB and S12, S13 around -3 dB for 2.4 and 2.6 GHz.

3.3 2.4 and 2.6 Ghz filters

When tested the initial 2.4 and 2.6 GHz filter designs that were fabricated had a shift in frequency of approximately 200 MHz. After further optimization, including EM simulations with the ports defined properly, second layouts were designed and the circuits manufactured shown in Figures (7) and (9).

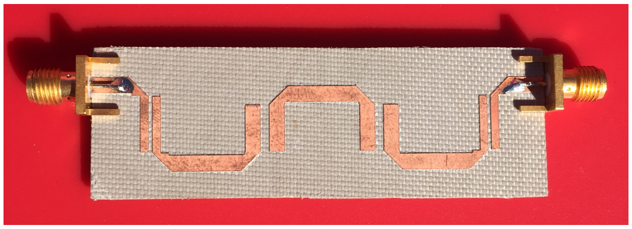

Figure 7: *Manufactured 2.4 GHz filter.*

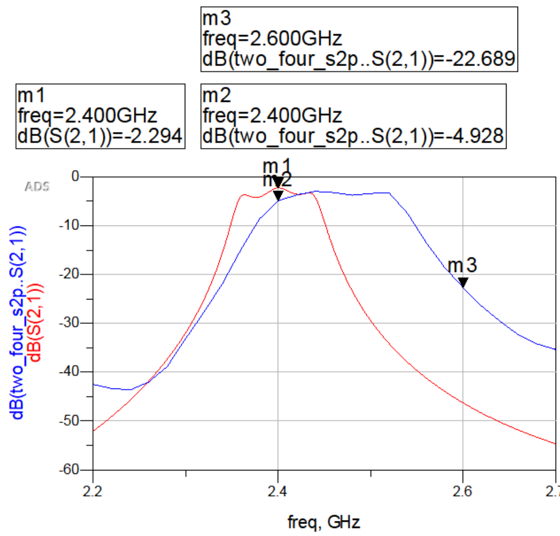

Figure 8: *Simulated vs. measured results of 2.4 GHz filter*

The manufactured 2.4 GHz filter response was slightly shifted by about +50 MHz and the gain dropped a few dB. Although the simulated 2.4 GHz filter met the specifications the manufactured one had less gain, a wider bandwidth, was shifted and only had attenuation of -22 dB at 2.6 GHz(An oversight at the time that will become important later in the performance of the FSK). Due to time constraints no further optimization of the circuit was performed.

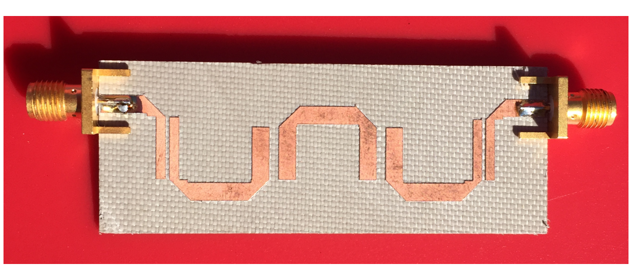

Figure 9: *Manufactured 2.6 GHz filter.*

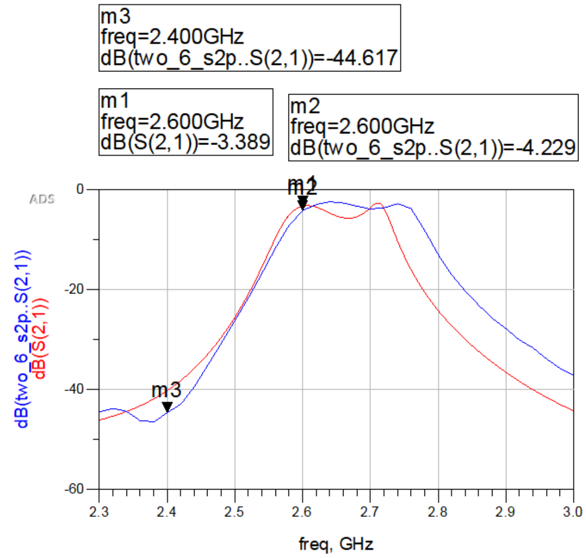

Figure 10: *Simulated vs. measured results of 2.6 GHz filter*

The 2.6 GHz filter simulation and measured results agreed much better with only a slight decrease in gain, a slightly wider bandwidth, and an attenuation of -44 dB at 2.4 GHz. This filter met all of the design specifications, although it was also shifted about +50 MHz as well.

3.4 2.4 and 2.6 GHz Diode Detectors

The design and fabrication of the diode detectors was a little less straightforward. We designed manufactured and tested many different versions using SMD components for matching, as well as single stub matching networks. In the end the 2.4 GHz detector that had the best performance utilized single stub matching and the 2.6 GHz detector that worked the best used SMD components. The final manufactured detectors are shown in Figures (11) and (13).

Figure 11: *Manufactured 2.4 GHz detector with single stub tuning.*

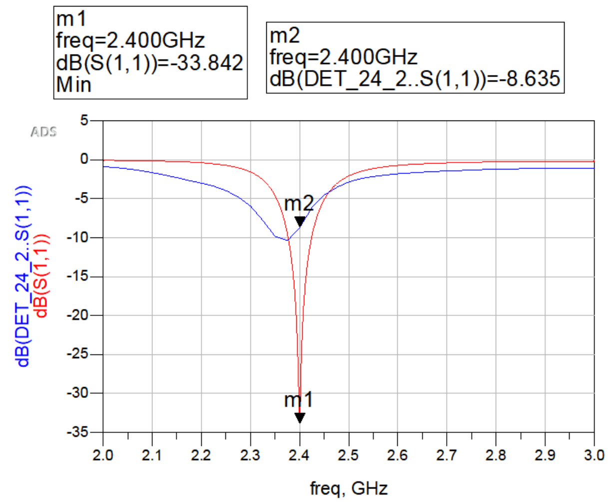

Figure 12: *Simulated vs. measured S11 of 2.4 GHz detector.*

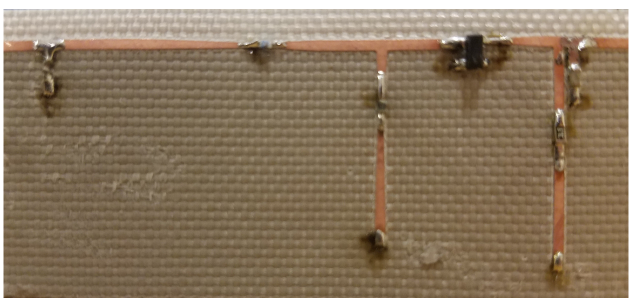

Figure 13: *Manufactured 2.6 GHz detector with SMD component matching.*

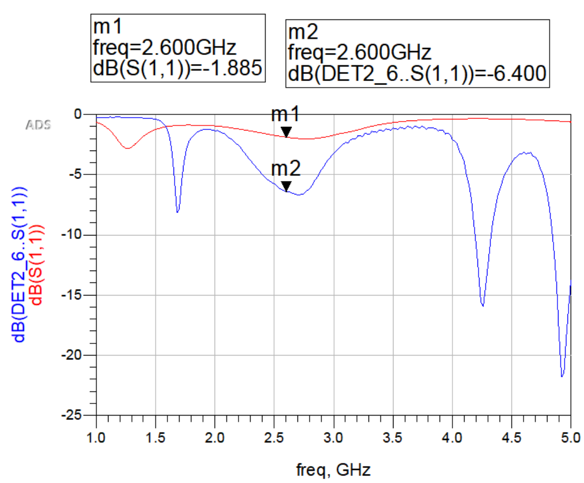

Figure 14: *Simulated vs. measured S11 of 2.6 GHz detector.*

Although the matching wasn't ideal on either one of the detectors the DC output from both detectors was within specification at well over 1 V at 0 dBm of input power, 500 mV at -10 dBm and around 50 mV at -25 dBm input power.

Project Demo Results

The results from the measurements of the FSK demo are shown in Table (2) below.

Input Power (dBm)	DC output (mV)		Isolation (mV)	
	2.4 GHz	2.6 GHz	2.4 GHz	2.6 GHz
-30	11	4.3	1	1
-25	29	13.4		
-20	71	40	11	1.1
-15	158	85		
-10	321	185	70	3.5
-5	633	394		
0	1100	756	330	23.8

Table 2: *Measured DC output and isolation vs. RF input power of FSK at 2.4 and 2.6 GHz*

The DC outputs for both 2.4 and 2.6 GHz were within the design specifications, however, when the isolation between the channels was measured the 2.4 GHz channel had a much higher output power in it's stop band at 2.6 GHz and failed to meet the specifications from [1] of <100 mV at 0 dBm input power.

Discussion of Results

As stated above the DC output power was within the design specifications, where the project failed was the isolation from the 2.4 GHz channel. This design flaw comes from the stop band of the 2.4 GHz filter. As shown in Figure (15) the stop band at 2.6 GHz for the 2.4 GHz filter was at -22 dB whereas the stop band at 2.4 GHz for the 2.6 GHz filter was at -44 dB.

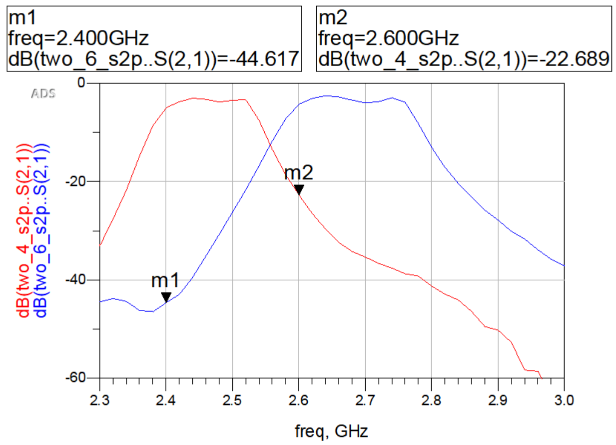

Figure 15: *Measured attenuation in stop bands of 2.4 and 2.6 GHz filters.*

Given the time, the 2.4 GHz filter would have been redesigned to have a smaller bandwidth and a response that was shifted -50 MHz. The amplifier could have had slightly more gain as well, and the matching on the diode detectors could have been improved for better results.

Conclusion

This project in FSK design provided us the opportunity to use the knowledge and experience from previous projects to design, build, and test first at the component then the system level. It was a valuable experience to see how minor deviations from design specifications at the component level can produce unwanted results at the system level. With an ADS workspace of the entire project being turned in as well, most of the schematics, design guides, and layouts were omitted to keep the paper concise and within the recommended length of 6-7 pages.

References

1. C. Furse, R.J. Woodward, and M.A. Jensen, "Laboratory Project in Wireless FSK Receiver Design," IEEE Trans. Education, vol. 47, no. 1, pp. 18-25, Feb. 2004.

2. Mini-Circuits. (n.d.). Retrieved from https://www.minicircuits.com/WebStore/dashboard.html?model=PSA4-5043