FSK Receiver
ECE 432 Microwave Circuit Design II

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***Abstract*—This report documents the successful completion of the Spring 2013 ECE 432 frequency-shift keying (FSK) design project. Topics covered are the design, simulation, and testing of microwave circuits suitable for operation between 2GHz to 3GHz. Specific circuits discussed include a 10+dB gain block, a Wilkenson power divider, high Q bandpass filters, and diode detectors. These elements were combined and tested to demonstrate that two microwave frequencies seperated by only 200MHz could accurately be differentiated from each other by comparing the output voltage of the diode dectors. The target fequencies of 2.4GHz and 2.6GHz had to be shifted down by 100MHz due to inconsistencies in the filters used. However, when adjusted for this issue, the FSK reciever functioned as desired and successfully differentiated between 2.3GHz and 2.5GHz inputs.**

I. FSK Receiver Design

The following sections describe the design and building procedures for each part of the FSK receiver. At the end, the results are documented and analyzed.

II. LNA Design

The gain block used in this design used a PSA4-5043+ MMIC with an input matching network and bias T's. This is a microwave amplifier IC with realizable gain of 10 to 11 dB at 2.4GHz. It is also internally biased so only a single supply voltage needs to be provided. For both simulation and testing, 5 volts was applied to the drain through an external bias T consisting of a 22nH inductor isolating the supply and a 33pF capacitor isolating the load. The input used a single 33pF capacitor to AC couple to the source. FR4 substrate was used with a height of 59mil and 1/2oz copper on both sides. The test board was created using a simple machanical circuit router.

III. LNA Simulation

Simulation of the gain block was done using Agilent's Advanced Design System (ADS) software suite and the provided characterization files for the PSA4-5043+ amplifier. The scattering matrix for the amplifier showed that S11 could be decreased by adding an input matching network.The unmatched S11 is shown in Figure 1. Given that the intention for this circuit is for it to be driven by an antenna, we decided to attempt to preform this matching. Using the Smith chart tool in ADS, a series/stub combination was calculated and used for simulaiton. This was then tuned to provide the minimal S11 at 2.5GHz. This can be seen in Figure 2. With input matching the simulation of the LNA showed a projection of 12 to 11.5 dB of gain over the frequency range of interest as can be seen in Figure 3. The completed simulated circuit schematic is shown in Figure 4.

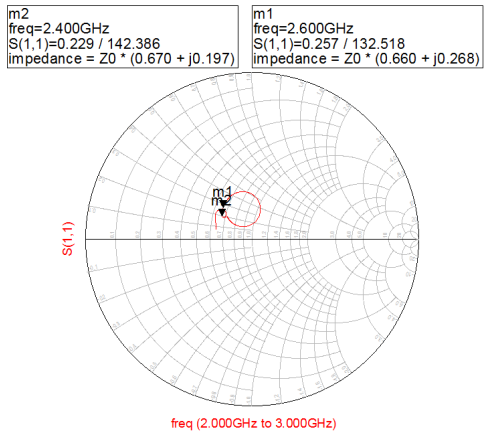

Fig. 1. Simulation results for LNA with matching.

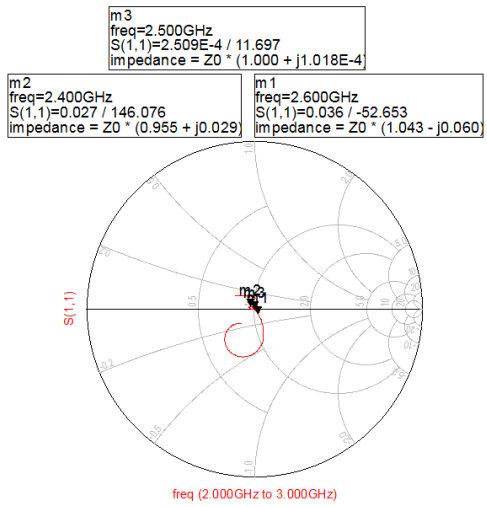

Fig. 2. Simulation results for LNA with matching.

IV. LNA Lab Results

The test board layout was generated using ADS and footprints for connectors were added. This layout was then routed using a mechanical circuit router on 59mil thick FR4 with 1/2oz copper on both sides. Vias to the ground plain were created by drilling 0.35mm holes and then pressing 30AWG

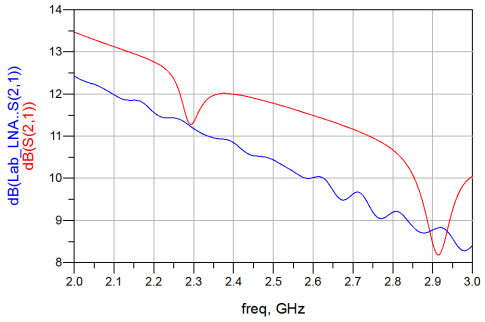

Fig. 3. Simulation gain projection.

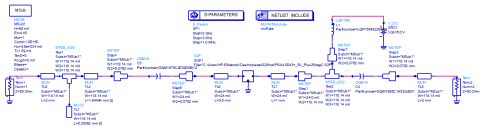

Fig. 4. LNA schematic.

bare copper wire through them. These were then soldered to ensure consistant electrical conectivity. Murata microwave components were used for the AC coupling capacitors and DC bias inductor. Total board size with connector footprints was approx. 1in x 2in. As the blue line in Figure 3 shows, this board was found to produce gain of approximately 11dB at 2.4GHz and 10dB at 2.6GHz. This was less than predicted by simulation but sufficient for the application's targets.

V. Wilkinson Divider Design

The design of the Wilkinson power divider was done with the aid of ADS's built in Wilkinson divider coupler tool[1]. The result can be seen in Figure 5. Transmission line was added on the outputs to be able to connect the bandpass filters. The simulation results, shown in Figure 6, gives close to a -3-dB insertion loss for both 2.4 GHz and 2.6 GHz as expected. Figure 7 shows the layout used when manufacturing the board in the EPL.

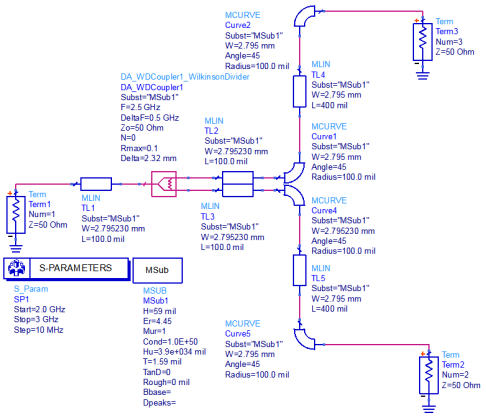

Fig. 5. Wilkinson power divider schematic.

[1]It is available in the DesignGuide -> Passive Circuit menu.

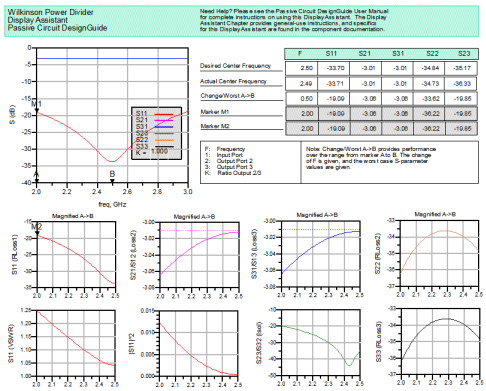

Fig. 6. Simulation results for the Wilkinson power divider.

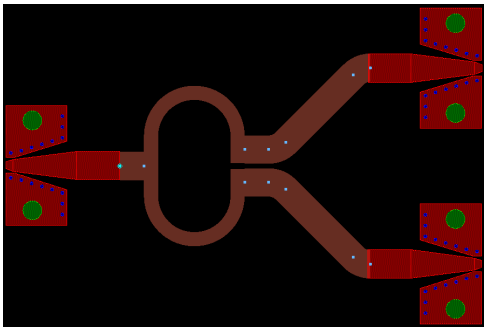

Fig. 7. Wilkinson power divider layout.

VI. Bandpass Filter Lab Results

The 2.4 GHz and 2.6 GHz bandpass filters were designed by our TA Lunan Zhang[4]. The results for the 2.4 GHz and 2.6 GHz bandpass filter are shown in Figure 8 and Figure 9, respectively. The filters were off by about 100 MHz and will have an impact on the overall FSK receiver design.

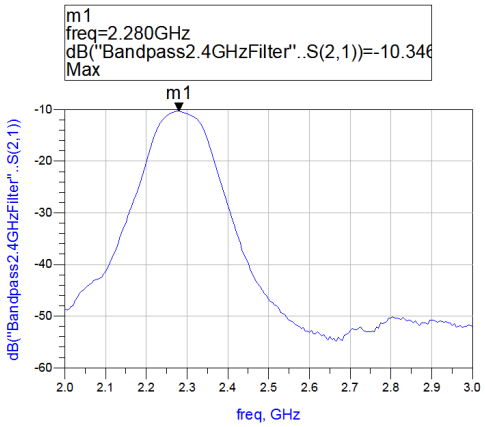

Fig. 8. Lab result for the 2.4 GHz bandpass filter.

VII. Diode Detector Background

Diode detectors are used to detect if a signal is present. Matching circuits are often required to detect a specifc frequency.

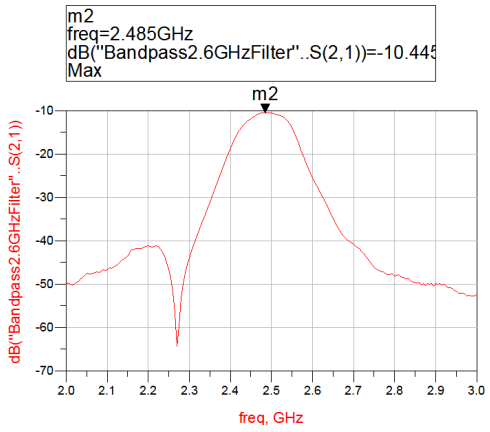

Fig. 9. Lab result for the 2.6 GHz bandpass filter.

VIII. Diode Detector Design

The design of the diode detector circuit consisted around the Avago HSMS-2860 Schottky detector diode. Figure 10 shows a simplified diode detector circuit. Supporting components including R1, R4, and C4. R1 and C4 act as a low pass filter to block out high frequencies. R4 creates the forward diode potential, thus turning the diode on. A secondary effect R4 imposes on the circuit is it moves the input impedance closer to the origin. Avago's AN 1124[1] was used to properly model the parasitics involved with packaging and wiring the diode detector, which is shown in Figure 11. In order to detect frequencies at 2.4 and 2.6 GHz, an input matching network will be required. Figure 12 shows the Smith chart plot for the simple diode detector circuit. In order to properly match for the correct frequencies, a built-in tool provided by ADS will be utilized. Figure 13 shows the Smith Chart tool that was used to design the input matching network. Table I shows the final microstrip line lengths. Tuning was used to obtain the final values. Figure 14 shows the final circuit schematic.

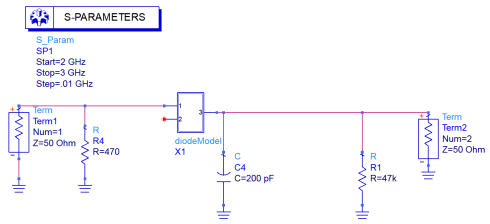

Fig. 10. Simple diode detector circuit with unmatched input.

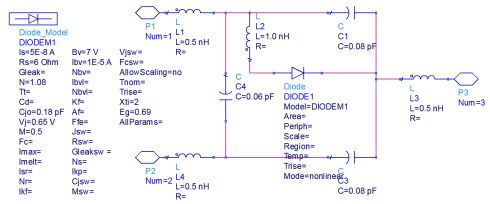

Fig. 11. Diode model based off Avago's AN 1124.

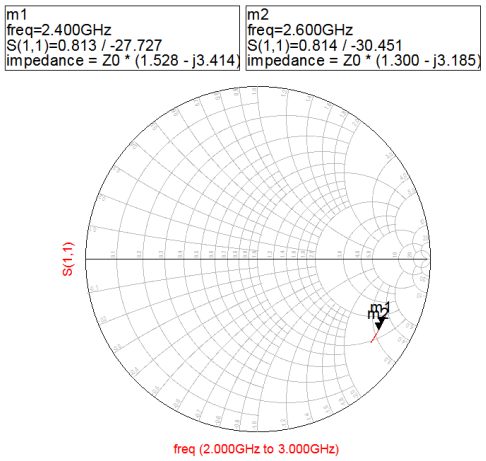

Fig. 12. Smith chart plot of simple diode detector circuit with unmatched input.

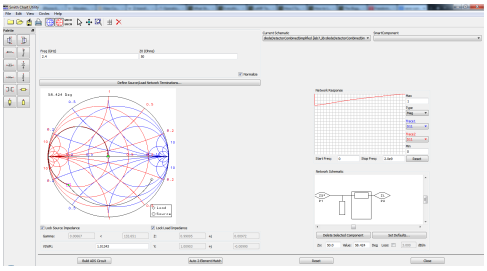

Fig. 13. ADS built-in Smith chart matching tool.

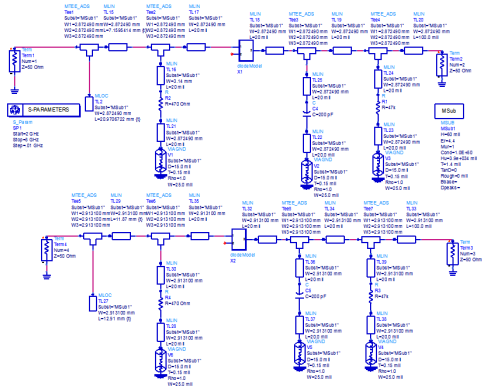

Fig. 14. Complete diode detector circuit with properly matched input (2.4 GHz detector above and 2.6 GHz detector below).

IX. Diode Detector Simulation

Figure 15 shows the Smith chart of the final circuit. The input matching network is verified to detect a signal at 2.4 GHz and 2.6 GHz. Figure 16 shows the S11 reflection. The simulation results a narrow point at the matched frequency. While the simulation shows impressive results, constructing

TABLE I. Final OC and microstrip lines for the 2.4 and 2.6 GHz diode detector circuits

Parameter	2.4 GHz	2.6 GHz
50 Ω Line (mm)	2.9131	2.9131
OC Stub Length (mm)	20.9706722	12.91
Microstrip Line Length (mm)	7.1595414	11.97

the two circuits in the EPL will be very difficult due to manufacturing variations. Thus, it is anticipated that the the center frequency will not be near 2.4 GHz and 2.6 GHz.

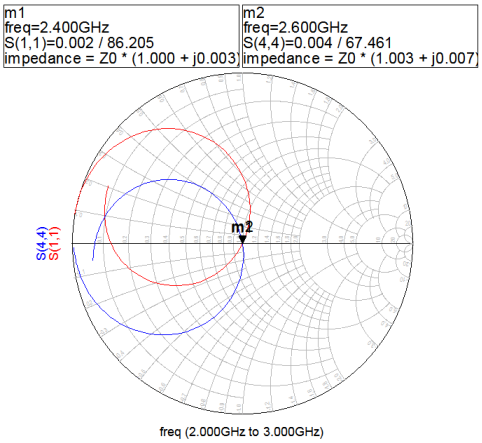

Fig. 15. Smith chart plot of complete diode detector circuit with properly matched input.

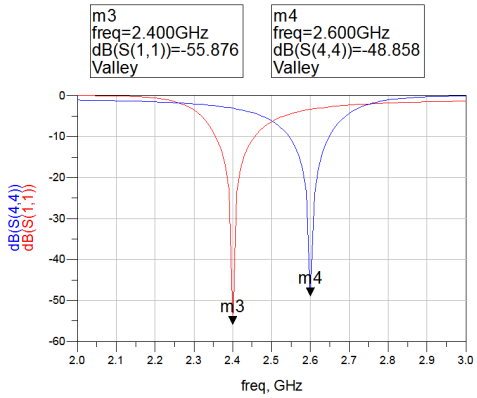

Fig. 16. S11 plot of complete diode detector circuit with properly matched input.

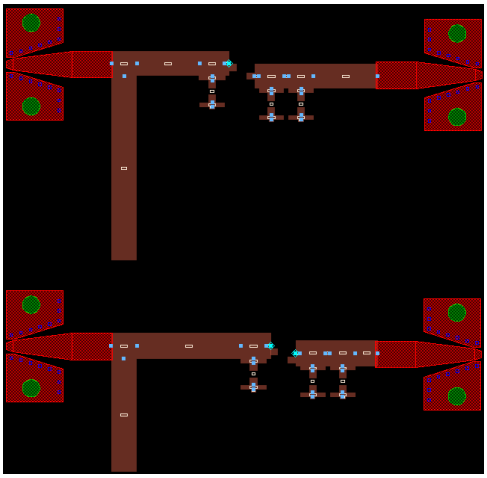

Fig. 17. Layout of complete diode detector circuit with properly matched input (2.4 GHz detector above and 2.6 GHz detector below).

X. Diode Detector Lab Results

Figure 17 shows the diode detector layout. The circuit was fabricated using the LPKF in the EPL.

A. 2.4 GHz Diode Detector

Figure 18 shows a comparison between the simulation and the actual measurements in the lab. The match did not work and will have significant signal loss. This will be verified by looking at the S11 magnitude. Figure 19 shows the S11 comparison. The poor result from the lab will have a negative impact on the overall FSK receiver.

B. 2.6 GHz Diode Detector

Figure 20 shows a comparison between the simulation and the actual measurements in the lab. The match is fairly close but the frequency sweep travels in a different direction than what ADS preditcs. This may prove to be a worthwhile and interesting point to explore. Figure 21 shows the S11 comparison. The lab results are not as impressive as the simulation but still show that the circuit works well and is matched very close to 2.6 GHz.

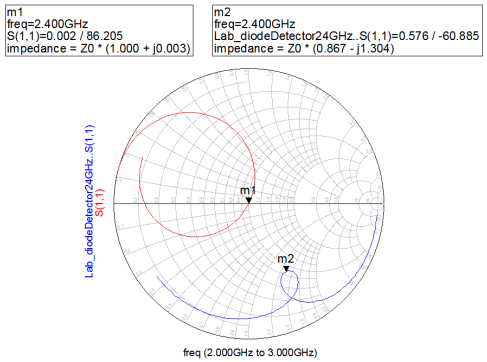

Fig. 18. Smith chart comparison between simulation and in-lab results for 2.4 GHz diode detector.

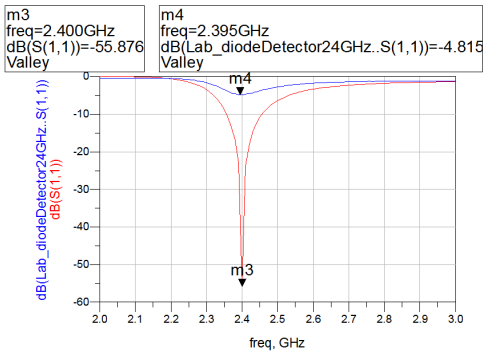

Fig. 19. S11 plot comparison between simulation and in-lab results for 2.4 GHz diode detector.

XI. FSK Receveiver Design

The FSK receiver was built using the results from above and connecting the subcircuits together[2]. Figure 22 shows the final FSK receiver.

[2]Due to the lack of components, the entire FSK receiver was not built on a single PCB.

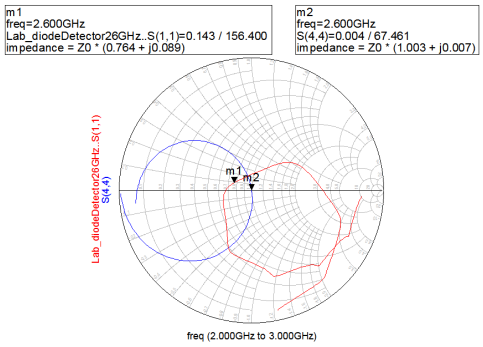

Fig. 20. Smith chart comparison between simulation and in-lab results for 2.6 GHz diode detector.

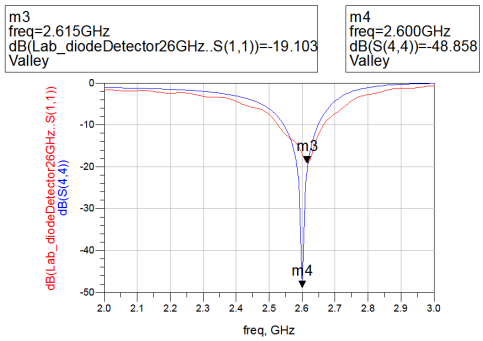

Fig. 21. S11 plot comparison between simulation and in-lab results for 2.6 GHz diode detector.

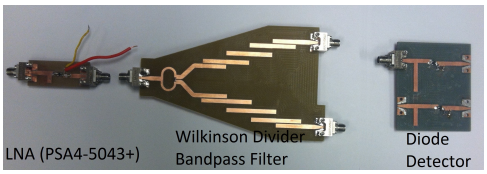

Fig. 22. FSK receiver.

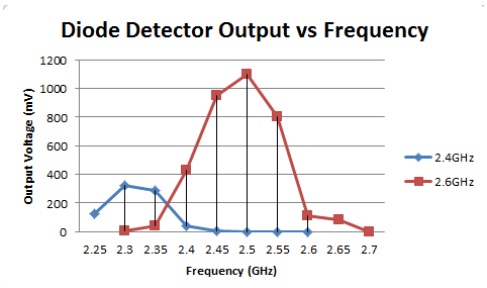

Fig. 23. FSK output voltage vs. frequency for each detector.

XII. FSK Receveiver Lab Results

Table II and Table III show the measured results obtained from the FSK receiver. The main problems in the design stem from the bandpass filter being off by 100 MHz as well as the mismatch on the diode detector. Improving these two circuits will yield better results. When displayed graphically, as in Figure 23, it is clear that even with the large S11 of the 2.4GHz diode detector that differentiating between the two frequencies is still possible. These results were acheived with an input power of 0dBm which is much larger than would be likely in a real world application. Much of the gain acheived in the gain block, if not all, was lost in the splitter and filters. While the 3dB loss from the splitter may well be acceptable, the roughly 7dB loss from the filters is quite unacceptable. Future revisions to this design should focus primarily on finding a more efficient filters and properly tuning them to the desired frequencies. After the filtering loss, the next area of improvement for this design would be the the inconsitent S11 measurement of the 2.4GHz diode detector. Acheiving an S11 measurement of closer to -20dB would produce approximately 800mV of margin at the target frequency alone. This margin would allow for additional reduction in input power required for achieving a differentiable output voltage.

TABLE II. FSK Receiver 2.4 GHz Frequency Sweep

Frequency Sweep (GHz)	Output Signal at 0 dBm (mV)
2.25	124
2.30	320
2.35	290
2.40	40
2.45	4
2.50	0.56
2.55	0.08
2.60	1.2

TABLE III. FSK Receiver 2.6 GHz Frequency Sweep

Frequency Sweep (GHz)	Output Signal at 0 dBm (mV)
2.30	4
2.35	44
2.40	430
2.45	950
2.50	1100
2.55	800
2.60	110
2.65	80
2.70	1.3

References

[1] Avago Application Note 1124

[2] K. Payne, "Practical RF Amplifier Design Using the Available Gain Procedure and the Advanced Design System EM/Circuit Co-Simulation Capability," Agilent Technologies (5990-3356EN), 2008.

[3] https://en.wikipedia.org/wiki/Frequency-shift_keying

[4] Zhang, Lunan, ECE 532/432 Microwave Circuit Design II Lab TA