Georgia Institute of Technology
ECE 4040: Final Report

5.2 GHz RF Group

April 24, 2000

Project Goals and Specifications

The ultimate goal of this project is to create a 5.2 GHz RF link that can be used to transmit digital video signals from a remotely operated vehicle. Eventually, the transmitter and receiver units will consist of components that have been fully integrated into one printed circuit board (PCB). Our goal for this semester, however, is to design and test a prototype transmitter and receiver, which will likely consist of various interconnected modules.

Our operating specifications are that the carrier frequency be 5.2 GHz, and that the usable range be between 100-150 meters. From a performance standpoint, we want to provide as large of a signal-to-noise ratio (SNR) at the receiver as possible, and we also seek to minimize the total cost of the project.

Background / Research

Having a good understanding of our project goals, we began to research the current state of the art in RF amplifiers. We wanted to see what kinds of gain, noise figure, and output power were available at this frequency. During the course of our Internet search, we came across a website containing resources and links for RF engineers. This site contained approximately 60 links to both large and small vendors of RF hardware. The site significantly accelerated our research. A partial list of the vendors we investigated can be found in Appendix A.

We looked at three types of RF amplifiers: low noise amps, power amps, and general-purpose amplifiers/gain blocks. We were interested only in amps whose operating frequency range included 5.2 GHz. Also, we also assumed that a transmitter output power of about 100mW (20 dBm) would be sufficient, so we looked at medium-power amplifiers with a P_{1db} of 20-25 dBm.

A typical cross-section of the amplifiers we found can be seen in Table 1. As the table shows, there are a number of general-purpose RF amps available, typically with a gain of 12-15 dB, a noise figure of 5-7 dB, and P_{1dB} of around +15dBm. However, there is neither an abundance of 5.2 GHz LNA's, nor medium-power amps capable of putting out 20 dBm.

Model	Manufacturer	Frequency Range	Gain	Noise Figure	P_{1dB}	Amplifier Type
ZRON-8G	Mini-Circuits	2-8 GHz	18 dB	7 dB	19dBm	Medium Power Amp
RF2335	RF Micro Devices	DC-6 GHz	10 dB	5.5 dB	15 dBm	General Gain Block
RF2047	RF Micro Devices	DC-6 GHz	13.5 dB	6.5 dB	15 dBm	General Gain Block
ALH102C	TRW Telecom	2-20 GHz	12 dB	5 dB	----	General Gain Block
MGA-64135	Agilent	2-6 GHz	12 dB	7.5 dB	12 dBm	General Gain Block
HMMC-5027	Agilent	2-26 GHz	85 dB	6.5 dB	24dBm	Medium Power Amp
HD12497	HD Communi-cations	2-8 GHz	24 dB	3.5 dB	15 dBm	General Gain Block
HD12498	HD Communi-cations	2-8 GHz	40 dB	4 dB	15 dBm	General Gain Block
A2060163A	Herotek	2-6 GHz	10 dB	5 dB	12 dBm	General Gain Block
A2060243A	Herotek	2-6 GHz	18 dB	5 dB	12 dBm	General Gain Block
HMC162C8	Hittite	5-8 GHz	15 dB	6 dB	15 dBm	General Gain Block

Table 1. Typical Amplifier Parameters at 5.2 GHz

System Design Process

The first step in the design process was to determine the architecture of our transmitter and receiver. A block diagram of the link can be seen in Appendix D. We decided to use 2.4 GHz as an intermediate frequency (IF). The main advantage would be that we could “piggyback” the signal from the 2.4 GHz RF Group. Under this scheme, we would input a modulated 2.4 GHz carrier, upconvert it to 5.2 GHz, and then amplify it until we had a suitable power to drive the transmitting antenna. The signal would then be received by another antenna some distance away, and amplified via a low noise amplifier (LNA). The amplified signal would then be downconverted back to 2.4 GHz, and passed on to demodulation stages.

In order to determine what kind of specifications our amplifiers would need to have (how much gain, what noise figures, etc.), some calculations were performed. First of all, we had already made the assumption about transmitter output power, believing +20dBm (100mW) to be sufficient for an operating range of 100-150 meters. Using a range of 150 meters and a frequency of 5.2 GHz, we calculated the free-space attenuation (FSA) between the two antennas to be –90 dB. This calculation can be found in Appendix B. We then used the Friis transmission formula to calculate the effective received power (ERP) at the receiving antenna. This calculation, also in Appendix B, yielded an ERP of –71 dBm.

Next, we needed to determine whether or not this received signal power would be strong enough to be detected, assuming a minimum signal-to-noise ratio (SNR) of 3 dB at the receiver. At standard temperature (300 K) and assuming a usable bandwidth of 100 MHz, the inherent noise floor was found to be –85 dBm. If the receiver were perfect and introduced no new noise (i.e., its noise figure were 0 dB), then we could project a SNR of about 15 dB. Due to the lack of LNA’s to choose from, and a limited budget, it was determined that we would forego a low noise amp in our receiver and instead use a general RF amp with a higher noise figure of 6.5 dB. This was acceptable because of the projected strength of the received signal.

In previous calculations, however, we assumed negligible losses due to the antennas. In order to test this assumption we used a network analyzer to measure the attenuation of the two identical antennas which we were planning to use. At 5.2 GHz and a separation of 1 meter, we measured the attenuation between the two antennas to be nearly 12 dB more than our calculations at that distance. We attributed this discrepancy to antenna losses, and recalculated the ERP taking this into account. This new calculation, found in Appendix B, indicated that the effective received power was no longer at least 3 dB greater than the minimum detectable signal.

At this point we had four choices. We could use a low noise amplifier in the receiver as initially planned. This would lower the overall noise figure of the receiver, thereby increasing the SNR. The main disadvantage was that the lowest noise figure we found was 2.2 dB, and this amp was twice as expensive as most of the general-purpose amps with comparable gains. In fact, RF Micro Devices was already willing to send us several free samples of one of their amplifiers, the RF2047, which had a noise figure of 6.5dB.

Another choice would have been to increase the transmitted power by using a more powerful amp to drive the antenna. We had assumed an output power of 20dBm, and higher power amps at this frequency were rare, and considerably more expensive. As a result, we decided to make do with 20 dBm, and eliminated this choice as a viable solution.

Alternatively, we could have tried to find antennas that did not have as much loss at our design frequency. This was not our first choice either, because we already had a pair of antennas and did not want to use precious time searching for new ones. Instead, we decided to decrease the operating range of the RF link, from 150 meters to 100 meters. This was still acceptable under our initial goals and specifications, and was "the path of least resistance." New calculations were made using this shorter antenna separation distance, and we calculated a new ERP of –78dBm. We again arrived at a SNR of about 7 dB. This was deemed acceptable and we proceeded to select and order our amplifiers.

Amplifier Selection

Given these requirements for the performance of the amplifiers (power, noise figure), we could finally search through our vendor data and make some final decisions. In regards to the power amp, one of the best amps we found was Agilent Technologies' HMMC-5027 medium power amplifier MMIC. This MMIC is truly a wideband amplifier, having a frequency range of 2 – 26 GHz. At 5.2 GHz, its P_{1dB} is +24 dBm, meaning it can be operated at 20 dBm without reaching its 1dB compression power. The 5027 has a moderate gain of about 8.5 dB, and a noise figure of 6.5 dB. In addition to all of this, we were able to obtain 10 free 5027 chips from Agilent Technologies, as well as 10 packaged amplifiers (1GG7-4203) which are not commercially available.

Since we were unable to find a suitable low noise amp, appropriate accommodations were made during the system design to allow for a general-purpose RF amplifier with a noise figure of 6 - 7 dB. These amplifiers will serve two main functions in our RF link. In the transmitter, this general amp will serve as a driver for the output power amp. In the receiver, this amp will take the place of the LNA in a standard superheterodyne receiver architecture. After investigating available amplifiers from a number of different vendors, we focused on amplifiers from three particular suppliers: Herotek, HD Communications and RF Micro Devices.

HD Communication's HD12497 has a typical gain of 30 dB, a typical noise figure of 2.2 dB and a P_{1dB} of 15 dBm. The cost for this amplifier was $1047. Herotek also offered a similar amplifier, the A2060103. This amplifier has a typical gain of 24 dB, a typical noise figure of 3.5 dB, and a P_{1dB} of 15 dBm. The cost of this amplifier was $460. CTT Inc. offers an amplifier, the APM/060-2720, which has a gain of 20 dB, a noise figure of 5.5 dB, and a P_{1dB} of 27 dBm. The cost for this amplifier was not obtained. RFMD's RF2047 operates from DC to 6 GHz, has a typical 16 dB small signal gain (13.5 dB at 5.2 GHz), a noise figure of 6.5 dB, and a P_{1dB} of 12 dBm. The RF2047 could be obtained at no cost if requesting three or fewer amplifiers. As a result, the RF2047 was chosen over the other amps, even though it is inferior to the other amplifiers in terms of performance. It is probable that two 2047 stages will be cascaded in the receiver in order to compensate for its lower gain. Since the 2047 will not be used as a power amplifier, only a small-signal amp, its lower P_{1dB} is largely irrelevant.

Board Design and Layout

At this stage, we were ready to create several printed circuit board layouts to serve as testbeds for the HMMC-5027 and the RF2047 amplifiers. Three sample 2047 amplifiers and an evaluation board, the RF2047 PCBA, have been received from RF Micro Devices. The functional block diagram and evaluation board schematic for the 2047 are shown in Figure1 and Figure 2, respectively.

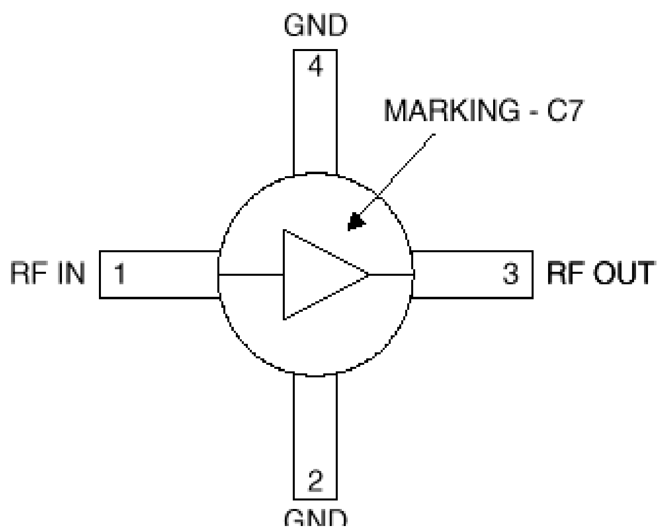


Figure 1. The functional block diagram of the RF2047.

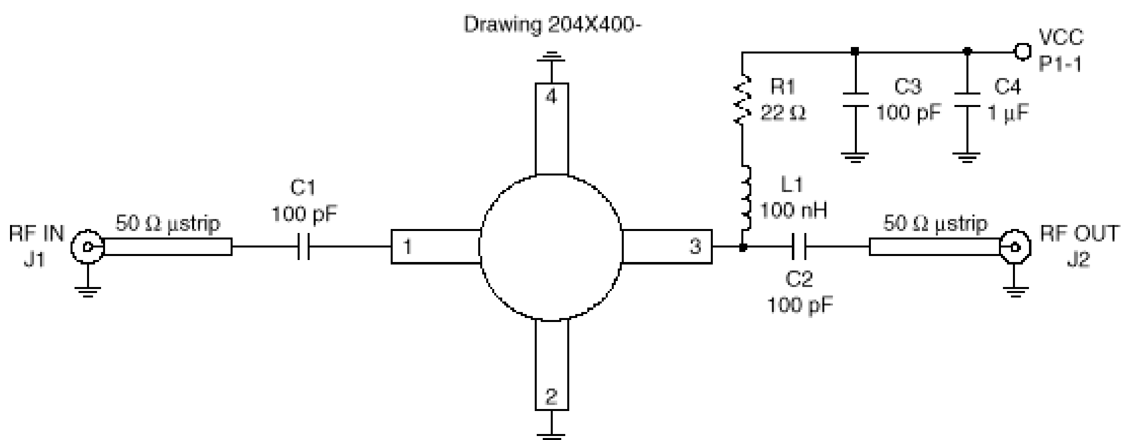


Figure 2. Schematic of the RF2047 PCBA evaluation board

The RF2047 PCBA board itself has been tested in the lab using the network analyzer in order to confirm its gain at 5.2 GHz. Indeed we measured a gain of 13.57 dB, which confirms the 13.5 dB gain listed in the 2047's data sheets. A plot of the 2047's gain versus frequency can be found in Appendix C. After testing, we created our own board layout using *SuperPCB*, and we generated a gerber file and gave it to Bob House. The layout is shown below in Figure 3. Although we hoped to assemble and test this board, we experienced difficulties in finding the necessary surface mount component values and sizes on hand. We ordered the necessary components from Digi-Key, but administrative delays made it impossible for the order to be placed in time for us to receive these components before the end of the semester.

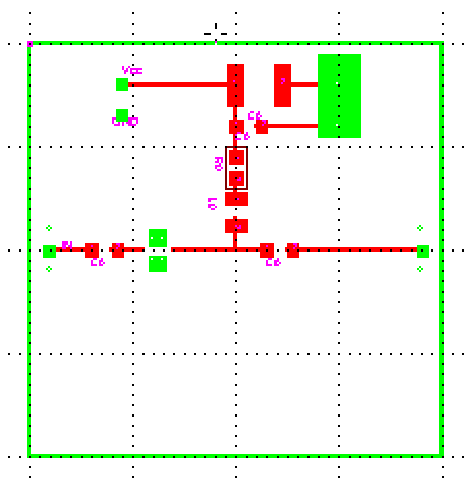


Figure 3. Super PCB layout for evaluating the RF2047

We have also done a layout for an evaluation board that could be used to test the Agilent HMMC-5027 amp (see Figure 4). In addition to this, we completed two more board layouts – one for a transmitter power amp and one for a receiver small-signal amplifier. The receiver amplifier basically consists of two RF2047 amps cascaded, along with appropriate biasing and coupling elements. Since the RF2047 is designed to be a cascadable gain block, it is internally matched to 50 ohms over a fairly wide bandwidth, and therefore no additional impedance matching was necessary between the two stages. The receiver amp layout is shown below in Figure 5.

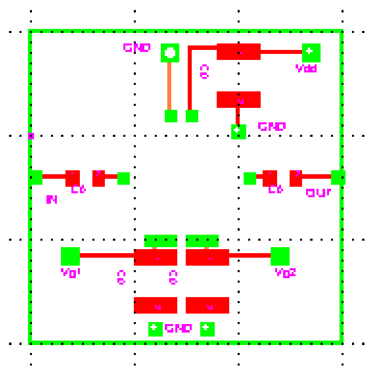


Figure 4. Super PCB layout of the HP 5027 amplifier.

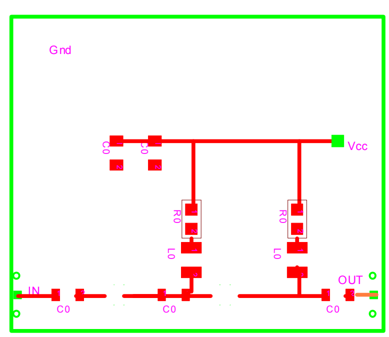


Figure 5. Super PCB layout of the receiver amplifier module

Finally, the layout for the transmitter's power amp is shown in Figure 6. The power amp consists of two cascaded 5027 chips. It is probable that impedance matching would be required between the two stages, but without being able to measure the 5027's s-parameters, we were unable to design such a matching network this semester.

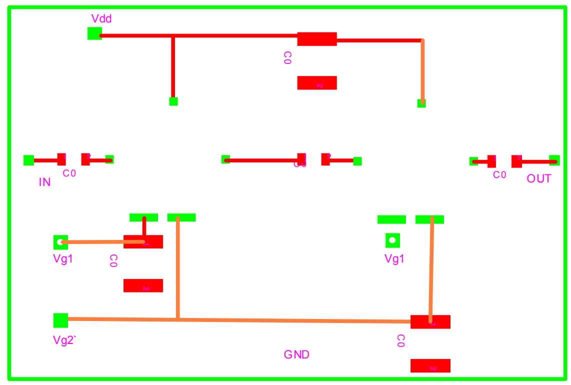


Figure 6. Super PCB layout for transmitter power amplifier module

Current Status and Conclusions

Recently we looked through a number of vendors' websites in search of a suitable frequency mixer. We settled on the HMC129G8, manufactured by Hittite Microwave Corporation, which operates with RF frequencies from 4-8 GHz, and an IF of DC to 3 GHz. We have repeatedly contacted Hittite's sales representatives, but the company is in the process of reorganizing its sales department and we have had little success in getting a solid quote.

With the semester coming to a close, we have finally suspended our efforts in this project. Our major accomplishments include selecting and successfully obtaining (at no cost) amplifiers from RF Micro Devices and Agilent Technologies. We have also completed four different board layouts, and experimentally measured the performance of the RFMD 2047 evaluation board. Our greatest source of problems was the unpredictable nature of relying on other people (i.e., Bob House, company representatives, Larry, etc.) for timely advice, information, quotes, and so forth. We hope that the documentation of the work we have done, although very preliminary, will provide the groundwork for future undergraduate student work on this project.

APPENDIX A

Partial List of Vendors Used in Research:

Amplifonix
Agilent
Delta Microwave
Future Communications
Herotek
HD Communications
IFR Systems, Inc.
Kalmus
Merrimac Industries
Microwave Communications Labs
Mini-Circuits
Powerwave Technologies
GHz Technology
Hittite Microwave
Microwave Power, Inc.
Motorola
National Semiconductor
RF Micro Devices
Siemens
Texas Instruments
Oki Semiconductor
TRW Telecom

For more complete list, please see:
http://ibme2.ibme.utoronto.ca/~anthony/subpages/hotsite.htm#RF

APPENDIX B

Summary of Calculations:

Initial Power & Noise Calculations:

Antenna Distance, R = 150 m
$f = 5.2 * 10^9$ Hz
$\lambda = c / f = 0.05769$ m
$P_T = 100mW = 20$ dBm
$T_0 = 300$ K
L = 1
BW = 100 MHz

Free Space Attenuation (FSA): $FSA = [\lambda / (4\pi R)]^2 = 9.368 * 10^{-10}$
$FSA_{dB} = 10 \log FSA = -90$ dB

Effective Received Power (ERP): $ERP = P_T * (1/L) * FSA$
$ERP_{dB} = 10 \log ERP = -73$ dBm

Minimum Detectable Signal (MDS): $MDS_{dB} = 10 \log(kTo*BW) + NF_{rec} + \text{margin (3 dB)}$
$MDS_{dB} = -85$ dBm

Calculations After Accounting for Antenna Loss:

L = 15.8 = 12 dB
Effective Received Power (ERP): $ERP = P_T * (1/L) * FSA$
$ERP_{dB} = 10 \log ERP = -83$ dBm

Calculations After Adjusting Antenna Distance:

R = 100m

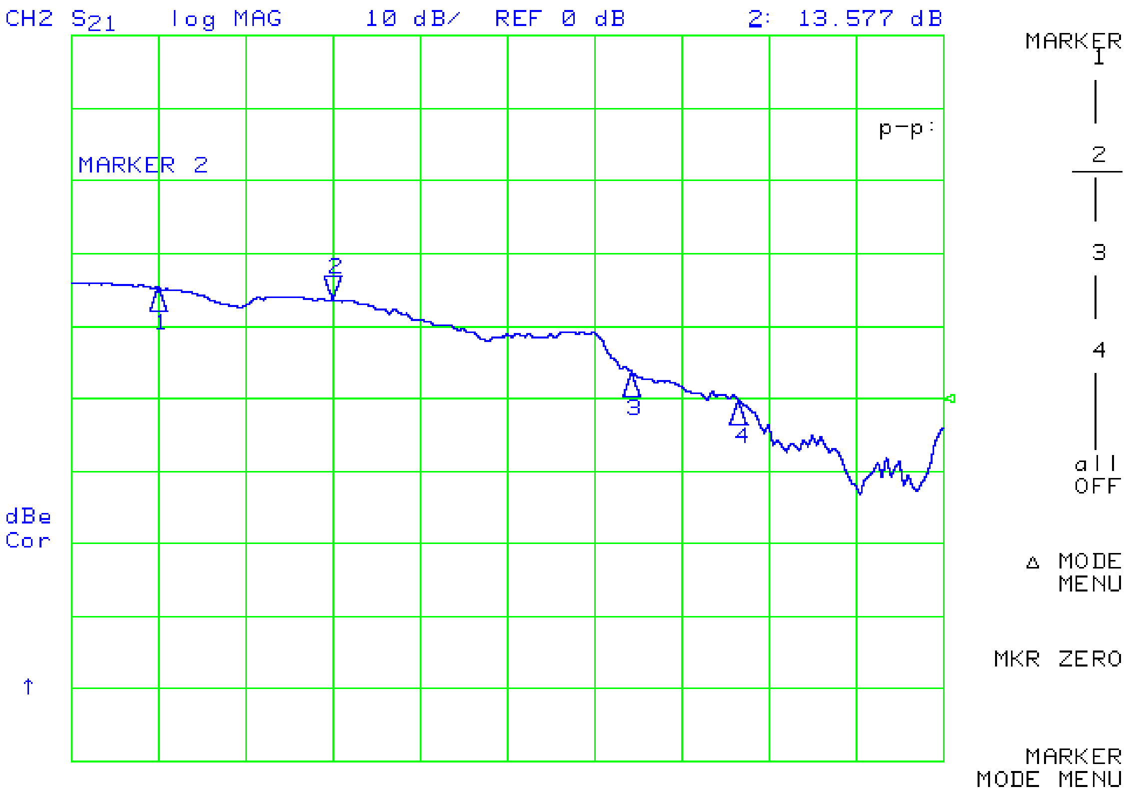
Free Space Attenuation (FSA): $FSA = [\lambda / (4\pi R)]^2 = 2.108 * 10^{-9}$
$FSA_{dB} = 10 \log FSA = -87$ dB

Effective Received Power (ERP): $ERP = P_T * (1/L) * FSA$
$ERP_{dB} = 10 \log ERP = -78$ dBm

Minimum Detectable Signal (MDS): $MDS_{dB} = 10 \log(kTo*BW) + NF_{rec} + \text{margin (3 dB)}$
$MDS_{dB} = -85$ dBm

APPENDIX C

Experimental Data from RF2047 PCBA Testing:



- Marker 1 is at f = 2.4 GHz
- Marker 2 is placed at f = 5.2 GHz, and indicates a S_{21} of 13.56 dB
- Marker 3 is at 10 GHz
- Marker 4 is placed at the frequency where the gain is 0 dB