Georgia Institute of Technology
School of Electrical and Computer Engineering

ECE 4040
2.4 GHz Transmitter/Receiver

Semester: Spring 2000

Prepared by:

1. Introduction

The purpose of the Spring 2000 ECE 4040 class is to research, design, and implement a model vehicle that operates on its own through on-board components. One of the components that is vital to the vehicle's operation is a 2.4 GHz transmitter/receiver link. It is through this link that the vehicle is to send and receive information. The 2.4 GHz transmitter/receiver link is the focus of this paper. In this section, a summary of the information that is known at the onset of this project is presented.

Michael Kleppinger and Robert Barrington of the Fall 1999 ECE 4040 class began the research and design of a general purpose 2.4 GHz radio frequency transmitter/receiver system operating in the ISM band. Federal Communication Commission (FCC) regulations, intermediate frequency (IF), and a system overview of the general purpose 2.4 GHz transmitter/receiver are the main areas examined that pertain to the aspect of this project.

From the previous semester, FCC regulations and standards information are known since the frequency of the transmitter/receiver is still to be 2.4 GHz. Part 15 of the FCC for Legal Unlicensed Transmitting on the ISM Band dictates the utilization of the 2400 – 2483.5 MHz band. As stated by FCC regulations, the maximum field strength of the fundamental frequency is 50 mV/m. This maximum field strength limit is used to determine the amount of power output required.

Another detail that is gained from last semester is the IF that might be needed for this phase of the project. Based on the complete system from last semester, an IF of 210 MHz was determined. While, at this early stage of the project, it is too premature to determine what an appropriate IF for the current project is, the previous IF of 210 MHz can be used as a comparison for the new design.

The design of last semester's general-purpose 2.4 GHz transmitter/receiver consists of five chips. These five chips, RF2128P, RF2422, RF2504, RF2667, and RF9986 are from RF Micro-Devices. A schematic of the system is illustrated in Figure 1.1 below. The RF2504 is used to supply the entire system with a single reference frequency. Since this was beyond the complexity of the design at that particular time, two external frequency sources are connected to the RF2667 and RF9986. The RF9986 receives a RF signal from the antenna, filters, amplifies, and sends it to the RF2667. The local oscillation signal of the RF2667 is used as an input to the RF2422 so that the transmitting and receiving frequencies are synchronized. (Barrington and Kleppinger)

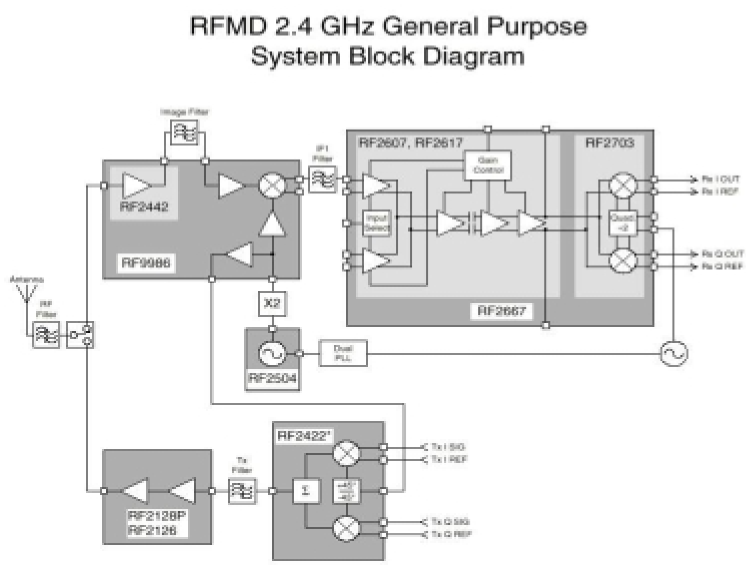

Figure 1.1. Schematic of Fall 1999 ECE 4040 2.4 GHz Transmitter/Receiver

Dr. Martin Brooke has also given additional information. For this semester, there are several goals to achieve. First, the 2.4 GHz transmitter/receiver is to be achieved using a single chip, the RF2938. Once this single chip 2.4 GHz transmitter/receiver is achieved, a complete analysis is to be done of this new system. Based upon the knowledge of the single chip operation, an "original" system is then to be designed and implemented.

In addition to these goals, Dr. Brooke has also given information about components and laboratory instruments available for implementation and testing purposes. The above mentioned chips are available for use in this project. Any additional components or materials that are needed are to be ordered. Also, the following laboratory instruments are available: 40 MHz – 20 GHz network analyzer, DC 500 MHz network analyzer, 1 bps – 16 bps bit error rate test set, DC 16 bps arbitrary wave form generator, and DC 200 MHz logic analyzer and data generator.

From all of the above initial information about the project, plans to achieve the goals are to be constructed through input from all members of the group. Along with ordering information, the following sections present a chronological account of this semester's progress.

2. Background

Once the group was formed, a plan for the semester was formulated. The first step was to determine what the previous group had accomplished to see if the previous work could be utilized as a foundation for the future. A decision was made to use some of the parts that the previous group had bought. The main component that will be utilized from the previous work is a 2.4GHz transceiver, part number RF2938, from RFMD. Some initial insight into the part was obtained through consultation with DR. Feeny and through the data sheets. His counsel was greatly appreciated. Initially there was some concern as to whether the 2938 would operate in full duplex mode. RFMD was contacted regarding this issue. It was stated that it would operate in full duplex. The phone support was excellent. Through testing, it was determined that it does indeed work in full duplex. This prompted us to order another 2938 for the remote location. The testing mentioned above will be discussed in more detail later in the report.

The next phase involved the purchasing of additional components. It was determined that 6 VCO's would be needed. Three at the truck and three for the remote site will be required. Purchasing processes will also be discussed in more detail in Section 3 of the report. A staff member familiarized us with the purchasing protocols. The VCO's proved to be difficult to procure. It seemed that most companies did not have oscillators of this type on the shelf. A great deal of time and effort was spent on this portion of the project. Fortunately, the VCO's are finally here. The second 2938 also arrived the same day.

The presentation delivered to the whole group contained different test set up configurations. Two of these will be examined in the following figures and explanations. Fig 2.1 below shows a test configuration that incorporates some of the previous groups components.

Test 3-no 2938

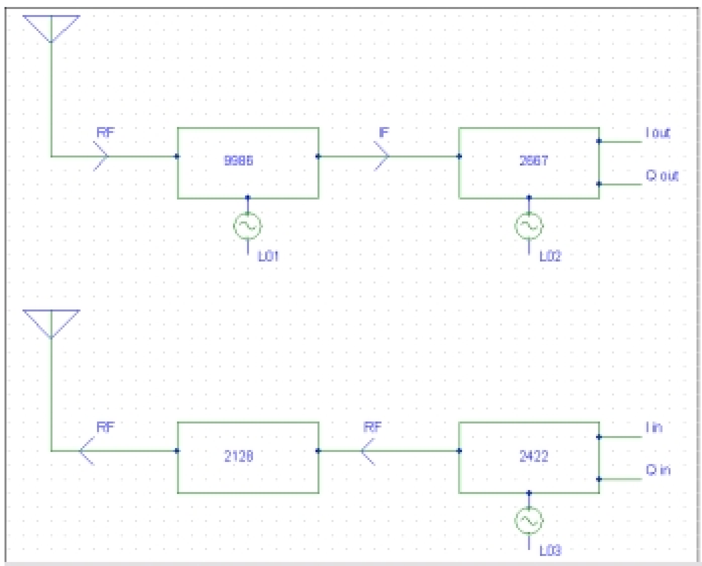

Figure 2.1 Test set up 3-previous group's components.

The figure is basically self-explanatory. A RF signal will be received from the antenna and feed to the 9986. The 9986 is a low noise amplifier. LO1 will be a 2.1GHz VCO. High side injection will be used. This IF frequency will be downconverted to the desired I and Q frequency. The RF out is accomplished by the bottom configuration in Fig.2.1. The 2422 ramps the I and Q signals to 2.4GHz. The 2128 is a RF PA with a gain of 25dB.

It has not yet been determined if this test set-up will be utilized. Determination of which configuration to use will be based on how accurate the design can transmit the received digital information.

Fig.2.2 shows an alternative test configuration to be tested in the lab.

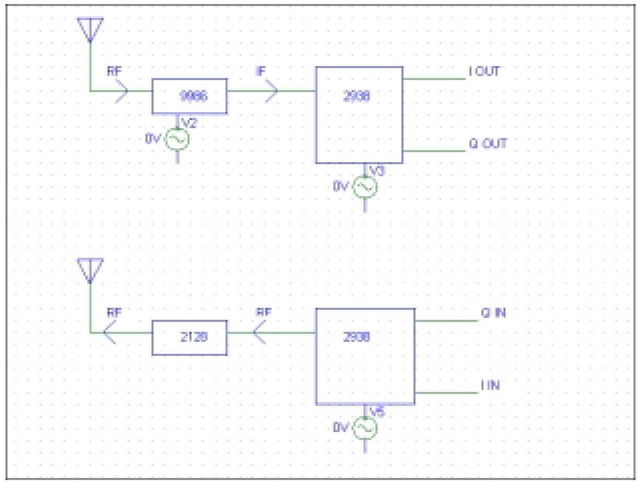

Figure 2.2 Final Test set up.

Again, the 9986 will set the IF frequency from the received RF signal. The IF frequency will be about 250MHz. The 2938 has a lot of onboard components. Should we decide we need another function in the future, the 2938 has a good probability of having the desired component. As mentioned previously, we will need three oscillators at each end of the system. A 2.4GHz VCO will be required to set the RF frequency. A 250 MHz VCO will be needed to set the IF frequency, and 2.1GHz VCO will set the IF frequency from the incoming 2.4GHz RF signal. This concludes the background section.

3. Ordering

The ordering and purchasing process began shortly after the RF group was formed. Several companies were researched before purchases were made. Although efforts were made to keep costs low, Dr. Brooke indicated that this should be of moderate concern. Several companies' advertisements claimed to have the necessary parts, but problems were found after talking on the phone with their representatives. The problems ranged from not having the parts in stock to not even carrying the certain VCO's that were needed. The RF2938 from RFMD and the V240ME01, V800-ME11, and V630-ME11 were received as of February 18, 2000.

There is a procedure to place orders for parts. First, one must know the company name, address, contact name, phone number and fax number, and the total cost of the product ordered, including shipping. All orders are put through Larry Carastro. After a company has been contacted and all necessary information has been collected, the order should be given to Larry. He faxes the orders to Lisa Novack. From there, a purchase order number (PO) is assigned and it is sent to the company.

The companies contacted were RF Micro Devices, Modco Inc., Minicircuits, Champtek, Eclpitek, and ZCOMM. RF Micro Devices had the RF2938, but did not have the voltage-controlled oscillators. The next company contacted was Modco Inc. This company specified that it would take four to nine weeks to deliver the parts that we required. The Minicircuits catalog had the proper oscillators designed, but they were out of stock. Champtek and Eklipteck did not have the oscillators, but were helpful in contacting other companies. ZCOMM was one of the last companies contacted. This company had the right oscillators, but didn't take Georgia Tech PO's. Dr. Dorsey was helpful in getting in touch with a person that allowed access to a p-card. After the order was placed, the parts were received the next day.

The following table is a list of the companies we are dealing with, along with the contact person and phone number.

Contact Information

Company	Phone Number	Contact Person
RFMD	336-664-1233 Voice 336-664-0292 Fax	Nancy McLean
ZCOMM	858-621-2700 Voice 858-621-2722 Fax	Dan Lomis

Table 3.1. Table of Contact Information

A second RF2938 2.4 GHz transceiver was ordered and received from RFMD. The cost of the transceiver was $350.00 plus $10.00 shipping. They also sent the following parts for free: 2 RF9986 PCS Low Noise Amplifier/Mixer chips, 2 RF2667 Receive AGC and Demodulator chips, 1 RF2422 2.5 GHz Direct Quadrature Modulator chip, and 2 Medium Power Linear Amplifier chips. Note: the parts did not come with evaluation boards.

The oscillators from ZCOMM have also been ordered and received. ZCOMM was the company that did not take Georgia Tech PO's. Four of each of the following oscillators were ordered: V240ME01 (250MHz), V800-ME11 (2.4GHz), and V630-ME11 (2.1GHz). The costs of these parts are $24.99 a piece. These parts did not come on evaluation boards. Three boards were ordered at $24.99 apiece. The cost of shipping these parts next day air was $23.00.

Fourteen-Barrel connectors for the SMA connectors were also purchased. The cost of these connectors was a total of $72 dollars. They were purchased from a ACK

Electronics Supply. Also, an HP E3631A triple output DC power supply was purchased from Hewlett-Packard. The cost of this device was $1007.

The total of what has been spent on parts for this project is shown in table 3.2.

Total Cost

Part Number	Manufacturer	Cost	Shipping	Quantity	Total
RF2938 w/ eval board	RFMD	$350.00	$10.00	1	$360.00
V240ME01 250MHz	ZCOMM	$24.99	$23.00	4	$122.96
V800-ME11 2.4GHz	ZCOMM	$24.99	Included	4	$99.96
V630-ME11 2.1GHz	ZCOMM	$24.99	Included	4	$99.96
SMA Barrel Connectors	ACK	$5.14	None	14	$72.22
E3631A Power Supply	HP	$1007.00	$10.00	1	$1017.00
					$1772.10

Table 3.2. Cost and List of Parts Ordered

The ordering process was a challenging process and can easily present many setbacks. Fortunately, we have managed to overcome most of these problems. Our group has all the parts needed to continue with the testing. A list of all parts collected is displayed in table 3.3.

Complete List of Parts

Part Number	Manufacturer	Quantity
RF2938 w/ eval board	RFMD	2
RF9986 w/ eval board	RFMD	1
RF2667 w/ eval board	RFMD	1
RF2422 w/ eval board	RFMD	1
RF2128 w/ eval board	RFMD	1
RF9986 chip	RFMD	2
RF2667 chip	RFMD	2
RF2422 chip	RFMD	1
RF2128 chip	RFMD	2
V240ME01 250MHz	ZCOMM	4
V800-ME11 2.4GHz	ZCOMM	4
V630-ME11 2.1GHz	ZCOMM	4
Evaluation Board	ZCOMM	3
SMA Connectors	ACK	14
Power Supply	HP	1

Table 3.3. All Available Parts

4. Testing the RF2938

During the first lab session, the following parts were in the group's possession: RFMD2938, RFMD9986, RFMD2667, RFMD2128, and RFMD2422 (all evaluation board parts). The objective of the lab session was to obtain a test setup with a limited amount of hardware, in order to determine the functionality of the RFMD2938. Before the lab session, there was doubt as to whether or not the 2938 would be capable of operating in full duplex mode. Background consulting with Dr. Feeney at Georgia Tech brought a section of the board to attention that depicts switching operations between the TX and RX enable pins. This switching could have indicated that the chip was only half duplex capable. However, contacts at RFMD (Dale Hoffman) indicated that the chip was capable of full duplex operation.

The three pieces of hardware used in the lab were the low speed network analyzer, high-speed network analyzer, and a dc power supply. The low speed analyzer was used to generate one local oscillating frequency. The high-speed analyzer was used to generate a signal for injecting in the I or Q port of the 2938.

The exact test setup may be found in Figure 4.1. An explanation of techniques and procedures follows. The input IF and output IF connections on the 2938 were tied together. This way, full duplex capability could be tested. The high-speed analyzer was used to inject a signal into either the I or Q inputs, one at a time. The output of the corresponding I or Q port was then fed back to the high speed analyzer in order to verify that the signal has successfully been passed through the 2938 test setup.

There were several options to be considered when choosing which pins to enable and which to disable for the setup. The data sheets on the 2938 from the RFMD website provided the following table. For this test setup, the full duplex pin assignments were implemented.

State Decode Table	Input Pins			Internally Decoded Signals		
	PD	RX EN	TX EN	BB EN	RXIF EN	TXRF EN
Sleep Mode	0	x	x	0	0	0
Baseband Only	1	0	1	1	0	0
Receive Mode	1	1	1	1	1	0
Transmit Mode	1	0	0	1	0	1
Full Duplex	1	1	0	1	1	1

Table 4.1. Enable Pin Values for RFMD 2938

In order to test the 2938's functionality, several factors were controlled. The oscillating frequency was varied in frequency, and adjusted for power output. The power was adjusted by using a variable attenuator shown in Figure 4.1. The oscillating frequency was swept between 0 and 500 MHz inside its operating range. While sweeping the oscillating frequency within this range, the output was monitored on the analyzer. When the response of the monitored wave was uniform, the oscillator was assumed to be operating within an acceptable range. This oscillator frequency was experimentally determined to be between 250MHz and 260MHz.

This lab session yielded two results. The first result determined was that the IF frequency set by the oscillator works best between 250MHz and 260MHz with a power between –5dB and 0dB. The other result found was that the 2938 was capable of full duplex mode operation. However, doubts still exist about the 2938's ability to produce a RF output while in full duplex mode. Since the 'TX EN' pin was disabled, the RF output of the chip is disabled. Thus, it is theorized that under full duplex mode the chip is only capable of receiving and transmitting an IF frequency. This result will be tested upon the successful implementation of a new test setup. In order to test this RF capability, more than one oscillator is needed. At the time of the first lab session, only one oscillator was obtainable.

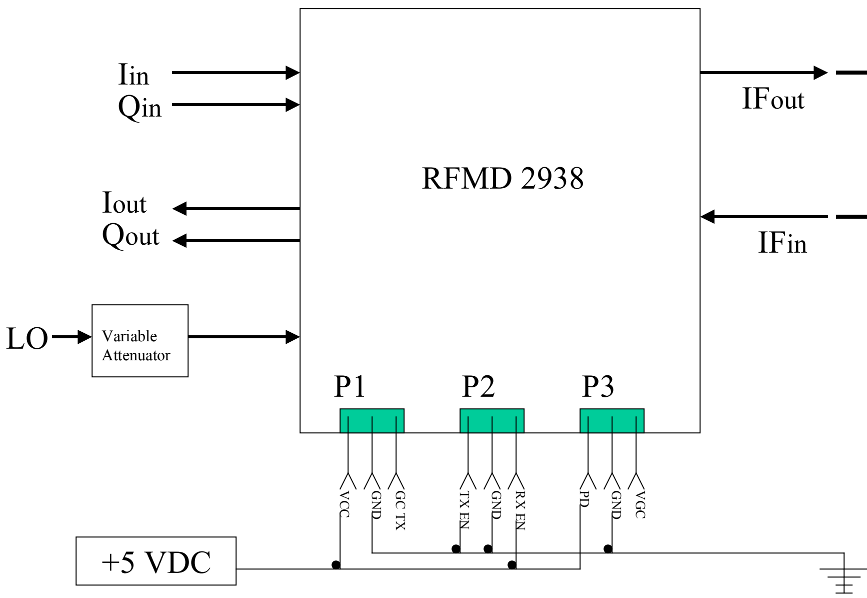

Figure 4.1. RFMD 2938 Lab Test Setup

5. Conclusion to RF2938 Testing

Thus far, a significant amount of work has been done on the RF portion of the senior design project for ECE 4040. The necessary background information researched pertains to the transmitting and receiving of digital information at 2.4 GHz. This research entailed the examination of last semester's report as well as certain FCC standards. The parts that were ordered last semester have been studied and two different test implementations have been out together two using those parts. One of the test implementations was actually confirmed to be a viable configuration in lab.

Unfortunately, only one implementation was tested in lab due to the fact that there were not enough oscillators to implement the other designed configuration. Yet, this setback was finally overcome. The needed oscillators were ordered from ZCOMM along with evaluation boards to set them on. In addition, the oscillators do have SMA connectors already on them so it would not be necessary to connect them manually. All of these parts have been delivered to Georgia Tech.

The group's current plan is first, to mount the oscillators on the evaluation boards and to figure out exactly what voltage is needed to operate them. To mount them soldering techniques will be employed and to determine the required voltages the product specification sheets will be examined. After this is done, additional lab meetings will be arranged so that the group may test the other designed configuration using the new oscillators. Based on these lab results the groups hopes to identify the best working designed configuration and use this implementation for the remote and the vehicle. The best design will be determined based on how accurately each configuration can transmit the received I and Q signals.

Once we have committed to the finalized design based on accuracy, we plan to let the other groups within our class use this implementation as needed for their testing procedures. If our design works well with the other groups designs we will then begin working on procedures to put all of our parts on a single bored. We hope that the ending result will be two separate boards, both boards being capable of transmitting and receiving the necessary information at 2.4 GHz. One board will be set on the remote for operation and the other board on the car.

6. Voltage Controlled Oscillators (VCO)

The initial steps concerning the VCOs were the determination of the appropriate frequencies required for the RF link. The high side injection method was chosen. It was determined that six VCOs would be needed to set the correct frequencies. Three are to be used on the front end of the system, and three on the back end. A 2.4GHz VCO will be needed to ramp the IF frequency to the appropriate level for transmission through the air. A 2.1GHz VCO will be needed to mix the incoming 2.4GHz signal down to an IF of 240-300MHz. A 240MHz VCO is required to set the IF to 240MHz. It was found through experiment that an IF of 240MHz to 280MHz would be best.

The procurement of the VCOs proved to be an arduous task. It seemed that most vendors did not have VCOs at the required frequencies on the self. A great deal of time and effort was spent in trying to locate the correct VCOs. Finally, they were found at a company located in California called Z-Comm.

Once in hand, the initial step was to solder the VCOs to the boards. Some difficulty was encountered during this process. The solder did not seem to want to stick to the boards. After consultation with persons more experienced in these techniques, the difficulties were overcome. The VCOs were now on the boards.

The next phase of the VCO process involved finding the correct supply and controlling voltages for each VCO. This was accomplished in the lab with the use of an oscilloscope. Each VCO was connected to two power supplies. Essentially, a supply voltage of 3.3V was chosen for all three VCOs. The reason for this was two fold. The first reason was that the data sheets seemed to indicate that this would be a good voltage. The second reason was that it was determined it would be best to have a common supply voltage for all the VCOs for simplicity. The 2.4GHz and 2.1GHz worked well at this voltage. However, the 240MHz VCO did not have a stable output at 3.3V. A supply voltage of 2.4V was determined to be a good value for this VCO.

Each VCO was then connected to the oscilloscope with the appropriate supply voltage. The tuning voltage was then varied for each VCO to determine the correct tuning voltage. The tuning voltages for the 2.4GHz, 2.1GHz, and 250MHz VCOs were respectively found to be 2V, .5V, and 2.15V. A sinusoidal output at the correct frequencies was seen for all three VCOs. The output waveforms are shown in Figures 6.1, 6.2, and 6.3.

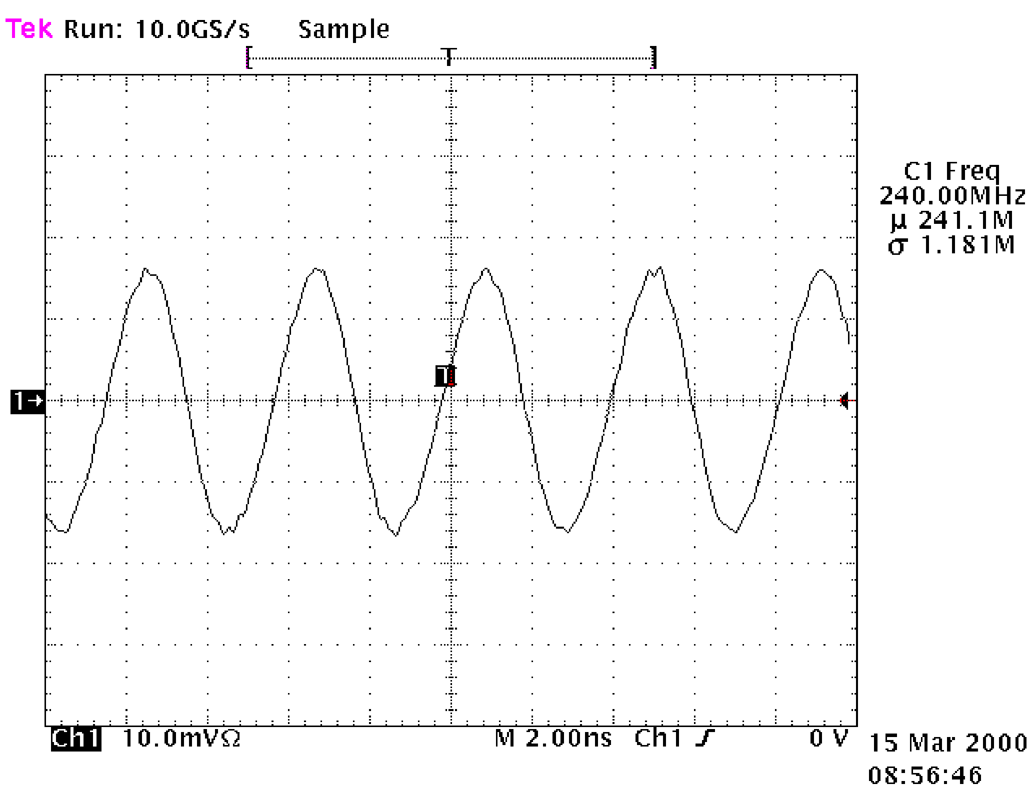

Figure 6.1. Output of 240MHz VCO.

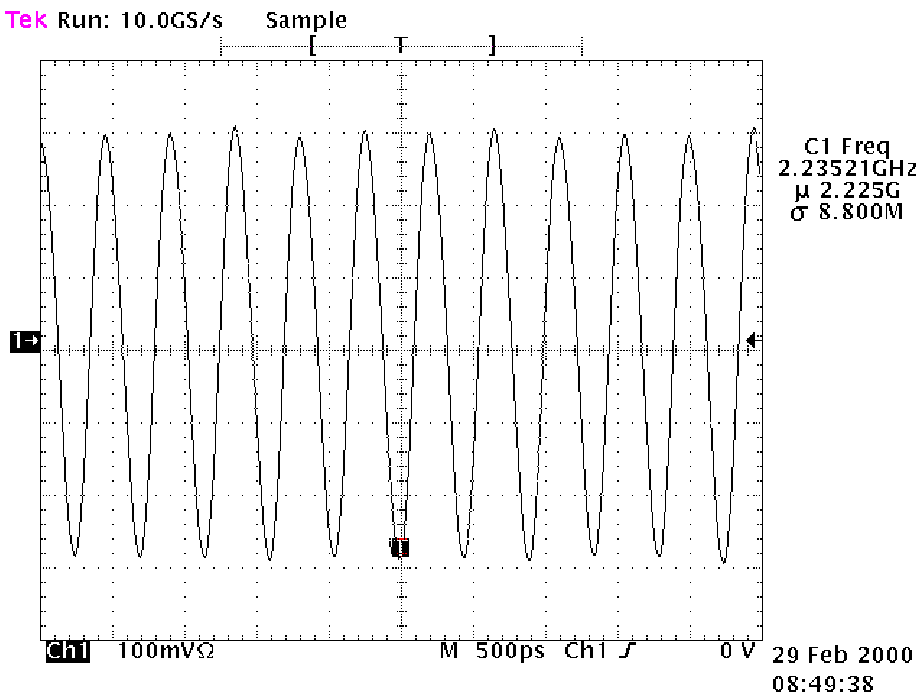

Figure 6.2. Output of 2.1GHz VCO.

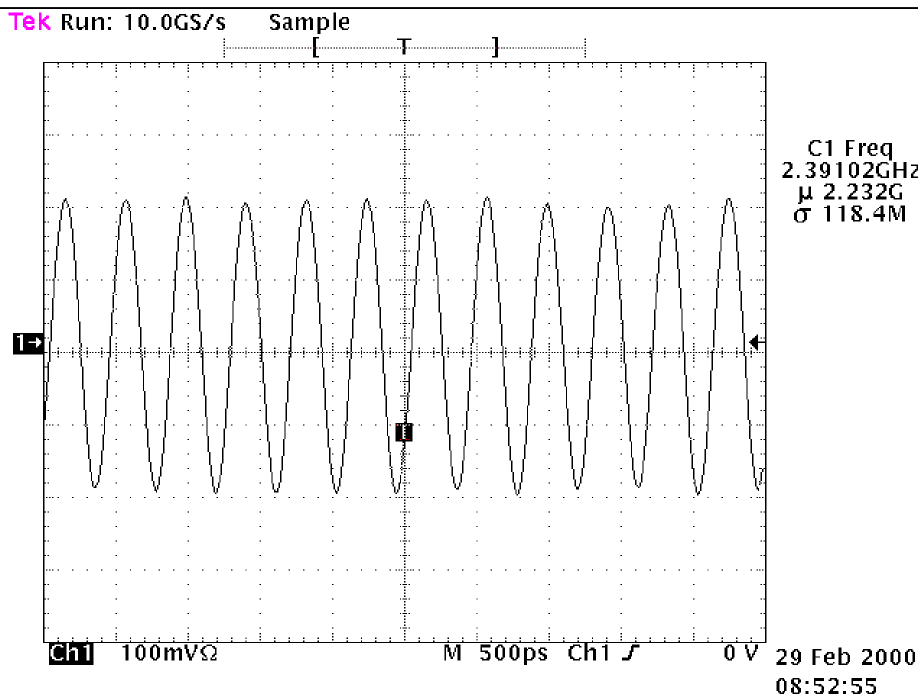

Figure 6.3. Output of 2.4GHz VCO.

7. Measurement with New Test Setup

One of the various test configurations includes the RF2422, RF9986, and RF2667 evaluation boards. To implement this configuration, several aspects of the design were determined. The network analyzer was used as an input Q signal into the RF2422 at approximately 200 kHz. It was expected that this signal would be mixed up to 2.4 GHz by the RF2422, which was controlled by a local oscillator, set to 2.4 GHz. Next, the signal would be sent to the RF9986. There, the signal would be mixed down to the intermediate frequency of 260 MHz using a local oscillator set to 2.14 GHz. Finally, the signal at the intermediate frequency would be sent to the RF2667, which was controlled with another local oscillator set to 260 MHz. To carry out this implementation, the proper voltages that each device needed were determined. The layout of this configuration can be seen in Figure 7.1.

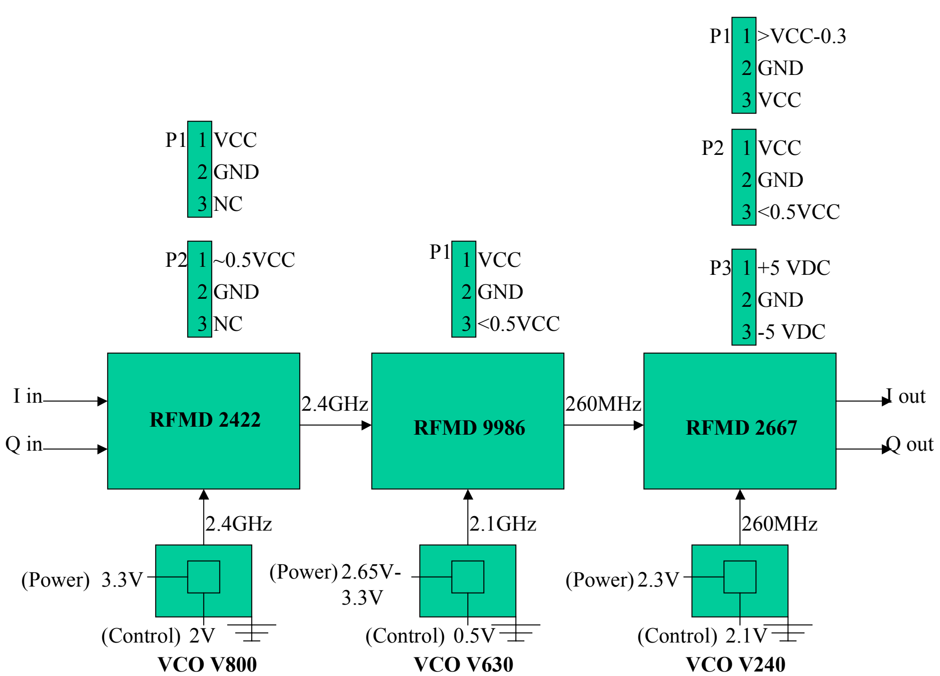

Figure 7.1. Test Set-up Using RFMD Evaluation Boards

The figures 7.2, 7.3, 7.4 show how the evaluation board are individually connected.

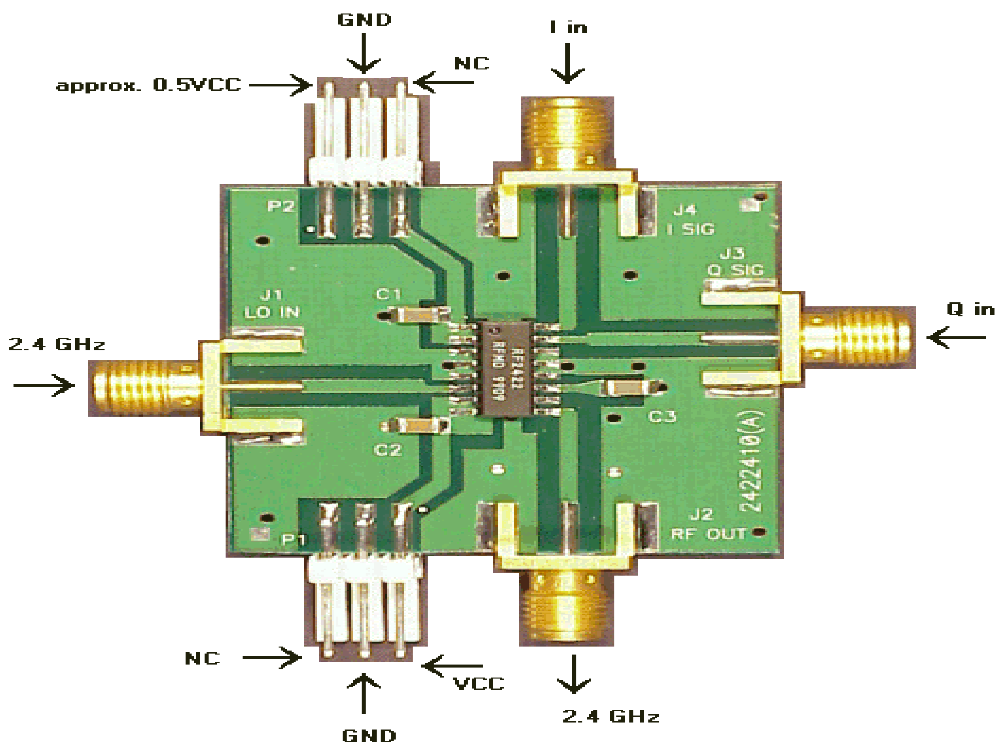

Figure 7.2. Test Set-up RFMD 2422

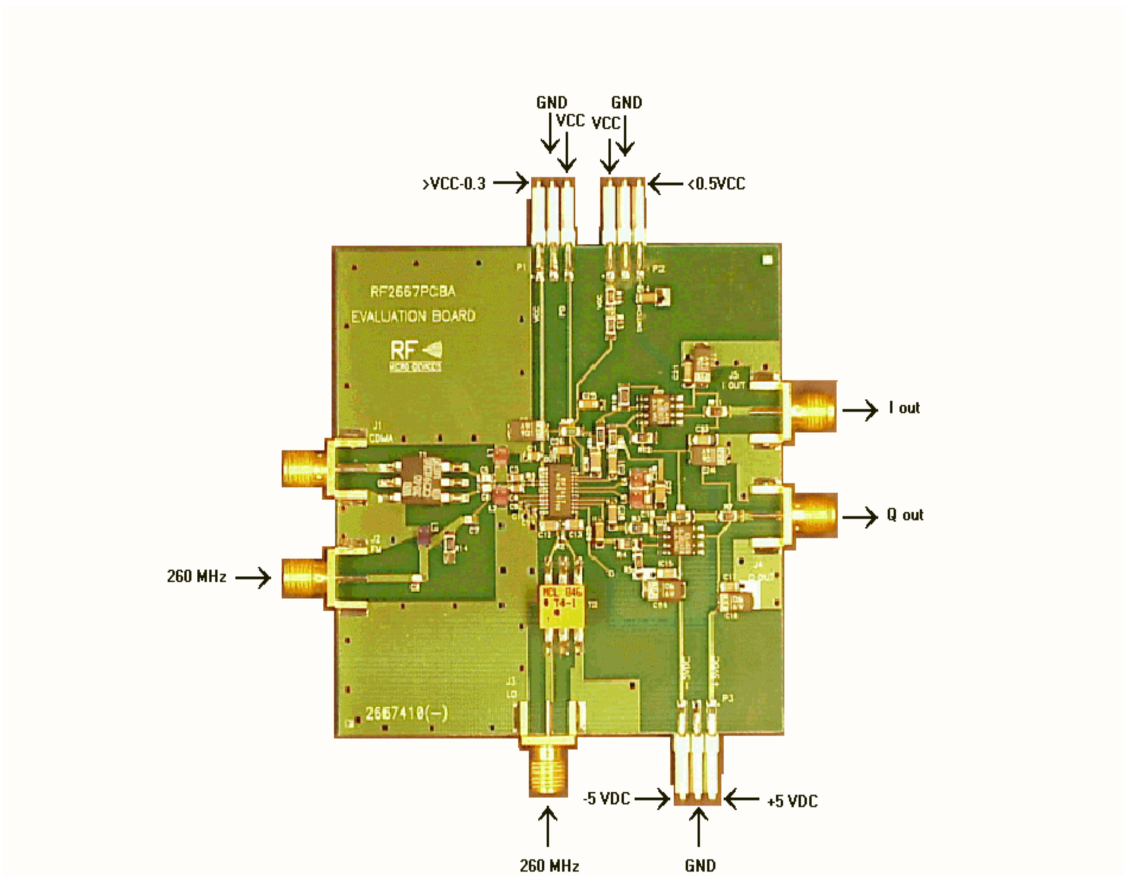

Figure 7.3. Test Set-up RFMD 2667

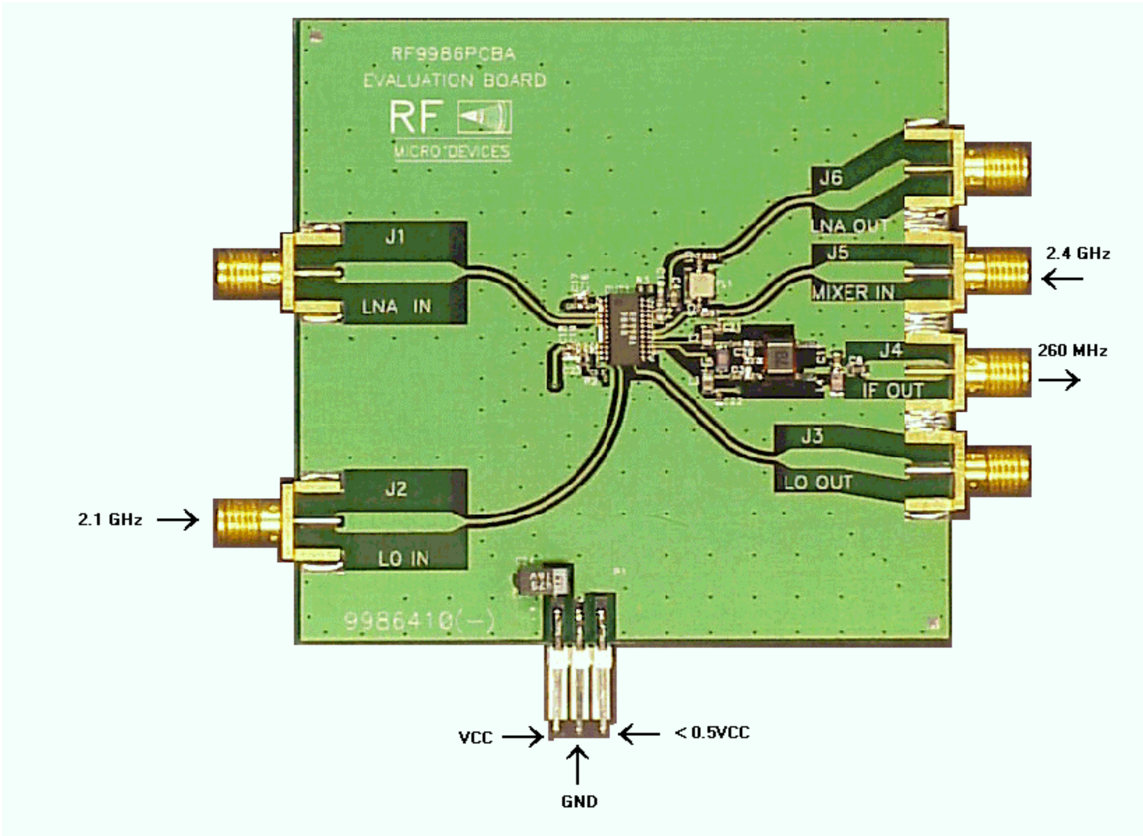

Figure 7.4. Test Set-up RFMD 9986

To generate the correct voltages with the available power sources, all V^- terminals were connected together. Upon doing this, a signal was generated from the network analyzer and then injected into the RF2422 Q_{in} port. The signal at the Q_{out} port was monitored using the network analyzer, but no signal was seen. It was suspected that the problem was that some voltages were being improperly delivered. This lead to the conclusion that troubleshooting each device separately would be necessary.

The RF2422 was tested alone to see if it would perform as expected. Dr. Brooke advised that the V_{ref} pin on the RF2422 had to be set to half the V_{CC} voltage. He also advised that if that did not work the voltage on that pin may have to be negative. Because the output of the RF2422 was expected to be higher than 500MHz, which is the maximum of the network analyzer we were using, Dr. Brooke suggested to look for the output on the oscilloscope. He also stated that the output should resemble a pulsating or modulated signal on the oscilloscope. Although the setup was tested by varying the V_{ref} pin as Dr. Brooke suggested, a correct output still was not detected on the oscilloscope.

Concentrating on getting data that proved that the RF2422 was putting out the correct output continued troubleshooting of the RF2422. First, it was affirmed that all the connections to the RF2422 were correct. However, there was question as to the whether or not the correct V_{ref} was being used.

According to the RFMD data sheet for the RF2422, V_{ref} should be 3.0V. This change was made and the set-up again was tested again to see if the output from the RF2422 was now correct. After adjusting the power on the network analyzer and scales on the oscilloscope, achieved a pulsating or modulated signal was detected. A graph of the output was saved for documentation and is shown in Figure 7.5.

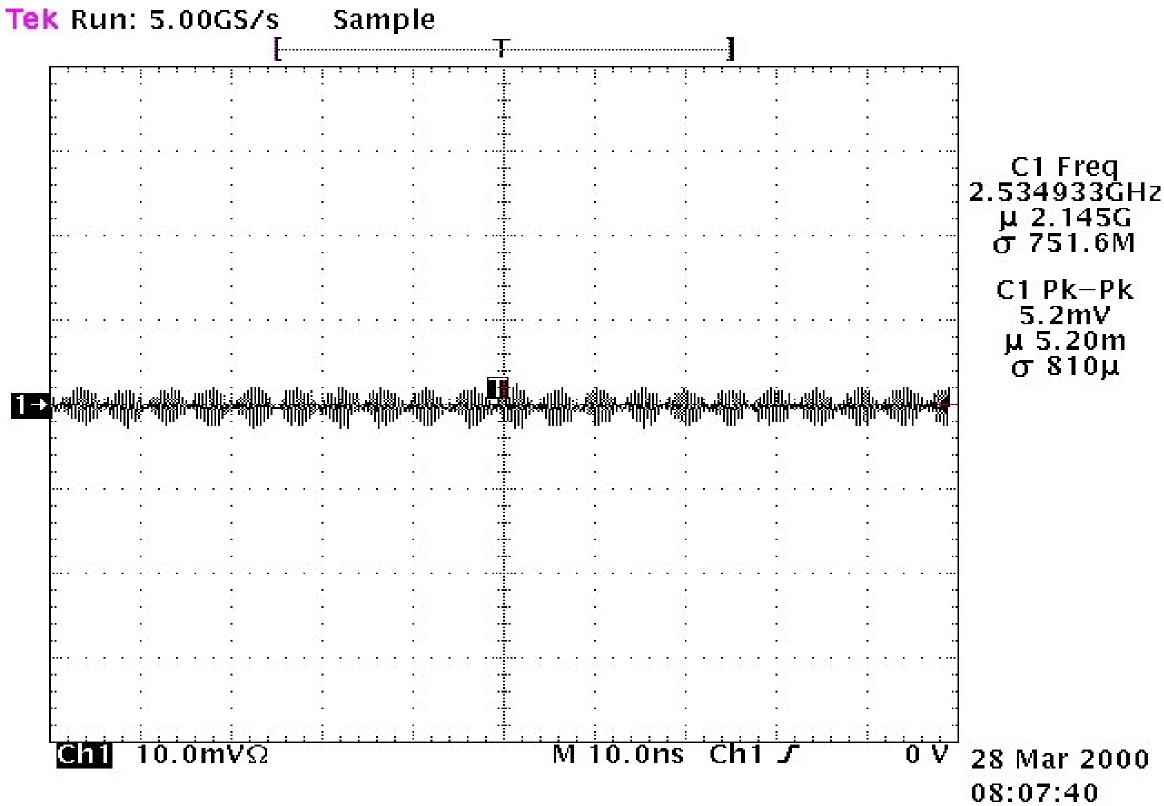

Figure 7.5. Output of RF2422 during Operation as Shown by Oscilloscope

Adding the RF9986 evaluation board to the RF2422 set-up continued the troubleshooting the configuration. However, the output at this chip was rather difficult to interpret. Dr. Brooke gave further guidance. First, he decided to personally take a look at the output of the RFRF2422. After increasing the power, changing frequencies on the network analyzer, and making various adjustments on the oscilloscope, he stated that the output that had previously resulted from testing might have been misleading. Furthermore, he believed that the output of the RFRF2422 was in fact incorrect. The oscillator used for the RFRF2422 was tested again. This testing showed that it was indeed working as expected.

At this point, various changes in our strategies and test set-ups were made. It was concluded that it would be more time efficient to stop testing the configuration shown in Figure 7.1 because accurate output from the RF2422 had not been detected. It was agreed that we would begin testing the configuration shown in Figure 7.6.

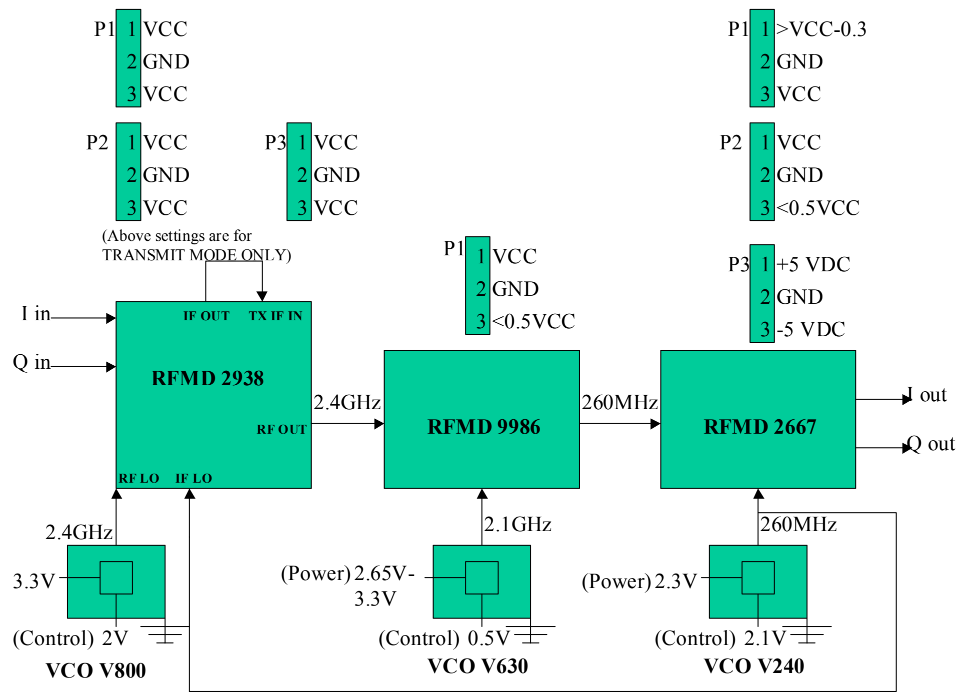

Figure 7.6. New Design Set-Up

Testing began with only the RF2938 as illustrated in Figure 7.6 to see if it would give the expected output. The board was connected as instructed by the data sheets from RFMD. A Q signal was injected into the Q_{in} port. An output was detected on the network analyzer at the intermediate frequency of approximately 260MHz. It was concluded that the board was indeed working as expected.

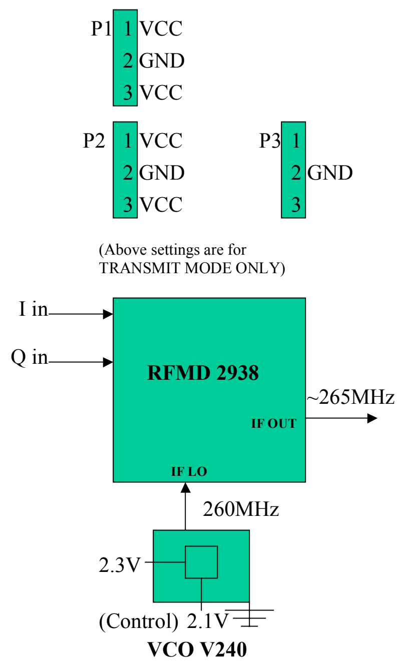

Figure 7.7. RFMD 2938 initial test setup

Upon implementing the 2.4 GHz output mode of the RF2938, the RF9986 evaluation board was connected in series with the RF2938. However, there was a reluctance to use the oscilloscope to check the output of the RF9986. The reasoning was that the expected output power was not known. It was originally planned to attenuate the output power, but the attentuator was no where to be found. Since it would not be desirable to send too much power into the instrument, it was decided that the group would wait for Dr. Brooke's instruction.

8. Conclusion to New Test Setup

After various delays due to the ordering and purchasing of the needed VCOs, they were finally attained. Immediately, the soldering process of the VCOs began. Although various difficulties arose during soldering, the VCOs were finally put on boards and were ready to be tested. First, it was decided that initially all VCOs were to have the same supply voltage. This was due to constraints on the number of power supplies available in lab. Each individual VCO was tested for accuracy. After adjusting the supply and tuning voltages, the proper voltages were determined for each VCO.

The next step was to implement the first test set-up that consisted of the RF2422, RF9986, and RF2667. Initially, the set-up began as that illustrated in Figure 7.1. However, after not obtaining the desired output, it was agreed upon to begin testing each evaluation board separately. After much effort in testing and through the guidance of Dr. Brooke, it was found that this configuration was going to prove difficult to properly achieve. Due to time constraints, this set-up was abandoned.

At this point in the semester, the second test set-up has been constructed since there is a unanimous feeling of confidence that this set-up will achieve the desired results needed for this project. From previous lab results, it was found that the RF2938 is capable of full duplex mode. However, the RF2938 is to be used in transmit mode only at this point. An illustration of the set-up is shown in Figure 8.1, which follows.

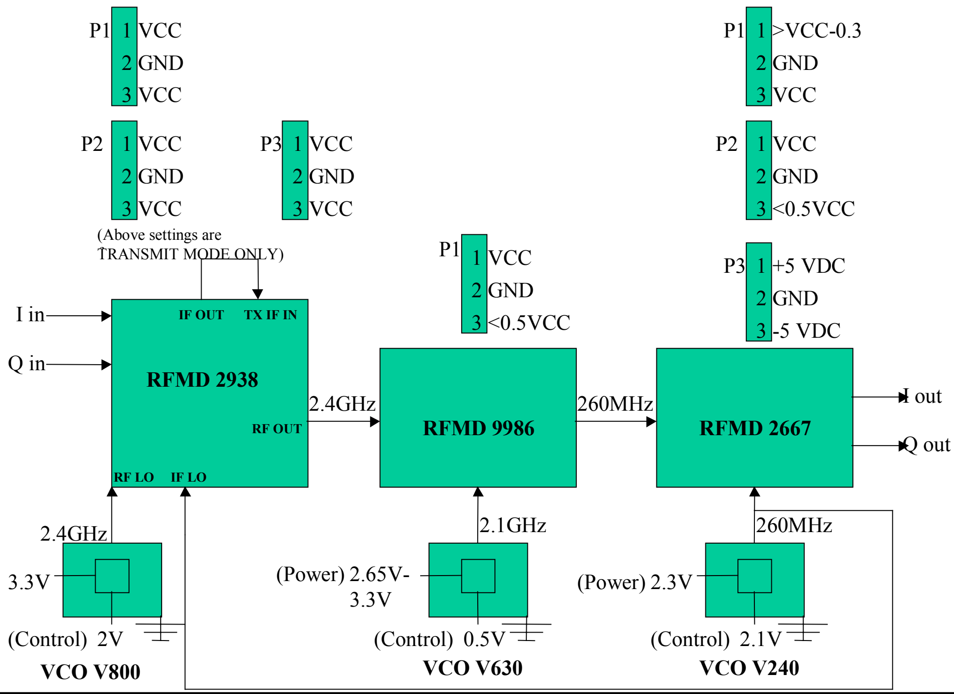

Figure 8.1. Second Test Set-Up

The second phase of testing has already begun on the above shown set-up. The RF2938 portion of the above set-up has proven to be accurate. At this point, the RF9986 portion of the set-up is currently under analysis. However, due to the unknown output power, analyzing results on the oscilloscope is not yet possible. Further guidance from Dr. Brooke is needed and will be sought for further progress in lab.

9. Results of Bit Error test

A test was conducted utilizing the Bit Error Rate Testing machine. A 1MHz signal was generated by the BERT and fed to the 2938. This was done to check to see if the board was up converting properly. It was found that the conversion to RF frequency did not work properly. The output was extremely noisy. To date, a reason for this has not been found; however, it is strongly suspected that a filter is required for this part. The frequency conversion from 1MHz to 250MHz was successful. A VNA was used to check the output. A center signal was seen at 250MHz. Two sidebands were seen at .5MHz from the center signal. The distance between the carrier and side band signals was seen to vary as the BERT was adjusted. This was an indication that the modulation worked properly.

10. Findings from Final Lab Tests

The final lab sessions were conducted with the following goals.

1. Obtain a functional RF link at a given frequency.
2. Understand the functionality of the RFMD 2938.
3. Create a test setup environment and purchase parts conducive to future developmental work done on the project.

Having seen the RF2938 function by modulating an incoming signal from the BERT, the functionality of the RF output stage was tested. As mentioned in conclusion number one, doubts existed regarding the functionality of the 2938 as far as transmission is concerned. In order to test its functionality, a test setup was conducted which enabled the chip's receiving of an I or Q signal. This signal was then mixed up to 2.4 GHz using the onboard mixers. The output, however, looked extremely noisy compared to that of the IF output stage.

Being wary of these results, the group decided to use the mixers off of the RF9986 chip to mix up to 2.4 GHz. The results were exactly the same. The modulated signal appeared to be drowning in noise. After deliberation and consultation with various professors, including Dr. Brooke, it was determined that a filter is needed at the output of any chip mixing to such a high frequency. This filtering must be done as depicted in the RFMD technical reference on the chips. RFMD, however, does not make the required filters. The filters must be either designed (probably the most time efficient method) or purchased (potentially the more time consuming procedure). The filters must attenuate anything outside of the operating band of approximately 2.4-2.5 MHz by at least 3 dB. It must also be impedance matched to the output port of either chip it is designed for. Consequently, the group determined that in order to operate the devices at 2.4 GHz, the RF2938 and any other mixing chip is in need of filtering for correct operation.

Having failed to transmit at 2.4 GHz, the next attempt was to simply transmit and receive at the determined IF frequency of 250 MHz. Testing yielded the following results. One of the RF2938 boards appears to be malfunctioning. Its operation was unsuccessful after repeated attempts. Upon this discovery, the RF2667 was implemented in order to decode the modulated I or Q signal being injected. This board was never brought into operation. The group decided that certain controlling voltages on several of the pins must be adjusted carefully in order to obtain functionality. As time was running out, the group did not have enough time to finish this testing procedure.

In order to simplify the overall circuit layout, a project board was purchased to place all devices on. Barrel connectors for the SMA connectors were also purchased. The barrel connectors were mounted in the board for the I and Q inputs and outputs. This was to allow future workers to tap into the circuitry easily and timely. Also, a triple output power supply was purchased in order to aid in the variety of voltages needed for the circuits to operate.

In an attempt to simplify the board layout, a basic voltage divider was constructed. The tap ports were soldered at the necessary voltages. However, this attempt was unsuccessful. The reason was that the input impedance of each chip's power connector must be taken into consideration. After several connections at one location in the power divider, the voltage was decreased at each node. The power issue is one that must be dealt with in depth by future workers because this could prove to be a serious issue when implementing the design in future single board designs.

11. Overall Conclusion

All testing has stopped due to the conclusion of the semester. The final testing consisted of getting a link to work at the IF frequency. Since one of the RF2938 does not seem to be functional, there can only be one path to transmit at 2.4 GHz or at the IF frequency. The final lab setup was the test setup for the IF frequency. This included the use of the RF2422. However, it was never proven that the correct signals were obtained from the RF2422, RF2667, or the RF9986. The tests performed should give the new directions to what needs to be done to make the RF link operational.

To get a 2.4 GHz link to work, a functioning RF2938 or RF2422 is needed. Without two operational boards, a link cannot be established. The next steps to get a link include finding RF filters according to the specifications made by the RF2938 data sheets. It may also be helpful to speak with engineers at RF-MicroDevices to get this link to work. Also, there needs to be a way to get power to the power connectors of the boards. These connectors determine if the board operates in transmit, receive, half-duplex, and full duplex. It may be helpful to find out what size connectors are on the boards and to purchase plugs that fit them. As long as the wires from the plugs are long enough, this should help reduce clutter over the test setups that are attempted.

In conclusion, the 2.4 GHz link was not established. Much was learned about how to test the RFMD boards. Hopefully, experiences and testing results from this semester will enable future project groups to succeed in creating the desired 2.4 GHz link.