TReX Progress Report

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TRX First Semester

Summary

The IME TReX group started this project about week five of the fall 2004 semester. Nearly all of the work put into this project has been just from research. Once we had a good idea of what exactly we were going to produce we created a basic block diagram of the components we would need. We started searching for the various components. Since a 2.4GHz transceiver chip seemed impossible to find, we figured we would have to build the transceiver from the ground up. We started researching all of the individual components needed to build the proposed transceiver. Most of the components were pretty standard, but a couple where impossible to find. For example, the only band-pass filters that could be found came from Amplitronix, LLC (www.amplitronix.com) and had a cost of about $69 dollars a piece, far too expensive to order and "experiment" with. There where other problems trying to build the transceiver from scratch. Some of the components where only available in BGA, (ball-grid array), packages, Michigan Tech does not currently have the ability to mount and solder BGA components. This means we would have to contract out the soldering. Also, due to the fact that at 2.4GHz is such a high frequency, we would need a 4-layer board with the top and the bottom layer to be ground plans to act as wave guides, so we called a few companies to get some prices. Considering all of this, we also had to look for a company to impedance match the entire board (without, there is a very probable chance of the transceiver not working at all). All of this amounted to a very expensive cost.

Our biggest breakthrough came when Andy announced that he found a single chip solution to the transceiver. GCT Semiconductor Inc. (www.gctsemi.com) produces a 2.4GHz 802.11g transceiver chip with out the "M.A.C." layer. Most single solution chips for a transceiver of this type have the M.A.C. layer (used in computer routing) included, rendering them unusable for our application. This brought the project into a more obtainable scope. Instead of needing 20-25 components to produce the transceiver, only 4-10 components would be needed. We drew up a new block diagram and reevaluated our strategy. GCT said they would send us a handful of these chips at no cost, with data sheets included. We are still waiting on the data sheets and chips.

Introduction

A wireless local positioning system (WLPS) has its uses in a wide range of applications, applications such as daycare, military, correctional, and automotive. This can be applied to military uses so a Commander or General can be apprised of the location of every one of his soldiers thereby making it so help can be sent when a soldier gets into a difficult situation. Daycare providers would use this system in a park setting so they can keep track of all the children and instantly know if one of the children is not where s/he is suppose to be. The automotive uses are numerous. Using the WLPS in conjunction with the Global Positioning System (GPS) would allow for self driving cars or to track a stolen vehicle. The possibilities for this system are endless. The parallels to other projects within IME were just too hard to ignore.

This project interested us because it related to some of our other projects that use wireless communication, namely the DAC and TRIcorder. We believe we can gain some valuable knowledge that can be implemented into future projects and improvements on projects already in motion. Several uses can already be seen and the project has barely gotten off the ground. However, is there a motivation behind the development of such a system?

The motivation behind the development of a WLPS would be a better ability of tracking the movements of just about anything. Unlike the GPS the need for a line of sight to a tracking station would be unwarranted. Using a radio transmitter to poll mobile transceivers would allow for the use in buildings, in heavily wooded areas, and other areas that the GPS satellites just cannot reach along with a small profile and low power consumption.

Design Development

Initial Specifications

Over the first few weekly meetings of the semester the three teams meet and decided on the specifications that were to be used for the wireless channel. First, an operating band was chosen based on the theoretical bandwidth requirements for the system. Specifically, a bandwidth of 320 MHz was recommended. Unfortunately for us, the lowest, unlicensed ISM band frequency that would allow such a large amount of bandwidth is at 61.25 GHz (refer to **Table 1**), making this particular bandwidth and spectrum out of the question. After some deliberation an operating frequency of 2.45 GHz was settled upon. This frequency was chosen for a couple reasons. First, at 2.45 GHz, a bandwidth of 100 MHz would be available for use. This amount of bandwidth, although far short of our theoretical mark, was thought to be sufficient enough to at least demonstrate the functionality of the system. Secondly, there are several existing technologies that operate at this frequency so we assumed that the parts would be fairly cheap and easy to obtain, specifically, a transceiver. The second and final item the three groups had to decide upon was the type of modulation scheme to use. The eventual range requirement that the system was to obtain was set at 1000m. A QPSK modulation scheme was decided upon based on this distance and because of its lower bit error rate compared to other modulation schemes.

Frequency	**Tolerance**
6.78 MHz	+- 15.0 kHz
13.56 MHz	+- 7.0 kHz
27.12 MHz	+- 163.0 kHz
40.68 MHz	+- 20.0 kHz
915 MHz	+- 13.0 MHz
2,450 MHz	+- 50.0 MHz
5,800 MHz	+- 75.0 MHz
24,125 MHz	+- 125.0 MHz
61.25 GHz	+- 250.0 MHz
122.50 GHz	+- 500.0 MHz
245.00 GHz	+- 1.0 GHz

Table 1 – ISM Frequency Bands

Initial Design Development

The 2.45 GHz approach

Once the initial specifications were laid out, our team began construction of a block diagram. Initially, it was believed that the transmitter and receiver could each be implemented through single IC's allowing the majority of the team's efforts to focus on things like power management, antenna design, etc. However, initial component research revealed that there were no products available that would allow for instantaneous data rates that even approached what was needed. As a result, the primary focus of the project shifted to creating the transmitter and receiver circuitry. Figure 1 shows the initial block diagram of the transceiver circuitry (Figure 2 shows a revised diagram that uses a numerically controlled oscillator instead of the phase locked loop for the local oscillator.).

Transceiver Circuitry

The next phase of the project was to assign specific components to the parts of the block diagram. The components that would be required are a DSP to handle the incoming data, DAC's, ADC's, a modulator and demodulator, Low Noise Amplifiers, bandpass filters, the phase lock loop or numerically controlled oscillator, and the up and down converters.

The TI DSP chosen was the TMS320C6713, Floating-Point Digital Signal Processor (http://focus.ti.com/docs/prod/folders/print/tms320c6713.html). This processor was chosen for a couple of reasons. First, it's a floating-point DSP. Given the accuracy a local positioning system must have, floating point arithmetic is a necessity. This chip, operating at 300 MHz, allows for 1800 million floating-point operations per second, and 2400 million instructions per second. Another aspect of this chip that was appealing to our application was the fact that it has 2 separate clock zones, one transmit, and one receive. The chip also contains extensive error checking and recovery features.

The digital-to-analog (DAC) and analog-to-digital (ADC) converters used needed to have a high enough sampling rate and resolution to accurately reproduce the incoming and outgoing data streams. For the transmitter portion, DAC's were chosen with a 10 MSPS (mega samples per second) sampling rate and 8 bit resolution. For the receiver portion, ADC's with a sampling rate of 25 MSPS and at least a 10 bit resolution were chosen. Samples were obtained from Maxim IC (www.maximic.com). The MAX5189 Dual, 8-Bit, 40MHz, Current/Voltage, Simultaneous-Output DACs were chosen for the transmit portion, while MAX 1186, Dual, 10-Bit, 40Msps, 3V, Low-Power ADC were chosen for the receiver portion. Both of these chips were chosen based their optimized performance in digital communications systems.

Given the nature of our project, a wireless local positioning system, system accuracy is an absolute necessity. The incoming signal and outgoing signals would need amplification and filtering to guarantee accuracy, hence low noise amplifiers and bandpass filters would need to be implemented. Finding a low-noise amplifier for the system wasn't very difficult, but finding a bandpass filter that could handle the high frequencies of this system was. The only one found was made by a company called Amplitronix (www.amplitronix.com), and was available only in a BGA package.

At this point, problems started to arise. Not only was filtering becoming a problem, but modulation/demodulation, up/down conversion, and the local oscillator were also creating their own problems. Also, at 2.45 GHz, due to the extremely small wavelengths at that frequency, board layout and impedance matching became issues; we wouldn't be able to mill the boards at Michigan Tech. Other solutions needed to be investigated.

The 900 MHz approach

Like the 2.45 GHz frequency range, the 900 MHz range was also available for license-free, wireless communication, and in the earliest stages of this project, was considered as a possible operating range for the project. At 900 MHz, components were plentiful and cheap and board design wasn't an issue, in fact, our enterprise has already built a device capable of transmitting at this frequency. All the soldering and board fabrication could be done at Michigan Tech, also. This would've kept costs way down.

There were some inevitable pitfalls, however, that made the 900 MHz approach unfeasible. System complexity in the form of required bandwidth was one of these. If you refer to Table 1, at 900 MHz, the maximum bandwidth available is around 26 MHz. This falls even farther short of the 320 MHz of bandwidth proposed, than the 100 MHz of bandwidth at the 2.45 GHz range. It was believed that, with such a low amount of available bandwidth, the system wouldn't be able to be accurately demonstrated.

Another problem with this solution is expandability. If a system could, in fact, be demonstrated at 900 MHz, it would be very limited, at best, say 10 of the proposed 1000m. To get any more distance, a complete redesign of the system would be needed to accommodate a higher bandwidth. New components would be needed and all the issues that were avoided with the 2.45 GHz solution would have to be faced again. Because of this, the team decided that the limited success of this proposed solution wouldn't justify the time or money spent on it.

Current Design Development

The GCT solution

After doing some research, a solution was stumbled upon that could possibly solve many of the transceiver issues the project faced initially. Available from GCT Semiconductor, the GRF5103 is a 2.45 GHz, 802.11b/g transceiver chip optimized for high-speed, 2.4-GHz, proprietary wireless transmission. This chip would integrate the modulator, demodulator, up and down converters, the filters and the local oscillator. To complete the system, all we would need is a 22MHz clock signal, a power amplifier for the transmit signal, and an antenna. The baseband receive and transmit signals are in I/Q format, so a dual channel ADC and dual channel DAC are required to convert these between the analog and digital domains. As with our previous designs a DSP is still required to process the received base band signals and transmit a response. A new block diagram is shown in Figure 3.

GCT Semiconductor (www.gctsemi.com) was contacted towards the end of the Fall 2004 semester to acquire samples and a data sheet for the GRF5103. Currently the team is waiting for the samples and the data sheet to arrive so work can begin on the prototype.

Design Implementation

Evaluation Board Design

Evaluation Board price list		
part	**eval kit/board**	**cost**
IF/RF Amp/Filter	AD8138 eval kit	pre-release $NA
variable gain amp	AD8367-EVAL	$99.00
IQ Mod	AD8346-EVAL	$99.00
IQ Demod	AD8347-EVAL	$99.00
ADC	AD9433/PCB	$300.00
DAC	AD9765-EB	$200.00
RSSI Phase Detection	AD8361-EVAL	$100.00
Dem Log Amp	AD8306-EVAL	$99.00
Numberically Controlled oscillator	AD9850/CGPCB	$250.00
TI DSP	TMDSDSK6713	$355.00
12 SMA cables	J3306-ND	$150.00
TOTAL		**$1,751.00**

Table 2 – Evaluation Board Price List

Table 2 – Evaluation Board Price List

The components involved are almost entirely surface mount, which eliminates the possibility of creating a prototype on a bread board. The high frequency of the system also means that microstrip PCB design should be employed. This requires three or more conducting layers on the PCB, which we do not have the capability to fabricate at MTU. Therefore, to create the first prototype, we will need to either work almost entirely with evaluation boards, or design prototype PCBs and have them fabricated elsewhere. **Table 2** (above) lists the evaluation boards that we would need to purchase, along with their prices. It also includes prices of the components without the evaluation boards. The minimum cost of all the boards will be $1750. This would allow us to create a transceiver with a theoretical bandwidth of the 70MHz.

Printed Circuit Board Design

Following the use of evaluation boards, the design could be transferred to a single PCB using as little as three iterations. We have requested quotes from several PCB fabrication houses and initial quotes for a board of the complexity that we anticipate. These initial quotes suggest that minimum price design iterations will be between $500 and $600, if no chips are placed on the board. In addition we anticipate a component cost of $250 per board. If we can solder the board in house (as long as no BGA components are needed) the soldering cost should be about $20 a board, in materials, and wear and tear on the equipment. A more detailed description of specifications used to generate these quotes is included in **Appendix 1.** The total cost of this approach to design would be approximately $5300 and is shown in **Table 3** below.

	Prototype Budget		
	Part Description	Eval Kit/Board	Cost
Eval Boards	IF/RF Amp/Filter	AD8138 Eval Kit	pre Realease N/A
	Variable Gain Amp	AD8367-EVAL	$ 99.00
	IQ Mod	AD8346-EVAL	$ 99.00
	IQ Demod	AD8347-EVAL	$ 99.00
	ADC	AD9433/PCB	$ 300.00
	DAC	AD9765-EB	$ 200.00
	RSSI Phase Detection	AD8361-EVAL	$ 100.00
	Dem Log Amp	AD8306-EVAL	$ 99.00
	Numerically controlled oscillator	AD9850/CGPCB	$ 250.00
	TI DSP	TMDSDSK6713	$ 355.00
	12 SMA cables	J3306-ND	$ 150.00
PCBs	First Iteration	Boards	$ 600.00
		Components	$ 250.00
		Soldering	$ 20.00
	Second Iteration	Boards	$ 600.00
		Components	$ 250.00
		Soldering	$ 20.00
	Third Iteration	Boards	$ 600.00
		Components	$ 250.00
		Soldering	$ 20.00
IDE Suite	Code Composer Studio v2.2	TMDSCCS6000	$ 900.00
	TOTAL		$ 5,261.00

Table 3 – Detailed Budget Proposal for Prototype with Eval Boards

A second approach [illegible] create a PCB directly; however, because problems with our initial design, both in layout and content, can be expected, we feel it would be reasonable to anticipate as many as 6 iterations of the board design, totaling a minimum of $3720 in board and soldering costs alone, plus $250 per board for components. In addition, to integrate the DSP chip, we will need to purchase a full version of the IDE, costing $900. This would bring the total cost to approximately $12000 to produce a reliable prototype. Prices are outlined in **Table 4.**

	Prototype Budget without Eval Boards		
	Part Description	Eval Kit/Board	Cost
PCBs	First Iteration	Boards	$ 600.00
		Components	$ 250.00
		Soldering	$ 20.00
	Second Iteration	Boards	$ 600.00
		Components	$ 250.00
		Soldering	$ 20.00
	Third Iteration	Boards	$ 600.00
		Components	$ 250.00
		Soldering	$ 20.00
	Fourth Iteration	Boards	$ 600.00
		Components	$ 250.00
		Soldering	$ 20.00
	Fifth Iteration	Boards	$ 600.00
		Components	$ 250.00
		Soldering	$ 20.00
	Sixth Iteration	Boards	$ 600.00
		Components	$ 250.00
		Soldering	$ 20.00
IDE Suite	Code Composer Studio v2.2	TMDSCCS6000	$ 900.00
	TOTAL		$ 6,120.00

Table 4 – Detailed Budget Proposal for Prototype without Eval Boards

We feel the best path to developing this device is using the evaluation boards. They are more costly off the bat, but allow for more experimentation, and we will be able to get more out of what we can really do with the components. While the PCB method is more costly than the evaluation board method, the upfront cost is cheaper. However, we would have to be far more careful with the development as every mistake would increase the cost of development by about $900.

900MHz Alternative Solution

If the 900MHz band was considered for the transceiver instead of the use of 2.4GHz, the price of the project could be substantially reduced, but it will come at the expense of overall system performance. Because the wave length in the 900MHz band is substantially larger than 2.4GHz, line impedance of the PCB traces becomes less important, and a prototype could be fabricated without the use of ground planes. This means that PCBs could be fabricated in house. The cost would be reduced to less than $100 dollars per iteration. However, we would still recommend a design using evaluation boards. In addition we would not need to outsource any of the soldering, so the total cost of a prototype would be around $3400. The performance trade off of using this frequency range is in the potential bandwidth. As noted in **Table 1** the bandwidth available in the 900MHz spectrum in only 26MHz. If a prototype were made at this frequency, and later the need for more bandwidth were to arise, a substantial redesign of key components would be needed, particularly the antennas and the PCBs. An analysis of the costs is included in **Table 5.**

	Prototype Budget		
	Part Description	Eval Kit/Board	Cost
Eval Boards	IQ Mod	AD8346-EVAL	$ 99.00
	IQ Demod	AD8347-EVAL	$ 99.00
	ADC	AD9433/PCB	$ 300.00
	DAC	AD9765-EB	$ 200.00
	Numerically controlled oscillator	AD9850/CGPCB	$ 250.00
	TI DSP	TMDSDSK6713	$ 355.00
	12 SMA cables	J3306-ND	$ 150.00
PCBs	First Iteration	Boards	$ 60.00
		Components	$ 250.00
		Soldering	$ 20.00
	Second Iteration	Boards	$ 60.00
		Components	$ 250.00
		Soldering	$ 20.00
	Third Iteration	Boards	$ 60.00
		Components	$ 250.00
		Soldering	$ 20.00
IDE Suite	Code Composer Studio v2.2	TMDSCCS6000	$ 900.00
	TOTAL		$ 3,403.00

Table 5 – Detailed Budget Proposal for Prototype with Eval Boards at 900MHz

Revised TRX Plan and Budget Utilizing GRF1503 from GCT Semiconductor

The GRF1503 transceiver chip is designed to operate as an 802.11g transceiver and can handle bit rates of up to 54Mbps in the 2.4GHz ISM band. It integrates most of the components of the RF portion of the transceiver, including the modulator and demodulator, low noise amplifiers, and RF local oscillators. The unit requires a 22MHz clock, a power amplifier for the Tx signal, and an antenna to operate. The baseband Rx and Tx signals are in I/Q format, so a dual channel ADC and dual channel DAC are required to convert these between the analog and digital domains. As with previous designs a DSP is required to process the received base band signals and transmit a response. A block diagram is included on the following pages.

Prototyping sequence

Phase 1

The first prototype will still be made using evaluation boards. However, because of the high level of integration of the GRF1503 chip, only ADC, DAC and DSP boards will be required. The GRF1503 does not have an evaluation board available. However, we feel that because of the low number of peripherals required, we can make the module with the fabrication tools available at MTU for approximately $60. The total cost of this phase would be approximately $1000, and it we hope if would lead to a stable RF platform on which we can develop the base band protocols.

Phase 2

The second phase of the project is to integrate all of the components onto a single board. Because of the small number of RF components we think that we may be able to complete all the fabrication at MTU. If this is a case we think it will take three iterations of the design process to get a fully functional module. This process will cost approximately $1550. Detailed budgets are available on the following pages (**Table 6**).

	2.4 GHz prototype with GRF1503		
	Part Description	Eval Kit/Board	Cost
Phase 1	ADC	AD9433/PCB	$ 200.00
	DAC	AD9765-EB	$ 200.00
	TI DSP	TMDSDSK6713	$ 355.00
	GRF1503 self constructed Eval		$ 60.00
	8 SMA Cables	J3306-ND	$ 115.00
		Total	
	2.4 GHz prototype with GRF1503		
	Part Description	Eval Kit/Board	Cost
Phase 2	First Iteration	Board	$ 60.00
		Components	$ 150.00
	Second Iteration	Board	$ 60.00
		Components	$ 150.00
	Third Iteration	Board	$ 60.00
		Components	$ 150.00
IDE Suite	Code Composer Studio v2.2	TMDSCCS6000	$ 900.00
		Total	$ 1,530.00

Table 6 – Price breakdown using the GCT single chip solution

Challenges

The main challenges will be interfacing the DSP with the ADC and DAC and the transceiver IC. When I contact GCT Semiconductor, they were willing to provide us with samples, documentation and application notes, but the sales rep that I talked to was very clear that they would not be able to provide any direct engineering support if we have problems. He also alluded to the fact that this is still not a "plug and play" solution, and that even some of their larger customer have had trouble with integration. However, even with this in consideration, we think that using this chip will still simplify the design process greatly.

Conclusions

It is obvious that the GCT single chip solution is the best solution because it gives us the maximum performance, with the least chances of error. It is also more cost effective than the 900MHz solution. The problem is that we have been waiting over a month for the chips to arrive, the company is hard to contact, and their support is non-existent. The amount of work that will have to go into the chip will be large, and the learning curve will be larger.

The second best option is the 900MHz option. We can actually get the PCB's made in-house and don't have to worry about things like impedance matching. All of the components are easy to find and the choices are many. The problem is that at 900MHz the allowed bandwidth is far below anything that is theoretically usable for this application. The cost is a little higher than the GCT single chip solution, but is very achievable.

The last option is to build the entire 2.4GHz transceiver from discrete components. This is not a very good path to take, most of the work has to be done outside of MTU, and it is all costly. Also, the amount of impedance matching would make the entire circuit finicky and problematic. The amount of cost and time in this solution far exceeds all expectations.

TRX Second Semester

Introduction

After all things considered, the decision was made to stay with a 2.4 GHz single chip solution. With the start of the second semester, plans are that everything will proceed more smoothly than the first semester.

Summary

The second semester of this project started off a little better than the first. We had communicated with GCT semi about using some of their chips in the TReX module. They sent us numerous samples and all the official data sheets. We were very discouraged when we found out the GCT chip required many support components that would have been very hard to manage. There was also no support available for the GCT chip.

Luckily, Mike Chase had found for us, two more reasonable single chip solutions, the Maxim/Dallas MAX2820/2822. Ideally, we wanted to use the MAX2822 because of its onboard band pass filters, power amplifier and RF switch. The only problem was the MAX2822 could only provide us with about 20 MHz of bandwidth. After a lot of communication with Maxim, we found the best 2.4 GHz single chip solution, the MAX2825.

The MAX2825 has the ability to give us 20-48 MHz of bandwidth, only 2 MHz less than the later projected 50 MHz. It also offers an adjustable frequency. The next step was to find the needed band pass filters and power amplifier (for the prototyping development stage we opted out of setting up an RF switch, and would just use the Rxin and Txout on separate antennas.

The band pass filters we had initially been looking at were from Amplitronix (www.amplitronix.com), they were very small, and their price of $69 was actually about mid-market for such a filter. The reason we could not opt to use these filters is because Amplitronix has a minimum purchase quantity of 25. The filters we ended up going with were a couple of very large, high power units from Digital Communications Incorporated. They are good enough to use for prototyping of this system.

The power amplifier chosen for this project was recommended with the transceiver we had chosen so its selection was fairly simple. The power amplifier has the capability of amplifying a signal up to 29 dB in the 2.4 to 2.5 GHz spectrum

The Analog to Digital converter was a MAX1198 from Maxim/Dallas. This is a dual channel converter that is made for QPSK modulation. The evaluation kit relies on a sine wave for a clock, but the chip itself uses a square wave.

The Digital to Analog converter was AD9767 from Analog Devices. This was also a dual channel converter for QPSK modulation. The board will convert up to 14 bits of data, but we are only using it to convert 8 bits in interleaving mode.

The DSP (Digital Signal Processor) used for the TReX was the TMS320C67x™ DSP. This high performance DSP is based on advanced very-long-instruction-word (VLIW) architecture which makes this particular device very adaptable and well suited for multi-channel and multifunction applications. The DSP, operating at 300MHz, is capable of performing up to 1800 million floating-point operations per second and processing 2400 million instructions per second. The speed and adaptability offered by the TI DSP gives the flexibility and freedom required for the intense development of the TReX system.

This system component is central to the performance of the TReX system. All programming to control the DSP is loaded and run by this device

The testing of this equipment got into great detail. To help simplify the use, documentation on what has been tested and what was needed is provided in the following sections. The sections will be discussed in the following order; transceivers, band pass filters, power amplifiers, analog to digital converters, digital to analog converters, and the digital signal processor (DSP).

Transceivers

Summary

The transceiver was chosen on a wide range of specifications. It had to have a carrier frequency range from 2.4 to 2.5 GHz therefore allowing for future frequency selection abilities. The transceiver also needed to have a minimum bandwidth of 50 MHz. GCT provided the project with many samples and full datasheets of their transceiver. Maxim/Dallas also had some likely candidates to be used in the project.

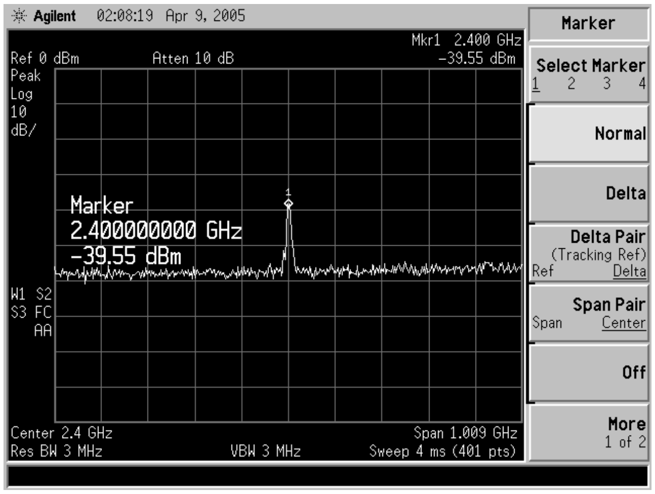
Part Search

Towards the end of the first semester, Andy Gross contacted GCT Semiconductor (http://www.gctsemi.com) concerning their 2.4 GHz one chip solution transceivers. It seemed this transceiver would be perfect; however the component support was much too great to be of use. Thanks to the help of Mike Chase, the MAX2820/2822 chip from Maxim/Dallas Semiconductor (http://www.maxim-ic.com) was discovered. This chip had integrated power amplifier, band pass filter, and Tx/Rx switch. However, it did not meet the bandwidth specification previously set forth. This discovery ultimately led to the discovery of two other chips made by Maxim/Dallas.

The MAX2825 and MAX2829 were also discovered. They both came close to meeting all specifications. The only problem was once again the bandwidth. However the bandwidth was so close that one of these chips was going to be selected. This decision came down to the features of each chip. The difference between these two chips was the fact that one chip supported smart antenna technology, basically the use of multiple transceivers, modulators, or demodulators depending on the application with multiple antennas, which would allow for phase locking the local oscillators and the other chip didn't. The need for phase locking in the TRX system was not needed so the MAX2825 was selected. It was realized that the MAX2829 could be used in the DBS and this information was passed onto the DBS development team.

Testing and Results

The datasheet on the evaluation board for the MAX2825 had detailed testing procedures to be used. This procedure included the equipment to be used and what the settings of each piece of equipment should be set two. The procedure was followed nearly to the letter. However, some of the test equipment was not available so the best was done with what was available. During testing it was found that a reference clock frequency of 40 MHz would be best. Using a 20 MHz signal put our output signal in the 2.2 GHz spectrum which was not what was needed. The testing of the transmit portion of the chip was performed first.


Agilent 02:08:19 Apr 9, 2005

Mkr1 2.400 GHz
-39.55 dBm

Ref 0 dBm Atten 10 dB
Peak
Log
10
dB/

Marker
2.400000000 GHz
-39.55 dBm

W1 S2
S3 FC
AA

Center 2.4 GHz Span 1.009 GHz
Res BW 3 MHz VBW 3 MHz Sweep 4 ms (401 pts)

Figure 4: Spectrum Analyzer showing a transmission spike at 2.4 GHz

In order to test whether the chip would transmit required a 40 MHz signal generator, a spectrum analyzer, a power supply capable of delivering 2.7 volts as well as ± 5 volts, and two phase locked signal generators set to a frequency 2 MHz with one generator set to a phase shift of 90º. These two generators formed the I/Q signal inputted into the system. The signal is shown in figure 4. The receive side was unable to be tested do to inadequate equipment.

Future Considerations

This part of the project is pretty much ready to move into the pre-production prototype stage. However, some things that should be looked are the maximum actual bandwidth on the transmit and receive ends as well as looking into microstrip technology, correct procedures for impedance matching, and multi-layer board manufacturing. Microstrip technology would cut down on the number of components required to be placed on the board there by freeing up board real-estate it is not, however, involved with multilayer board manufacturing. Information on multi-layered board manufactures has been looked into, but whether or not a student discount can be subtracted has not been determined.

Band-Pass Filters

Summary

Band-filtration was used to eliminate frequencies outside the 2.45 GHz carrier frequency to help increase the efficiency of the transceiver module. On the receive end, it was used to narrow the incoming frequency band to reduce the amount of noise that would otherwise enter the system. On the transmit side it was used to eliminate any lower or higher frequency noise that would be sent to the power amplifier before transmission, thus increasing the efficiency of the amplifier.

Part Search

The search for band-pass filters that would operate in the 2.45 GHz range was difficult. The first filter found was the ABFF0123 RF Band-pass Filter from Amplitronix (http://www.amplitronix.com). This filter came in an ultra-small SMD package measuring approximately 2.0 mm wide, 2.5mm long, and 1.0mm high. The center frequency of this filter was 2.45 GHz with a pass-band width of no more than ±50 MHz. This created a very small pass-band from about 2.40 GHz to 2.50 GHz, ideal for this set-up. Acquiring these filters for further analysis turned out to be a problem, however. First, price was an issue. These filters cost $69 a piece with a minimum order of 25 needed. This brought the total cost of these filters to $1725. Due to the ultra small size of the component, no available evaluation board, and the extremely high cost, it was extremely impractical to go with this particular band-pass filter for a simple prototype. For more details on the ABFF0123, the data sheet can be viewed at http://www.amplitronix.com/pdf/ABFF0123.pdf.

The next band-pass filter found was a unit from Digital Communications Inc. (http://www.dci.ca). It gave acceptable filtration in the pass-band and was a much more affordable option than the Amplitronix unit, only $50 per unit. Due to the size and package of the DCI filter it is impractical to use in the actual implementation of the mobile transceiver but will be acceptable for a prototype. There was no accompanying data sheet with the DCI units but one was not needed. They are simple passive-filter designs, pre-tuned at the factory, with 2 SMA terminals, either being the input and the other the output. These are the units used in the prototype.

Testing and Results

The procedure to test the band-pass filters was fairly straight forward. First, a RF signal generator was connected to one of the two SMA terminals. The other terminal was connected to a spectrum analyzer. A 2.0 GHz to 2.70 GHz signal with some known amplitude was feed into the input terminal of the filter. It was found, for these particular filters, that high-pass cutoff occurred at around 2.2 GHz and low-pass cutoff occurred at approximately 2.6 GHz. These ranges were acceptable for the specifications of this project.

Future Considerations

To move into the pre-production prototype of the mobile transceiver it will be required to find filters that will be able to be placed on a printed circuit board (PCB). The filters from Amplitronix are good candidates due to their small size and surface mount capabilities but the price may be a drawback. Maxim-IC may be a good place to start because most of the other components were select from there but Analog Devices (http://www.analog.com) would also be a good place to look. Cost, package type, and availability will be the deciding factors here.

Power Amplifier

Summary

When dealing with low power signals in wireless transfer, amplification is necessary to ensure that the signal integrity remains strong throughout transmission. On the transmitter side, amplification is needed to make sure the signal will be able to reach its intended target with enough power to be useful. The receiver also needs amplification to make the signal powerful enough for the electronics to process it. For the proposed system, the amplifier must be able to operate between 2.4 GHz and 2.5 GHz.

The MAX2247 Power Amplifier

A suitable power amplifier was found fairly quickly at http://www.maxim-ic.com. The MAX2247 Power Amplifier (PA) was chosen because it came recommended with the MAX2825 transceiver that was selected for the project. For approximately $100, an evaluation kit for this chip was purchased.

The MAX2247 has a few characteristics that made it an ideal amplifier for this project. The first was its operating frequency. This PA could amplify a signal up to 29dB anywhere from 2.4 GHz to 2.5 GHz. Another nice feature of this amplifier was that it has a variable gain. For improved efficiency, the MAX2247 provides bias circuitry to vary the gain from +10dBm to +24dBm. Another nice feature of this PA is its built-in shutdown mode, which allows the unit to turn off when not needed, greatly increasing efficiency.

Digital to Analog Converter

About the Analog Devices AD9767 DAC

The DAC we choose was the AD9767, from Analog Devices (www.analog.com) we choose it because it is a high performance converter and can handle 8bit interleaving conversion. This document will help clear up some of the confusing parts of the evaluation and use of this device. Unfortunately this board has not been tested because we were waiting on a piece of equipment that did not arrive until the end of the year.

The equipment needed to test the DAC is:

- 16 Bit Logic (Word Generator), this can be tested without the logic generator if the DSP can be made to produce a functional interleaving digital signal.
- 2 3-5V DC power supplies for digital and analog inputs
- Function generator IF the clock is not being provided from the logic generator.
- Dual channel oscilloscope.

The evaluation of the digital to analog converter is a much harder evaluation. The way it uses a clock takes a little extra thinking and more jumper settings. The following is the jumper clock set up to make testing and use the easiest.

- JP1, JP2 need to be inserted, this is to allow interleaving mode by an alternating logic signal for IQSEL.
- JP3, needs to be removed, this is so an onboard clock will control IQSEL and IQRESET
- JP4 should stay in the "I" position, unless you want to control the IQRESET clock signal, but for ease of use, you can just leave JP4 tied low ("I" position).
- JP6, JP7 are used to synchronize the input data with IQSEL. To do this Refer to page 3 of the evaluation board data sheet.
- JP8 enables interleaving mode.
- JP9 is enabled if the clock is from the logic (word) generator.
- JP16 is enabled if the clock is from a function generator connected to S1.

The power for the converter is provided by connecting the power supplies to the 4 banana jacks at the top of the board. Ideally the logic input should be the same as the voltage input of the DVDD. If this is not the case the board provides plug in resistor packs to pull up or down the voltage of the logic signal. I could only assume that the blue IC's near ports one and two are these resistors they are talking about.

That is about all that can be said about the DAC without just repeating information on the evaluation sheet. The wait on equipment delayed the evaluation of this device.

The Digital to Analog converter is what changes the output of the DSP into an analog wave that the transceiver can convert to RF and send out.

Analog to Digital Converter

About the MAX1198 Analog to Digital converter

The ADC we choose was the MAX1198, we choose it because it has a very high sampling speed, and it is from a trusted name, Dallas Maxim (www.maximic.com). The following are the key pointers to working with the 1198 Evaluation Kit so that the next person to work with it will have not problems hooking it up and using it.

There is equipment recommended by the manufacturer that you will need to evaluate this chip. They are:

- Voltage for the Digital Side 2.5V @ 100mA
- Voltage for the Analog Side 3.3V @ 200mA
- Low noise and low jitter function analyizer
- 2 PHASE LOCKED function generators for the differential analog signal input
    - Michigan Tech only has on type of function generator that will phase lock, the 80Mhz Agilent Function generators, it is possible to borrow two of them from Mike Chase, the only other location for these function generators is in the 619 undergraduate lab
- Some type of logic analyzer
- A Digital Multimeter (to verify correct operating voltages)
- They also recommend some band pass filters, but I have no idea how required these are, they are something that would probably be very important in a preproduction single board prototype, but if the signal from the function generator is clean enough, these should not be an issue

Procedure to analyze the MAX1198EV Kit (This can be found on the data sheet, but I am going to explain everything here:

- For jumpers JU5-JU8 make sure they short pins 2-3 on all of them. These are the jumpers the enable the board in general (bottom of board right above “MAXIM”)
    - JU5- (offset binary digital output)
    - JU6- (normal operation)
    - JU7- (enable MAX1198)
    - JU8- (enable outputs)
        - For better understanding of what they jumpers actually do, refer to the evaluation board data sheet.

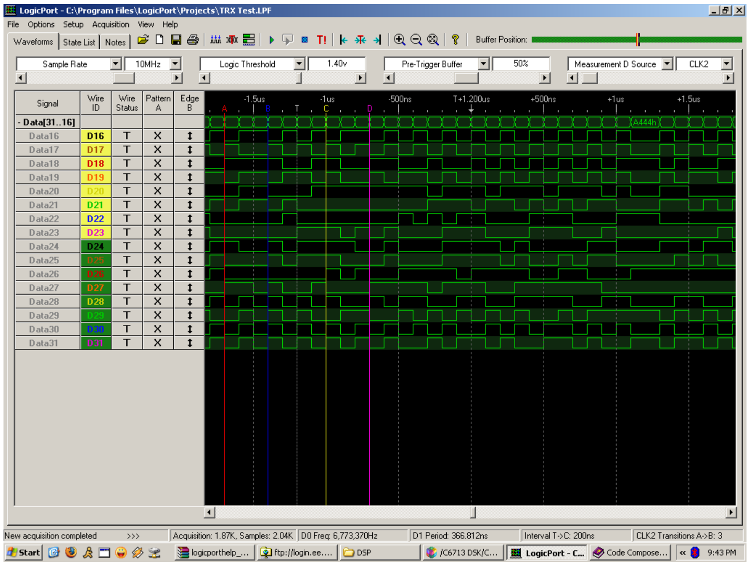
- The single function generator will be connected to the CLOCK input, a BNC to SMA connector is required to make this connection (lowest SMA connector on the board)
    - The input signal will be 2.4Vpp (not to exceed 2.6Vpp) and any frequency less than 100 MHz (frequency sets the sample rate). I do not know how low the signal can go but I would recommend 40 MHz (that is what the MAX2825 is clock is set to run from).
    - The clock on the evaluation kit takes a sine wave and converts it into a clock signal; the duty cycle can be adjusted with the potentiometer (R34) at the lower left side of the board. To get a 50% duty cycle turn the potentiometer until you get 1.32V over TP1 and TP2 (two small through holes near the top of the potentiometer).

- The input the 1198 is receiving is a differential signal. Jumpers JU1-JU4 must all be set for pins 2-3; this enables differential signals on channels A and B.
    - The two SMA inputs labeled D/E_INA and D/E_INB (top to bottom respectively) on the left side of the board are the differential inputs. Each of those terminals will be connected to the phase locked function generators with a BNC-SMA cable.
    - It should be noted again that only the Agilent 80 MHz function generators can be phase locked, the sync port on the front of the generators is NOT for phase locking.

  - The two signals should be set to the frequency that the Transmitter will send to it (approx 5Mhz) and have an amplitude of less than 2Vpp
- At the top of the board there are 7 header pins, the 6 on the right are the ones needed for power hookup.
  - The very right 3 are the digital voltage input. They require 2.5V (but can be operated from 1.7V to 3.6V, ideal performance isVD>>VA); the ground from this source connects in the middle at the headers labeled "DGND." Two positive leads are required and connect to the "VD" header and the "VDUT" header.
  - The 3 headers immediately to the left of it are the analog voltage headers. They require 3.3V (the eval kit MUST have 3.3V-3.6V) and have the same layout as the digital voltage inputs. The negative 3.3V connection goes to the header labeled "AGND" and two positive 3.3V leads connect to the "VA" and "VADUT" headers.
  - You must be careful with this, you will have 6 leads terminating at a very small area, keep them as neat as possible.

- The logic analyzer gets hooked up to the two 8bit outputs. Header row J1 gets the outputs.
  - Channel A is at pins 1-15 (labeled A0-A7) and Channel B is at pins 27-41 (labeled B0-B7).
  - The clock signal is output at J-43 (labeled CK)
  - The AB monitor at J-23 is not used in this evaluation.
  - Set the logic analyzer to capture on the clocks rising edge.

If everything goes well the output should look like figure 5.



LogicPort - C:\Program Files\LogicPort\Projects\TRX Test.LPF

Sample Rate: 10MHz

Logic Threshold: 1.40v

Pre-Trigger Buffer: 50%

Measurement D Source: CLK2

Signal	Wire ID	Wire Status	Pattern A	Edge B
- Data[31..16]				
Data16	D16	T	X	↕
Data17	D17	T	X	↕
Data18	D18	T	X	↕
Data19	D19	T	X	↕
Data20	D20	T	X	↕
Data21	D21	T	X	↕
Data22	D22	T	X	↕
Data23	D23	T	X	↕
Data24	D24	T	X	↕
Data25	D25	T	X	↕
Data26	D26	T	X	↕
Data27	D27	T	X	↕
Data28	D28	T	X	↕
Data29	D29	T	X	↕
Data30	D30	T	X	↕
Data31	D31	T	X	↕

New acquisition completed | Acquisition: 1.87K, Samples: 2.04K | D0 Freq: 6,773,370Hz | D1 Period: 366.812ns | Interval T->C: 200ns | CLK2 Transitions A->B: 3

Figure 5: The output of the A/D with (2) phase locked 5MHz sine wave inputs offset by 90 degrees.

The analog to digital converter plays the role of output from the Transceiver and input to the DSP. The DSP will be waiting for the correct sequence of data from the converter in order to know when to send the TReX's response.

The TI DSP

The DSP (Digital Signal Processor) used for the TReX was the TMS320C67x™ DSP. This high performance DSP is based on advanced very-long-instruction-word (VLIW) architecture which makes this particular device very adaptable and well suited for multichannel and multifunction applications. The DSP, operating at 300MHz, is capable of performing up to 1800 million floating-point operations per second and processing 2400 million instructions per second. The speed and adaptability offered by the TI DSP gives the flexibility and freedom required for the intense development of the TRex system.

This system component is central to the performance of the TReX system. All programming to control the TReX is loaded onto and run by this device. The DSP is responsible for the processing received and requested unique 6 bit ID's (with 2 bit correction code) of the WLPS. Detailed software development is required to control the TReX system. The DSP's external clock is required to sync all devices. Also the general interface functionality of the DSP allows advanced control of the transceiver.

The TI DSP was the first component to be ordered. When it arrived, the device was tested and found to be dead on arrival. The team promptly returned the device and awaited the return of a working DSP. The unfortunate return processes took a substantial amount of time and was a major deficit to the development of the TReX system. Due to the lack of expertise the TReX Group had with C programming (the operational language) as well as time needed to familiarize team members with the component presented a key obstacle was encountered.

In an effort to recoup much of this lost development time the TReX team members sought the help and support of WCE's DBS team. As the DBS system shared the exact same DSP components as the TReX system, cooperation between the two groups was a logical approach to solving our situational problem. WCE's lack of progress with their DSP development did not offer much assistance in the overall design of the system.

This obstacle was a major setback in effectively completing all deliverables of the design process. The DSP was by far the best choice in meeting out design requirements as well as providing the flexibility, adaptability, and general control of the system needed for initial development.

Future Considerations of the TReX

The prototype board that IME has been working on producing barely scratches the surface of other features the TReX will need to have. Once a working prototype of the TReX is produced, building a single board prototype will be the next step.

Things to note on the first single board prototype:

1. The DSP will need to be a Quad Flat Pack package to be milled here at Michigan Tech. The Ball Grid Array version would require a board with plated through holes and probably would contain at least 4 layers. Also this would need to be soldered professionally.

2. In circuit serial programming abilities will be needed so that changes to the TReX firmware can be made and developed without changing DSPs or making a new board for every change.

3. The DSP should be explored for its ability to do D/A and A/D conversions. This would cut down on the physical number of components the board would need, and cut down board size and cost.

4. The DSP will need to connect to all of the major devices to provide them all with a clock signal. The DSP will also need to connect to several pins of the transceiver to control the registers on it.

5. This board is going to need at least two separate power lines, one in the vicinity of 2.5-2.7 volts and one around 3.3 volts.

6. Since the TReX is going to be the more mobile device of the WLPS, power consumption will be an issue. The sleep and standby modes of all the devices will need to be explored.

Conclusion

Overall this project went relatively well. Some changes could be made to the way the project is managed and how the purchasing of equipment should proceed. The concept of a Wireless Local Positioning System is great. So many uses can be found for this idea making it worth the time and expense of researching and developing a system that can accurately calculate the position of a car, person, or package.

The accurate communication between individuals and groups was seriously lacking, however. It was a classic case of the left hand not knowing what the right hand was doing. Had detailed specifications and better communication channels been laid out from the get go instead of a graduate paper being given to the groups tasked with designing the system, the problems that plagued the semester could have been avoided. Looking back on everything that happened, the hope that everyone involved has learned from this experience exists and everyone will walk away feeling better that if nothing had been accomplished at least a good lesson had been taught.

TRX Block
Diagram
10-5-04

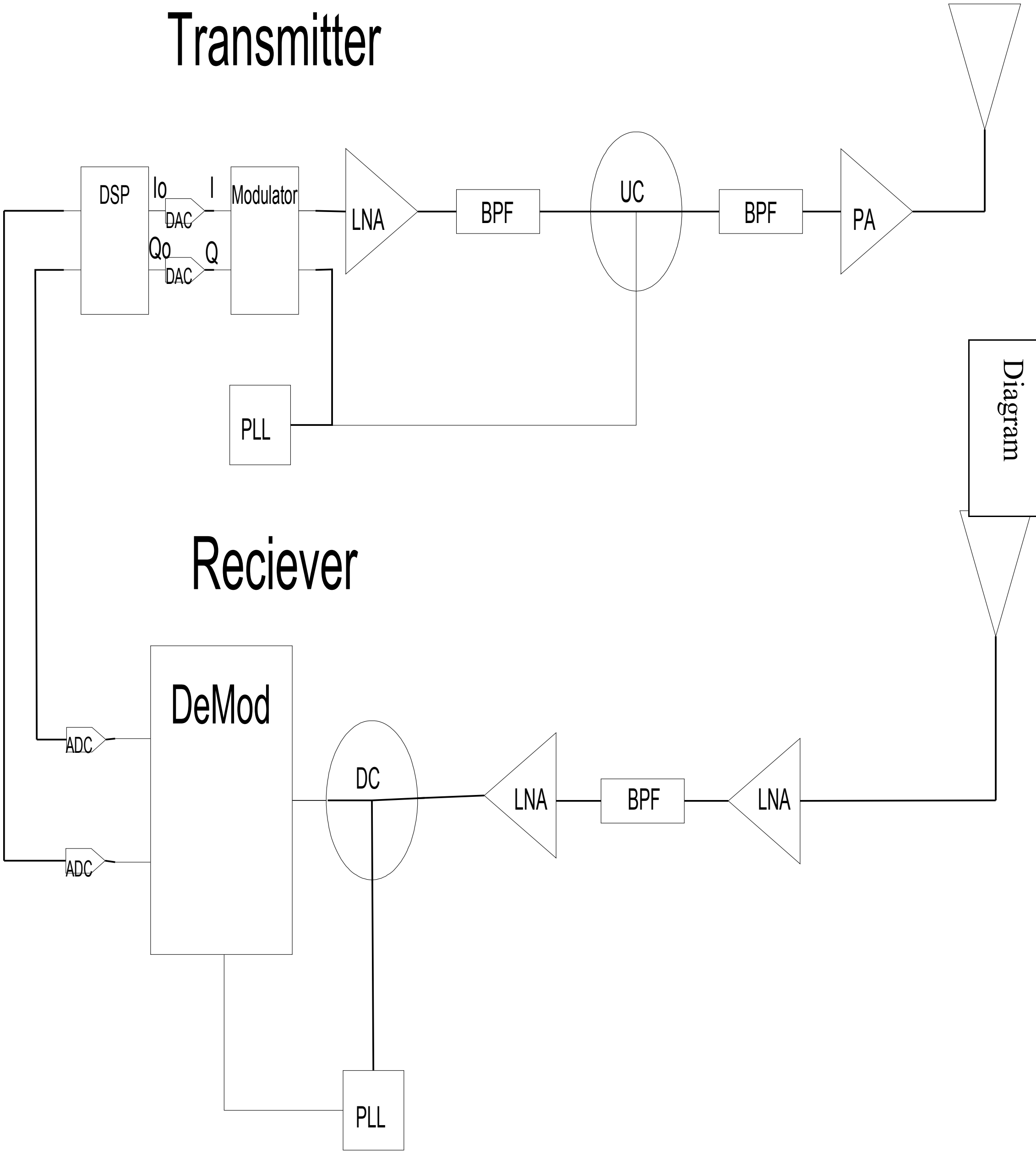


Figure 1
Initial
Block
Diagram

TRX Block
Diagram
11-2-04

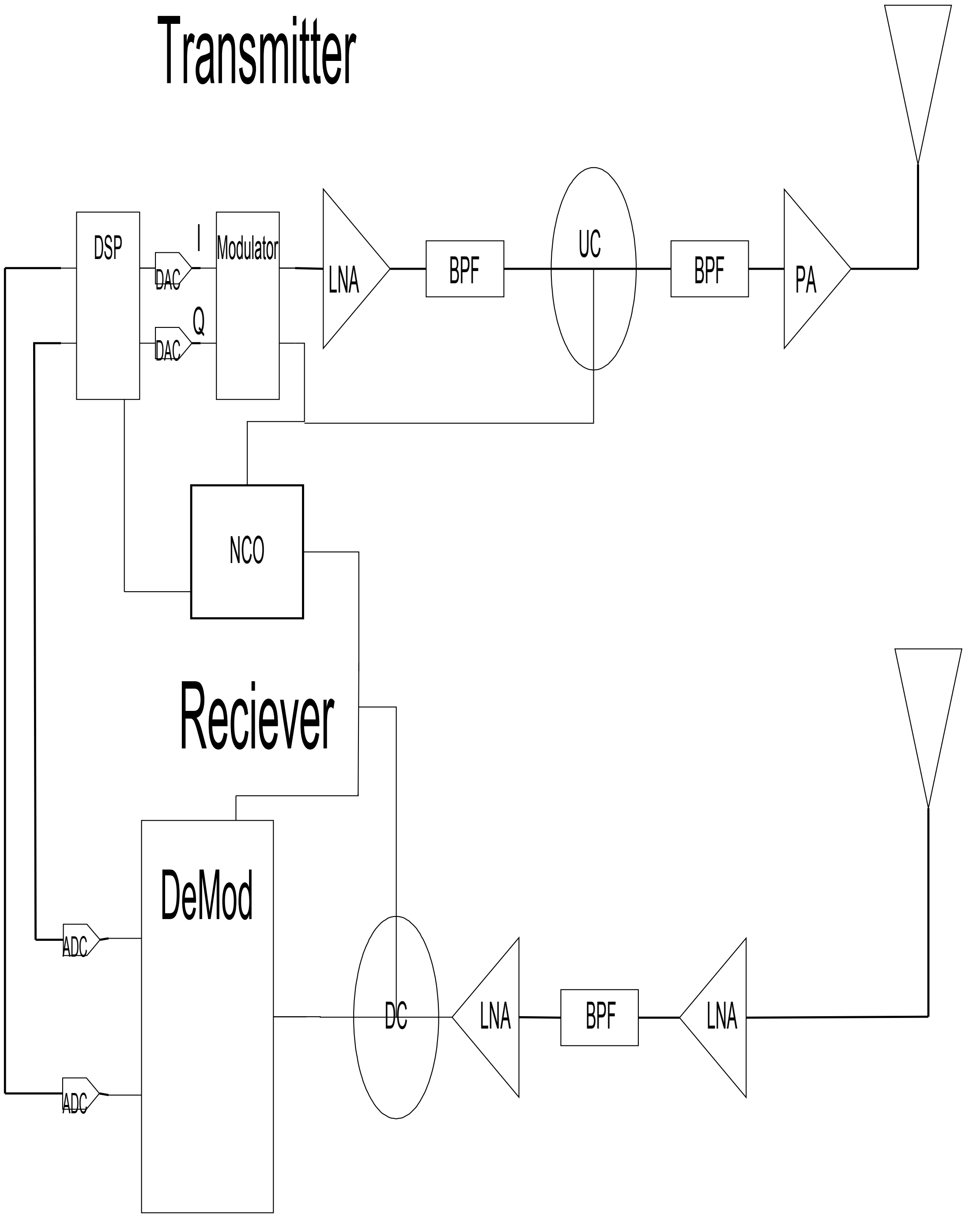
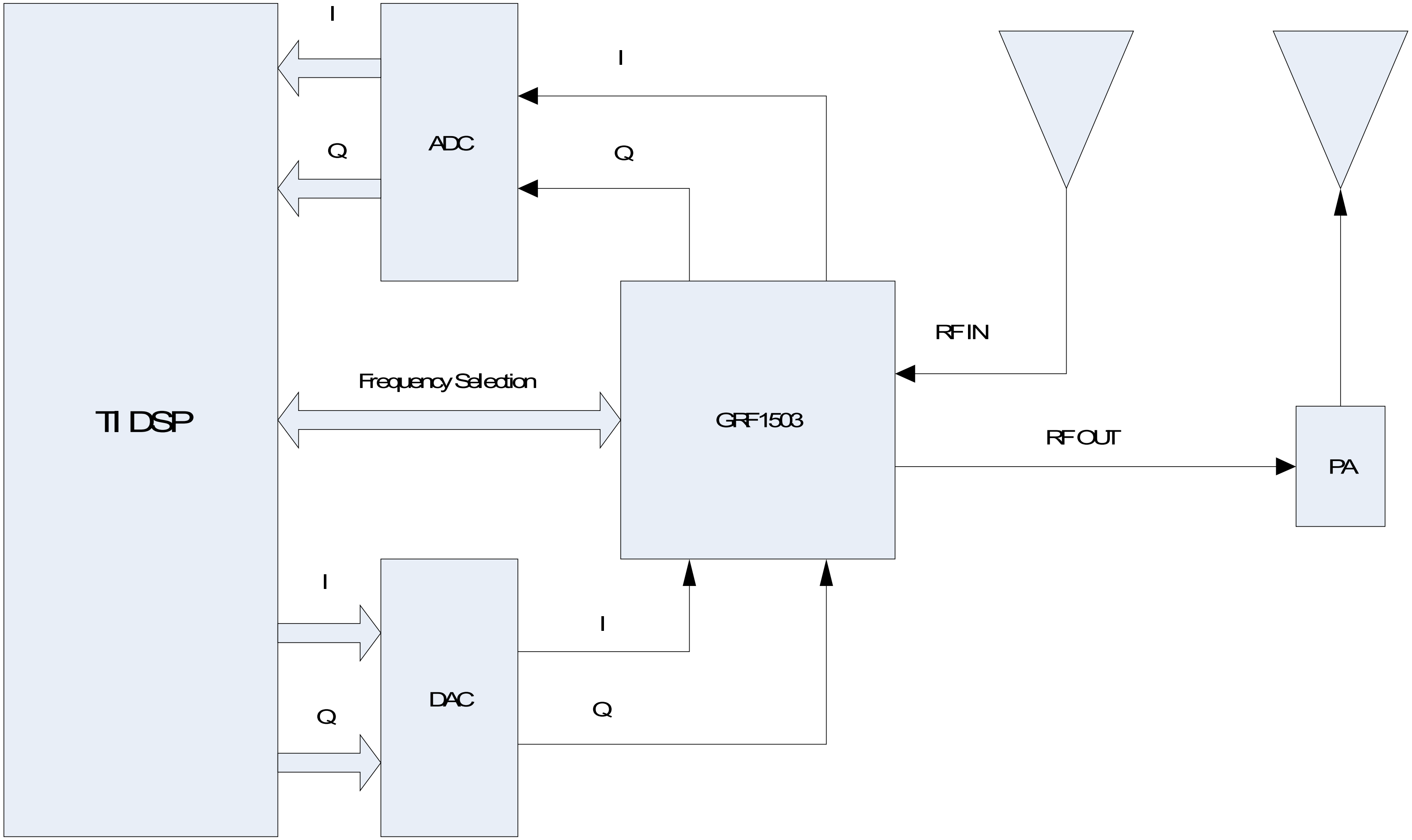


Figure 2
Revised
Block
Diagram

Figure 3 GCT Single Chip Block Diagram



Appendix 1

Possbile Suppliers

Company	Address	Phone	Web	est
K&F Electronics	33041 Groesbeck Hwy Frasier Mi, 48026-1514	586-294-8720	www.circuitboards.com	info@circuitboards.com everthing that we can give him, block diagram, components, size, etc
Advanced Circuits	21101 East 32nd parkway Aurora, CO 80011	1-800-979-4pcb	www.4pcb.com	www.4pcb.com/commerce/quote_frame.asp quote order form for circuit board specs.
Quality Circuits Inc	1102 Progressive Drive Fergus Falls, MN 56537	gen phone:218-739 9707	www.qciusa.com	Minn sales office:877-878-0975
PPC Electonics AG	Riedstrasse 2 Post Box 5270 CH-6330 Cham Switzerland	text +41 (0)41 749 45 45	www.ppc-electronic.com	www.ppc-electronic.com/english/kontakt/offertanfr.html

Board Specifications

# of Layers	4
material type	FR4
thickness	0.062
dimension	4 X 4
finish plation	solder
copper weight	2 oz.
trace width/space	.010 (10 mil)
smallest hole	0.02
qty smd pads: top	300
qty smd pads: btm	0
smd pitch	0.01
solder mask sides	both sides
solder mask type	LPI
legend silk screen	top side
cnc routpoints	4
tab route	no
scoring	no
prototype qts	5,10
production qts	50,150,250

Quotes

prototype	unit cost	number	Does not include solder costs	from
2 day	118.6	10	🟥	Advanced Circuits
2day	1,043.00	1	🟥	Advanced Circuits
5 day	58.6	10	🟥	Advanced Circuits
5 day	443	1	🟥	Advanced Circuits

Component Placement	20 Components	1-10 boards with surface mount	1-10 boards with through hole
Journey Electronic	513-539-9836	$1,000	$200