ALL-IN-ONE APRS TRANSMITTER

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ABSTRACT

The Automatic Packet Reporting System (APRS) is a digital radio system that allows transmission of data using an analog FM radio link. APRS allows position, brief messages, and other data to be distributed across a network, independent of infrastructure, making it ideal for applications such as search and rescue, asset management, and event tracking, while maintaining low cost and operating even when cellular and internet services are unavailable. This project encompasses the design, build, and test of a compact, low-cost APRS transmitter, which will include a 5W radio, GPS, and LCD-based user interface, to allow full utilization of APRS.

ACKNOWLEDGEMENTS

I would like to thank my professors and faculty in the EE department who have made my education what it is today, my friends and family for supporting me throughout my college career, and my advisor, Dr. John Saghri for giving me the opportunity to work on this project.

I. Introduction

This project was conceived as an improvement on currently available APRS trackers. There are three basic classes of APRS devices: trackers, which contain only the hardware to generate audio packets from an incoming data stream (e.g. from a computer or external GPS module); transmitters, which contain a built in radio in addition to the packet generator, and may or may not contain a built in GPS; and transceivers, which contain all functionality of transmitters with the addition of being able to receive packets. As of 2012, there are many trackers and several transmitters, but few transceivers available on the market. Of the common all-in-one transmitters, none have a built in user interface, and require that the device be pre-programmed with settings and information before use. This project aims to create a simple, low cost APRS transmitter with built in GPS and LCD, enabling configuration without the need of a computer.

The data transmitted by an APRS tracker may be decoded directly with the aid of an FM receiver and either a computer or terminal node controller (TNC), which performs the job of decoding the incoming packets either with software through a computer sound card, or with hardware/software in the TNC. The APRS network is composed of digipeaters, which are transceivers which receive packets, determine whether the packet should be repeated based on its path settings, and retransmits if necessary. The APRS network also contains IGates, which are receivers or digipeaters that are connected to a networked computer, thus able to send the packet over the APRS internet system (APRS-IS). These packets can be viewed online and plotted on maps in real time. Figure 1 shows packets viewed online and received locally.

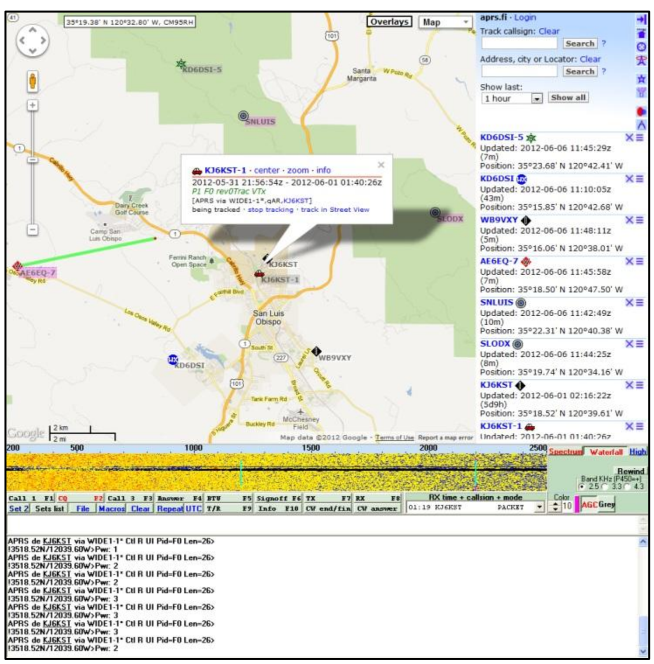


Figure 1: APRS packets on online map (top), and received directly (bottom)

II. Background

APRS History

The history of APRS began in 1974 with the release of the AX.25 specification. Bob Bruninga, the creator of APRS, began with the creation of a computer system that would decode Navy position reports and plot them. The system was later modified and used with the AX.25 protocol in 1984, then called the Connectionless Emergency Traffic System (CERT) [1]. Bob Bruninga published the first paper on APRS in 1993, describing the system widely used today.

APRS Technical Details

APRS is based on the AX.25 packet protocol, which defines the link layer for a communications system [2]. APRS uses AX.25 unconnected information (UI) frames to transmit data between multiple stations, and defines several message types that can be used. The most widely used implementation of APRS uses audio tones sent over an analog FM radio, typically operating in the VHF amateur band.

At the highest level, APRS is a packet radio protocol, meaning all data is formatted in packets following a defined standard, with each packet encoding information such as destination addresses, source address (the user's callsign), and error checking, along with the intended data. Figure 2 shows the packet format used in APRS.

	APRS Packet Format								
Field Type	Flag	Destination Address	Source Address	Digipeater Addresses	Control Field	Protocol ID	Information Field	FCS	Flag
# of Bytes	1	7	7	0-56	1	1	1-256	2	1

Figure 2: AX.25 Unnumbered Information (UI) packet format used in APRS [3]

The packet is made up of 8 different types of data fields. These are listed and described below.

Flag: (0x7E) This field marks the beginning and end of the packet and is not found anywhere else within the packet. The space between two consecutive packets can also be filled with continuous flags.

Destination Address: (Ex. 0x82, 0xA0, 0xA4, 0xA6, 0x40, 0x40, 0xE0) This field indicates who the packet is being sent to. In this example, the destination address is `APRS  -0`, one of the standard APRS calling destinations. The SSID of this field (`-0`) defines what digipeater path the packet should take; in this example the VIA path, defined below in the Digipeater Addresses field. All bytes in this field (except the last) are encoded as standard ASCII bytes left shifted by 1 (i.e., their hex value is multiplied by 2.) The last byte of this field follows the SSID byte format of 0bCRRSSID0, where C is the command/response bit (1 for APRS), RR is 11, SSID is the SSID value, from 0-15, and the LSB is 0. For this example, this gives 0b11100000 = 0xE0.

Source Address: (Ex. 0x96, 0x94, 0x6C, 0x96, 0xA6, 0xA8, 0xE2) This field indicates who the packet is being sent from. In this example, the source address is the author's callsign, `KJ6KST-1`. A user may have up to 16 (-0 to -15) different APRS stations on the air, each with different SSIDs. [4] All bytes in this field are left shifted by 1, with the last byte following the SSID byte format listed above.

Digipeater Addresses: (Ex. 0xAE, 0x92, 0x88, 0x8A, 0x62, 0x40, 0x63) This field is a list of the digipeater addresses (call signs) or indicates a generic path for the packet to follow. In this example, the generic path `WIDE1-1` is used, meaning it will be repeated in one "hop", with each digipeater decrementing the SSID until it reaches -0. The first digipeater(s) to hear this packet will retransmit it once more for other stations or IGates to receive. The last address in this field must end with an LSB of 1 to indicate the end of the address fields.

Control Field: (0x03) This field indicates that the packet is an unnumbered information (UI) frame, the default for APRS.

Protocol ID: (0xF0) This field indicates that there is no layer 3 (network layer) implementation, as is standard for APRS.

Information Field (Ex. 0x21, 0x30, 0x30, 0x30, 0x30, 0x2E, 0x30, 0x30, 0x4E, 0x2F, 0x30, 0x30, 0x30, 0x30, 0x30, 0x2E, 0x30, 0x30, 0x57, 0x3E) This field contains the information the user wants to send, following one of the ten main types of data as defined in the APRS specification. In this example, the information field contains a basic GPS position report: (`!0000.00N/00000.00W>`). This field begins with the "!" character, and ends with the ">" character. The "/" character between the latitude and longitude defines what symbol table the station uses (primary: "/" or secondary: "\"), and the ">" character defines which symbol in the table is used; in this example, a car. A list of these symbols is found in the APRS specification. The information field can be followed by a comment field directly after the data, and may include any characters except "|" and "~".

Frame Check Sequence (Ex. 0x38, 0x76) This field contains a Cyclic Redundancy Check (CRC) of all bytes in the packet except the flags and the FCS itself. The CRC follows the 16-bit CRC-CCITT format, with a polynomial of 0x8408. The FCS is sent low-byte first.

Flag (0x7E) The end of the packet is marked by another flag.

APRS packets are transmitted over the air using the modulation scheme of a Bell 202 modem, called AFSK (Audio Frequency-Shift Keying), at a baud rate of 1200 (bits per second). The modulation is most commonly used over an analog FM radio link, but single sideband (SSB) and Gaussian frequency shift keying (GFSK) modulations are also used at 300 and 9600 baud. The Bell 202 modem uses two audio tones of different frequencies to represent binary 1 and 0, with a 1200Hz tone as the mark (1) bit, and a 2200Hz tone as the space (0) bit. However, if data were sent without further encoding, certain strings of data may create an unintentional flag (0x7E), which would be seen to the receiver as the end of the packet. To prevent this problem from occurring, a scheme called bit stuffing is used. Any time a sequence of 5 consecutive 1s are seen in the data, a 0 is inserted, ensuring that no flags (sequence of six 1s) are found anywhere but the beginning and end of the packet. To assist with receiver synchronization, the packet is non-return to zero inverted (NRZI) encoded. This encodes a 0 as a change in state (i.e. from a 0 to a 1 or from a 1 to a 0), and a 1 as no change in state. Together with bit stuffing, this ensures that there is a bit transition at least every 5 bits to aid in clock recovery. Unlike bit stuffing, NRZI encoding is applied to the entire packet, including flags and FCS. All bytes are sent least significant bit (LSB) first.

Previous Work

APRS has been adopted by many amateur radio operators as an easy-to-use system for transmitting position data, usually from a GPS, in order to track people, vehicles, or other assets in real time. Two of the most common trackers are the OpenTracker series, developed by Scott Miller, and the TinyTrak series, developed by Byon Garrabrant. In January 2011, the author developed an APRS tracker, using information primarily from the AX.25 protocol, APRS specification, and from a document written by John Hansen on sending AX.25 UI frames using a PIC microcontroller [5]. During Summer 2011, the author developed a board to be used with an MSP430 Launchpad development board, that in conjunction with a Python script, could generate an analog audio output or digital bitstream from user-input data. These two projects served as the backbone for the software design of this project.

III. Requirements and Specifications

The APRS Transceiver fulfills the following specifications as defined by the project goals; to capture and transmit GPS coordinates using the APRS protocol, display GPS data and device status, and operate according to FCC regulations and frequency allocations.

Table 1: All-In-One APRS Transmitter Requirements and Specifications

Marketing Requirements	Engineering Specifications	Justification
1, 2	Contains radio transmitter operating in the amateur 2M band to transmit APRS data at a duty cycle no greater than 10% with a power of up to 5W	Must have a sufficient transmit power to cover a large area. APRS packets are typically sent at a low duty cycle, e.g. once per 15-30 seconds, to minimize network usage.
1, 2	Can operate for at least 6 hours transmitting APRS position data at a rate of once per 15 seconds	Must be able to operate for a sufficient time before requiring a recharge.
3	Fits 12 x 5 x 4 cm, and weighs less than 180g	Must be compact and lightweight to not hinder the user.
4	Uses USB for PC interface and charging	Needs to use standard interface to receive firmware updates and charge the battery.
5	Displays current position and status on built in LCD display	Allows the user to change settings and get current location and battery status without the use of a computer.
6	Spurious emissions must not exceed -40dBc or 25µW [6]	Must comply with the FCC Part 97 emissions standards for amateur radio transmitters.
Marketing Requirements	1. Transmit APRS data at high power 2. Long battery life 3. Low weight/size 4. Interface with computer for firmware upgrade and charging 5. Displays position and device status 6. Meets FCC Part 97 requirements	

IV. Design

This project was designed through a series of prototypes, each testing an individual building block of the final transmitter. This enables each module to be tested more easily over a wider range of parameters, and facilitates changes before the system grows too complex. Once each module is tested and working to specifications, it can be integrated into the complete system. The overall system block diagram is shown in Figure 3, which shows the six basic building blocks of the transmitter (excluding the LCD). The following sections describe the development and testing of each of these blocks.

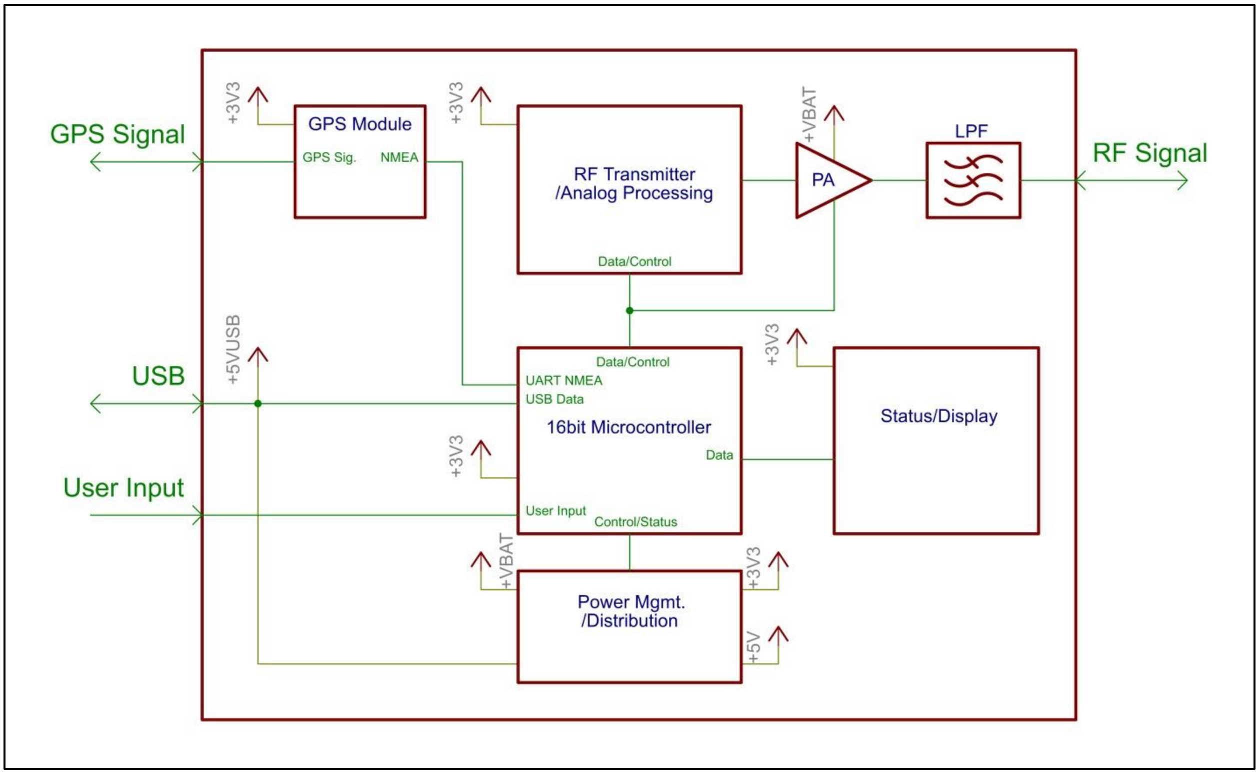


Figure 3: All-In-One APRS Transmitter Block Diagram

MICRF112 Transmitter

This module is a test board for the MICRF112 433MHz transmitter IC, manufactured by Micrel. The circuit is based on the example circuit given in the datasheet. After performing a basic functional test of the device, the circuit was modified to allow tuning of the reference crystal by means of a variable capacitor. After determining the frequency vs. voltage transfer characteristic using a spectrum analyzer and power supply, the voltage needed to produce a 4.8kHz FM deviation was calculated. Using a signal generator, 400Hz, 1.2kHz, and 2.2kHz modulating tones were then applied and the FM spectra were measured using a spectrum analyzer.

Circuit Schematic and Theory

The MICRF112 is a single-chip ASK/FSK transmitter IC designed for short range wireless devices. [7] Short range devices (SRDs) are defined by the European Telecommunications Standards Institute (ETSI) as "radio devices that offer a low risk of interference with other radio services, usually because their transmitted power, and hence their range, is low." [8] There are many similar devices available for the SRD market, usually containing an on-board PLL, VCO, and control circuitry. The simplicity of their operation and widespread use makes these a good low-cost solution for generating analog FM in a transmit-only application. This device allows data to be transmitted via amplitude shift keying (ASK) or frequency shift keying (FSK) via two pins. RF is generated by a fixed on-board 32x PLL, using an external crystal or reference frequency as the input. An internal power amplifier provides an output power of up to 10dBm. A block diagram for the device is shown in Figure 4.

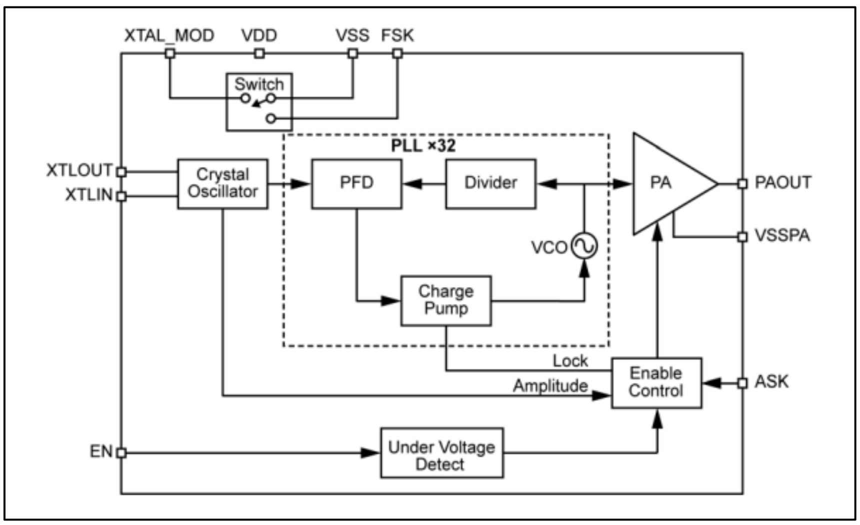


Figure 4: MICRF112 Functional Block Diagram [7]

The circuit schematic (shown in Figure 5) is based on the application circuit given in the device datasheet. A 13.56MHz crystal was chosen for the device to transmit on 433.92MHz. The datasheet suggested matching network was used to match the device to 50Ω, connecting to an SMA port. Power, ground, and the ASK pin (used as transmit/device enable) are routed to external pins, and a test point and SMA port are routed the crystal input and output, respectively.

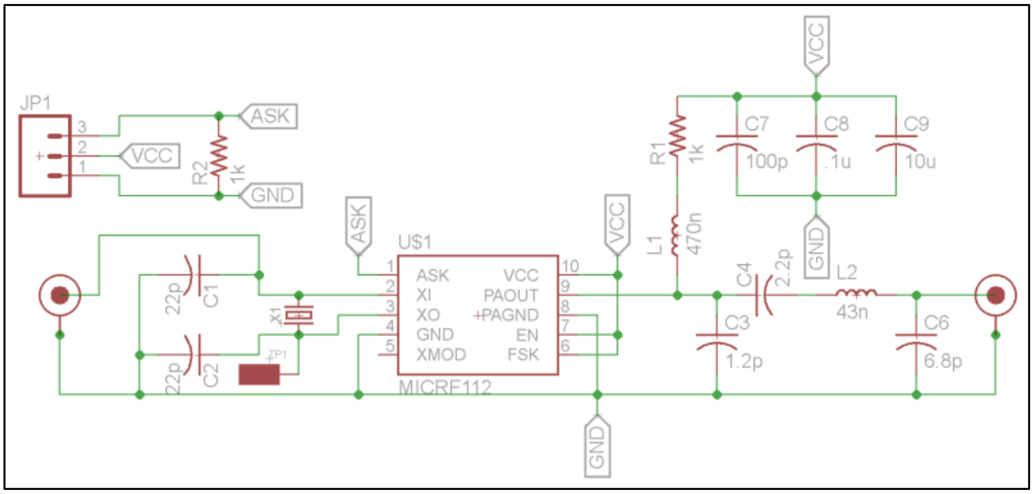


Figure 5: MICRF112 Test Board Schematic

The circuit was then modified to allow modulation of the reference frequency by pulling the crystal oscillator through the load capacitors, C1 and C2. A varactor diode replaces C1, with the tuning voltage being applied through a 10kΩ resistor. The resistor value was chosen empirically for the highest FM deviation. The varactor diode was chosen based on availability and capacitance range. The device used is a Philips BAT754 dual Schottky diode. A graph of the capacitance vs. reverse voltage is shown in Figure 6.

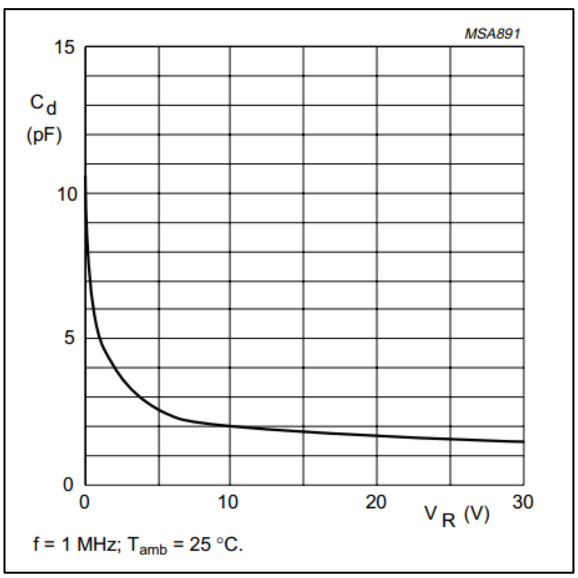


Figure 6: BAT754 Diode Capacitance vs. Reverse Voltage [9]

Using both diodes in the BAT754 in parallel, a capacitance range of approximately 20pF to 5pF could be achieved using a 0-5V tuning voltage. This is within the range of load capacitance needed by the 13.56MHz reference crystal. The modified circuit is shown in Figure 7, and the modified PCB is shown in Figure 8.

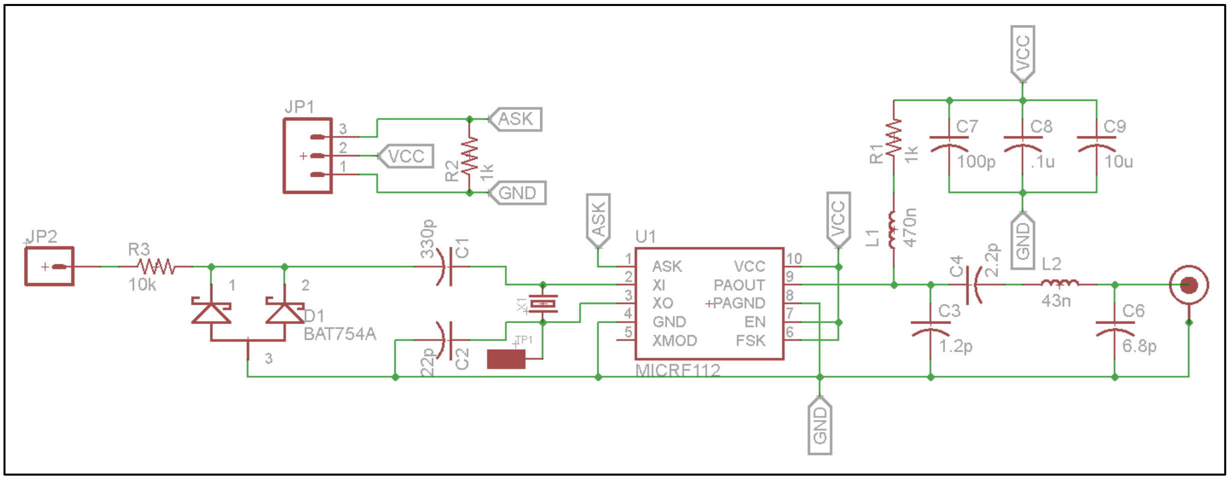


Figure 7: Modified MICRF112 Test Board Schematic

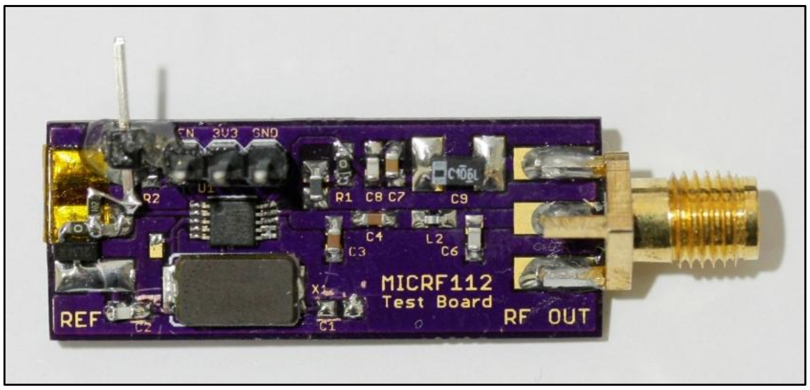


Figure 8: Modified MICRF112 Test Board

Testing

A table of frequency vs. tuning voltage was recorded using an HP 8922M spectrum analyzer to measure carrier frequency while varying the tuning voltage using a power supply. A graph summarizing the results is shown in Figure 9.

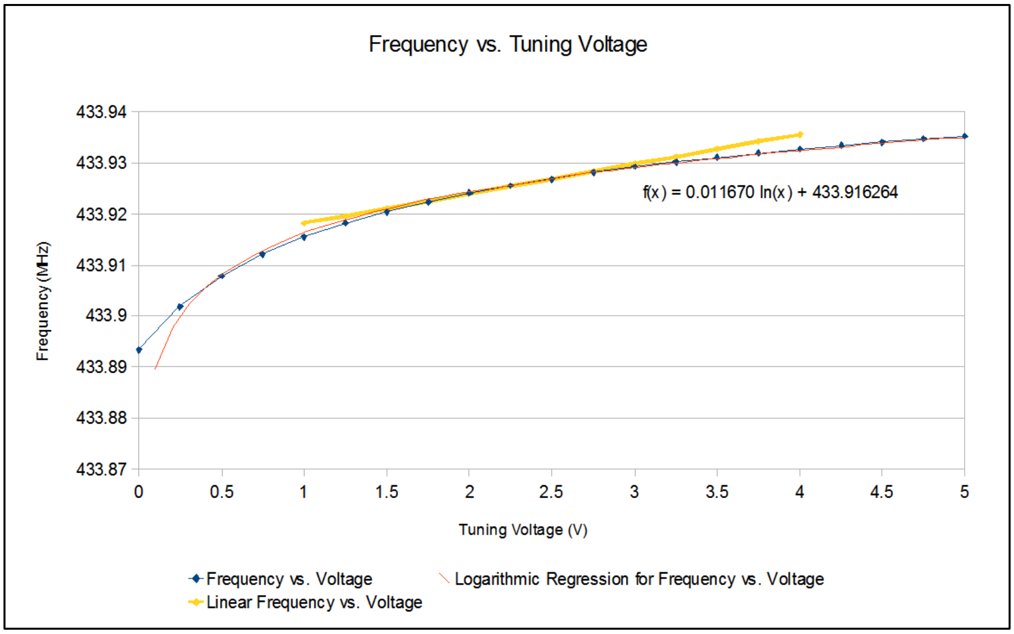


Figure 9: Frequency vs. Tuning Voltage Transfer Characteristic

A logarithmic regression was applied to the data to obtain a curve with the following formula:

$$F(v) = 0.01167 \cdot \ln(v) + 433.9163\ MHz$$

Where *v* is the tuning voltage in volts, and *F(v)* is the resulting frequency. Taking a derivative results in the FM deviation vs. bias voltage of the overall system:

$$\frac{dF(v)}{dv} = \frac{11.67}{v} kHz/V$$

A typical VHF/UHF FM transceiver uses a deviation of 4.8kHz when transmitting voice, thus 4.8kHz was chosen as the desired deviation. A bias voltage of 2.5V was chosen to remain within the power rails of 0-3.6V and to provide the best linearity within the tuning range (a higher bias voltage yields a more linear slope, as seen in Figure 9.) Using the derivative at 2.5V yields a required voltage swing of 1.03$V_{p\text{-}p}$ for the desired deviation. Thus the minimum and maximum voltages are 1.99 and 3.01V. Solving for frequency using the first formula yields and actual minimum and maximum frequency of 433.9243 and 433.9291MHz, giving an actual deviation of 4.87kHz, close to the linear estimate. The linear estimate is overlaid on the graph in order to visualize the error over the range of 1-4V. A signal generator was used to produce 400Hz, 1.2kHz and 2.2kHz tones with a 1.03$V_{p\text{-}p}$ amplitude at 2.5V DC offset. The spectra were then measured as shown in Figure 10.

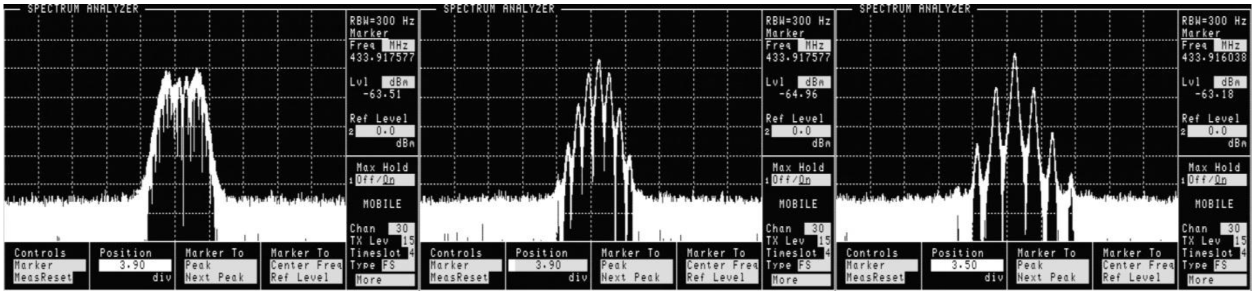


Figure 10: FM Spectra of 400Hz (left), 1200Hz (center) and 2200Hz (right) Tones

The bandwidths of the three tones were measured as 10.3, 9.6, and 13.9kHz, respectively. According to Carson's rule, the expected bandwidth is: [10]

$$BW = 2(\Delta f + f_m)$$

Where Δf is the FM deviation and f_m is the modulating frequency. The expected bandwidths are thus 10.4, 12, and 14kHz. The actual bandwidths of the 400Hz and 2200Hz tones closely match the expected bandwidth, with an unknown deviation from the expected 1200Hz bandwidth.

Conclusions

The MICRF112 demonstrates that a simple analog FM transmitter can be created using a low-cost transmitter IC as a PLL and amplifier block in a simple indirect FM modulator. By applying a modulating signal to a varactor, the reference crystal was frequency modulated at a low deviation, producing a larger deviation RF signal at the output. The device can be turned into an APRS transmitter by injecting an APRS baseband signal at the modulation input, once conditioned to produce the correct deviation as calculated. The device used in this prototype is locked to 32x the reference oscillator frequency, severely limiting its capability. However, other devices such as the ADF7012 by Analog Devices implement a fractional-N PLL, allowing many RF frequencies to be used.

ADF7012 Transmitter

The ADF7012 is a single-chip ASK/FSK transmitter IC supporting multiple modulation types and integrating a fractional-N PLL, allowing the transmit frequency to be selected by an external microcontroller. Similarly to the MICRF112, the ADF7012 is designed for digital modulations via clock and data pins on the device, with the carrier generated by a PLL with a crystal oscillator as the reference. The device is capable of 14dBm output power and covers a frequency range of 75MHz to 1GHz via the PLL and output divider. The test board provides a low-pass filter, access to the SPI bus, and control voltage for an external 20MHz VCXO, which is used as the reference. The schematic for this test board, again based on the example circuit given in the datasheet, is shown in Figure 11, and the layout is shown in Figure 12.

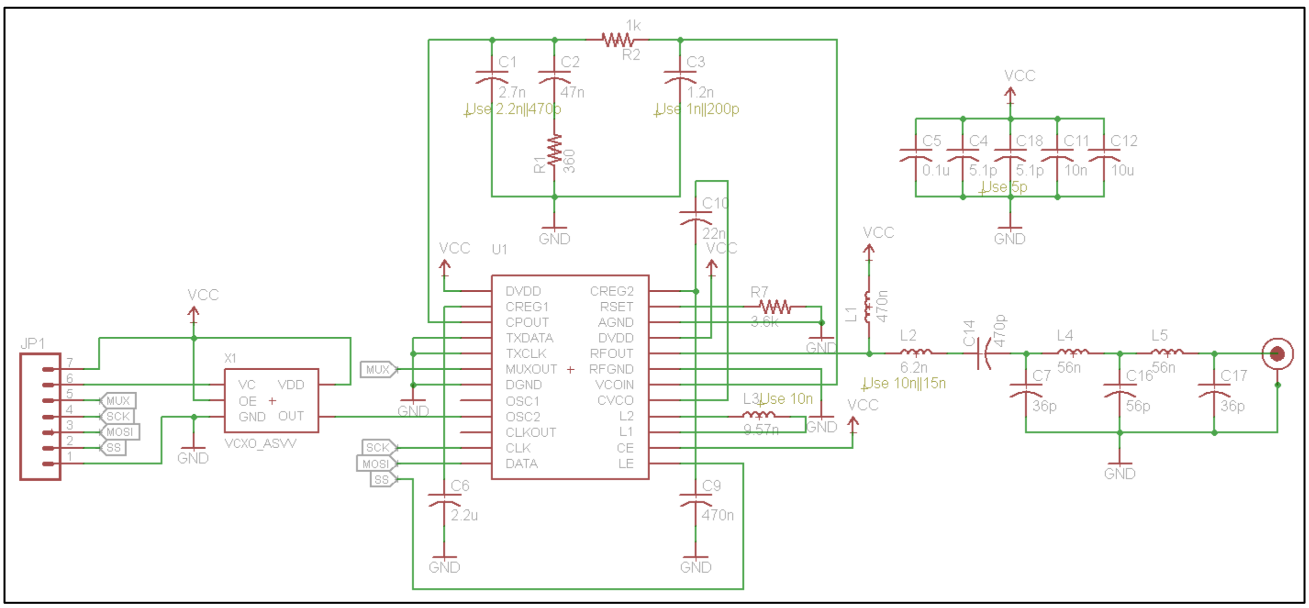


Figure 11: Schematic for the ADF7012 Test Board

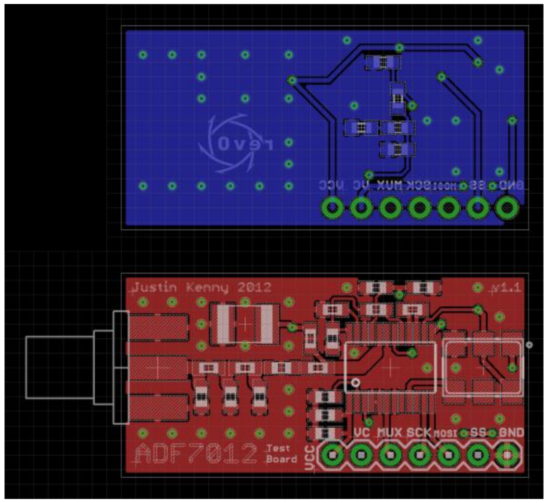


Figure 12: PCB Layout for the ADF7012 Test Board

Two copies of this PCB were built, the first being a hand-etched prototype. The layout was modified slightly to accommodate larger vias in order to fit the smallest drill bit that was available. The design was printed on paper and taped to the board. Two holes were drilled for registration of the top and bottom layers. The PCB artwork was then printed for the top side (mirrored) and bottom side on Staples Photo Basic paper, recommended for the toner transfer method of etching PCBs. Once the toner was transferred to the copper clad board, the paper was removed and the board was etched using ferric chloride. After etching, the board was cleaned, and the top and bottom layers were connecting using 30ga wire soldered between vias. These solder joints were ground down to prevent interference with components placed above. The board was electrically tested to ensure no shorts were present, and the components were soldered. The board was then electrically tested after soldering and a short at the loop filter output was corrected. Pictures of the hand-etched board are shown in Figure 13 below. Pictures of the commercially made board are shown in Figure 14 below.

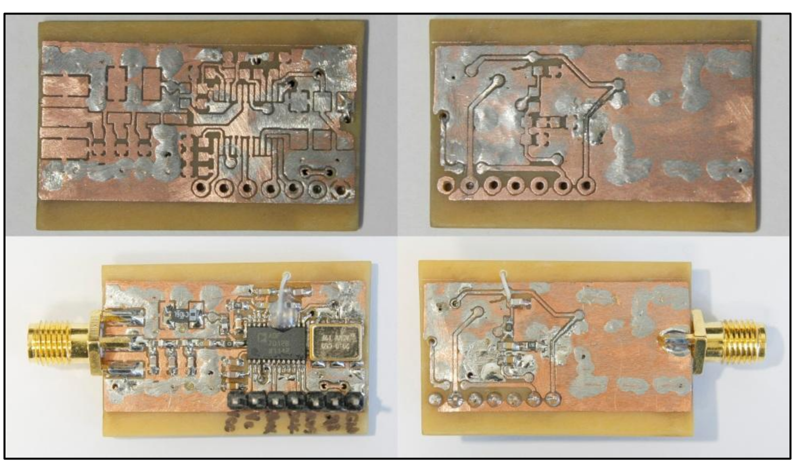


Figure 13: Handmade PCB for the ADF7012

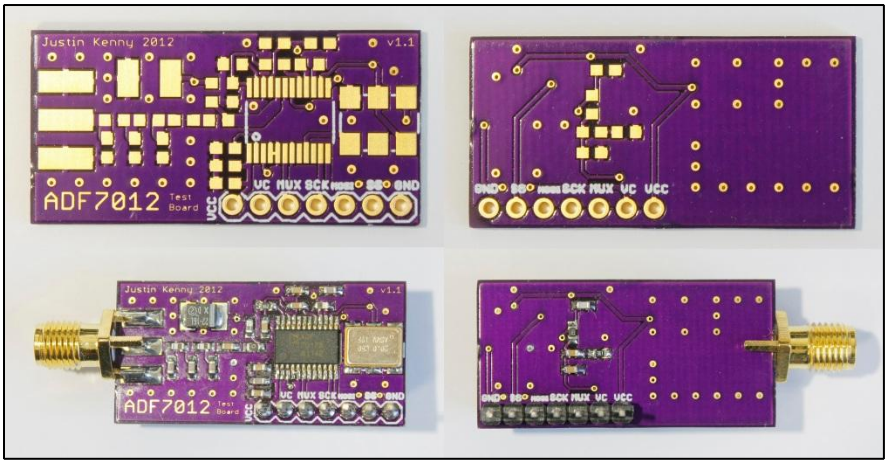


Figure 14: Commercially fabricated PCB for the ADF7012

A bill of materials for the test board is shown in Table 2 below.

Table 2: Bill of Materials for the ADF7012 Test Board

Part	Quantity	Unit Cost	Total Cost	Source
Female SMA Connector	1	$0.50	$0.50	Dealextreme
ADF7012	1	$4.28	$4.28	Digi-Key
20MHz VCXO	1	$3.63	$3.63	Digi-Key
0603 Capacitor	15	$0.009	$0.14	eBay
1206 Tantalum Capacitor	1	$0.44	$0.44	Digi-Key
0603 Resistor	3	$0.003	$0.01	eBay
0603 Inductor	4	$0.064	$0.26	Digi-Key
Male Header	7	$0.01	$0.07	eBay
PCB	1.4”x0.7”	$5.00	$1.63	OSH Park
Total Unit Cost			**$10.96**	

Programming and Debugging

Programming the device was achieved using an MSP430 Launchpad with an MSP430G2553 microcontroller, using the USCI module in SPI mode with code written to send 24 and 32 bit messages to the ADF7012. A spreadsheet was created containing the four configuration registers, broken down into individual options (e.g. R divider, N divider values, PA on/off) for ease of configuration. The working configuration is shown in Figure 15.

Register 0				**Register 1**			
N/A	0	00000		N/A	0	0	
Output Divider	2	10		Prescaler	1	1	
VCO Adjust	0	00		8-bit Integer N	109	01101101	
Clkout Divider	2	0010		Fractional N	0.5		
Xtal Osc Enable	1	1		MSB Fractional N	8	1000	
Xtal Doubler	0	0		LSB Fractional N	0	00000000	
4-bit R Divider	15	1111		Address Bits	1	01	
MSB Freq. EC	0	000					
LSB Freq. EC	0	00000000		Qword		010110110110000000000001	5B6001
Address Bits	0	00		MSB	5B	01011011	
					60	01100000	
Qword		00000100000101011110000000000000	0415E000	LSB	01	00000001	
MSB	04	00000100		**Register 3**			
	15	00010101		SD Test	0	0000	
	E0	11100000		PLL Test	0	00000	
LSB	00	00000000		PA Bias	4	100	
Register 2				VCO Bias	5	0101	
N/A	0	0000000		LD Precision	0	0	
Index Counter	0	00		Mux Out	4	0100	
GFSK Mod Ctl.	0	000		VCO Disable	0	0	
Mod. Deviation	16	000010000		Bleed Current	0	00	
PA	16	010000		Charge Pump	3	11	
GOOK	1	1		Data Invert	1	1	
Mod Control	2	10		Clkout Enable	1	1	
Address Bits	2	10		PA Enable	0	0	
				PLL Enable		0	
Qword		00000000000000001000001000011010	0000821A	Address Bits	3	11	
MSB	00	00000000					
	00	00000000		Qword		00000000010001010010000011110011	004520F3
	82	10000010		MSB	00	00000000	
LSB	1A	00011010			45	01000101	
					20	00100000	
				LSB	F3	11110011	

Figure 15: Configuration register worksheet and working values.

The first step in verifying the board's functionality was applying power after checking for shorts, and verifying the quiescent current of the device. The VCXO output was then verified with an oscilloscope to ensure the proper 20MHz output. The SPI code was first tested by viewing the waveform on the oscilloscope and using a known good SPI LCD to ensure no software errors. The ADF7012 was then initialized and the MUXOUT pin was selected to output a divided reference clock. The divider was modified to ensure the SPI code was working. The MUXOUT pin was then selected to output R and N divider outputs. These were found to be different frequencies, indicating the PLL was not able to lock. The input and output of the loop filter were measured on the oscilloscope and it was determined that the output of the loop filter was shorted to ground underneath the ADF7012 IC. The shorted trace was cut and the pin was reconnected using 30ga wire to the output of the loop filter. PLL operation was then verified by viewing the R and N divider outputs on the MUXOUT pin. Trial and error showed that the power amplifier was enabled when setting the device to ASK mode with the data inverted bit set, since TxData and TxClock pins were grounded by design.

Testing

The spectra of the ADF7012 were captured for a carrier at 146MHz, the second through fourth harmonics, and an FM signal with 400 and 1000Hz modulating tones at 400mV$_{p-p}$. The spectra of the 400Hz tone, using -3dB points, was measured to be 7.8kHz, and the spectra of the 1kHz tone was measured to be 7.45kHz, as shown in Figure 16.

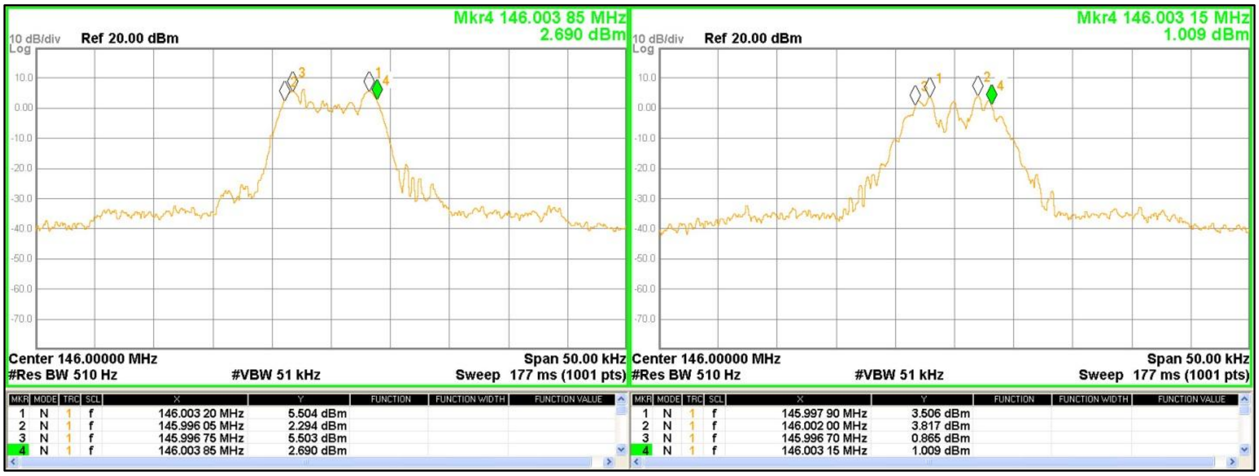


Figure 16: FM spectra of a 400Hz (left) and 1kHz (right) tone at 400mV$_{p-p}$

A table of the harmonic powers is shown in Table 3. The data shows that the 5th order low-pass filter keeps harmonics at least 4.15dB below the FCC specification of -40dBc [11]. However, filtering after the power amplifier will be more critical since the power amplifier will produce additional power at the harmonics since it is operating near its compression point.

Table 3: Carrier and Harmonic Powers at 146MHz.

Frequency (MHz)	Power (dBm)	Power (dBc)
146	10.23	0.00
292	-40.75	-50.98
438	-33.92	-44.15
584	-71.59	-81.82

Following the procedure used with the MICRF112 test board, a plot of the frequency vs. tuning voltage was obtained using an external power supply to bias the VCXO. The results in Figure 17 show that the VCXO has a nearly linear tuning curve, especially around a bias point near half the supply voltage. From this data, it was determined that a 217mV$_{p-p}$ signal provides a 4.8kHz FM deviation.

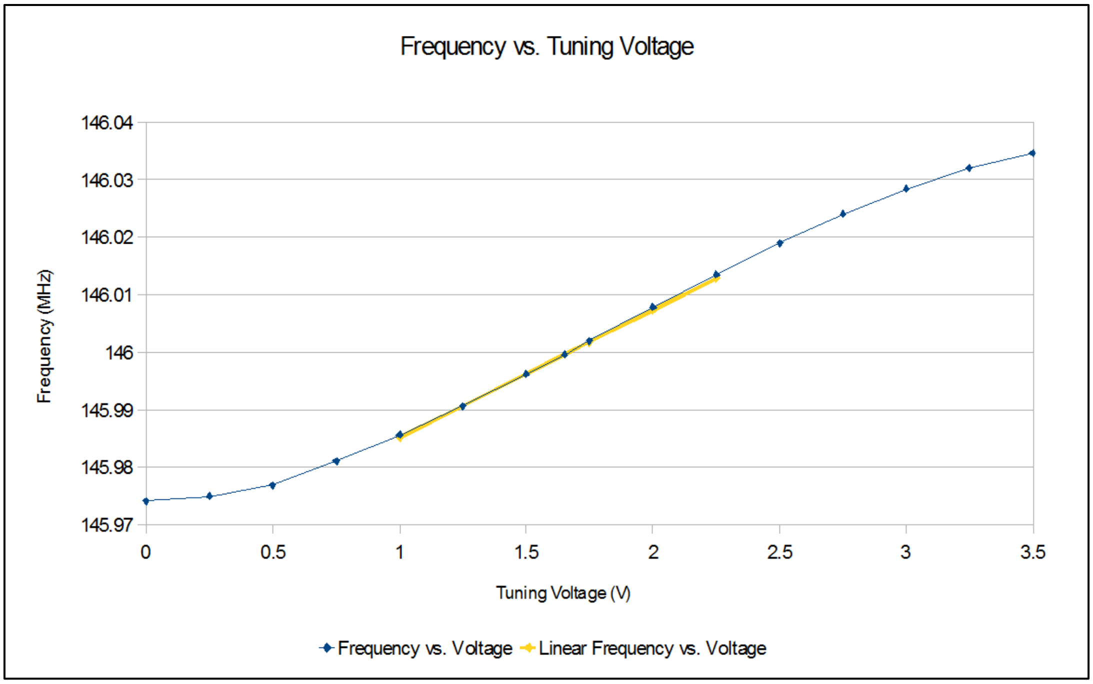


Figure 17: Frequency vs. tuning voltage for the ADF7012 with Abracon 20MHz VCXO

The output power vs. power level setting at 146MHz (set via the R2 register) was measured suing a spectrum analyzer and is shown in Figure 18. The maximum power was 10.33dBm at 146MHz.

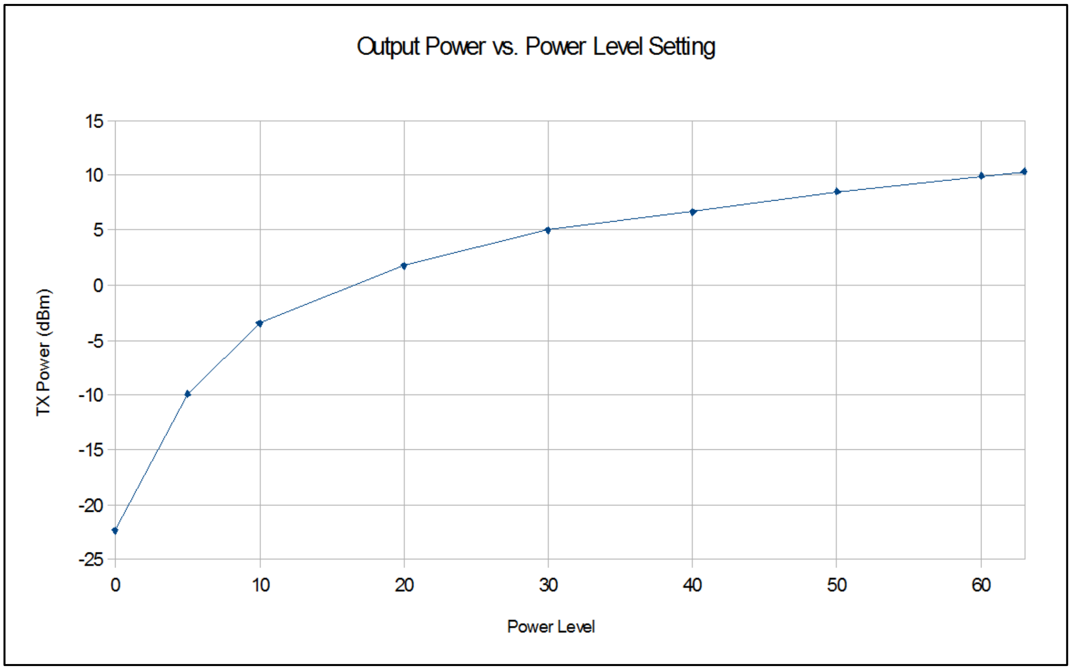


Figure 18: Output power vs. power level setting for the ADF7012, measured at 146MHz

The upper and lower ranges of the PLL, under the condition of phase noise <-20dBc, were measured to be approximately 158MHz and 141.083MHz, yielding a total tuning range of 16.9MHz, just above the range needed to cover the amateur 2m band plus 10.7MHz for LO generation if used in a transceiver application. However, the phase noise of this device would be unacceptable for use in a receiver. Reducing the VCO bias to a value of 5 (2.5mA) and the charge pump at maximum current (largest loop bandwidth) was experimentally determined to yield the lowest phase noise.

Conclusion

The ADF7012 is a much more capable transmitter IC, capable of covering the entire 2m amateur band as selected in the requirements for an APRS transmitter. A VCXO reference shows much greater linearity compared to a simple crystal oscillator and varactor configuration, making FM generation easier.

Power Amplifier

Two devices were under review for the power amplifier to be used in this project. The project specification calls for a 5W 50Ω output power over the frequency range of 144-148MHz. The first method is a design using discrete RF MOSFETs. The second method is to use a pre-packaged power amplifier module manufactured by Mitsubishi, which integrates input/output matching. An application note for a 135-175MHz amplifier using the STMicroelectronics PD54008 and PD84001 MOSFETs was used for the schematic design. [12] The application note included full schematics, board layout, and test data for the complete amplifier. From the provided schematics, a PCB was designed for the STMicroelectronics amplifier, and a cost comparison was performed against the Mitsubishi amplifier module.

STMicroelectronics Amplifier

The PD54008 is an N-channel RF MOSFET capable of 8W output power with 11.5dB gain at 500MHz. [13] The PD84001 is an N-channel RF MOSFET capable of 1W output power with 15dB gain at 870MHz. [14] The test board provides all necessary matching, DC biasing, and output filtering. The schematic for this test board is shown in Figure 19, and the board is shown in Figure 20.

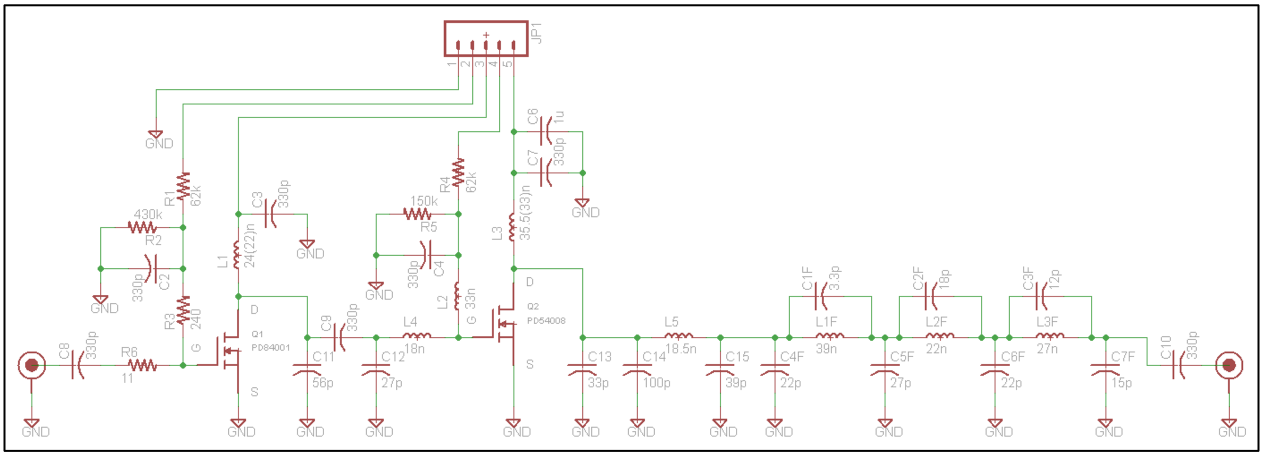


Figure 19: Schematic for the ST Power Amplifier Test Board

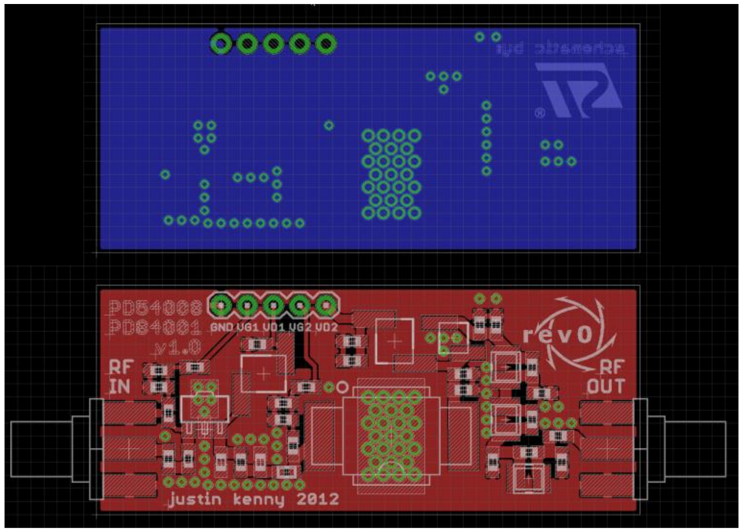


Figure 20: PCB Layout for the ST Power Amplifier Test Board

A bill of materials for the board is shown in Table 4. The total cost for a power amplifier module using the STMicroelectronics MOSFETs including a low-pass filter is $28.38.

Table 4: Bill of Materials for the STMicroelectronics Power Amplifier Board

Part	Quantity	Unit Cost	Total Cost	Source
PD54008	1	$7.50	$7.50	Digi-Key
PD84001	1	$3.19	$3.19	Digi-Key
SMA Female Connector	2	$0.50	$1.00	Dealextreme
0603 Capacitor	23	$0.009	$0.22	eBay
0603 Resistor	6	$0.003	$0.02	eBay
0603Hc-18NX	1	$0.79	$0.79	Coilcraft
1008CS-xxxX	3	$0.79	$2.37	Coilcraft
1812SMS-22N	2	$0.95	$1.90	Coilcraft
A05T	1	$0.91	$0.91	Coilcraft
Male Header	5	$0.01	$0.05	eBay
PCB	2.075”x0.875”	$5.00	$3.03	OSH Park
Total Unit Cost			**$28.38**	

Mitsubishi Amplifier

The RA07M1317M MOSFET amplifier module is a two-stage amplifier capable of outputting 6.5W with approximately 35dB gain, internally matched to 50Ω over the frequency range of 135-175MHz. [15] The test board provides two SMA connectors and bypassing capacitors for the gate and drain voltage inputs to the module. The schematic for this test board is shown in Figure 21, and the board is shown in Figure 22.

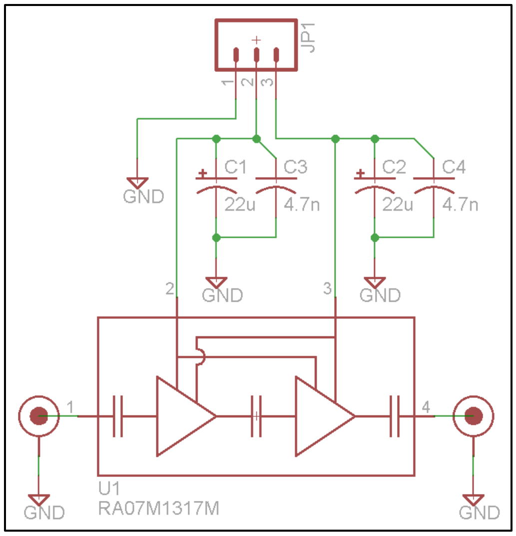


Figure 21: Schematic for the Mitsubishi Power Amplifier Test Board

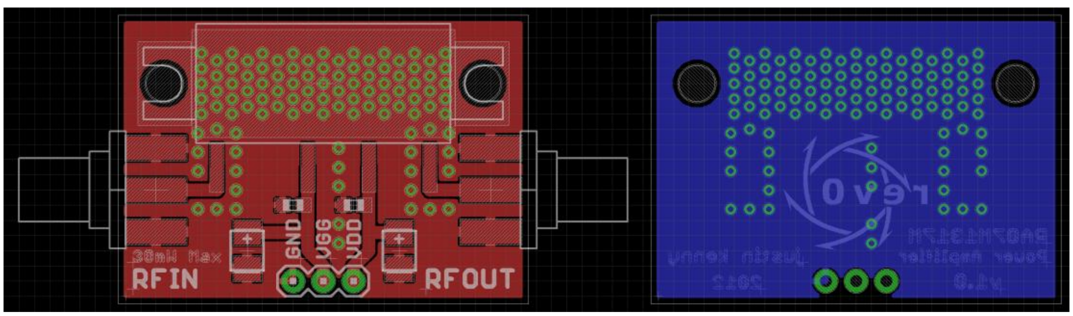


Figure 22: PCB Layout for the Mitsubishi Power Amplifier Test Board

A bill of materials for the Mitsubishi power amplifier test board is shown in Table 5.

Table 5: Bill of Materials for the Mitsubishi Power Amplifier Test Board

Part	Quantity	Unit Cost	Total Cost	Source
RA07M1317M	1	$19.95	$19.95	RFParts
SMA Female Connector	2	$0.50	$1.00	Dealextreme
0603 Capacitor	2	$0.009	$0.02	eBay
3216 Tantalum Capacitor	2	$0.64	$1.28	Digi-Key
Male Header	3	$0.01	$0.03	eBay
PCB	1.35”x0.95”	$5.00	$2.14	OSH Park
Total Unit Cost			**$24.42**	

Although the test board does not include the low-pass filter, the Mitsubishi amplifier has a lower overall cost and required board area, and the complexity is reduced by a significant margin. Based on these criteria, the Mitsubishi amplifier was chosen to be built and tested for use in the final transmitter.

Testing

The amplifier was tested using an HP 8922M GSM Test Set, using the Aux. RF Output supplying 0-9dBm at 144-148MHz, while reading the RF OUT power through the RF In/Out port on the Test Set. V_{DD} was supplied at 6-8.4V, the working voltage range of a 2-cell lithium polymer battery pack, through an HP 6284A power supply. V_{GG} was supplied at 0-3.5V using a power supply and potentiometer. Gate voltage was monitored using an HP 3466A multimeter, and current was read from the built-in meter of the 6284A. The output power, gain, and efficiency vs. gate voltage is shown in Figure 23. The output power vs. gate voltage at drain voltages of 6, 7.4, and 8.4V is shown in Figure 24. The input power for a fixed 5W power output at drain voltages of 6, 7.4, and 8.4V is shown in Figure 25.

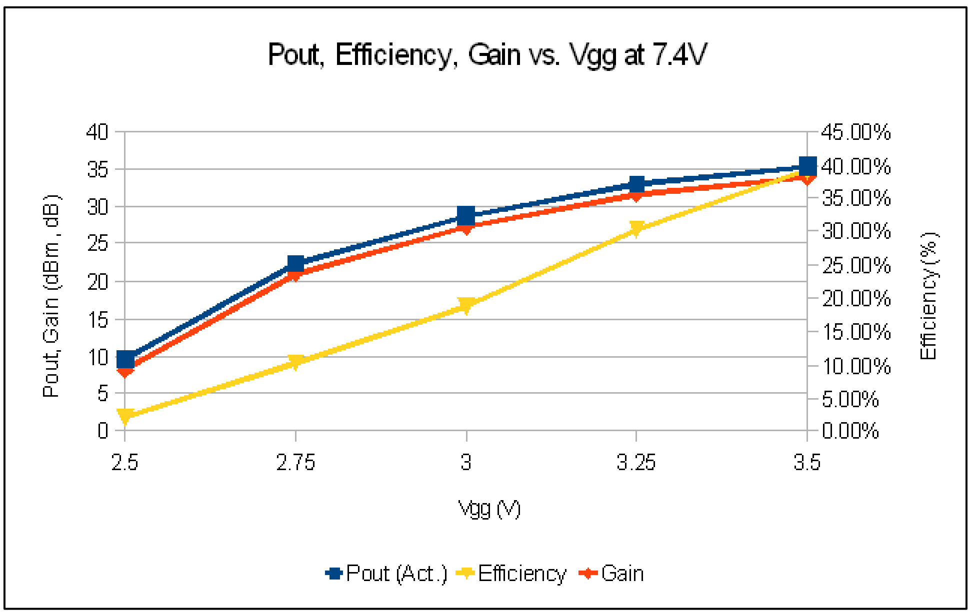


Figure 23: P_{out}, Gain, and Efficiency vs. V_{GG} at V_{DD} = 7.4V

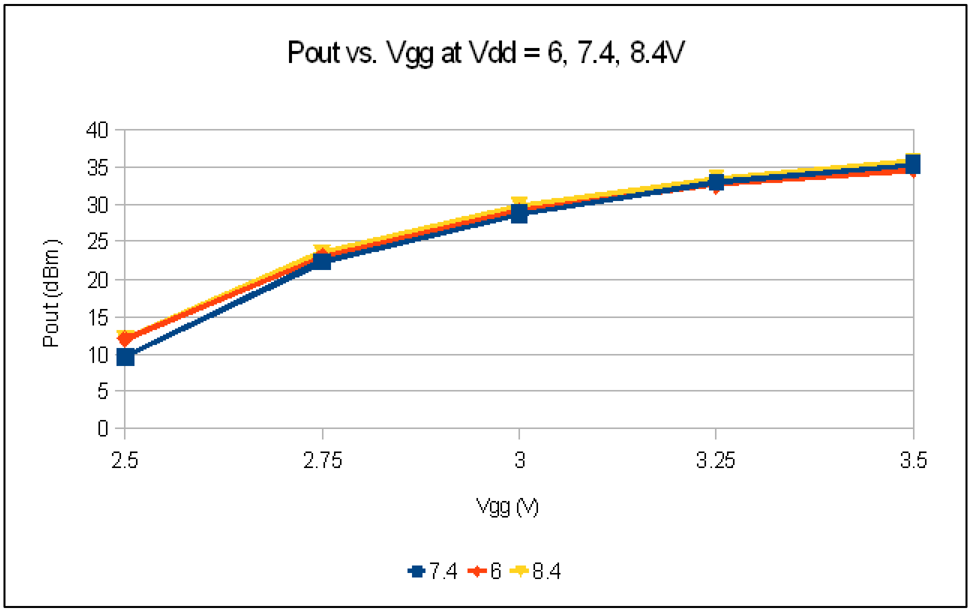


Figure 24: P_{out} vs. V_{GG} at V_{DD} = 6, 7.4, 8.4V

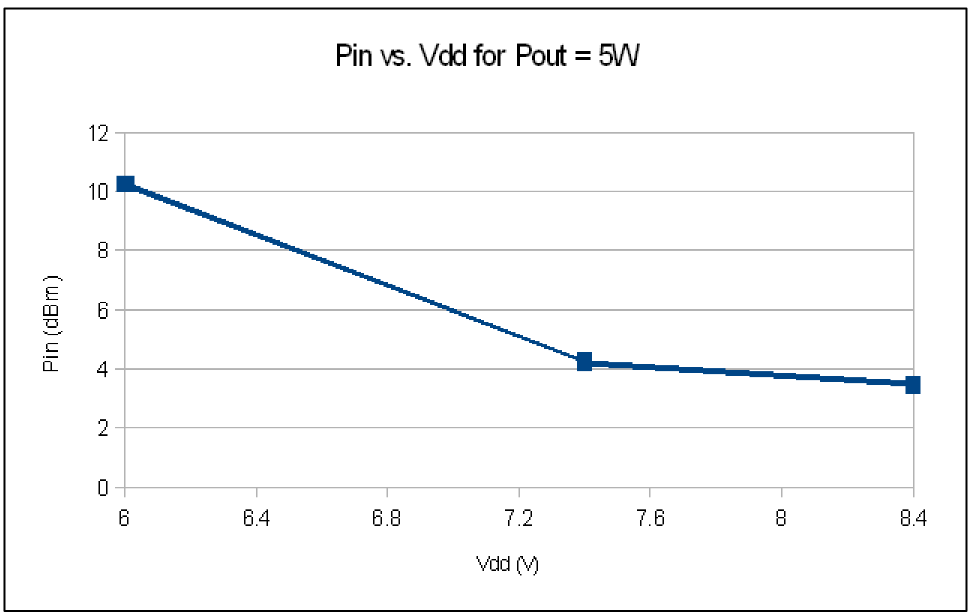


Figure 25: Input power for 5W output power at V_{DD} = 6, 7.4, 8.4V

Using the data for constant 5W output power at varying drain voltage in conjunction with the measured output power of the ADF7012 will allow constant RF output power as the battery voltage decreases. Varying the gate voltage provides a means of changing output power, at the expense of efficiency when used at lower output powers. At a gate voltage of 0V, the device draws only 7µA at 8.4V, which allows the amplifier to be connected directly to the battery with little impact on standby/off current. The constructed power amplifier test module is shown in Figure 26.

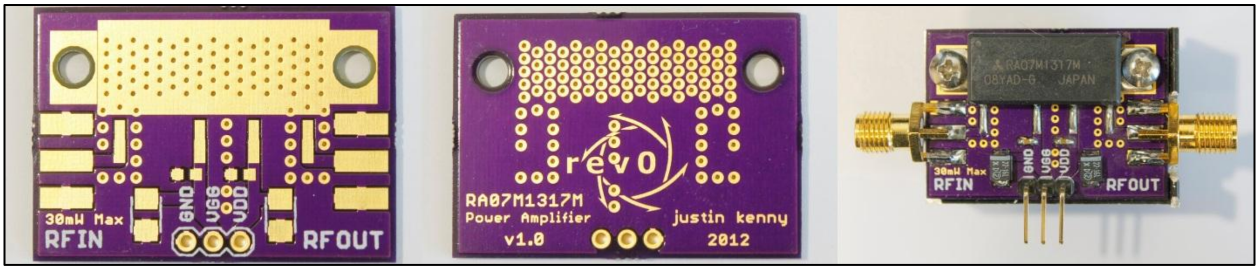


Figure 26: Mitsubishi Power Amplifier Test Board

Conclusions

The Mitsubishi amplifier meets the project specifications and remains the simplest and cheapest solution for this project. Although the discrete solution may result in lower costs per board at volume, this project benefits from the simplicity and board space savings of the Mitsubishi amplifier module.

Boost Converter and LiPo Battery Charger

The product requirements state that the device must operate on battery for at least 6 hours transmitting a packet once every 15 seconds, the required battery size can be calculated. The maximum transmit current was determined from the power amplifier module testing to be 1.42A. The duty cycle of the device can be calculated using assumptions about an APRS packet. An APRS position packet with no comment and a generic path contains 47 bytes, plus a preamble of 10 bytes. At 1200 baud, the time this packet takes to transmit is calculated below:

$$t = \frac{(47 + 10) \cdot 8}{1200} s = 0.38s$$

Taking into an additional 0.5s for the receiving radio to open squelch, plus 0.25s after ceasing transmission, the total time is then 1.13s. For a worst-case estimate, assume 3s of transmit every 15s period. This yields a duty cycle of 3/15 = 20%. The average current draw, assuming a worst-case 80mA standby current is then calculated below:

$$I_{avg} = 0.2 \cdot 1.42 + 0.8 \cdot 0.08\ A = 0.384\ A$$

The necessary battery life is then calculated below:

$$Capacity = I_{avg} \cdot t = 0.384\ A \cdot 6\ hours = \ 2.088\ AH$$

Based on availability and physical size, a 2-cell 2.2AH lithium polymer (LiPo) battery was chosen. Lithium polymer batteries require special charging circuitry to deliver a constant-current/constant-voltage charge cycle. Since the device will be charged from a standard USB port, the charging voltage must be obtained from the USB maximum of 5V at 500mA. [16]

Boost Converter/LiPo Charger Test Board

The TI TPS61085 is a 650kHz/1.2MHz boost converter capable of boosting an input voltage of 2.3-6V up to an output of 18.5V, with a 2A switch current. [17] This device will produce the 9V required by the LiPo charging IC from the 5V of the USB port. The MCP73844 is a dual-cell LiPo charge management controller, providing an adjustable charge current via an external sense resistor and P-channel MOSFET. The IC can precondition cells that have dropped below 2.85V per cell, and perform the constant current/constant voltage charge cycle afterwards. [18] The test board provides all necessary support components for the TPS61085 and MCP73844, including the datasheet suggested components for the 5V to 9V step up, and an external MOSFET and sense resistor, specifying a charge current of 220mA, selected from the formulas below:

$$P_{in} \cdot \eta = P_{out}$$

Where η is the switching regulator efficiency, specified at approximately 85% at 220mA load.

$$P_{in} = I_{in} \cdot V_{in}$$

$$P_{out} = I_{out} \cdot V_{out}$$

$$I_{out} = \frac{I_{in} \cdot V_{in} \cdot \eta}{V_{out}}$$

Thus, given a 500mA 5V supply, the maximum output current at 9V is approximately 240mA. The schematic for the test board is shown in Figure 27, and the layout is shown in Figure 28.

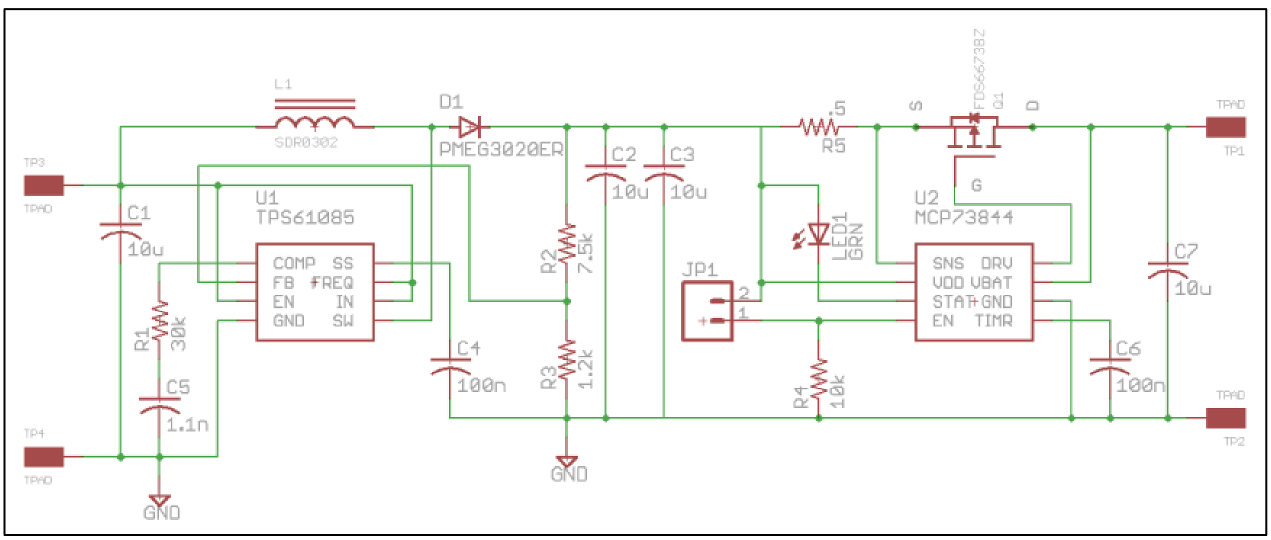


Figure 27: Schematic for the Boost Converter/LiPo Charger Test Board

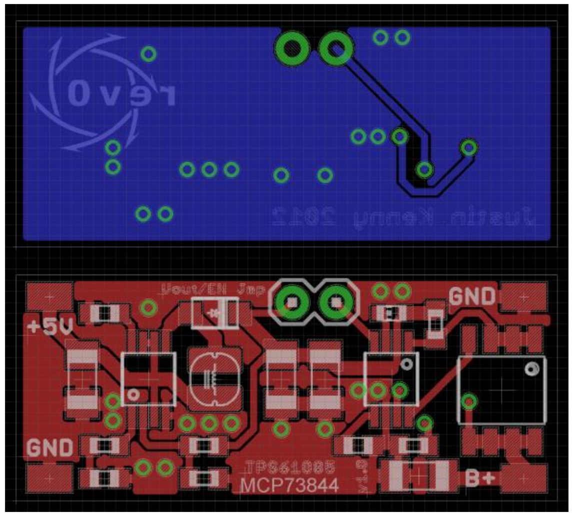


Figure 28: PCB Layout for the Boost Converter/LiPo Charger Test Board

Testing

The boost converter and charger IC were tested, with results summarized in Table 6 below.

Table 6: Boost Converter/LiPo Charger Summary of Test Results

Output Voltage	9.009V
Charge Current	212.3mA
Charge Termination Voltage	8.382V
Output Power	1.913W
Input Voltage	4.974V
Input Current	437.5mA
Input Power	2.176W
Efficiency	87.9%
Heat Power	263mW
Reverse Leakage Current (Charger disabled)	0.2µA
Reverse Leakage Current (Charger unpowered)	895µA

The results show that the charger/boost converter produce the necessary voltages to function (within 0.2%), and maintain a current draw of less than 500mA at the full charge current, as required by USB. [16] Additionally, the reverse leakage current is negligible (a concern for battery drain when in use and when the device is off). The boost converter has an efficiency of 87.9%, higher than the datasheet's specification, so little power is wasted as heat. The constructed PCB is shown in Figure 29.The bill of materials for the device is shown in Table 7.

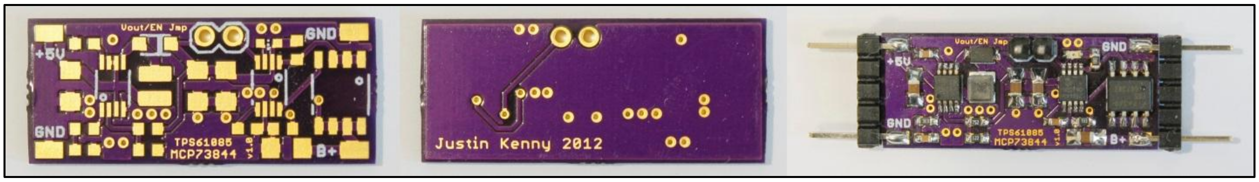


Figure 29: Boost Converter/LiPo Charger PCB

Table 7: Bill of Materials for the Boost Converter/LiPo Charger

Part	Quantity	Unit Cost	Total Cost	Source
TPS61085DGKT	1	$3.30	$3.30	Digi-Key
MCP73844-840I/MS	1	$1.56	$1.56	Digi-Key
0603 Capacitor	3	$0.009	$0.03	eBay
0603 Resistor	5	$0.003	$0.02	eBay
1206 10uF Capacitor	4	$0.30	$1.19	Digi-Key
PMEG3020ER	1	$0.48	$0.48	Digi-Key
STS5PF20V	1	$0.24	$0.24	Digi-Key
0603 Green LED	1	$0.11	$0.11	Digi-Key
SDR0302-3R3ML	1	$0.42	$0.42	Digi-Key
Male Header	3	$0.01	$0.03	eBay
PCB	1.225"x0.5125"	$5.00	$1.05	OSH Park
Total Unit Cost			**$8.43**	

Conclusion

Both devices in this test board meet the need of this project, namely charging the battery over USB at a reasonably high efficiency. Since the device uses a 2-cell LiPo, a cell balancing solution is also recommended to prevent either cell from dropping below 3V or exceeding 4.2V. An IC is available from TI to perform this task and is used in the final transmitter.

Microcontroller

The system will be controlled by an MSP430F5510 microcontroller. This microcontroller was selected due to previous experience with MSP430 microcontrollers, and for its memory size and peripheral set. The MSP430F5510 is a 16-bit microcontroller featuring 32kB of program memory, 4kB of program SRAM, two timers with multiple compare registers, a USCI module supporting I^2C, SPI, and UART, a 10-bit ADC, and USB functionality. [19] These features will be utilized in the final transmitter, with applications including reading the battery voltage, interfacing with the GPS module, LCD, RF transmitter, PC, and generating the transmit analog waveforms. The test board provides access to the four main I/O ports, JTAG and Spy-Bi-Wire programming ports, and necessary support components and connector for USB. The board also includes a button and LED for basic user interaction. The schematic for the test board is shown in Figure 30, and the layout is shown in Figure 31.

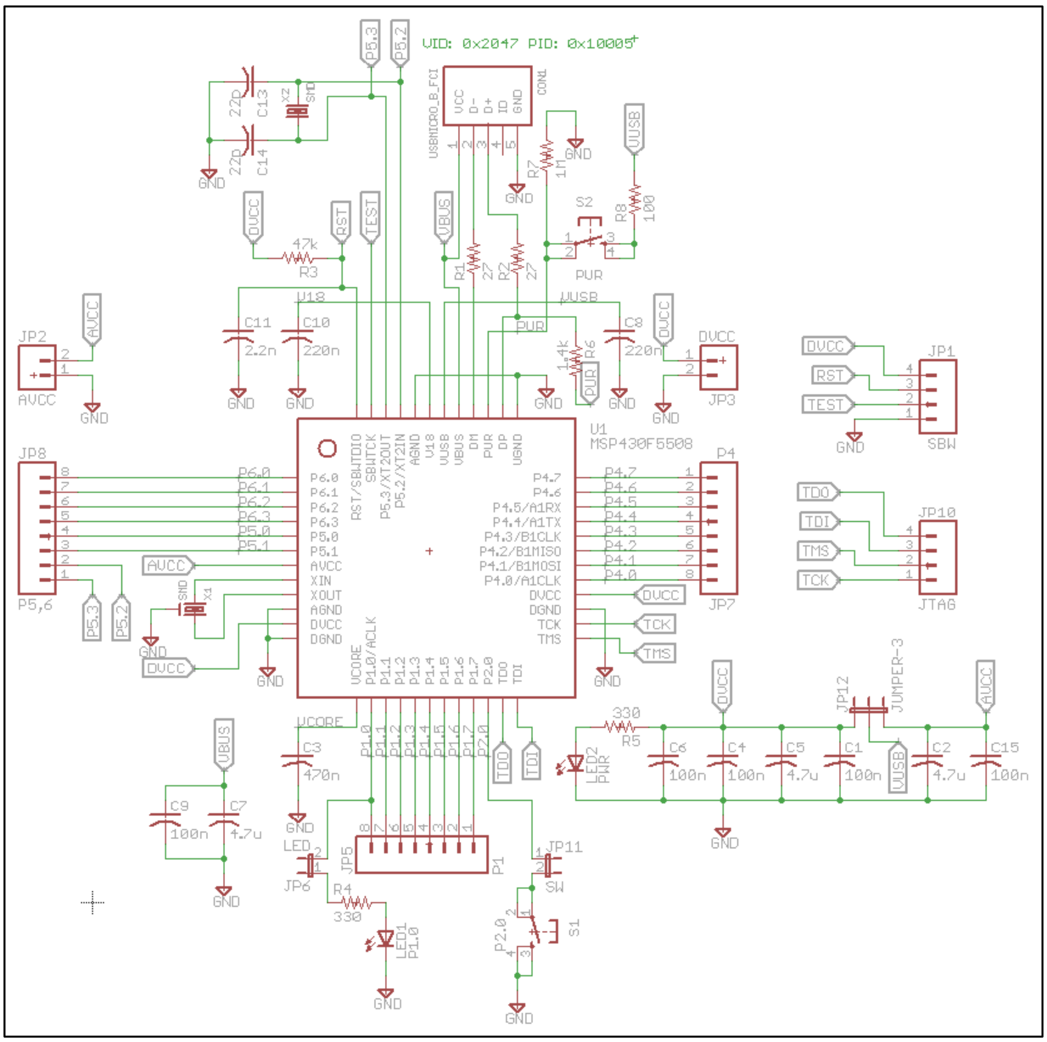


Figure 30: Schematic for the MSP430F5510 Test Board

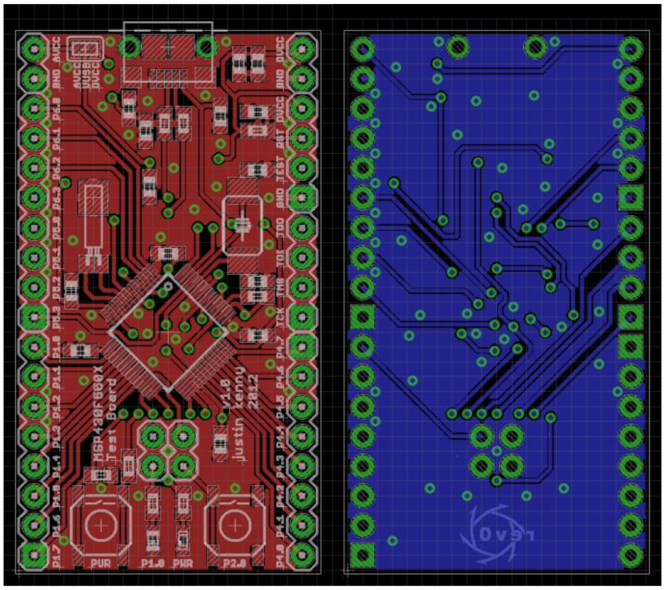


Figure 31: PCB Layout for the MSP430F5510 Test Board

The device contains a USB bootloader by factory default. By holding down the PUR switch while inserting a USB cable, the MSP430 bootloader is initialized, allowing a new user firmware to be loaded. The capabilities of this device combined with the bootloader functionality and options for future expansion make it a good choice for this project. The bill of materials is shown in Table 8, and the constructed PCB is shown in Figure 32.

Table 8: Bill of Materials for the MSP430F5510 Test Board

Part	Quantity	Unit Cost	Total Cost	Source
MSP430F5510	1	$4.27	$4.27	Digi-Key
USB Micro B Connector	1	$0.87	$0.87	Digi-Key
0603 Capacitor	14	$0.009	$0.13	eBay
0603 Resistor	8	$0.003	$0.02	eBay
SMD Tacticle Switch	2	$0.12	$0.24	eBay
SMD 24MHz Crystal	1	$1.43	$1.43	Digi-Key
0603 Green LED	1	$0.11	$0.11	Digi-Key
0603 Red LED	1	$0.13	$0.13	Digi-Key
Male Header	36	$0.01	$0.36	eBay
PCB	1.025"x1.825"	$5.00	$3.12	OSH Park
Total Unit Cost			**$10.68**	

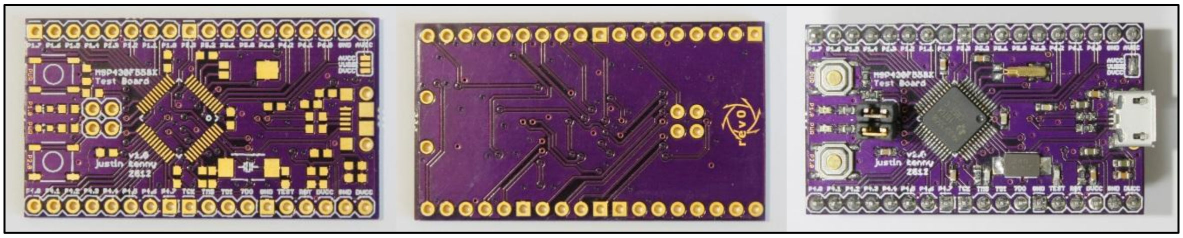


Figure 32: MSP430F5510 Test Board

GPS Module

The MT-3329, made by MediaTek, is an ultra-compact GPS module containing a built in patch antenna. The module outputs positional information over a 38400 baud UART using the NMEA-0183 protocol. [20] This device is used to record position data to be broadcast on the APRS network.

Testing

The initial configuration of the MT-3329 was with the V_{BACKUP} pin unconnected and the LED cathode connected to the 3D-FIX pin. After connecting V_{BACKUP} to 3.3V as directed in the datasheet, the device transmitted serial data at approximately 24000 baud. The solution to the problem was found on the seller's forum, which stated that the 3D-FIX pin acts as an input on startup, and if read high starts the device in the 24000 baud mode. The pin must be pulled low on startup for the device to start normally. The MT-3329 was tested on a Spirent GSS6300 GPS simulator, which revealed that the GPS stops sending serial data at just over 60,000 feet, indicating that the maximum altitude/velocity limit is an *or* relation (stops working if either is exceeded). This is due to the ITAR, which states that sale of GPS receivers capable of reporting position above 60,000 feet *and* 1000 knots is restricted. [21] This is primarily a concern in the use of GPS and APRS trackers in high altitude balloon or high power rocketry applications. The bill of materials is shown in Table 9. The schematic for the test board is shown in Figure 33, and the test board is shown in Figure 34.

Table 9: Bill of Materials for the MT-3329 Test Board

Part	Quantity	Unit Cost	Total Cost	Source
MT-3329	1	$29.99	$29.99	DIYDrones
TC1185	1	$0.45	$0.45	Digi-Key
0603 Capacitor	3	$0.009	$0.03	eBay
0603 Resistor	3	$0.003	$0.01	eBay
0603 Green LED	1	$0.11	$0.11	Digi-Key
USB Micro B Connector	1	$0.87	$0.87	Digi-Key
Male Header	4	$0.01	$0.04	eBay
Protoboard	1.5"x0.75"	$3.99	$0.19	Radio Shack
Total Unit Cost			**$31.69**	

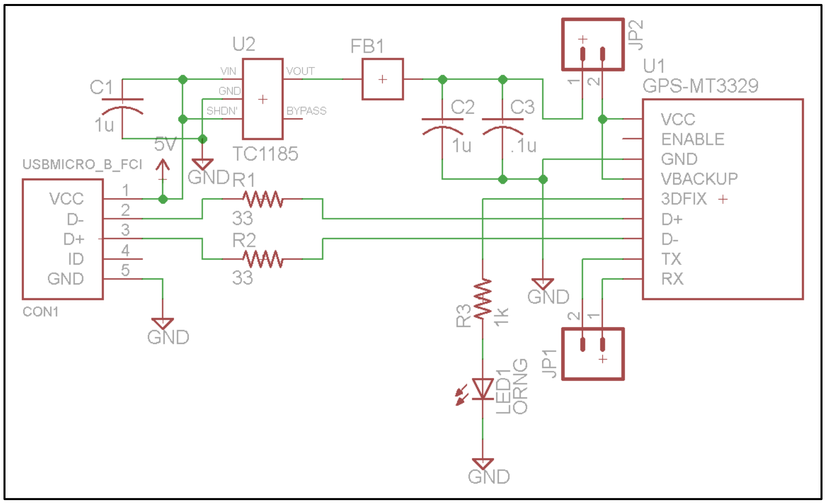


Figure 33: Schematic for the MT-3329 Test Board

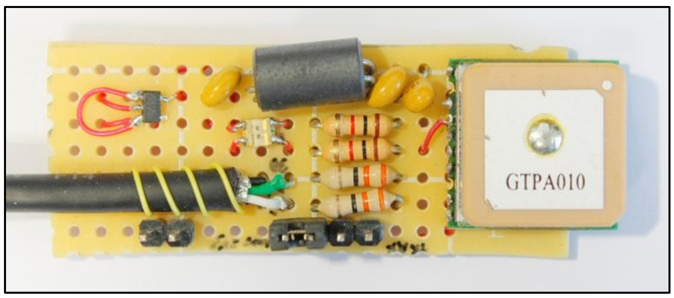


Figure 34: MT-3329 Test Board

Low Pass Filter

Due to the internal structure of the transmitter IC and non-linear nature of the power amplifier, it is necessary to add a low pass filter to the output of the device to reduce any harmonics and spurious emissions above the intended frequency of operation. For this design, a 5^{th} order pi-type Chebyshev filter with a cutoff frequency of approximately 150MHz was designed and simulated in LTSpiceIV.

Simulation

Component values for the filter were first determined using Elsie. The nearest components were then chosen from Coilcraft and Digi-Key. Using Coilcraft's "Highest Q" design tool, a 56nH 1812SMS air-core inductor was chosen for its power handling capability and quality factor. The 36pF and 56pF capacitors were found through Digi-Key's search tools, both selected for RF applications. Using data from Coilcraft and the capacitor datasheets, an approximate non-ideal model was determined and input into LTSpiceIV schematic for simulation. The resulting circuit and frequency plot are shown in Figure 35 and Figure 36.

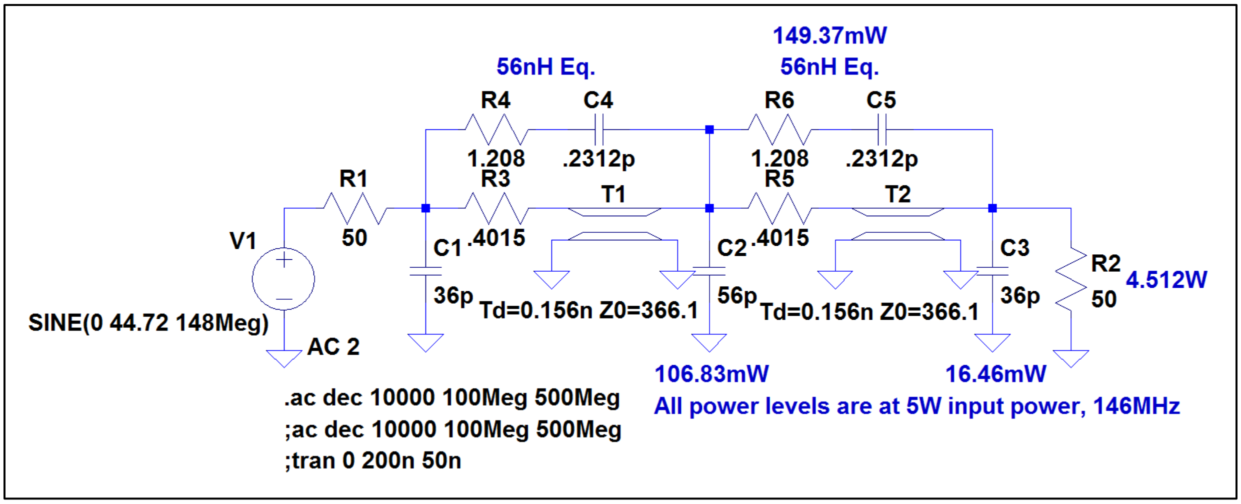


Figure 35: Non-ideal filter schematic with power dissipation.

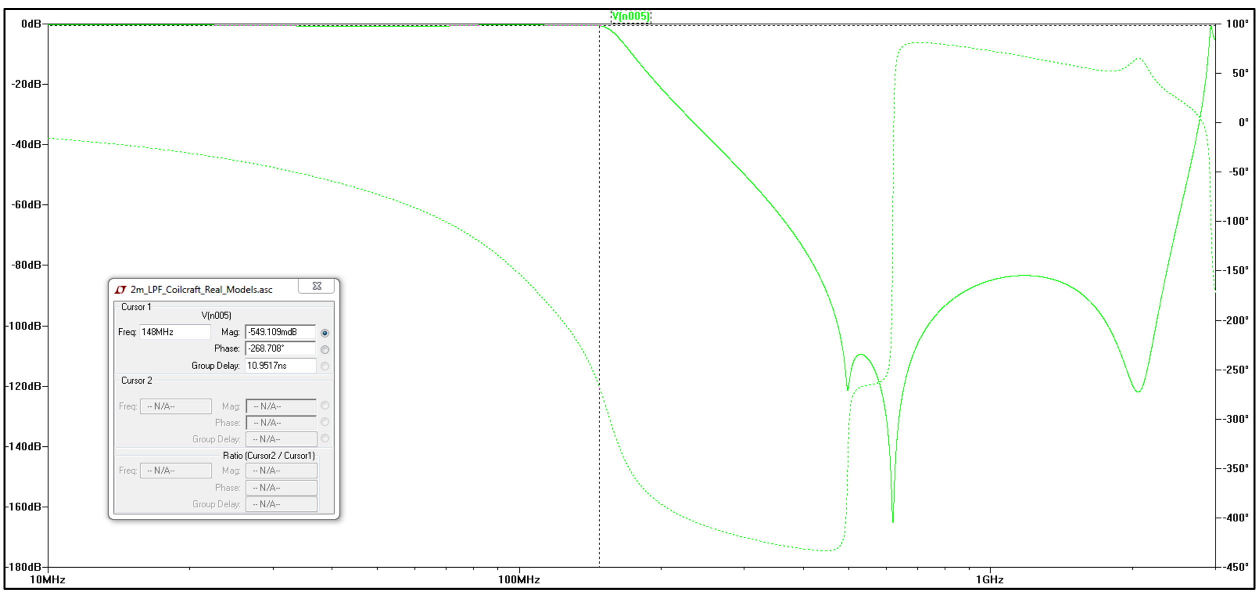


Figure 36: Magnitude plot showing passband insertion loss and spurious responses.

Conclusion

The filter has good harmonic rejection, with >46.9dB rejection at the second harmonic, and >83.2dB rejection at the third harmonic. The filter maintains >83dB rejection until >2.35GHz, well beyond any significant harmonics generated by the transmitter and amplifier. The filter has a maximum insertion loss (with nominal values) of 0.55dB at 148MHz, taking into account capacitor and inductor losses. Using a transient simulation with a source set to 5W output power at 146MHz, the power dissipation through the ESR of the inductors and capacitors was also calculated as shown in Figure 35. This indicated that the 56pF capacitor must be able to dissipate >100mW during transmit.

rev0Trac VTx APRS Transmitter and Final Integration

Once all prototype modules had been tested and modified, a final "all-in-one" transmitter schematic was created. The schematic design was done by copying each of the prototype modules into a new schematic and connecting the individual blocks, as well as making any modifications noted in the testing process. The new additions to the schematic were the linear voltage regulators, LiPo balancer, power control/waveform generation DACs and filters, user interface (LCD and encoder/pushbuttons), and battery voltage sense circuitry.

3D Model

The design of the rev0Trac VTx involved the creation and evolution of a 3D model, made in Autodesk Inventor. The batteries were modeled and used as the main size determinant for the PCB; the PCB should be no larger than, but need not be smaller than the batteries. The PCB was then chosen to be as wide as the LCD (45mm) and as long as the batteries. The power amplifier was positioned below the LCD, since it was too tall to fit beneath the LCD. The GPS was positioned on a daughter board at 45 degrees with respect to the main PCB, to save space and allow the device to work well when positioned either horizontally or vertically. The encoder and push button were then positioned, as well as the battery connector and SMA connector. The inductors were also modeled to ensure their fit beneath the LCD. A heatsink was then added to the design, positioned in the lower left corner beneath the power amplifier. The amplifier would be on as often as every 15s with an on-time of up to 3s, yielding a duty cycle of 20%. The amplifier dissipates up to 7.5W, as determined in the Power Amplifier testing, giving an maximum average dissipation of 1.5W. A 1.1" square heatsink was chosen, placed on the top side of the board below the power amplifier. The finished model is shown in Figure 37.

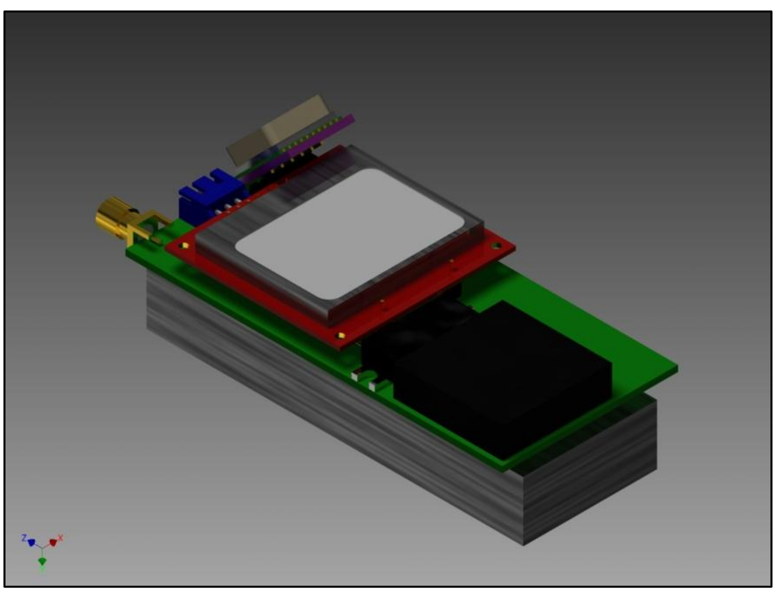


Figure 37: Autodesk Inventor 3D Model of the rev0Trac VTx

Electrical Design

The system design follows directly from the individually tested modules. The microcontroller is an MSP430F5510, which takes in data from the GPS and user input and controls the transmitter IC, LCD, and amplifier. The battery is charged through the boost converter and LiPo charger IC, which are enabled when the device is plugged into a USB port. The analog modulation signal and gate voltage of the amplifier are controlled through a pair of 12-bit TI DAC7311 SPI digital to analog converters, chosen for their small size and ease of interfacing. The output of the amplifier is fed through a Chebyshev low pass filter to reduce harmonics. The final circuit was designed for 7 mil spacing, 8 mil width, and 15 mil vias, and was manufactured by Imagineering, Inc. The version 1.0 schematic and PCB layout are shown in Figure 38 and Figure 39.

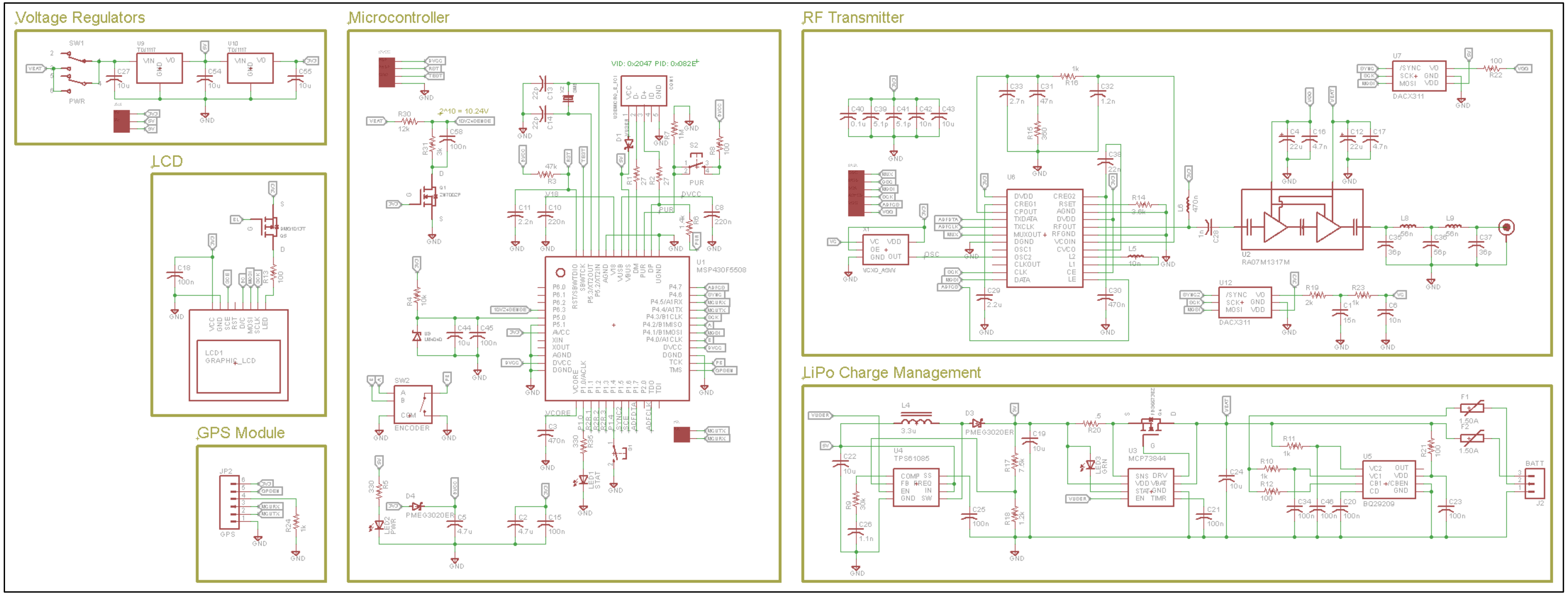


Figure 38: rev0Trac VTx v1.0 Schematic

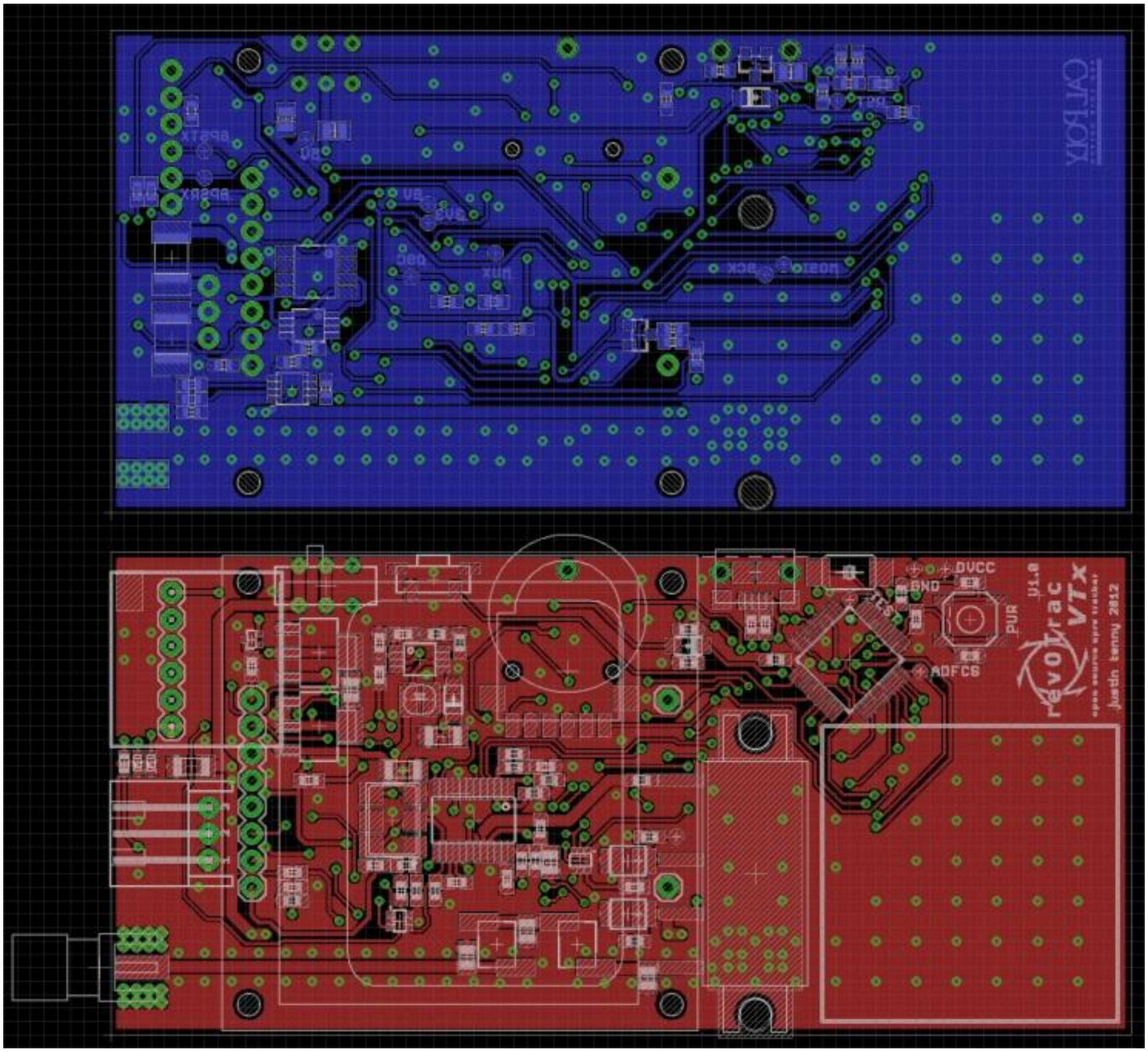


Figure 39: rev0Trac VTx v1.0 PCB Layout

V. Testing and Debug

The microcontroller section was assembled first and the device was plugged into a computer in bootloader mode to verify correct operation. The remainder of the board except the GPS, LCD and PA was assembled, and power was applied to the battery input by a current-limited power supply. The boost converter and charger IC were enabled when the device was powered from battery, which should not have been the case. The enable lines of these devices were tied to the USB V_{CC} line, which is connected through a Schottky diode to the 5V line. The diode has a specified 55μA leakage current. The enable inputs of the boost converter and charger IC are only 0.1μA and 0.01μA, respectively, well below the leakage current. Thus, these devices were enabled since the leakage current of the diode is more than sufficient to meet the logic high voltage on these ICs. The solution, from ohm's law, was to add a resistor of much less than 9.1k ohms, which would reduce the voltage below the 1.4V necessary to act as a logic low signal to both ICs. A 1k ohm resistor was added from the USB V_{CC} line to ground, eliminating the problem. The bare and partially soldered boards are shown in Figure 40.

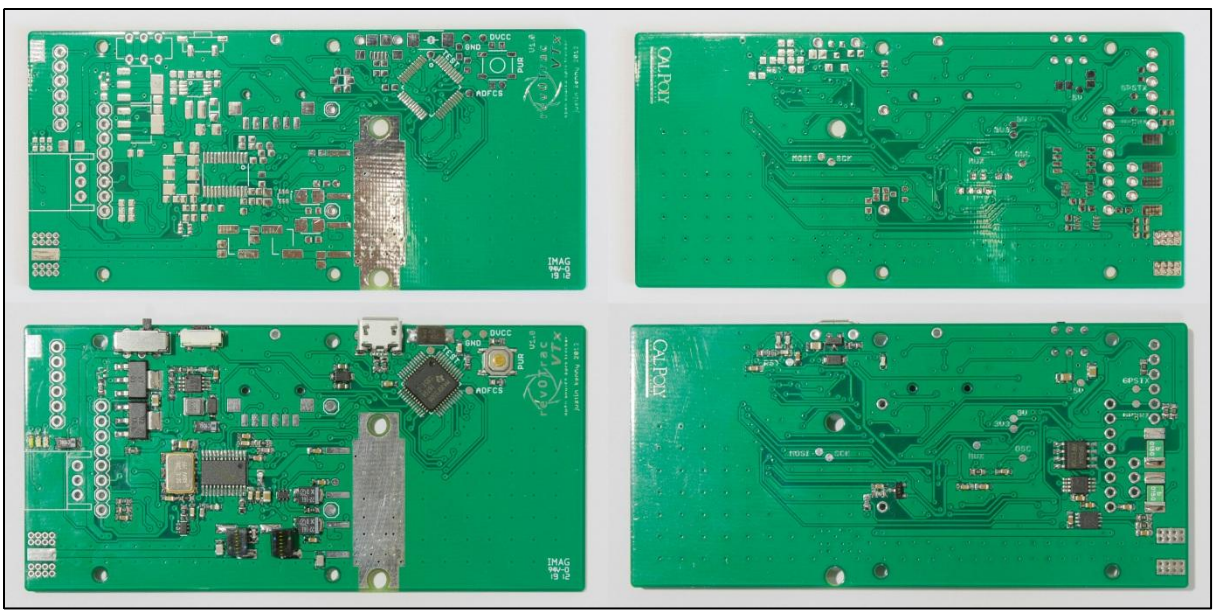


Figure 40: Bare and partially-soldered rev0Trac VTx PCBs

The PA was soldered to the board and mechanically attached using two 1/4"-20 stainless machine screws, with a thermal pad and Arctic Silver 5 thermal compound to improve heat transfer. The board was then powered and loaded with a program to test the two DACs. The power amplifier control DAC was first set to output 3.5V, the nominal gate voltage during transmit operation. This test passed, with the actual output being 3.481V. A heatsink was then temporarily attached to the PCB with some thermal adhesive strips, and the program was set to operate the PA with a 13.3% duty cycle (2s on, 13s off), representative of the worst-case power dissipation the device will see. This resulted in a case temperature (measured at the base of the

PA) of 50.5°C average, which indicated a junction temperature of 54.5°C, well below the maximum operating temperature of 90°C. The waveform DAC was then tested. After observing no output from the DAC, the PCB was inspected, which showed that the SCLK line of the IC was not properly soldered. After correcting the error, the program was then set to generate 1200Hz and 2200Hz tones at 217mVpp, representative of the APRS 1s and 0s to be used in the final application. These waveforms were recorded before and after the low pass filter and are shown in Figure 41 and Figure 42.

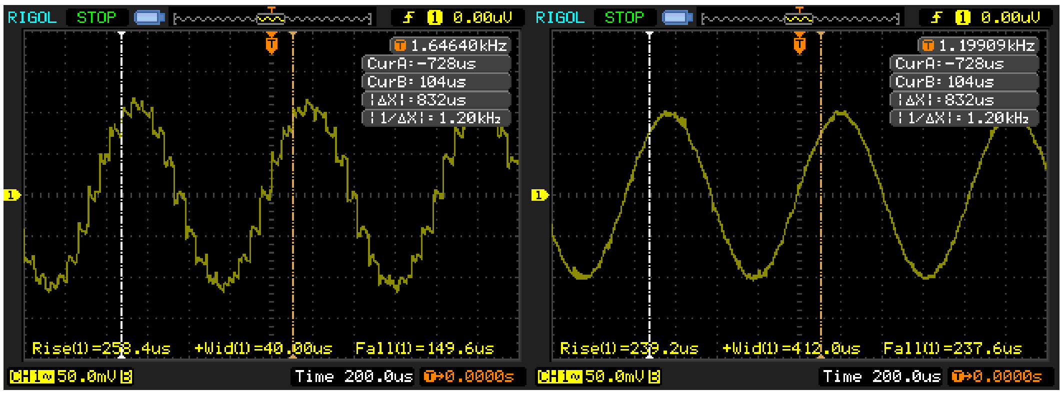


Figure 41: 1200Hz tone before and after the low pass filter

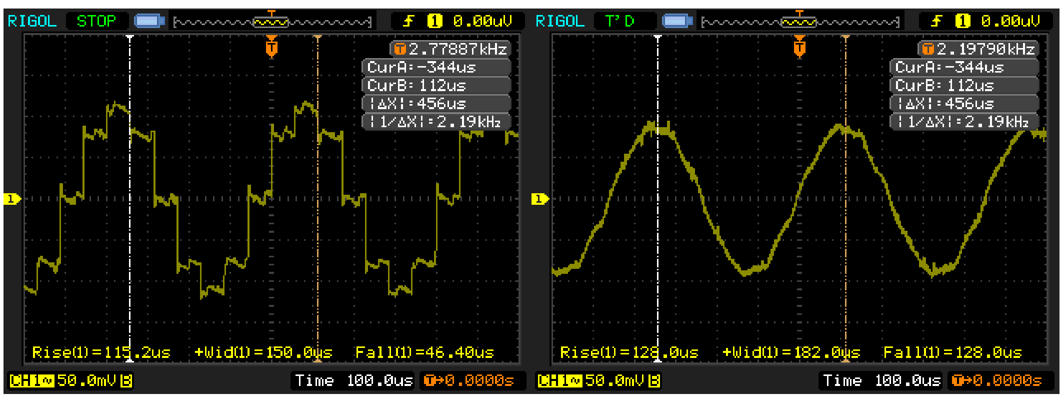


Figure 42: 2200Hz tone before and after the low pass filter

The program was then set to generate a tone burst of 84 bits of alternating 1s and 0s, which was recorded and is shown in Figure 43.

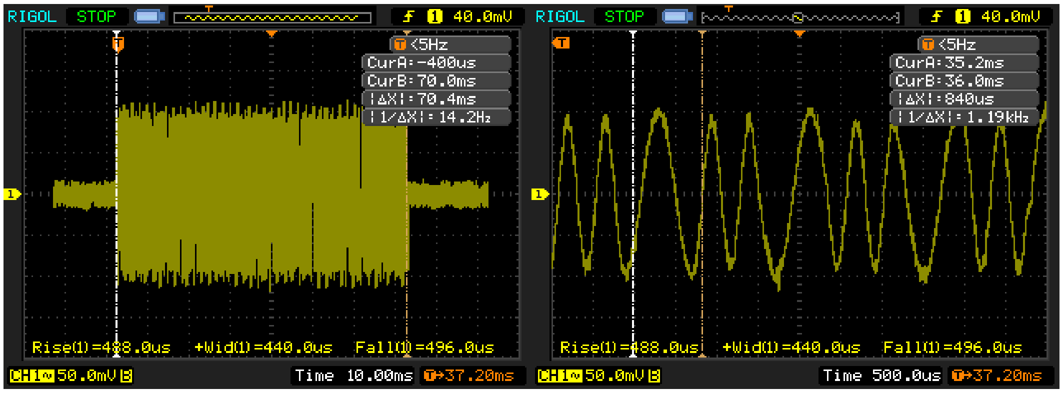


Figure 43: Tone burst of 1200Hz/2200Hz tones after the low pass filter

The program was then modified to transmit a pre-defined bitstream, allowing the board to transmit its first APRS packet, as verified in MULTIPSK. The LCD and GPS were then soldered. When the board was powered, it was observed that the 3.3V rail was being shorted to ground. Inspection of the LCD and GPS indicated that the footprint for the GPS was reversed. This was fixed by rotating the GPS 180 degrees and soldering a new 45 degree header to it and to the main board. The program was then updated to use the LCD. Two circuit errors were discovered in debugging; first, the data/command line of the LCD was not connected to any I/O pins, second, the reset line was left floating. I corrected these errors by tying the D/C line to pin P1.1 on the MCU, and shorting reset to V_{CC}. Although this worked initially, further testing showed the LCD had intermittent errors such as the screen blacking out, or addressing being misaligned. The solution was to tie the reset line to an I/O pin and perform a proper reset on startup. The program was modified to receive and parse GPS data, and displayed Sattelites, Fix, UTC Time, Latitude, Longitude, and Altitude on the screen. The program was also modified to use the ADC to read the battery voltage. A 5-point calibration was done, which indicated an offset error of 20mV, which was corrected in software. The APRSGen program, originally written by the author in Python, was modified to C, in order to format GPS data and other information into a packet and convert it into a bitstream that can be transmitted out as tones. This was then implemented in the microcontroller code, allowing transmission of real-time GPS data. The program was modified to allow control of the output power via the push switch, cycling through 0.1, 0.5, 1, and 5W. Pre-emphasis was added to the 2200Hz tone to improve the copy on standard FM receivers. The new amplitudes of the two waveforms are: .217$V_{p\text{-}p}$ 1200Hz, .52$V_{p\text{-}p}$ 2200Hz. The program was hard-coded to transmit on 144.390MHz so the packets can be received on the national APRS network. The LCD displays the current frequency as a variable, so changes to frequency will be reflected on screen.

The transmitter was tested at a battery voltage of 7.78V on the CXA N9000A spectrum analyzer to measure harmonics, bandwidth, and output power. A series of attenuators was required to drop the 5W transmit power to a safe level to measure on the spectrum analyzer. The attenuator chain, including cables was measured on the Anritsu MS4622B VNA to have a total loss of 16.15dB, which was corrected for in the spectrum analyzer settings. A diagram of the test setup is shown in Figure 44. A summary of test results is shown in Table 10. Harmonics are less than -67dBc, exceeding the FCC specifications of -40dBc and spurious power of <25uW for a <25W transmitter. [11]

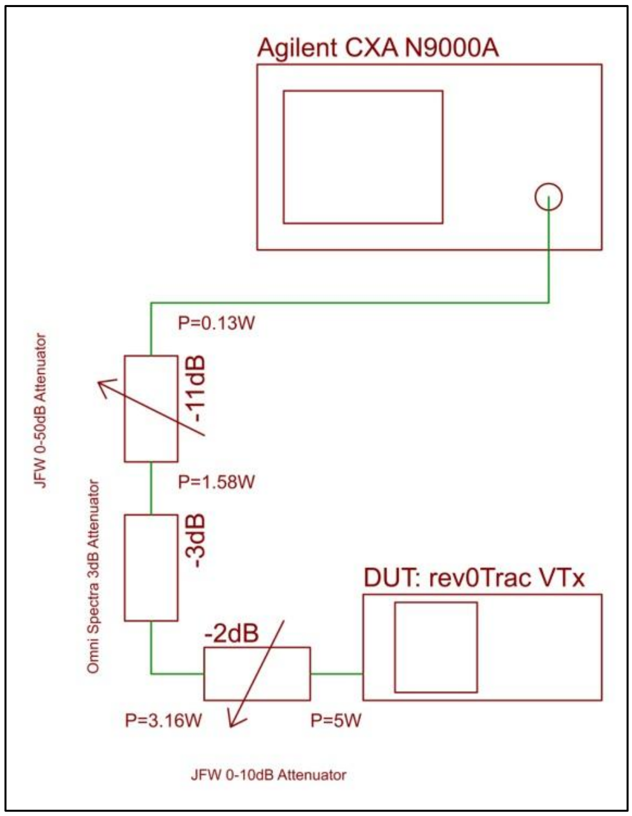


Figure 44: Test Setup for measuring rev0Trac VTx Output Power/Spectra

Table 10: Measured Carrier and Harmonic Powers of the rev0Trac VTx

Specified Power	Carrier Power	2nd Harmonic Power	3rd Harmonic Power	4th Harmonic Power
5W	37.20dBm	-30.00dBm	-46.94dBm	-53.72dBm
1W	30.42dBm	-39.54dBm	-56.64dBm	-52.51dBm
0.5W	27.81dBm	-45.39dBm	<-60.0dBm	<-60.0dBm
0.1W	20.91dBm	-51.40dBm	<-60.0dBm	<-60.0dBm

VI. Conclusions and Future Work

Due to time limitations, the device was only programmed to transmit a packet of a fixed type (simple GPS position packet), and the frequency was hard-coded and requires recompiling and updating the firmware to change. However, the framework, including hardware and software, has been laid to upgrade to a more flexible program that would allow the user to modify packet type and information on the device, and have the new data stored to on-board flash. The prototyped hardware (version 1.0) contains several errors, but a revised version (1.1) has been created, containing the changes listed in Appendix C, and an updated PCB layout is available for future use. The revised schematic and layout can be found in Appendix B and C. The final version 1.0 transmitter prototype is shown in Figure 45.

The completed device fulfills all stated marketing requirements and engineering specifications. Namely, the device is self-contained and compact, transmits real-time GPS data on the APRS network at a power greater than 5W, contains a battery that can operate the device for over 6 hours under the worst-case use conditions, and contains a user interface to display status and allow the user to change settings.

Figure 45: Final working rev0Trac VTx APRS Transmitter

VII. Bibliography

[1] B. Bruninga, "APRS Articles," 14 March 1999. [Online]. Available: http://www.aprs.org/APRS-docs/ARTICLES.TXT. [Accessed 3 June 2012].

[2] W. A. Beech, D. E. Nielsen and J. Taylor, "AX.25 Link Access Protocol for Amateur Packet Radio," July 2008. [Online]. Available: http://www.tapr.org/pdf/AX25.2.2.pdf. [Accessed 3 June 2012].

[3] A. W. Group, "APRS Protocol Reference Version 1.0," 29 August 2000. [Online]. Available: http://www.aprs.org/doc/APRS101.PDF. [Accessed 3 June 2012].

[4] A. Wiki, "Symbols and SSIDs," 29 May 2010. [Online]. Available: http://info.aprs.net/index.php?title=SymbolsAndSSIDs. [Accessed 3 June 2012].

[5] J. Hansen, "PIC-et Radio: How to Send AX.25 UI Frames Using Inexpensive PIC Microprocessors," [Online]. Available: www.tnc-x.com/dcc.doc. [Accessed 3 June 2012].

[6] F. C. Commission, "Code of Federal Regulations Title 47 Volume 5 Part 97.307: Emission Standards," 1 October 2011. [Online]. Available: http://www.gpo.gov/fdsys/pkg/CFR-2011-title47-vol5/xml/CFR-2011-title47-vol5-part97.xml#seqnum97.307. [Accessed 3 June 2012].

[7] Micrel Inc., "MICRF112 QwikRadio UHF ASK/FSK Transmitter," December 2011. [Online]. Available: http://www.micrel.com/_PDF/micrf112.pdf. [Accessed 5 June 2012].

[8] ETSI, "Short Range Devices," 2011. [Online]. Available: http://www.etsi.org/website/Technologies/ShortRangeDevices.aspx. [Accessed 5 June 2012].

[9] NXP Semiconductors, "BAT754 series Schottky barrier (double) diodes," 25 March 2003. [Online]. Available: http://www.nxp.com/documents/data_sheet/BAT754_SERIES.pdf. [Accessed 6 June 2012].

[10] A. C. Ltd., "Frequency Modulation Bandwidth, Spectrum & Sidebands," [Online]. Available: http://www.radio-electronics.com/info/rf-technology-design/fm-frequency-modulation/spectrum-bandwidth-sidebands.php. [Accessed 5 June 2012].

[11] F. C. Commission, "Title 47, Part 97, Sec. 307 Emission Standards," October 2000. [Online].

Available: http://www.gpo.gov/fdsys/pkg/CFR-2000-title47-vol5/xml/CFR-2000-title47-vol5-sec97-307.xml. [Accessed 5 June 2012].

[12] STMicroelectronics, "2 stages RF power amp: PD84001-E + PD54008L-E + LPF N-Channel Enhancement-Mode Lateral MOSFETs," April 2007. [Online]. Available: http://www.st.com/internet/evalboard/product/205439.jsp. [Accessed 5 June 2012].

[13] STMicroelectronics, "PD54008-E RF power transistor, LdmoST plastic family N-channel enhancement-mode, lateral MOSFETs," May 2011. [Online]. Available: http://www.st.com/internet/analog/product/133432.jsp#DATASHEET. [Accessed 5 June 2012].

[14] STMicroelectronics, "PD84001 RF power transistor the LdmoST plastic family," August 2008. [Online]. Available: http://www.st.com/internet/analog/product/138263.jsp. [Accessed 5 June 2012].

[15] Mitsubishi Electric, "RA07M1317M 135-175MHz 6.5W 7.2V, 2 Stage Amp. For Portable Radio," 30 June 2010. [Online]. Available: http://www.mitsubishielectric-mesh.com/products/pdf/ra07m1317m.pdf. [Accessed 5 June 2012].

[16] R. Kollman, "Power electronics from the USB port," 2002. [Online]. Available: http://www.ti.com/lit/an/slyt118/slyt118.pdf. [Accessed 5 June 2012].

[17] Texas Instruments Inc., "TPS61085 650 kHz/1.2 MHz, 18.5 V Step-Up DC-DC Converter," June 2008. [Online]. Available: http://www.ti.com/lit/ds/symlink/tps61085.pdf. [Accessed 5 June 2012].

[18] Microchip Technology Inc., "MCP73841/2/3/4 Advanced Single or Dual Cell Lithium-Ion/Lithium-Polymer Charge Management Controllers," 2004. [Online]. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/21823c.pdf. [Accessed 5 June 2012].

[19] Texas Instruments Inc., "MSP430F550x MSP430F5510 Mixed Signal Microcontroller," March 2011. [Online]. Available: http://www.ti.com/lit/ds/symlink/msp430f5510.pdf. [Accessed 5 June 2012].

[20] MediaTek Inc., "Mediatek - 3329 Datasheet," 30 April 2010. [Online]. Available: https://docs.google.com/fileview?id=0B_dHj7E2weiiNmUzNDA3OTktNTNhNy00Y2Y5LTg0YTQtMzIyNzJhZmFiNjcy&hl=en. [Accessed 5 June 2012].

[21] "ITAR Category XV," [Online]. Available: http://www.oria.cornell.edu/export/keywords/categoryXV.htm. [Accessed 6 June 2012].

A. Senior Project Analysis

Project Title: **All-In-One APRS Transmitter**

Student's Name: **Justin Kenny** Student's Signature:

Advisor's Name: **John Saghri** Advisor's Initials: Date:

• Summary of Functional Requirements

The Automatic Packet Reporting System (APRS) is a digital radio system that allows transmission of data using an analog FM radio link. APRS allows position, brief messages, and other data to be distributed across a network, independent of infrastructure, making it ideal for applications such as search and rescue, asset management, and event tracking, while maintaining low cost and operating even when cellular and internet services are unavailable. This project encompasses the design, build, and test of a compact, low-cost APRS transmitter, which will include a 5W radio, GPS, and LCD-based user interface, to allow full utilization of APRS.

• Primary Constraints

The primary constraints for this project are size, weight, and power. The system must be portable and lightweight in order to not hinder the user or end application, and must operate for a significant duration of time while transmitting at a high output power. Some of the difficulties of this project include finding an amplifier that can operate at 5W output power while running from a battery of 6-8.4V, and determining and managing a power source that is capable of the project requirements. This project is limited by the battery in both size and operating life, and the output power is a limitation of the chosen power amplifier.

• Economic

The economic impacts are mainly due to the procurement of parts and equipment needed to complete the project. I provided most of the research and labor for this project, as well as purchasing of all components and PCBs. The test equipment at Cal Poly was also used during the course of this project. Some of the program design was done prior to the start of this project, both from previous personal projects and from work I did at the Naval Postgraduate School. Natural resources involved are primarily the use of electricity, which comes from the consumption of natural resources.

Costs mostly accumulate through the prototyping and development part of the project life cycle. Once the project is built and completed, it requires very little maintenance and costs, providing benefit through its lifetime.

This project will not earn any money directly, but its use can benefit its users, by assisting in the tracking and reporting of people, vehicles, or objects, which may alleviate the costs of other solutions, such as a human radio operator, or cellular/internet based device.

The project has been completed on June 6, 2012, and should have an operational life of approximately 10 years. The licensing of an operator is required for the use of the radio. The maintenance costs are only the electricity used to charge the main battery, and the replacement of the battery every 2 years. Once the project is completed, the user may upgrade firmware as fixes and upgrades are released. At the end of the product lifecycle, components should be recycled properly through electronic waste services. See Appendix E for timing details.

• If manufactured on a commercial basis:

There are no plans for commercial development of this device. The manufacturing cost of this device is approximately $100-150 (excluding labor), and the purchase price is $200-250, providing a profit of approximately $50-100. The cost to operate this device is approximately $6.54/year based on a usage of 100 recharges per year, at an electricity cost of $0.171/kWh, as well as a cost of $12.53 to replace the battery every 2 years.

• Environmental

The environmental impacts of the device are mainly from the procurement of parts and energy usage, however serious consideration must be made to dispose of the battery safely and properly every 2 years. Although the batteries are landfill safe, care must be taken in properly discharging the battery and inspecting for damage before disposal. This project uses natural resources indirectly through the use of power when charging and in operation.

• Manufacturability

The main challenge to manufacturing is the construction of the device, which will require fine-pitch surface mount soldering. For the initial prototypes and completed project, construction was be done by hand.

• Sustainability

The only maintenance this system requires once built is proper charging and storage of the battery, which must also be replaced and properly disposed of every 2 years. If possible, this project should use renewable energy sources for charging the battery. This project may be improved by using better and more refined means of data transfer, as wireless technologies improve, which would provide a faster data link for general purpose use, beyond simply reporting GPS coordinates. Challenges in upgrading the system are mainly in programming; however the hardware is also speed limited by the PLL bandwidth.

• Ethical

This project provides means of tracking people or vehicles, with or without their knowledge, and the dissemination of this information across the APRS network, including internet servers. The intended application for this project would be for tracking vehicles or people at events, or tracking autonomous vehicles, which would benefit the users of the device. The ethical use of the device requires that all parties involved in tracking are aware of the device and its capabilities.

• Health and Safety

The only health and safety concerns are in the construction and manufacture of the project. Care will be taken to use lead-free solder and RoHS compliant components in its manufacture, however some components or systems used may not meet this requirement, and there are dangers involved in soldering and construction of the product. In use, there are little health and safety concerns, but the charging process must be monitored and done in a safe location to ensure the battery or device does not become damaged.

• Social and Political

There are social and political issues involved with the ethical use of this project. As mentioned previously, it can be used to track many objects, which may lead to its misuse if those being tracked are unaware of the device. It is up to the end user to use this device in an ethical and safe manner. The stakeholders are the users or organizations that will use this project. The stakeholders would benefit equally from the proper use of this project, and this project does not directly cause any inequities.

• Development

The development of this project involves research of new components to meet the project requirements, including battery, power amplifier, RF IC, and supporting circuitry. This project involved the use of the vector network analyzer, spectrum analyzer, and simulation software to analyze the amplifier and filter, as well as software tools and calculations for the RF IC and power management circuitry.

B. Schematic

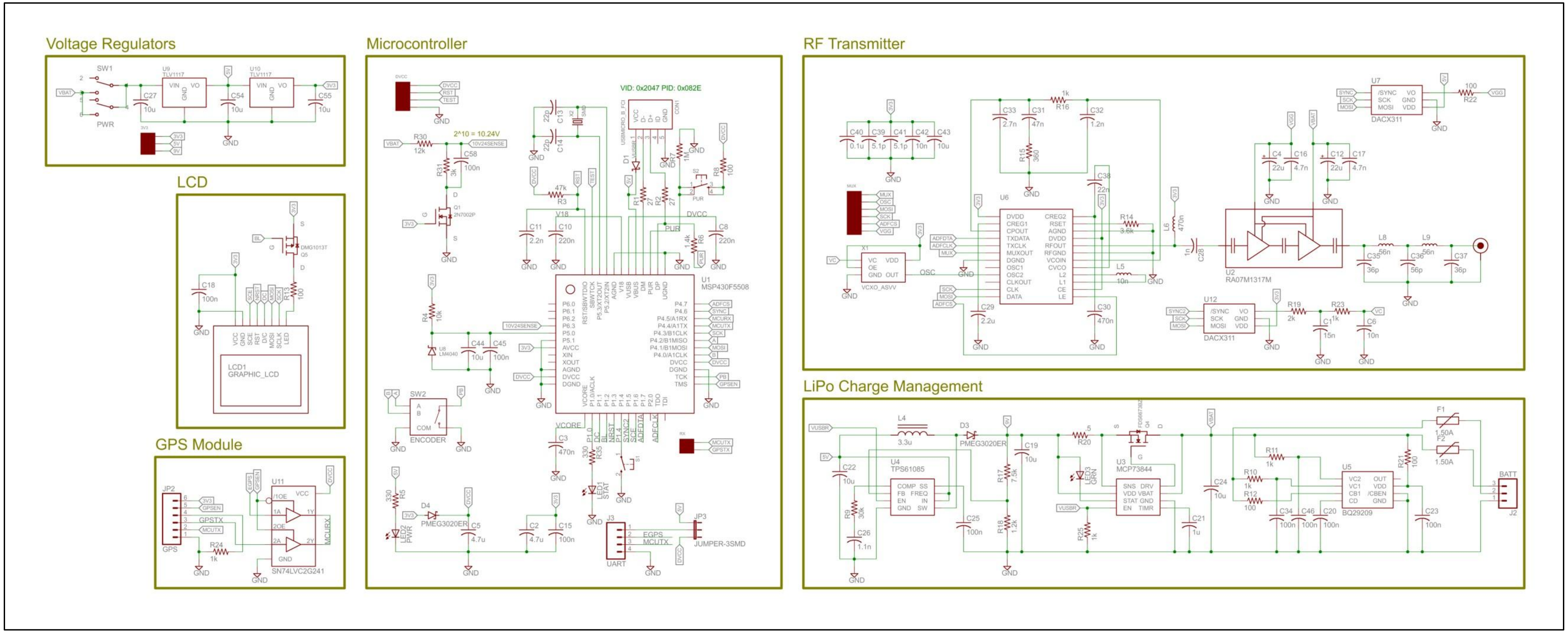


Figure 46: Revised rev0Trac VTx Schematic

C. PCB Layout

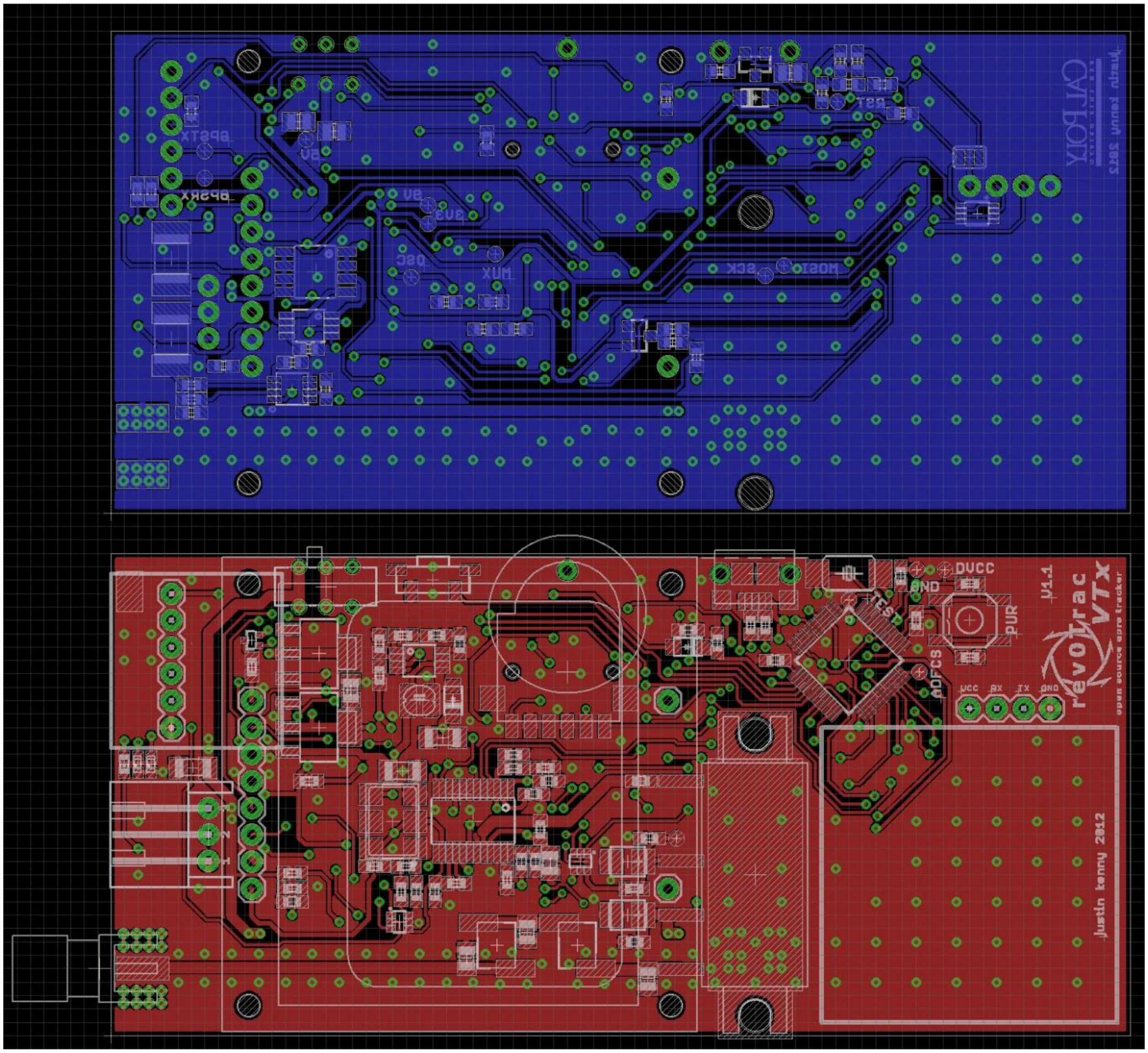


Figure 47: Revised rev0Trac VTx PCB Layout

List of Changes in version 1.1:

- Added trace from MCU to LCD RST line
- Added trace from MCU to LCD D/C line
- Added trace from MCU to LCD backlight PMOS
- Added 1k resistor to ground on VUSBR line
- Added tri-state buffer and header to accommodate an external GPS or serial UART connection

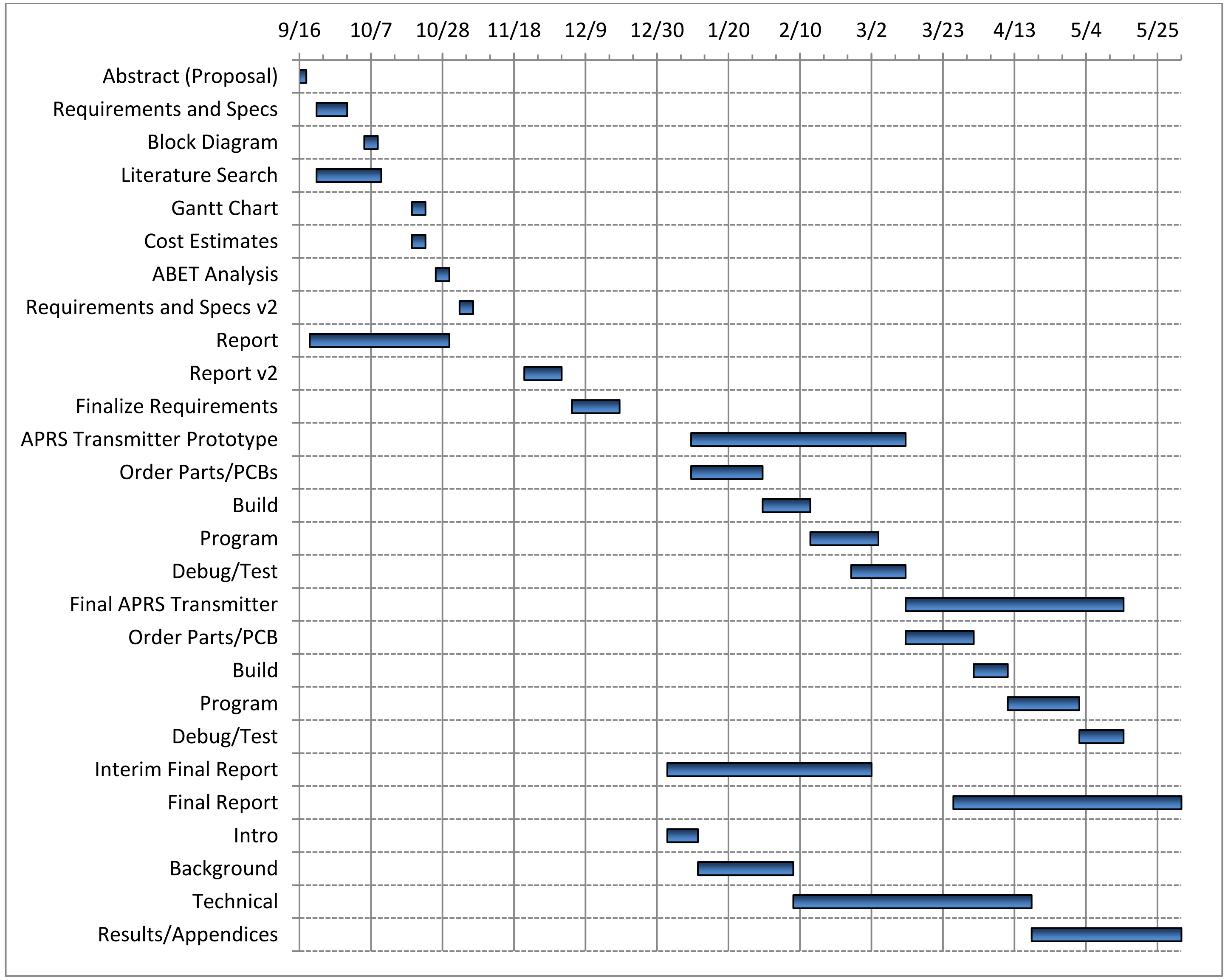
D. Bill of Materials

Table 11: Bill of Materials for rev0Trac VTx Version 1.1

Item #	Qty	Reference Designator	Type	Value	Package	Manufacturer	Manufacturer Part #	Digi-Key Part #	Unit Price	Subtotal
1	2	C39, C41	Ceramic Capacitor	5.1pF, C0G 50V, ±0.25pF	0603	Standard			$ 0.01	$ 0.02
2	2	C13, C14	Ceramic Capacitor	22pF, C0G 50V, ±5%	0603	Standard			$ 0.01	$ 0.02
3	2	C35, C37	Ceramic Capacitor	36p, C0G 50V, ±5%	0805	Standard			$ 0.01	$ 0.02
4	1	C36	Ceramic Capacitor	56p, C0G 50V, ±5%	0805	Standard			$ 0.01	$ 0.01
5	1	C28	Ceramic Capacitor	1n, X7R 50V, ±10%	0603	Standard			$ 0.01	$ 0.01
6	1	C26	Ceramic Capacitor	1.1n, X7R 50V, ±10%	0603	Standard			$ 0.12	$ 0.12
7	1	C32	Ceramic Capacitor	1.2n, X7R 50V, ±10%	0603	Standard			$ 0.07	$ 0.07
8	1	C11	Ceramic Capacitor	2.2n, X7R 50V, ±10%	0603	Standard			$ 0.01	$ 0.01
9	1	C33	Ceramic Capacitor	2.7n, X7R 50V, ±10%	0603	Standard			$ 0.08	$ 0.08
10	2	C16, C17	Ceramic Capacitor	4.7n, X7R 50V, ±10%	0603	Standard			$ 0.01	$ 0.02
11	2	C6, C42	Ceramic Capacitor	10n, X7R 25V, ±10%	0603	Standard			$ 0.01	$ 0.02
12	1	C1	Ceramic Capacitor	15n, X7R 25V, ±10%	0603	Standard			$ 0.01	$ 0.01
13	1	C38	Ceramic Capacitor	22n, X7R 25V, ±10%	0603	Standard			$ 0.01	$ 0.01
14	1	C31	Ceramic Capacitor	47n, X7R 25V, ±10%	0603	Standard			$ 0.01	$ 0.01
15	11	C15, C18, C20, C21, C23, C25, C34, C40 C45, C46, C58	Ceramic Capacitor	100n, X7R 25V, ±10%	0603	Standard			$ 0.01	$ 0.11
16	2	C8, C10	Ceramic Capacitor	220n, X7R 16V, ±10%	0603	Standard			$ 0.01	$ 0.02
17	2	C3, C30	Ceramic Capacitor	470n, X5R 10V, ±10%	0603	Standard			$ 0.01	$ 0.02
18	1	C29	Ceramic Capacitor	2.2u, X5R 10V, ±10%	0603	Standard			$ 0.01	$ 0.01
19	2	C2, C5	Ceramic Capacitor	4.7u, X5R 10V, ±10%	0603	Kemet	C0603C475K8PACTU	399-5503-1-ND	$ 0.23	$ 0.47
20	3	C19, C22, C24	Tantalum Capacitor	10u, 16V, ±20%, 3Ω	1206	Vishay	293D106X0016A2TE3		$ 0.07	$ 0.21
21	5	C27, C43, C44, C54, C55	Ceramic Capacitor	10uF, X5R 10V, ±10%	0805	Yaego	CC0805KKX5R6BB106	311-1460-1-ND	$ 0.13	$ 0.65
22	2	C4, C12	Tantalum Capacitor	22u, 16V, ±10%, 1.9Ω	3528	Vishay	293D226X9016B2TE3	718-1138-1-ND	$ 0.91	$ 1.82
23	1	R20	Resistor	0.5	0603	Standard			$ 0.00	$ 0.00
24	2	R1, R2	Resistor	27	0603	Standard			$ 0.00	$ 0.01
25	5	R8, R12, R13, R21, R22	Resistor	100	0603	Standard			$ 0.00	$ 0.01
26	2	R5, R35	Resistor	330	0603	Standard			$ 0.00	$ 0.01
27	1	R15	Resistor	360	0603	Standard			$ 0.00	$ 0.00
28	5	R10, R11, R16, R23, R24	Resistor	1k	0603	Standard			$ 0.00	$ 0.01
29	1	R18	Resistor	1.2k	0603	Standard			$ 0.00	$ 0.00
30	1	R6	Resistor	1.4k	0603	Yaego	RC0603FR-071K4L	311-1.40KHRCT-ND	$ 0.01	$ 0.01
31	1	R19	Resistor	2k	0603	Standard			$ 0.00	$ 0.00
32	1	R31	Resistor	3k	0603	Yaego	RC0603FR-073KL	311-3.00KHRCT-ND	$ 0.01	$ 0.01
33	1	R14	Resistor	3.6k	0603	Standard			$ 0.00	$ 0.00
34	1	R17	Resistor	7.5k	0603	Standard			$ 0.00	$ 0.00
35	1	R4	Resistor	10k	0603	Standard			$ 0.00	$ 0.00
36	1	R30	Resistor	12k	0603	Yaego	RC0603FR-0712KL	311-12.0KHRCT-ND	$ 0.01	$ 0.01
37	1	R9	Resistor	30k	0603	Standard			$ 0.00	$ 0.00
38	1	R3	Resistor	47k	0603	Standard			$ 0.00	$ 0.00
39	1	R7	Resistor	1M	0603	Standard			$ 0.00	$ 0.00
40	1	L5	Chip Inductor	10n	0603	Taiyo Yuden	HK160810NJ-T	587-1545-1-ND	$ 0.06	$ 0.06
41	2	L8, L9	Air Core Inductor	56n	1812SMS	Coilcraft	1812SMS-56NJLB		$ 0.95	$ 1.90
42	1	L6	Chip Inductor	470n	0603	Taiyo Yuden	HK1608R47J-T	587-1565-1-ND	$ 0.06	$ 0.06
43	1	L4	Power Inductor	3.3u	SMD 3mm	Bourns	SRN3015-3R3M	SRN3015-3R3MCT-ND	$ 0.33	$ 0.33
44	2	F1, F2	PTC Resettable Fuse	1.50A	1812	Bel Fuse	0ZCC0150FF2C	507-1503-1-ND	$ 0.33	$ 0.66
45	3	D1, D3, D4	Schottky Diode	PMEG3020ER	SOD123W	NXP	PMEG3020ER,115	568-6518-1-ND	$ 0.48	$ 1.44
46	1	LED1	LED	STAT	0603	Standard			$ 0.27	$ 0.27
47	1	LED2	LED	PWR	0603	Standard			$ 0.11	$ 0.11
48	1	LED3	LED	GRN	0603	Standard			$ 0.10	$ 0.10
49	1	Q1	N-Channel MOSFET	2N7002P	SOT-23	NXP	2N7002P,215	568-5818-1-ND	$ 0.12	$ 0.12
50	1	Q4	P-Channel MOSFET	FDS6673BZ	SOIC-8	Fairchild	FDS6673BZ	FDS6673BZCT-ND	$ 1.28	$ 1.28
51	1	Q5	P-Channel MOSFET	DMG1013T	SOT-323	Diodes Inc	DMG1013T-7	DMG1013T-7DICT-ND	$ 0.20	$ 0.20
52	1	U1	Microcontroller IC	MSP430F5508	TQFP-48	TI	MSP430F5508IPT	296-29602-5-ND	$ 4.13	$ 4.13
53	1	U2	RF Power Amplifier IC	RA07M1317M	RA07M1317M	Mitsubishi	RA07M1317M		$ 19.95	$ 19.95
54	1	U3	LiPo Charger IC	MCP73844	MSOP-8	Microchip	MCP73844-840I/MS	MCP73844-840I/MS-ND	$ 1.56	$ 1.56
55	1	U4	Boost Converter IC	TPS61085	MSOP-8	TI	TPS61085DGKT	296-23550-1-ND	$ 3.17	$ 3.17
56	1	U5	LiPo Balancer IC	BQ29209	SON-8	TI	BQ29209DRBR	296-27677-1-ND	$ 1.08	$ 1.08
57	1	U6	RF Transmitter IC	ADF7012	TSSOP-24	Analog Devices	ADF7012BRUZ	ADF7012BRUZ-ND	$ 4.26	$ 4.26
58	2	U7, U12	DAC IC	DACX311	SOT-363	TI	DAC7311IDCKR	296-23717-1-ND	$ 2.73	$ 5.46
59	1	U8	Voltage Reference IC	LM4040	SOT-23	TI	LM4040A20IDBZR	296-20857-1-ND	$ 2.88	$ 2.88
60	2	U9, U10	Voltage Regulator IC	TLV1117	TO-261	TI	TLV1117-33CDCYR	296-21112-1-ND	$ 0.66	$ 1.32
61	1	U11	Dual Tri-State Buffer IC	SN74LVC2G241	8-VFSOP	TI	SN74LVC2G241DCUR	296-11936-1-ND	$ 0.28	$ 0.28
62	1	GPS	GPS Module	FGPMMOPA6B	SMD	GlobalTop	FGPMMOPA6B		$ 29.99	$ 29.99
63	1	LCD	Graphic LCD	GRAPHIC_LCD	GRAPHIC_LCD				$ 4.95	$ 4.95
64	1	X1	VCXO	VCXO_ASVV	VCXO_ASVV	Abracon	ASVV-20.000MHZ-N152-T	535-9344-1-ND	$ 3.63	$ 3.63
65	1	X2	Crystal	SMD	5x3.2mm	Abracon	ABM3-24.000MHZ-B2-T	535-9106-1-ND	$ 1.43	$ 1.43
66	1	J1	Female SMA Connector	SMA F	SMA F	Standard			$ 0.50	$ 0.50
67	1	J2	JST-SB3 Connector	BATT	JST-SB3	JST		455-2250-ND	$ 0.21	$ 0.21
68	1	JP2	Male Header 0.1"	GPS	M06	Standard			$ 0.06	$ 0.06
69	1	J3	Male Header 0.1"	GPS	M04	Standard			$ 0.04	$ 0.04
70	1	CON1	Micro USB Connector	USBMICRO_B_FCI	USBMICRO_B	FCI	10118193-0001LF	609-4616-1-ND	$ 0.87	$ 0.87
71	1	S1	Tactile Switch Rt. Angle	SW	SWITCH-MOM-RT	E-Switch	TL3330AF260QG	EG4389CT-ND	$ 0.53	$ 0.53
72	1	S2	Tactile Switch	PUR	TAC_SWITCHSMD	Standard			$ 0.12	$ 0.12
73	1	SW1	Slide Switch	PWR	SLIDE_SW_9.5MM	Standard			$ 0.25	$ 0.25
74	1	SW2	Rotary Encoder	ENCODER	ENCODER	Panasonic	EVQ-WKA001	P13381SCT-ND	$ 6.11	$ 6.11
75	2	BATT	LiPo Battery	2200mAH 3.7V	BATT	HobbyKing			$ 3.61	$ 7.22
76	1	HS	Heatsink		28x28mm	Wakefield	345-1097-ND	658-45ABT3	$ 2.44	$ 2.44
77	1	J2F	JST-SB3 Female Conn.		JST-XHP-3	JST	XHP-3	455-2219-ND	$ 0.10	$ 0.10
78	3	J2P	JST-Crimp Pins		SXH	JST	SXH-001T-P0.6	455-1135-1-ND	$ 0.04	$ 0.11
79	1	GPS-PCB	Printed Circuit Board	GPS-PCB	0.8x0.65"	OSH Park			$ 0.87	$ 0.87
80	1	PCB	Printed Circuit Board	PCB	3.8x1.8"	Imagineering			$ 25.00	$ 25.00
								Total Cost		$138.90

E. Schedule – Time Estimates

Task Description	Start Date	End Date	Duration
Abstract (Proposal)	9/16/2011	9/18/2011	2
Requirements and Specs	9/21/2011	9/30/2011	9
Block Diagram	10/5/2011	10/9/2011	4
Literature Search	9/21/2011	10/10/2011	19
Gantt Chart	10/19/2011	10/23/2011	4
Cost Estimates	10/19/2011	10/23/2011	4
ABET Analysis	10/26/2011	10/30/2011	4
Requirements and Specs v2	11/2/2011	11/6/2011	4
Report	9/19/2011	10/30/2011	41
Report v2	11/21/2011	12/2/2011	11
Finalize Requirements	12/5/2011	12/19/2011	14
APRS Transmitter Prototype	1/9/2012	3/12/2012	63
Order Parts/PCBs	1/9/2012	1/30/2012	21
Build	1/30/2012	2/13/2012	14
Program	2/13/2012	3/4/2012	20
Debug/Test	2/25/2012	3/12/2012	16
Final APRS Transmitter	3/12/2012	5/15/2012	64
Order Parts/PCB	3/12/2012	4/1/2012	20
Build	4/1/2012	4/11/2012	10
Program	4/11/2012	5/2/2012	21
Debug/Test	5/2/2012	5/15/2012	13
Interim Final Report	1/2/2012	3/2/2012	60
Final Report	3/26/2012	6/1/2012	67
Intro	1/2/2012	1/11/2012	9
Background	1/11/2012	2/8/2012	28
Technical	2/8/2012	4/18/2012	70
Results/Appendices	4/18/2012	6/1/2012	44



F. Program Listing

main.c

```
//******************************************************************************
//  rev0Trac VTx APRS Transmitter
//
//  Description: Receives GPS data as NMEA-0183 via UART, formats data into
//  a packet, creates bitstream from packet, and transmits as analog FM via
//  DAC and ADF7012 RF IC. Contains power control and displays system status
//  via graphic LCD.
//
//  Justin Kenny
//  June 6, 2012
//  Built with CCS Version 4.2.4
//******************************************************************************

#include "main.h"
#include "SPI.h"
#include "DAC.h"
#include "Nokia.h"
#include "UART.h"
#include <math.h>

volatile u08 i = 0, drate = 0, j = 0;

volatile u08 bitstream[355] = {0x55, 0x55, 0x55, 0x55, 0x55, 0x55, 0x55, 0x55, 0x55, 0x55, 0x1,
0x1, 0x1, 0x2b, 0x53, 0x6c, 0xec, 0xa9, 0x56, 0xaf, 0x1b, 0x64, 0x8e, 0xe4, 0xec, 0xb3, 0x2f,
0xc, 0xdb, 0x4b, 0x34, 0xd1, 0x56, 0x2f, 0xd5, 0x50, 0x61, 0x4c, 0xc8, 0xef, 0x4f, 0x27, 0x78,
0xf7, 0x15, 0xc7, 0x7f, 0x7f, 0x7f, 0x0};

volatile u08 bitindex = 0;
volatile u16 byteindex = 0;
volatile u16 maxbyte = 49;
volatile u08 maxbit = 0;

//APRS Packet variables
unsigned char data[355] = {0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x7E,0x7E,0x7E};
u16 index = 12;
char tcall[7] = "APRS\0";     //Default destination callsign
char fcall[7] = "KJ6KST\0";   //Default source callsign
u08 tssid = 0;                         //Default destination SSID
u08 fssid = 1;                         //Default source SSID
char path[8] = "WIDE1 1\0";    //Default digipeater path or address
char msg[256] = "Testing\0";   //Default message

volatile u16 battv[8] = {0,0,0,0,0,0,0,0};
volatile u08 battvindex = 0;

volatile u16 count = 10;
volatile u08 power = 0;

void clk_init(void); //Initializes MCU system clocks to 24MHz XTAL
void io_init(void); //Initializes IO to safe defaults
void tx(void); //Enables ADF7012 PA (via SPI)
void off(void); //Disables ADF7012 PA
void pa_on(u16 power); //Enables Mitsubishi PA (via power ctrl DAC)
void pa_off(void); //Disables Mitsubishi PA
void tone(u16 timer, u08 on); //Sets timer for interrupt
void adc_init(void); //Initializes ADC
u16 adc_sample(void); //Returns raw ADC sample
void print_battv(u08 y); //Prints battery voltage at vertical pos. y
void print_declat(void); //Prints decimal latitude
void set_led(u08 on); //Turns on/off red LED at P1.0
u08 get_pb(void); //Returns state of pushbutton (on encoder wheel)
u08 get_sw(void); //Returns state of push switch
u16 len(char* data); //Returns length of a string/array (until '\0')
void make_packet(void); //Assembles APRS packet from GPS/callsign data
void make_bitstream(void); //Assembles bitstream from APRS packet
```

```
void main(void)
{
	WDTCTL = WDTPW + WDTHOLD;		//Stop watchdog timer

	clk_init();

	/* Main Program Begin */
	io_init();
	spi_init();
	pa_off();
	uart_init();
	adc_init();
	nlcd_init();
	nlcd_clear();

	float freq = 0;
	u16 freqint = 0;
	u16 freqdec = 0;
	u16 frac = 1199;
	u08 integer = 108;
	u08 i = 0;
	u08 j = 0;
	char temp[21] = {0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0};
	char chr[5];

	spi_out32(0x0415,0xE000);		//R0 Set
	_delay_us(100);
	spi_out24(0x40|(integer>>2),0x0001|(integer<<14)|(frac<<2));		//R1 Set
	_delay_us(100);
	spi_out32(0x0000,(0x802A|(16<<5)));	//R2 Set
	_delay_us(100);
	spi_out32(0x004A,0x2037);		//R3 Set

	//tx();
	TA0CTL = (2<<8) | (1<<4);		//Set TA0 using SMCLK, in Up mode
	TA1CTL = (2<<8) | (1<<4);		//Set TA1 using SMCLK, in Up mode
	TA1CCR0 = 20000;		//1200 baud interrupt
	_BIS_SR(GIE);				//Global interrupt enable
	tone(1250,0);

	s16 num = 0;
	u08 flag = 0;

	while(1)
	{
		if(count > 15 || count < 7)
		{
			nlcd_clear();
			nlcd_string(0,0,"Sats:");
			nlcd_string(36,0,"Fix:");
			nlcd_string(0,8,"UTC:");
			nlcd_string(0,16,"Lat:");
			nlcd_string(0,24,"Lng:");
			nlcd_chr5(56,0,gpsdata.valid); //Valid flag
			nlcd_string(24,0,gpsdata.sats); //Sattelites in view
			for(j=0;j<6;j++)
			{
				temp[j] = gpsdata.time[j];
			}
			temp[j] = '\0';
			nlcd_string(20,8,temp); //UTC Time
			for(j=0;j<9;j++)
			{
				temp[j] = gpsdata.lat[j];
			}
			temp[j++] = gpsdata.ns;
			temp[j] = '\0';
			nlcd_string(20,16,temp); //Latitude
			for(j=0;j<10;j++)
			{
```

```
                temp[j] = gpsdata.lng[j];
        }
        temp[j++] = gpsdata.ew;
        temp[j] = '\0';
        nlcd_string(20,24,temp); //Longitude

        /* Frequency Display */
        nlcd_string(36,40,"Frq:");
        freq = 20.0/15.0*(integer+(frac)/4096.0);
        //Integer Part
        freqint = (u16)freq;
        chr[2] = (freqint/100)%10+0x30;
        chr[1] = (freqint/10)%10+0x30;
        chr[0] = freqint%10+0x30;
        for(j=0,i=3;i>0;i--,j++)
        {
                nlcd_chr5(56+(j<<2),40,chr[(i-1)]);
        }
        //Decimal Part
        freqdec = (u16)((freq - (u16)freq)*1000);
        nlcd_chr5(68,40,'.');
        chr[2] = (freqdec/100)%10+0x30;
        chr[1] = (freqdec/10)%10+0x30;
        chr[0] = freqdec%10+0x30;
        for(j=0,i=3;i>0;i--,j++)
        {
                nlcd_chr5(72+(j<<2),40,chr[(i-1)]);
        }
        /* End Frequency Display */

        if(get_pb())
        {
                count = 0;
        }
        if(get_sw())
        {
                power = (power==4) ? 0 : power+1;
        }

        print_battv(32);
        nlcd_string(0,40,"Pwr: ");
        if(power == 0)
                nlcd_string(20,40,".1W");
        else if(power == 1)
                nlcd_string(20,40,".5W");
        else if(power == 2)
                nlcd_string(20,40,"1W ");
        else
                nlcd_string(20,40,"5W ");
}
if(count == 0)
{
        bitindex = 0;
        byteindex = 0;
        UCA1IE = 0; //Disable receive interrupt
        make_packet();
        make_bitstream();
        if(power == 0)
                pa_on(LOW);
        else if(power == 1)
                pa_on(MED);
        else if(power == 2)
                pa_on(HI1);
        else
                pa_on(HI2);
        tx();
}
else if(count == 7)
{
        TA1CCTL0 = (1<<4);      //Enable CCR0 interrupt
}
```

```
		else if(count == 30)
		{
			pa_off();
			off();
		}

		count = (count==1800) ? 0 : count+1;
		_delay_ms(100);
	}
}

void clk_init(void)
{
	/* Initialize Clocks */
	UCSCTL6 = (3<<14)|(1);  //XT2 16MHz, XT1 Off
	UCSCTL3 |= (2<<4);              //FLL uses REFO
	UCSCTL4 = (2<<8)|(3<<4)|(3);    //ACLK = REFOCLK, SMCLK = DCOCLK, MCLK = DCOCLK

	sbi(P5SEL,2);

	do
	{
	    UCSCTL7 &= ~(XT2OFFG + XT1LFOFFG + DCOFFG); // Clear XT2,XT1,DCO fault flags
	    SFRIFG1 &= ~OFIFG;                                // Clear fault flags
	    _delay_us(1);
	} while (SFRIFG1 & OFIFG);                            // Test oscillator fault flag

	UCSCTL4 = (5<<8)|(5<<4)|(5);    //ACLK = XT2, SMCLK = XT2, MCLK = XT2
	/* End Clock Initialization */
}

void io_init(void)
{
	//Check IO Map in main.h for Details
	//Port 1 Init
	P1DIR = 0xEB;
	sbi(P1OUT,3); //Set RST on LCD
	sbi(P1REN,4); //Pullup on Switch In
	sbi(P1OUT,4);
	sbi(P1OUT,5); //Deselect FM DAC
	sbi(P1OUT,6); //Deselect LCD

	//Port J Init (JTAG as IO)
	PJDIR = 0x04;
	sbi(PJOUT,2); //Enable GPS
	sbi(PJREN,3); //Pullup on Rotary Switch PB In
	sbi(PJOUT,3);

	//Port 4 Init
	P4DIR = 0xDA;
	sbi(P4REN,0); //Pullup on Rotary Switch A In
	sbi(P4OUT,0);
	sbi(P4REN,2); //Pullup on Rotary Switch B In
	sbi(P4OUT,2);
	sbi(P4OUT,6); //Deselect Gate DAC
	sbi(P4OUT,7); //Deselect ADF

	//Port 5 Init
	sbi(P5SEL,0); //Select VeREF+
	sbi(P5SEL,1); //Select VeREF-

	//Port 6 Init
	P6SEL = 0x08; //Select ADC Input
}

void set_led(u08 on)
{
	if(on)
		sbi(P1OUT,0);
	else
		cbi(P1OUT,0);
```

```
}

u08 get_pb(void)
{
	return !(PJIN & 0x08);
}

u08 get_sw(void)
{
	return !(P1IN & 0x10);
}

void tone(u16 timer, u08 on)
{
	if(on)
	{
		TA0CCR0 = timer;		//Default to 1200*16 Hz
		TA0CCTL0 = (1<<4);		//Enable CCR0 interrupt
	}
	else
	{
		wdac_direct(31,252);
		TA0CCTL0 = 0;		//Disable CCR0 interrupt
	}
}

void tx(void)
{
	spi_out32(0x0045,0x20FF);	//PA On
}

void off(void)
{
	spi_out32(0x004A,0x2037);	//PA Off
}

void pa_on(u16 power)
{
	set_led(1);
	dac_out(power,PDAC,PD0); //5.0ms to turn on
}

void pa_off(void)
{
	dac_out(0,PDAC,PD0); //1.8ms to turn off
	set_led(0);
}

void adc_init(void)
{
	ADC10CTL0 = ADC10ON; //Turn on ADC10_A
	ADC10CTL1 = ADC10DIV_6|ADC10SSEL_1|ADC10SHP; //Select ACLK/6 for ADCCLK
	ADC10MCTL0 = ADC10SREF_6; //Select VeREF+ (Buffered) and VeREF- as refs
}

u16 adc_sample(void)
{
	ADC10CTL0 = ADC10ON; //Turn on ADC10_A
	ADC10MCTL0 = ADC10SREF_6|3; //Select channel 3
	ADC10CTL0 |= ADC10ENC; //Enable conversions
	ADC10CTL0 |= ADC10SC; //Start conversion

	while(ADC10CTL1 & ADC10BUSY);

	return ADC10MEM0;
}

void print_battv(u08 y)
{
	float temp = 0; //Intermediate result
	u08 iresult = 0; //Integer voltage
```

```
	u08 fresult = 0; //Fractional voltage

	battv[battvindex] = adc_sample();

	for(;iresult<8;iresult++)
	{
		temp += battv[iresult];
	}

	temp = temp/8192.0*10.24+0.02;
	if(temp<0)
		temp = 0;
	iresult = (int)temp;
	fresult = (int)((temp - iresult)*100);

	nlcd_string(0,y,"Bat:");
	nlcd_chr5(24,y,'.');
	nlcd_s16(20,y,iresult);
	if(fresult<10)
	{
		nlcd_string(28,y,"0");
		nlcd_s16(32,y,fresult);
	}
	else
	{
		nlcd_s16(28,y,fresult);
	}

	battvindex = (battvindex==7) ? 0 : battvindex+1;
}

u16 len(char* data)
{
	u16 i = 0;

	while(data[i]!='\0')
		i++;

	return i;
}

void make_packet(void)
{
	u16 i;
	u16 temp = 0;
	index = 12;

	//Select destination callsign
	temp = len(tcall);
	for(i=0; i<temp; i++)
	{
		//Print left-shifted tocall
		data[++index] = (tcall[i]<<1);
	}
	for(i=0; i<(6-temp); i++)
	{
		//Print left-shifted spaces
		data[++index] = 0x40;
	}
	//Print tocall SSID
	data[++index] = (0xE0+(tssid<<1));

	//Select source callsign
	temp = len(fcall);
	for(i=0; i<temp; i++)
	{
		//Print left-shifted tocall
		data[++index] = (fcall[i]<<1);
	}
	for(i=0; i<(6-temp); i++)
	{
```

```
        //Print left-shifted spaces
        data[++index] = 0x40;
}
//Print tocall SSID
data[++index] = (0xE0+(fssid<<1));

//Select path
temp = len(path);
for(i=0; i<temp; i++)
{
        //Print left-shifted path
        if(i==6)
                data[++index] = (0xE1 | path[i]<<1);
        else
                data[++index] = (path[i]<<1);
}
for(i=0; i<(7-temp); i++)
{
        //Print left-shifted spaces
        data[++index] = 0x40; //Need to add condition for 0xE1 | 0x40
}

//Append Control Field and Protocol ID Bytes
data[++index] = 0x03;
data[++index] = 0xF0;

//Generate GPS Message
msg[0] = '!';
for(i=0; i<7; i++)
        msg[i+1] = gpsdata.lat[i];
msg[8] = gpsdata.ns;
msg[9] = '/';
for(i=0; i<8; i++)
        msg[i+10] = gpsdata.lng[i];
msg[18] = gpsdata.ew;
msg[19] = '>';
msg[20] = 'P';
msg[21] = 0x30+power;
msg[22] = ' ';
msg[23] = 'F';
if(gpsdata.valid=='0')
        msg[24] = '0';
else
        msg[24] = '1';
msg[25] = ' ';
msg[26] = 'r';
msg[27] = 'e';
msg[28] = 'v';
msg[29] = '0';
msg[30] = 'T';
msg[31] = 'r';
msg[32] = 'a';
msg[33] = 'c';
msg[34] = ' ';
msg[35] = 'V';
msg[36] = 'T';
msg[37] = 'x';
msg[38] = '\0';

//Append Message
temp = len(msg);
for(i=0; i<temp; i++)
{
        data[++index] = msg[i];
}

data[++index] = 0xFF;
data[++index] = 0xFF;
data[++index] = 0x7E;
data[++index] = 0x7E;
data[++index] = 0x7E;
```

```
}

void make_bitstream(void)
{
	u16 i;
	u08 j, last = 1, onecount = 0;
	u16 fcs = 0xFFFF;
	u08 shiftbit = 0;
	u16 bi = 0, bj = 0;

	for(i=0;i<=index;i++)
	{
		if(i==(index-4))
		{
			fcs ^= 0xFFFF;
			data[(index-3)] = ((fcs >> 8) & 0x00FF);
			data[(index-4)] = (fcs & 0x00FF);
		}
		for(j=0;j<8;j++)
		{
			if(data[i]>>j & 0x01)
			{
				if(last)
					bitstream[bi] |= (1<<(7-bj));
				else
					bitstream[bi] &= ~(1<<(7-bj));
				bj++;
				if(bj==8)
				{
					bj = 0;
					bi++;
				}
				onecount++;
				if(i < 13 || i > (index-3))
					onecount = 0;
				if(onecount == 5)
				{
					if(last)
					{
						bitstream[bi] &= ~(1<<(7-bj));
						last = 0;
					}
					else
					{
						bitstream[bi] |= (1<<(7-bj));
						last = 1;
					}
					onecount = 0;
					bj++;
					if(bj==8)
					{
						bj = 0;
						bi++;
					}
				}
			}
			else
			{
				if(last)
				{
					bitstream[bi] &= ~(1<<(7-bj));
					last = 0;
				}
				else
				{
					bitstream[bi] |= (1<<(7-bj));
					last = 1;
				}
				onecount = 0;
				bj++;
				if(bj==8)
```

```
                        {
                                bj = 0;
                                bi++;
                        }
                }
                if((i < (index-4)) && (i > 12))
                {
                        //Store bit rotated off in variable shiftbit
                        shiftbit = 0x0001 & fcs;
                        fcs = fcs >> 1; //Shift fcs right by 1
                        //If shiftbit doesn't match data being sent, xor with 0x8408
                        if(shiftbit != ((data[i]>>j) & 0x01))
                                fcs ^= 0x8408;
                }
        }
    }
    maxbyte = bi;
    maxbit = bj;
}

#pragma vector=TIMER0_A0_VECTOR
__interrupt void Timer0_A0 (void)
{
    if(drate == 0)
    {
        wdac_direct(wdac_msb[i], wdac_lsb[i]);
        i = (i>=15) ? 0 : i+1;
    }
    else
    {
        wdac_direct(wdachf_msb[i], wdachf_lsb[i]);
        if(i%2)
            i++;
        i = (i>=14) ? 0 : i+2;
    }
}

#pragma vector=TIMER1_A0_VECTOR
__interrupt void Timer1_A0 (void)
{
    if(bitstream[byteindex] & (1<<(7-bitindex))) //Next bit 1?
    {
        drate = 0;
        tone(1250,1);
    }
    else //Next bit 0
    {
        drate = 1;
        tone(1364,1);
    }

    bitindex++;

    if(byteindex >= maxbyte)
    {
        if(bitindex >= maxbit) //Transmission complete
        {
            TA1CCTL0 = 0;   //Disable CCR0 interrupt
            tone(1250,0);
            _delay_ms(350);
            off();
            pa_off();
            UCA1IE = UCRXIE; //Enable receive interrupt
        }
    }
    if(bitindex>7)
    {
        bitindex = 0;
        byteindex++;
    }
}
```

main.h

```c
#ifndef MAIN_H_
#define MAIN_H_

#include <msp430f5508.h>

#define F_CPU 24000000

#define sbi(a, b) ((a) |= 1 << (b))      //sets bit B in variable A
#define cbi(a, b) ((a) &= ~(1 << (b)))   //clears bit B in variable A
#define tbi(a, b) ((a) ^= 1 << (b))      //toggles bit B in variable A

#define _delay_ms(x) (_delay_cycles((F_CPU/1000)*x))
#define _delay_us(x) (_delay_cycles((F_CPU/1000000)*x))

typedef unsigned char               u08;
typedef signed char                 s08;
typedef short unsigned int          u16;
typedef short signed int            s16;
typedef volatile unsigned char      vu08;
typedef volatile signed char        vs08;
typedef volatile unsigned short int vu16;
typedef volatile signed short int   vs16;

/* IO Map
 * P1.0 Status LED Out
 * P1.1 LCD Data/Command Out
 * P1.4 Switch In (Pullup)
 * P1.5 /FM DAC Sync Out
 * P1.6 /LCD Chip Select Out
 * P1.7 ADF Data Out
 * PJ.0 ADF Clock In
 * PJ.2 GPS Enable Out
 * PJ.3 Rotary Switch PB In (Pullup)
 * P4.0 Rotary Switch A In (Pullup)
 * P4.1 MOSI Out
 * P4.2 Rotary Switch B In (Pullup)
 * P4.3 SCK Out
 * P4.4 RX Out
 * P4.5 TX In
 * P4.6 /Gate DAC Sync Out
 * P4.7 /ADF Chip Select Out
 * P5.0 2.048V Ref In
 * P5.1 0V Ref In
 * P5.2 XT2 In
 * P5.3 XT2 Out
 * P6.3 10.24V Sense In
 * */

//Calibrated at 7.78V
//Do not exceed 3000
#define LOW 2240 //100mW
#define MED 2365 //500mW
#define HI1 2450 //1W
#define HI2 2780 //5W

#define PI 3.141593
#define D2R 0.0174533  //Multiply by D2R to convert decimal to radian
#define R2D 57.2958    //Multiply by R2D to convert radian to decimal
#define MER 3956.6             //Mean Earth radius in miles

#endif /*MAIN_H_*/
```

SPI.c

```c
#include "SPI.h"

void spi_init(void)
{
	//1) Set UCSWRST
	UCB1CTL1 |= 1; //UCSWRST = 1

	//2) Initialize all USCI registers with UCSWRST=1 (including UCxCTL1)
	UCB1CTL1 = (2<<6)|1; //BRCLK = SMCLK, UCSWRST = 1
	//Set CLK polarity/phase, MSB first, master mode, 3-pin mode, synchronous
	UCB1CTL0 = (CLKPHS<<7)|(CLKPOL<<6)|(1<<5)|(0<<4)|(1<<3)|(0<<1)|1;
	//Set clock prescalar value
	UCB1BR0 = BR;

	//3) Configure ports
	P4SEL |= PIN_MOSI | PIN_SCLK;

	//4) Clear UCSWRST via software
	UCB1CTL1 &= ~(1); //UCSWRST = 0
}

void spi_out(u08 byte)
{
	P4OUT &= ~(PIN_SS);
	UCB1TXBUF = byte;
	while(UCB1STAT & 0x01); //Wait until USCI not busy
	_delay_us(1);
	P4OUT |= PIN_SS;
}

void spi_out24(u08 msb, u16 lsb)
{
	P4OUT &= ~(PIN_SS);
	UCB1TXBUF = msb;
	while(UCB1STAT & 0x01); //Wait until USCI not busy
	UCB1TXBUF = ((lsb>>8) & 0xFF);
	while(UCB1STAT & 0x01); //Wait until USCI not busy
	UCB1TXBUF = (lsb & 0xFF);
	while(UCB1STAT & 0x01); //Wait until USCI not busy
	_delay_us(1);
	P4OUT |= PIN_SS;
}

void spi_out32(u16 msb, u16 lsb)
{
	P4OUT &= ~(PIN_SS);
	UCB1TXBUF = ((msb>>8) & 0xFF);
	while(UCB1STAT & 0x01); //Wait until USCI not busy
	UCB1TXBUF = (msb & 0xFF);
	while(UCB1STAT & 0x01); //Wait until USCI not busy
	UCB1TXBUF = ((lsb>>8) & 0xFF);
	while(UCB1STAT & 0x01); //Wait until USCI not busy
	UCB1TXBUF = (lsb & 0xFF);
	while(UCB1STAT & 0x01); //Wait until USCI not busy
	_delay_us(1);
	P4OUT |= PIN_SS;
}
```

SPI.h

```
/* Application generic SPI driver; must be used in conjunction
 * with user written device driver containing SPI write functions */

#ifndef SPI_H_
#define SPI_H_

#include "main.h"

#define PIN_MISO 0x04          //SPI MISO pin = P4.2
#define PIN_MOSI 0x02          //SPI MOSI pin = P4.1
#define PIN_SCLK 0x08          //SPI SCLK pin = P4.3
#define PIN_SS  0x80           //SPI SS pin = P4.7
#define CLKPOL 0               //Clock idles high
#define CLKPHS 1               //Bit read on clock rising edge
#define F_SCLK 1000000 //Clock speed in Hz (F_CLK/256 to F_CLK)
#define BR (F_CPU/F_SCLK)

void spi_init(void);
void spi_out(u08 byte);
void spi_out16(u16 word);
void spi_out24(u08 msb, u16 lsb);
void spi_out32(u16 msb, u16 lsb);

#endif /*SPI_H_*/
```

UART.c

```c
#include "UART.h"

u08 uart_byte = '\0';
u08 rawgps[82];
u08 gpsgga[82];
u08 gpsindex = 0;
u08 gpsdone = 0;
Gps gpsdata = {"3518.5230\0", "12039.6090\0", "123456.789\0", "00\0", "000000.0\0", 'N', 'W',
'0'};

void uart_init(void)
{
	//1) Set UCSWRST
	UCA1CTL1 |= UCSWRST; //UCSWRST = 1

	//2) Initialize all USCI registers with UCSWRST=1 (including UCxCTL1)
	UCA1CTL1 = (2<<6)|UCSWRST; //BRCLK = SMCLK, UCSWRST = 1
	UCA1CTL0 = 0; //Async, 8-bit, LSB first, no parity
	//Set baud rate registers
	UCA1BR0 = (UART_BR & 0xFF);	//24,000,000/(2*256+113) = 34,800
	UCA1BR1 = (UART_BR >> 8);
	UCA1MCTL = 0x00;		//No oversampling

	//3) Configure ports
	P4DIR &= ~(1<<PIN_RX);
	P4DIR |= (1<<PIN_TX);
	P4SEL |= (1<<PIN_TX)|(1<<PIN_RX);

	//4) Clear UCSWRST via software
	UCA1CTL1 &= ~(UCSWRST);
	UCA1IE = UCRXIE; //Enable receive interrupt
}

void uart_send(char byte)
{
	UCA1TXBUF = byte;
	while(UCA1STAT & 0x01); //Wait until USCI not busy
}

void uart_string(char* input)
{
	u08 i;

	for(i=0;input[i]!=0x00;i++)
	{
		UCA1TXBUF = input[i];
		while(UCA1STAT & 0x01); //Wait until USCI not busy
	}
}

float conv_latlong(char* string, char cardinal)
{
	int i;
	float output = 0.0;
	float minutes = 0.0;

	for(i=0;string[i]!='.';i++); /* Count up until decimal */
	if(i == 5) /* This is a longitude */
	{
		/* 01131.230 = 11 deg. 31.230 min. W = -11.5205 deg. */
		output += 100 * (string[0] - 0x30);
		output += 10  * (string[1] - 0x30);
		output += (string[2] - 0x30);
		minutes += 10 * (string[3] - 0x30);
		minutes += (string[4] - 0x30);
		minutes += 0.1 * (string[6] - 0x30);
		minutes += 0.01 * (string[7] - 0x30);
		minutes += 0.001 * (string[8] - 0x30);
```

```
		output += minutes / 60;
		if(cardinal == 'W')
			output *= -1;
		return output;
	}
	else if(i == 4) /* This is a latitude */
	{
		/* 4807.038 = 48 deg. 7.038 min. N = +48.1173 deg. */
		output += 10  * (string[0] - 0x30);
		output += (string[1] - 0x30);
		minutes += 10 * (string[2] - 0x30);
		minutes += (string[3] - 0x30);
		minutes += 0.1 * (string[5] - 0x30);
		minutes += 0.01 * (string[6] - 0x30);
		minutes += 0.001 * (string[7] - 0x30);
		output += minutes / 60;
		if(cardinal == 'S')
			output *= -1;
		return output;
	}
	else
	{
		return 0;
	}
}

void parse_nmea(void)
{
	UCA1IE = 0; //Disable receive interrupt
	u08 commas[MAXCOMMAS];
	u08 i = 0, n;

	for(n=0;n<MAXCOMMAS;n++) //Find the positions of all commas in the NMEA sentence, put
positions in commas[]
	{
		for(;rawgps[i]!=','||i>MAXGPS;i++); //Find next comma; continue stepping through
the array until we find 0x2C (,)
		commas[n] = i; //Store the index in commas[] array
		i++;
	}
	if(rawgps[commas[5]+1] != '0') //Make sure we have GPS fix; 0 = invalid
	{
		for(i=commas[1]+1;i<commas[2];i++)
		{
			gpsdata.lat[i-(commas[1]+1)] = rawgps[i]; //Load latitude into lat[] array
from stored NMEA string
		}
		gpsdata.lat[i-(commas[1])-1] = '\0';
		gpsdata.ns = rawgps[commas[2]+1];

		for(i=commas[3]+1;i<commas[4];i++)
		{
			gpsdata.lng[i-(commas[3]+1)] = rawgps[i]; //Load longitude into lng[]
array from stored NMEA string
		}
		gpsdata.lng[i-(commas[3])-1] = '\0';
		gpsdata.ew = rawgps[commas[4]+1];

		for(i=commas[6]+1;i<commas[7];i++)
		{
			gpsdata.sats[i-(commas[6]+1)] = rawgps[i]; //Load sats into sats[] array
from stored NMEA string
		}
		gpsdata.sats[i-(commas[6])-1] = '\0';

		for(i=commas[8]+1;i<commas[9];i++)
		{
			gpsdata.alti[i-(commas[8]+1)] = rawgps[i]; //Load alt into alti[] array
from stored NMEA string
		}
		gpsdata.alti[i-(commas[8])-1] = '\0';
```

```
		for(i=commas[0]+1;i<commas[1];i++)
		{
			gpsdata.time[i-(commas[0]+1)] = rawgps[i]; //Load time into time[] array 
from stored NMEA string
		}
		gpsdata.time[i-(commas[0])-1] = '\0';
		gpsdata.valid = rawgps[commas[5]+1];
	}
	else //Else update the timestamp, but retain old GPS data
	{
		for(i=commas[0]+1;i<commas[1];i++)
		{
			gpsdata.time[i-(commas[0]+1)] = rawgps[i];
		}
		gpsdata.time[i-(commas[0])-1] = '\0';

		for(i=commas[6]+1;i<commas[7];i++)
		{
			gpsdata.sats[i-(commas[6]+1)] = rawgps[i]; //Load sats into sats[] array 
from stored NMEA string
		}
		gpsdata.sats[i-(commas[6])-1] = '\0';
		gpsdata.valid = '0';
	}
	UCA1IE = UCRXIE; //Enable receive interrupt
}

#pragma vector=USCI_A1_VECTOR
__interrupt void UART_A1 (void)
{
	uart_byte = UCA1RXBUF;

	if(uart_byte == '$') //$ = Start of NMEA Sentence
	{
		gpsindex = 0;
		gpsdone = 0;
	}
	else if(uart_byte == '*') //<CR> = End of Transmission
	{
		gpsdone = 1;
		if(rawgps[4] == 'G') //Make sure this is a GGA sentence
		{
			parse_nmea();
		}
	}
	if(gpsdone != 1)
	{
		rawgps[gpsindex] = uart_byte;
		gpsindex++;
	}
	if(gpsindex > 81)
	{
		gpsindex = 0;
	}
}
```

UART.h

```c
#ifndef UART_H_
#define UART_H_

#include "main.h"

#define PIN_RX 5                //UART RX pin = P4.5
#define PIN_TX 4                //UART TX pin = P4.4
#define F_BAUD 9600             //Baud rate in Hz
#define UART_BR (F_CPU/F_BAUD)

#define MAXCOMMAS 14   //Max commas to store positions of (14 for GGA sentence)
#define MAXGPS 82               //Max NMEA string size
#define MAXLAT 9                //Max latitude size in bytes
#define MAXLONG 10              //Max longitude size in bytes
#define MAXTIME 10              //Max time size in bytes
#define MAXSATS 2               //Max sats size in bytes
#define MAXALTI 8               //Max altitude size in bytes

typedef struct
{
       char lat[MAXLAT+1];
       char lng[MAXLONG+1];
       char time[MAXTIME+1];
       char sats[MAXSATS+1];
       char alti[MAXALTI+1];
       char ns;
       char ew;
       char valid;
} Gps;

void uart_init(void);
void parse_nmea(void);
void uart_send(char byte);
void uart_string(char* input);
float conv_latlong(char* string, char cardinal);

extern u08 uart_byte;
extern u08 rawgps[MAXGPS];
extern u08 gpsgga[MAXGPS];
extern u08 gpsindex;
extern u08 gpsdone;
extern Gps gpsdata;

#endif /*UART_H_*/
```

DAC.c

```c
#include "DAC.h"

u08 wdac_msb[] = {34,33,33,32,31,31,30,30,29,30,30,31,31,32,33,33};
u08 wdac_lsb[] = {24,236,120,204,252,44,128,12,224,12,128,44,252,204,120,236};
u08 wdachf_msb[] = {37,36,35,33,31,30,28,27,26,27,28,30,31,33,35,36};
u08 wdachf_lsb[] = {8,164,140,232,252,16,108,84,240,84,108,16,252,232,140,164};

void wdac_direct(u08 msb, u08 lsb)
{
	P1OUT &= ~(WDAC_SS);
	UCB1TXBUF = msb;
	while(UCB1STAT & 0x01); //Wait until USCI not busy
	UCB1TXBUF = lsb;
	while(UCB1STAT & 0x01); //Wait until USCI not busy
	_delay_us(1);
	P1OUT |= WDAC_SS;
}

void dac_out(u16 value, u08 dac, u08 pdmode)
{
	u16 data = (value<<2)|(pdmode<<14);

	if(dac == PDAC)
	{
		P4OUT &= ~(PDAC_SS);
	}
	else
	{
		P1OUT &= ~(WDAC_SS);
	}

	UCB1TXBUF = ((data>>8) & 0xFF);
	while(UCB1STAT & 0x01); //Wait until USCI not busy
	UCB1TXBUF = (data & 0xFF);
	while(UCB1STAT & 0x01); //Wait until USCI not busy

	if(dac == PDAC)
	{
		P4OUT |= PDAC_SS;
	}
	else
	{
		P1OUT |= WDAC_SS;
	}
}
```

DAC.h

```c
/* SPI Driver for TI DAC7311; must be used in conjunction
 * with generic SPI driver after SPI initialization */

#ifndef DAC_H_
#define DAC_H_

#include "main.h"

#define PDAC_SS 0x40   //Power Control DAC Sync Pin = P4.6
#define WDAC_SS 0x20   //Waveform Generation DAC Sync Pin = P1.5
#define PDAC 0
#define WDAC 1
#define PD0 0                  //Normal Operation
#define PD1    1                       //Output 1k to GND
#define PD2    2                       //Output 100k to GND
#define PD3    3                       //Output Hi-Z

void dac_out(u16 value, u08 dac, u08 pdmode);
void wdac_direct(u08 msb, u08 lsb);

extern u08 wdac_msb[];
extern u08 wdac_lsb[];
extern u08 wdachf_msb[];
extern u08 wdachf_lsb[];

#endif /*DAC_H_*/
```

Nokia.c

```c
#include "Nokia.h"

/* Internal Functions */
static void nlcd_line8(u08 x, u08 y, u08 height);
static void nlcd_line(u08 x, u08 y, u08 height);
/* Internal Framebuffer Functions */
#if NOKIA_FB == 1
static void nlcd_line8fb(u08 x, u08 y, u08 height, u08 fill);
static void nlcd_linefb(u08 x, u08 y, u08 height, u08 fill);
static void nlcd_linehfb(u08 x, u08 y, u08 h, u08 byte, u08 fill);
#endif
/* Internal Character Functions */
#if NOKIA_CHR == 1
static void nlcd_lineh(u08 x, u08 y, u08 h, u08 byte);
#endif

/* 3x5 character font */
#if NOKIA_CHR == 1
unsigned char chrarray[][3] = {
 {0x00, 0x00, 0x00} // 20
,{0x00, 0x17, 0x00} // 21 !
,{0x03, 0x00, 0x03} // 22 "
,{0x1E, 0x0A, 0x0F} // 23 #
,{0x14, 0x1F, 0x0A} // 24 $
,{0x09, 0x04, 0x12} // 25 %
,{0x1E, 0x19, 0x0C} // 26 &
,{0x00, 0x03, 0x00} // 27 '
,{0x0E, 0x11, 0x00} // 28 (
,{0x00, 0x11, 0x0E} // 29 )
,{0x05, 0x02, 0x05} // 2a *
,{0x04, 0x0E, 0x04} // 2b +
,{0x10, 0x08, 0x00} // 2c ,
,{0x04, 0x04, 0x04} // 2d -
,{0x00, 0x10, 0x00} // 2e .
,{0x18, 0x0E, 0x03} // 2f /
,{0x1F, 0x11, 0x1F} // 30 0
,{0x12, 0x1F, 0x10} // 31 1
,{0x19, 0x15, 0x12} // 32 2
,{0x11, 0x15, 0x0B} // 33 3
,{0x07, 0x04, 0x1F} // 34 4
,{0x17, 0x15, 0x09} // 35 5
,{0x1E, 0x15, 0x1D} // 36 6
,{0x19, 0x05, 0x03} // 37 7
,{0x1B, 0x15, 0x1B} // 38 8
,{0x07, 0x05, 0x1F} // 39 9
,{0x00, 0x0A, 0x00} // 3a :
,{0x10, 0x05, 0x00} // 3b ;
,{0x04, 0x05, 0x00} // 3c <
,{0x05, 0x05, 0x05} // 3d =
,{0x00, 0x05, 0x04} // 3e >
,{0x01, 0x15, 0x07} // 3f ?
,{0x09, 0x15, 0x0E} // 40 @
,{0x1E, 0x05, 0x1E} // 41 A
,{0x1F, 0x15, 0x0A} // 42 B
,{0x0E, 0x11, 0x11} // 43 C
,{0x1F, 0x11, 0x0E} // 44 D
,{0x1F, 0x15, 0x11} // 45 E
,{0x1F, 0x05, 0x01} // 46 F
,{0x0E, 0x11, 0x1D} // 47 G
,{0x1F, 0x04, 0x1F} // 48 H
,{0x11, 0x1F, 0x11} // 49 I
,{0x11, 0x11, 0x0F} // 4a J
,{0x1F, 0x04, 0x1B} // 4b K
,{0x1F, 0x10, 0x10} // 4c L
,{0x1F, 0x02, 0x1F} // 4d M
,{0x1F, 0x06, 0x1F} // 4e N
,{0x1F, 0x11, 0x1F} // 4f O
,{0x1F, 0x05, 0x02} // 50 P
```

```
,{0x0F, 0x09, 0x1F} // 51 Q
,{0x1F, 0x05, 0x1A} // 52 R
,{0x12, 0x15, 0x09} // 53 S
,{0x01, 0x1F, 0x01} // 54 T
,{0x0F, 0x10, 0x1F} // 55 U
,{0x0F, 0x10, 0x0F} // 56 V
,{0x1F, 0x0C, 0x1F} // 57 W
,{0x1B, 0x04, 0x1B} // 58 X
,{0x03, 0x1C, 0x03} // 59 Y
,{0x19, 0x15, 0x13} // 5a Z
,{0x1F, 0x11, 0x00} // 5b [
,{0x0B, 0x1C, 0x0B} // 5c ¥
,{0x00, 0x11, 0x1F} // 5d ]
,{0x02, 0x01, 0x02} // 5e ^
,{0x10, 0x10, 0x10} // 5f _
,{0x00, 0x01, 0x02} // 60 `
,{0x18, 0x14, 0x1C} // 61 a
,{0x1F, 0x14, 0x08} // 62 b
,{0x08, 0x14, 0x14} // 63 c
,{0x08, 0x14, 0x1F} // 64 d
,{0x0C, 0x1A, 0x14} // 65 e
,{0x04, 0x1E, 0x05} // 66 f
,{0x14, 0x1A, 0x0E} // 67 g
,{0x1F, 0x04, 0x18} // 68 h
,{0x00, 0x1A, 0x00} // 69 i
,{0x10, 0x0D, 0x00} // 6a j
,{0x1F, 0x08, 0x14} // 6b k
,{0x00, 0x0F, 0x10} // 6c l
,{0x1C, 0x08, 0x1C} // 6d m
,{0x1C, 0x04, 0x18} // 6e n
,{0x1C, 0x14, 0x1C} // 6f o
,{0x1E, 0x0A, 0x04} // 70 p
,{0x04, 0x0A, 0x1E} // 71 q
,{0x1C, 0x04, 0x04} // 72 r
,{0x14, 0x1A, 0x0A} // 73 s
,{0x04, 0x1F, 0x04} // 74 t
,{0x0C, 0x10, 0x1C} // 75 u
,{0x0C, 0x10, 0x0C} // 76 v
,{0x0C, 0x18, 0x0C} // 77 w
,{0x14, 0x08, 0x14} // 78 x
,{0x16, 0x08, 0x06} // 79 y
,{0x1A, 0x16, 0x12} // 7a z
,{0x04, 0x0E, 0x11} // 7b {
,{0x00, 0x1F, 0x00} // 7c |
,{0x11, 0x0E, 0x04} // 7d }
,{0x0C, 0x0C, 0x00} // 7e . (game ball)
};
#endif

void nlcd_data(u08 byte, u08 dc)
{
   if(dc)
      sbi(P1OUT,DC); //Set D/C'
   else
      cbi(P1OUT,DC);

       cbi(P1OUT,SCE);
       UCB1TXBUF = byte;
       while(UCB1STAT & 0x01); //Wait until USCI not busy
       _delay_us(1);
       sbi(P1OUT,SCE);
}

void nlcd_init(void)
{
   sbi(P1OUT,SCE);

   sbi(P1OUT,RES);
   _delay_us(1);
   cbi(P1OUT,RES);
   _delay_us(1);
```

```c
   sbi(P1OUT,RES);

   nlcd_data(0x21,0); // LCD Extended Commands
   nlcd_data((0x80|VOP),0); // Set LCD Vop (Contrast) (0x80 | Vop)
   nlcd_data(0x04,0); // Set Temp coefficent
   nlcd_data(0x14,0); // LCD bias mode 1:48
   nlcd_data(0x20,0); // LCD Normal Commands
   nlcd_data(0x0C,0); // LCD in normal mode. 0x0D for inverse
}

void nlcd_clear(void)
{
   int i,j;

   for(j=0;j<6;j++)
   {
      for(i=0;i<84;i++)
      {
         nlcd_data(0x00,1);
      }
   }
}

void nlcd_move(u08 x, u08 y)
{
   if(x>83)
      x=83;
   if(y>5)
      y=5;
   nlcd_data((0x80|x),0);
   nlcd_data((0x40|y),0);
}

void nlcd_line8(u08 x, u08 y, u08 height)
{
   nlcd_move(x,(y>>3));
   nlcd_data((((1<<height)-1)<<(y%8)),1);
}

void nlcd_line(u08 x, u08 y, u08 height)
{
   u08 bank = (y>>3), i, h1, h2;
   if((y+height)<=((bank+1)<<3))
   {
      nlcd_line8(x,y,height);
   }
   else
   {
      h1 = (((bank+1)<<3)-y);
      h2 = (y+height)-(((y+height)>>3)<<3);
      for(i=bank;i<((bank<5)?(((y+height)>>3)+1):6);i++)
      {
         if(i==bank)
            nlcd_line8(x,y,h1);
         else if(i==((y+height)>>3))
            nlcd_line8(x,(i<<3),h2);
         else
            nlcd_line8(x,(i<<3),8);
      }
   }
}

void nlcd_box(u08 x, u08 y, u08 width, u08 height)
{
   int i;
   for(i=x;i<(x+width);i++)
   {
      nlcd_line(i,y,height);
   }
}
```

```c
/* LCD Framebuffer Functions */
#if NOKIA_FB == 1
void nlcd_line8fb(u08 x, u08 y, u08 height, u08 fill)
{
   // Set address to x, y/8 (0<=y<=4)
   if(fill)
      framebuf[x][(y>>3)] |= (((1<<height)-1)<<(y%8)); // Make line of height with (1<<height)-1,
with position y%8
   else
      framebuf[x][(y>>3)] &= ~(((1<<height)-1)<<(y%8)); // Make line of height with (1<<height)-
1, with position y%8
}

void nlcd_linefb(u08 x, u08 y, u08 height, u08 fill)
{
   u08 bank = (y>>3), i, h1, h2;
   if((y+height)<((bank+1)<<3))
   {
      nlcd_line8fb(x,y,height,fill);
   }
   else
   {
      h1 = (((bank+1)<<3)-y); // Height of the top byte
      h2 = (y+height)-(((y+height)>>3)<<3); // Height of the bottom byte
      for(i=bank;i<((bank<5)?(((y+height)>>3)+1):6);i++)
      {
         if(i==bank)
            nlcd_line8fb(x,y,h1,fill);
         else if(i==((y+height)>>3))
            nlcd_line8fb(x,(i<<3),h2,fill);
         else
            nlcd_line8fb(x,(i<<3),8,fill);
      }
   }
}

void nlcd_boxfb(u08 x, u08 y, u08 width, u08 height, u08 fill)
{
   int i;
   for(i=x;i<(x+width);i++)
   {
      nlcd_linefb(i,y,height,fill);
   }
}

void nlcd_clearfb(void)
{
   int i,j;

   nlcd_move(0,0);

   for(j=0;j<6;j++)
   {
      for(i=0;i<84;i++)
      {
         framebuf[i][j] = 0x00;
      }
   }
}

u08 nlcd_read_pixel(u08 x, u08 y)
{
   return ((framebuf[x][(y>>3)] & (1<<(y%8)))>>(y%8));
}

void nlcd_write_frame(unsigned char frame[84][6])
{
   int i,j;

   for(j=0;j<6;j++)
   {
```

```
      for(i=0;i<84;i++)
      {
         nlcd_data(frame[i][j],1);
      }
   }
}
#endif

/* Character/Font Functions */
#if NOKIA_CHR == 1
void nlcd_chr5(u08 x, u08 y, u08 chr)
{
   u08 i;
   for(i=0;i<3;i++)
   {
      nlcd_lineh((x+i),y,5,chrarray[(chr-0x20)][i]);
   }
   nlcd_lineh((x+3),y,5,0x00); //Add space between consecutive characters
}

void nlcd_string(u08 x, u08 y, char* input)
{
   u08 i;

   for(i=0;input[i]!=0x00;i++)
   {
      nlcd_chr5((x+(i<<2)),y,input[i]);
   }
}

void nlcd_s16(u08 x, u08 y, s16 var)
{
       u08 i=1,j; //Initialize i to 1 for case of var < 9
   char chr[5];

   if(var < 0)
   {
      nlcd_chr5(x,y,'-');
      var *= -1;
   }

   if(var > 9)
   {
      for(i=0; var>0; var/=10,i++)
      {
         chr[i] = 0x30 + (var%10);
      }
   }
   else
      chr[0] = var + 0x30;

   for(j=0;i>0;i--,j++)
   {
      nlcd_chr5(x+(j<<2),y,chr[(i-1)]);
   }
}

void nlcd_s16z(u08 x, u08 y, s16 var)
{
       u08 i,j;
   char chr[5];

   chr[4] = (var/10000)%10+0x30;
   chr[3] = (var/1000)%10+0x30;
   chr[2] = (var/100)%10+0x30;
   chr[1] = (var/10)%10+0x30;
   chr[0] = var%10+0x30;

   for(j=0,i=4;i>0;i--,j++) //i=5 normally, i=4 eliminates excess 0
   {
      nlcd_chr5(x+(j<<2),y,chr[(i-1)]);
```

```
    }
}

#if NOKIA_FB == 1
void nlcd_chr5fb(u08 x, u08 y, u08 chr, u08 fill)
{
   u08 i;
   for(i=0;i<3;i++)
   {
      nlcd_linehfb((x+i),y,5,chrarray[(chr-0x20)][i],fill);
   }
   nlcd_linehfb((x+3),y,5,0x00,fill); //Add space between consecutive characters
}

void nlcd_stringfb(u08 x, u08 y, char* input, u08 fill)
{
   u08 i;

   for(i=0;input[i]!=0x00;i++)
   {
      nlcd_chr5fb((x+(i<<2)),y,input[i],fill);
   }
}

void nlcd_s16fb(u08 x, u08 y, s16 var, u08 fill)
{
       u08 i=1,j;
   char chr[5];

   if(var < 0)
   {
      nlcd_chr5fb(x,y,'-',fill);
      var *= -1;
   }

   if(var > 9)
   {
      for(i=0; var>0; var/=10,i++)
      {
         chr[i] = 0x30 + (var%10);
      }
   }
   else
      chr[0] = var + 0x30;

   for(j=0;i>0;i--,j++)
   {
      nlcd_chr5fb((x+(j<<2)),y,chr[(i-1)],fill);
   }
}
#endif
#endif

/* Internal Functions */
void nlcd_lineh(u08 x, u08 y, u08 h, u08 byte)
{
   u08 bank = (y>>3), h1, h2;
   nlcd_move(x,bank);
   if((y+h)<((bank+1)<<3)) //If data doesn't overflow to next y row
   {
      nlcd_data((byte<<(y%8)),1);
   }
   else
   {
      h1 = (byte<<(y%8)); //Data for upper half
      h2 = (byte>>(h-((y+h)-(((y+h)>>3)<<3)))); //Data for lower half (on next row)
      nlcd_data(h1,1);
      nlcd_move(x,bank+1);
      nlcd_data(h2,1);
   }
}
```

```c
#if NOKIA_FB == 1
void nlcd_linehfb(u08 x, u08 y, u08 h, u08 byte, u08 fill)
{
   u08 bank = (y>>3), h1, h2;
   if((y+h)<((bank+1)<<3)) //If data doesn't overflow to next y row
   {
      if(fill)
         framebuf[x][bank] |= ((byte<<(y%8)));
      else
         framebuf[x][bank] &= ~((byte<<(y%8)));
   }
   else
   {
      h1 = (byte<<(y%8)); //Data for upper half
      h2 = (byte>>(h-((y+h)-(((y+h)>>3)<<3)))); //Data for lower half (on next row)
      if(fill)
      {
         framebuf[x][bank] |= (h1);
         framebuf[x][bank+1] |= (h2);
      }
      else
      {
         framebuf[x][bank] &= ~(h1);
         framebuf[x][bank+1] &= ~(h2);
      }
   }
}
#endif
```

Nokia.h

```
#ifndef NOKIA_H_
#define NOKIA_H_

#include "main.h"
//Dependencies: SPI.c, SPI.h

/* User Defines/Constants */
#define NOKIA_FB  0    //Use framebuffer and assoc. functions (requires 94B constant data)
#define NOKIA_CHR 1 //Use characters and assoc. functions (requires 504B variable data)
#define SCE  6 //P1.6 = SCE'
#define RES  3 //P1.3 = RES'
#define DC   1 //P1.1 = D/C'

#define VOP 0x1C //Contrast value ranging between 0x00-0x4F

#if NOKIA_FB == 1
unsigned char framebuf[84][6];
#endif

/* User Functions */
void nlcd_data(u08 byte, u08 dc); //Writes a data byte to the LCD
void nlcd_init(void); //Initializes LCD
void nlcd_clear(void); //Writes 0's to all LCD pixels
void nlcd_move(u08 x, u08 y); //Moves cursor to position 0<=x<=83, 0<=y<=5
void nlcd_box(u08 x, u08 y, u08 width, u08 height); //Draws a box with upper left corner at
(x,y), of width x, height y

/* Framebuffered Functions */
#if NOKIA_FB == 1
void nlcd_boxfb(u08 x, u08 y, u08 width, u08 height, u08 fill); //Draws a box (filled in or no
fill) at x,y of width x, height y
u08 nlcd_read_pixel(u08 x, u08 y); //Returns a 1 if the pixel at x,y in the framebuffer is filled
(dark)
void nlcd_clearfb(void); //Clears framebuffer (same as lcd_clear for framebuffer)
void nlcd_write_frame(unsigned char frame[84][6]); //Updates LCD memory with local framebuffer
contents
#endif

/* Font Functions */
#if NOKIA_CHR == 1
void nlcd_chr5(u08 x, u08 y, u08 chr);
void nlcd_string(u08 x, u08 y, char* input);
void nlcd_s16(u08 x, u08 y, s16 var);
void nlcd_s16z(u08 x, u08 y, s16 var);
#if NOKIA_FB == 1
void nlcd_chr5fb(u08 x, u08 y, u08 chr, u08 fill);
void nlcd_stringfb(u08 x, u08 y, char* input, u08 fill);
void nlcd_s16fb(u08 x, u08 y, s16 var, u08 fill);
#endif
#endif

#endif /*NOKIA_H_*/
```