Everywhere Transmitter

Design Study Report

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1 Executive Summary

The Everywhere Transmitter will allow almost any audio source to be transmitted to any nearby FM receiver. It has been taken from a conceptual state and broken down into blocks that have been researched and designed independently, while still keeping the other blocks in mind. Loosely defined these blocks are control, power, user input/output, and audio transmission.

For the control block the Z8F0412 microcontroller was selected to integrate the system components due to its easy programmability (C compiler), input/output flexibility, and low cost. The MAXIM MAX863 integrated circuit has been chosen to meet the power needs of the system. It is capable of taking a small voltage input and outputting the two independent voltage levels required for operation while supplying enough current to the handle worst-case conditions of system components. The user will provide input via simple momentary pushbuttons and the output will be provided via the LUMEX LCM-S00801-DSF liquid crystal display. This LCD was chosen because it is 8 by 1 characters, providing enough space for all output situations. Also, it includes a backlight and has many sources of interfacing information. The ROHM BH1415F integrated circuit was chosen to create the frequency modulated audio output signal. Chip features include: small size, accuracy, and easily programmed transmission frequency. These system components have been thoroughly researched separately and are now in the process of being integrated to produce a working prototype Everywhere Transmitter.

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3 Design Problem and Objectives

The Everywhere Transmitter seeks to create an easy to use, universal method of connecting audio systems by solving the following problem statement, "not all audio devices have a simple, efficient and portable method of transmitting clear signals to a wide range of audio output systems." This statement grew from an initial problem of the lack of simple methods for connecting various audio devices to home and car stereos. Upon further examination, it was determined that many audio devices suffer from compatibility issues when attempting to connect to stereos. Those that are capable of connections are often difficult and bothersome to use. The Everywhere Transmitter is ideal for "connecting" audio systems in an efficient manner without the clutter or restrictions of cords. It was designed to produce a simple, efficient, and portable method of transmitting audio signals to a wide range of output systems.

The most important characteristic of this device was portability. It had to allow for communication between devices with as few restrictions as possible. From a power standpoint, this meant that the device should be battery operated, so there would be no power supply wires to hinder the portability of the device. Compatibility was another important quality. This presented the interesting problem of interfacing with the variety of audio systems in existence. How can audio devices be connected without wires? The solution is transmitting the output using radio frequencies. Since most sound systems contain a radio, using the FM radio frequency spectrum for transmission provides a common, compatible, and portable medium for "connecting" most devices.

Due to FCC regulations, along with its expected primary uses being limited to automobile and in home use, the transmission range was limited to 30 feet. Also keeping in mind the desire to have the audio retain high quality, FM stereo modulation was a must.

From a physical dimensions perspective, the device had to be handheld. Dimensions of 5 inches wide, 5 inches high, 2 inches deep were defined as the maximum and eight ounces was defined as the maximum weight. Also due to size constraints, the antenna had to be self-contained.

Being transmitted in FM stereo to retain high quality sound, a frequency response from 50Hz to 15kHz was determined necessary. As was previously stated, it was chosen to transmit in the FM band due to its ease of compatibility with other audio devices. The design will be capable of transmitting over the entire FM band (88.1 – 107.9MHz) to provide the widest range of operating frequencies to the user.

Again, keeping sound quality in mind, clarity of the signal was important; 60dB was selected as the minimum signal-to-noise ratio. For similar reasons, digital tuning was selected due to analog tunings tendency to suffer from frequency drifting. To obtain phase stability in the transmitting stage, phase lock loop control was utilized.

To provide an interface to the user, pushbuttons will provide the inputs of FREQUENCY UP and FREQUENCY DOWN along with ON/OFF. An LCD module will be used to display the current frequency, display a low battery indicator and have backlight capability to improve readability.

With emphasis on portability, the device must be powered by a means that will continue this emphasis. As stated earlier, it will be battery powered. This will permit for a minimum allowable battery life of 8 hours of continuous use.

From the characteristics described above, the specifications for the Everywhere Transmitter were created.

Major Specifications

- **Physical**
  - Size ....Less than 5 in. x 5 in. x 2 in.
  - Weight...Less than 8 oz.
  - Antenna......................................Self-contained

- **Electronic**
  - Operating range ....30 feet maximum (FCC Regulation)
  - Type of tuning............................Digital
  - Battery life ....8 hours continuous use
  - Transmitting frequency range.....88.1MHz – 107.9MHz
  - Display.......................................Backlit 3.5 digit LCD with battery indicator
  - Modulation.................................FM Stereo
  - Modulation frequency response..50Hz – 15kHz
  - Signal to noise ratio ....≥60dB
  - Phase stability ....Phase lock loop control

Meeting all of these specifications will create a simple, efficient, and portable method of transmitting audio signals to a wide range of audio output systems. Further detail of the design that will meet all and even exceed some of the above specifications is located in the following sections of this report.

4 Design Procedure

The design of the Everywhere Transmitter can be broken up into four major components: microcontroller, LCD module, audio modulating/transmitting circuitry, and power supply. Additional smaller components include: antenna, pushbuttons, printed circuit board, and protective shell. Figure 1 shows a general system level block diagram of the Everywhere Transmitter.

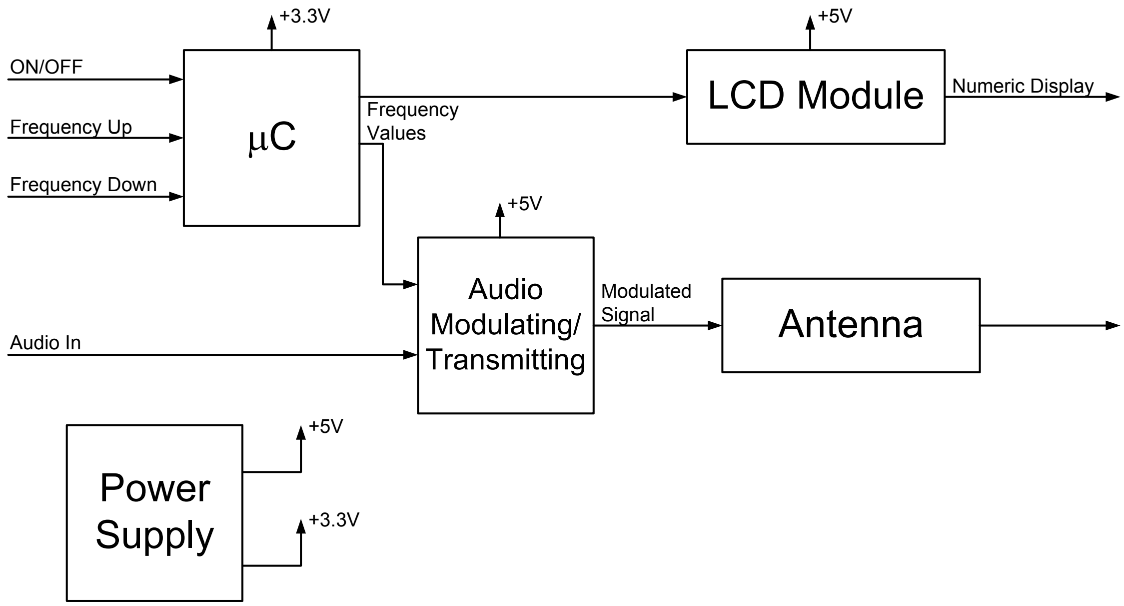


Figure 1 Everywhere Transmitter Block Diagram

The microcontroller uses three user inputs consisting of FREQUENCY UP, FREQUWNCY DOWN, and ON/OFF, to control the processes of the transmitter. It outputs the transmission frequency to the LCD module and the audio modulating/transmitting IC. The microcontroller also controls power-saving features that will turn off the LED backlight on the LCD module, turn off the LCD module, and display a low-battery icon.

The LCD module uses a 14 pin interface to write characters to the screen. The module displays the transmitted frequency along with a low-battery icon when needed. When the modulating frequency is being changed, the LED backlight turns on, so the screen is more visible. After a certain time of inactivity, the LED backlight and the LCD module are turned off to extend battery life.

The audio modulating/transmitting IC interfaces with the microcontroller using 3 pins for a chip enable, clock, and 16 bit serial data bus to control the modulation frequency. The left and right channel audio input signals are connected directly to the audio IC. The circuitry inside the integrated circuit multiplexes the audio input signals with a pilot signal, frequency modulates the composite signal, and outputs a signal ready for transmission through an antenna.

Because the microcontroller requires a 3.3V power supply and the LCD module and audio modulating/transmitting IC require 5 V, the power supply circuitry is a dual output supply. Being a portable device it is able to produce both voltages level from 2 AA batteries. The power supply circuitry produces a signal to the microcontroller indicating a low-battery condition.

5 Microcontroller Design And Test

A microcontroller will be used to handle user input and data output along with integration of the system components. Specifically the microcontroller must handle user input in the form of two buttons that will change the set frequency. This frequency will then be displayed on the LCD module and set in the Audio IC. The microcontroller must also handle power saving features such as turning off the LCD and backlight after a certain period of user inactivity. In power saving mode the unit will still transmit, and the LCD and backlight will turn on when the user presses one of the input buttons. When the power IC sends a low battery signal, the microcontroller must detect it and display an appropriate message on the LCD module.

The Zilog Z8Encore! Flash microcontroller has been selected due to its programming ease, versatility of features, and the availability of a C development environment. Specifically the Z8F0412 has been selected which has the following features:

- Up to 20MHz Clock Speed
- 4Kbytes Flash Memory
- 1Kbyte RAM
- 19 I/O Pins
- 19 Interrupts
- Two 16-bit Timers
- Single-pin On-chip Debugger
- 1 UART
- 2.7–3.6V Operating Voltage with 5V-tolerant Inputs

This microcontroller was chosen because it has enough Input/Output pins to meet the needs demanded by integrating all of the system components. Also the development kit for this microcontroller family is only $40 and includes an ANSI C compliant development environment for easy programming. The chip can be programmed from a personal computer via the serial port. In singular quantities, each Z8F0412 chip costs approximately $4.50 and will cost quite a bit less for much larger quantities.

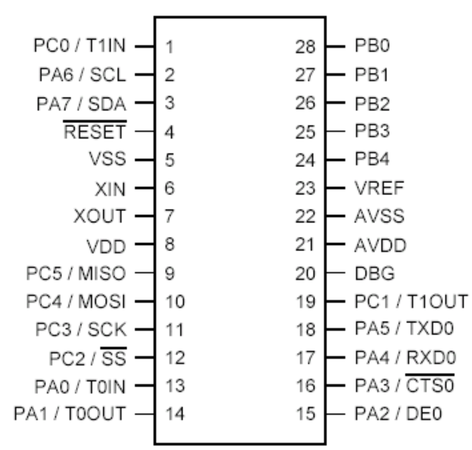


Figure 2 Z8F0412 Pin Configuration

After the development kit was acquired from Zilog, it was soon determined not to be of much use. The development kit made programming the microcontroller very simple through the PC serial port. The drawbacks to the board were many: many pins inaccessible, only 2 buttons and 3 LEDs to test with, and no easy prototyping or external interfacing. It was determined very soon after receiving the board that an alternative method of testing needed to be devised. A 28-pin SOIC to DIP converter was purchased through epboard.com. A Z8F0412 chip has been soldered to this board and placed onto a breadboard where all of the pins can be easily accessed. Using the development kit as a model, integral circuits for microcontroller operation have been created on the breadboard.

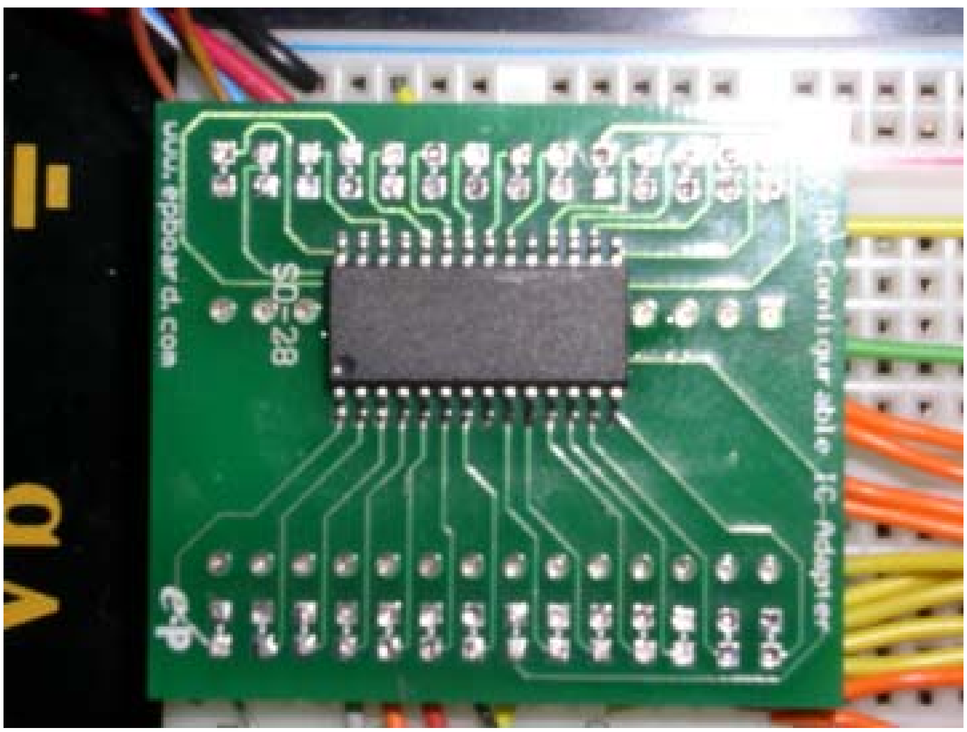


Figure 3 SOIC to DIP Adaptor with Z8F0412 Chip

To reset the microcontroller a low logic level must be applied to the RESET pin. For the microcontroller to operate the RESET pin must be at logic high. This pin was wired high and a pull-down momentary push-button has been applied to bring the signal to ground for a manual reset.

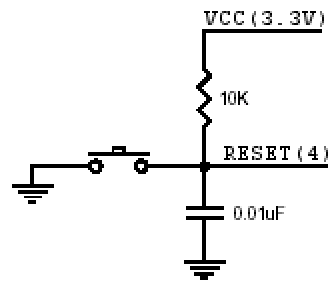


Figure 4 Microcontroller Reset Circuitry

The serial connector provided with the development kit provides a simple programming interface and thus a header was wired to the breadboard so this adaptor could still be used. With the use of the Zilog Development Environment and this adaptor, the microcontroller can be programmed and debugged.

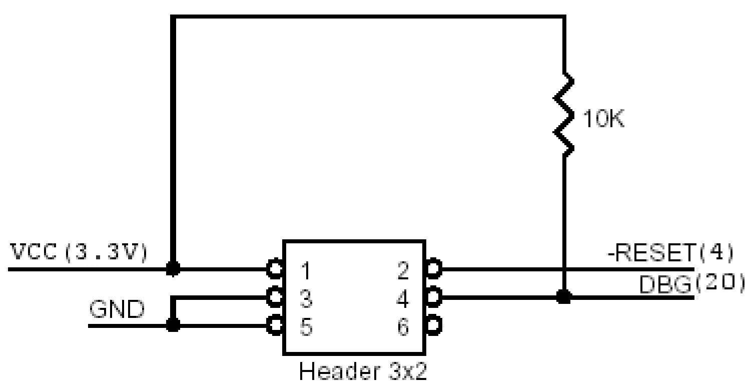


Figure 5 Zilog Serial Programming Adaptor Pinout

The microcontroller needs to be clocked externally and can vary in speed from kilohertz to 20MHz. A RC network can be used to set the clock for speeds under 3.5 MHz. For higher speeds a quartz oscillator must be used. For the final product a RC network will be used because the components are cheap and there is no need for speeds over 3.5MHz since the microcontroller will be dealing with user input and interfacing, all of which are not time critical. The circuit and parameter selection criteria follows:

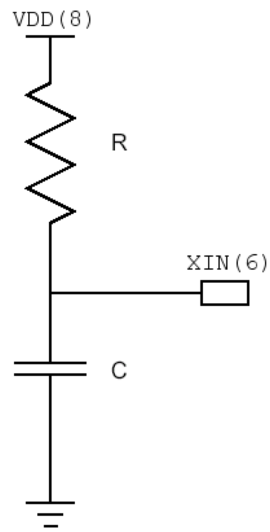


Figure 6 Setting the Microcontroller Speed via RC Network

In Figure 6, the R and C values are selected via the following formula:

$$F = \frac{1000}{(8.875 \times R \times C) + 40}$$

Where: F = frequency in MHz
R = resistance in kOhms
C = capacitance in picoFarads
Note: R must be greater than 10kOhm

In the following table a frequency and resistor value has been chosen and the capacitance has been solved for. This was done several times until an acceptable combination of components and speed was attained. Lower frequencies produce more attainable capacitor values. Future research may lead to a clock speed that is smaller than any values in the table.

Frequency [MHz]	Resistance [kΩ]	Capacitance [pF]
3.5	10	2.77
2.0	100	0.518
1.0	47	2.3
1.0	12	9

Table 1 Clocking RC Parameters

The RC network from the last line of the table was implemented on the microcontroller breadboard, but the development software would not connect to the module. To speed along the development process, the 18.432MHz crystal oscillator from the development board has been placed on the breadboard and the RC network pushed aside. The crystal circuit follows:

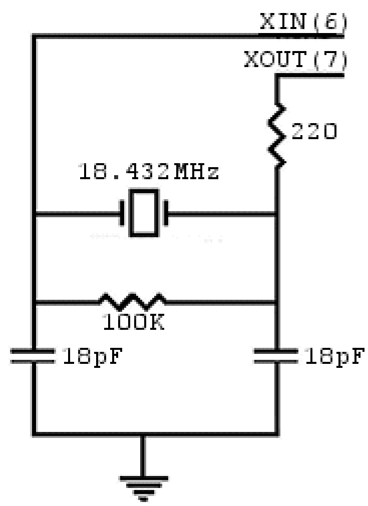


Figure 7 Crystal Oscillator Clocking Circuit

With the crystal oscillator in place the development software connected to the microcontroller immediately and coding could begin. A few LEDs were connected to port A and a pushbutton connected to port C so the example code that came with the development kit could be tested. When tested it worked as expected. The code was examined and found to be very simple. The ports and registers are all easily accessible using C syntax.

LCD Module Interfacing: The microcontroller needs to be able to display the current frequency setting on the LCD module. To begin, the LCD module data segment was wired to port A and the control bits were wired to port C. After overcoming timing problems, simple messages were easily displayed on the module. Then a button was added to port C and mapped to an interrupt so that the frequency was incremented and displayed on each button press. This code can be seen on the appendix compilation disc as code\LCD_test\main.c.

Due to the interrupt capabilities of each port and pin, it was determined that the pin configuration for the LCD module would need to be re-evaluated. All of the pins and their uses were considered and the newest pinout can be seen in Figure 8. This new pin configuration required splitting the LCD data segment into two 4-bit pieces. The code to accomplish this can be seen in code\newLCD\main.c. In this code the LCD numerical display function was updated to support the decimal point and all code was examined and simplified for clarity. Figure 9 shows the current function to display the set frequency on the LCD Module.

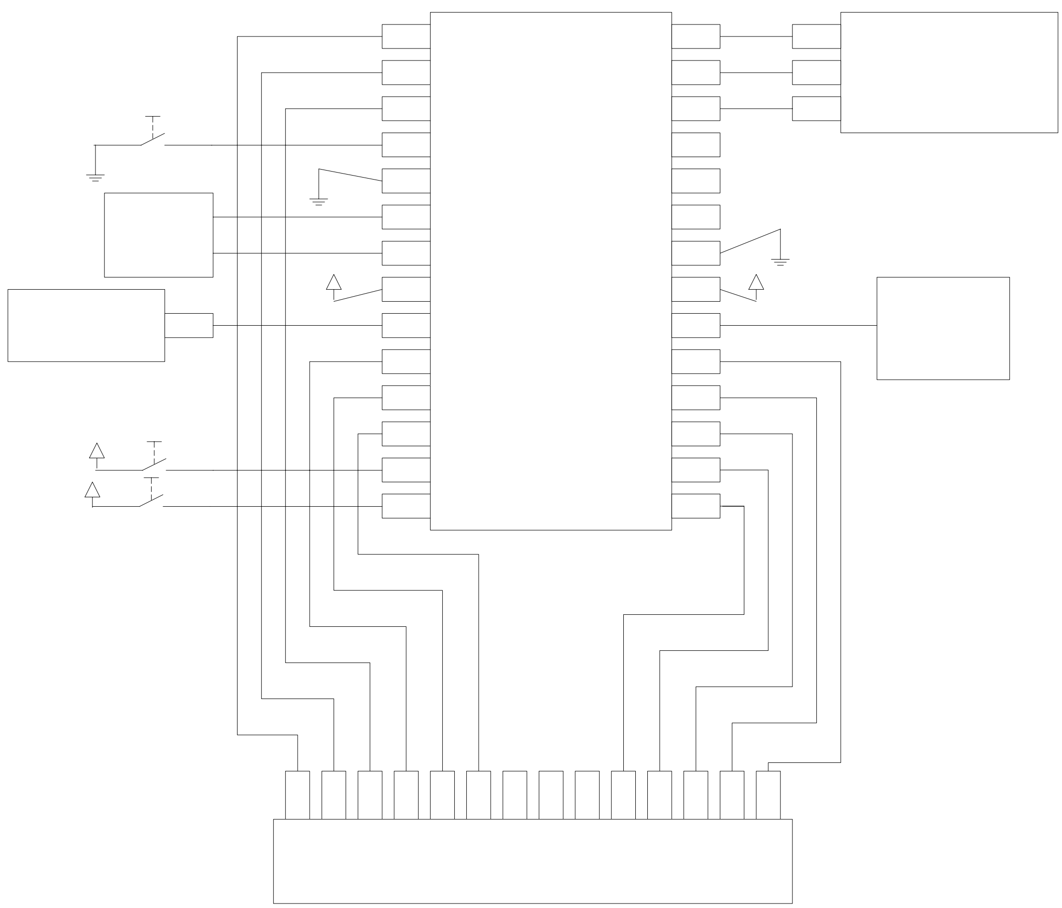


Figure 8 Current Z8F0412 Pinout

```
// table of needed LCD characters:
//    '0', '1', '2', '3', '4', '5', '6', '7',
//    '8', '9', '.', ' ', 'L', 'B'
int char_tab1[] = { 0x00, 0x10, 0x20, 0x30, 0x40,
       0x50, 0x60, 0x70, 0x80, 0x90, 0xE0, 0x00, 0xC0, 0x20 };
int char_tab2[] = { 0x03, 0x03, 0x03, 0x03, 0x03,
       0x03, 0x03, 0x03, 0x03, 0x03, 0x02, 0x02, 0x04, 0x04 };
int cur_freq = 881; // set starting frequency

void disp_freq(void){
       int k = 4;
       int j = 0;
       // get the current frequency in a temporary location
       unsigned int fTemp = cur_freq;
       unsigned int digit[5] = {0};      // initialize all digits to 0
       digit[3] = 10;                    // set the decimal point

       while(fTemp != 0){   // loop to obtain individual digits
              if(k==3)      // by saving remainders and dividing by 10
                     k--;
              digit[k] = fTemp % 10;
              fTemp -= digit[k--];
              fTemp /= 10;
       }

       // if the first digit is '0' change it to a space
       if(digit[0] == 0)
              digit[0] = 11;

       // loop to display all saved digits to the LCD
       for (j = 0; j <= 4; j++) {
              k = digit[j];
              write_char(j+3, k);
       }
}
```

Figure 9 Current C Code to Display Frequency to LCD

In the latest code revision a function to display to each LCD position individually was also implemented. Before this all writing to the LCD had to be done sequentially. This new function will allow easier implementation of the low battery indicator and make it easier to implement new features in the future.

```
// write the character stored at c_inded of the characer table
// to the LCD position indexed by pos
void write_char(int pos, int c_index){
       PAOUT &= 0xF7;   // set to instruction mode

       PAOUT &= 0x0F;
       PCOUT &= 0xF0;

       PAOUT |= (pos << 4);     // set cursor to 3rd position
```

```
        PCOUT |= 0x08;
        enable();


        PAOUT |= 0x08;      // set to character mode

        PAOUT &= 0x0F;
        PCOUT &= 0xF0;
        PAOUT |= char_tab1[c_index];  // lower nibble to D0-D3
        PCOUT |= char_tab2[c_index];  // upper nibble to D4-D7
        enable();
}
```

Figure 10 C Code to Display a Character to Any LCD Position

Audio IC Interfacing: The microcontroller must send a 16-bit signal to the BH1415F audio link chip. This signal is sent serially and contains the frequency number and some control information. The timing diagram for sending this information is shown below.

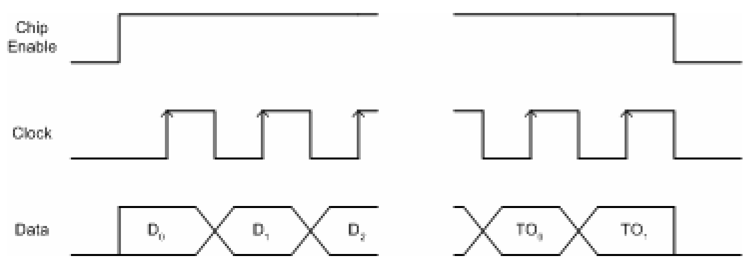


Figure 11 Audio IC Timing Diagram

The following options were explored for transmitting this data from the microcontroller:

- UART Communication
- I^2C Communication Protocol
- Hard Code

UART stands from Universal Asynchronous Receiver Transmitter and this particular UART conforms to the RS-232 standards for data transfer. RS-232 allows for sending and receiving 8 or 9 bits at a time with parity and stop bits appended. This choice was eliminated because more than 9 bits need to be transmitted sequentially and the parity and stop bits would not interface well with the audio IC.

The I^2C protocol is used for communication between devices, usually in a master/slave fashion. This protocol allows for transmitting and receiving as many bits as are needed in a sequential manner. The problem with this protocol is that it attached a device ID to the beginning of every transmission. These extra bits would make the correct timing very difficult to attain.

Hard coding was chosen as the most viable solution. The function below will create an enable signal then simulate a clock by using assembly nop (no operation) instructions to create the desired clock delay. This will output the data in the setFreq array one bit at a time and create a rising clock edge every time the data bit has been set. Figure 13 shows a scope capture of the microcontroller output using this code. The timing appears to fit the specifications, but at the time of this report the audio IC support circuitry was not available and thus could not be tested.

```
int setFreq[] = {1,0,1,1,1,1,1,1,1,1,1,0,1,0,0,1,0};
// set the frequency to 102.1 MHz and other config bits for audio IC

// write_to_chip - write enable, clock, and data bits to audio IC
void write_to_chip(){
	int i,j;
	PBOUT |= 0x01;
	for(j = 0; j <= 10; j++)	// set a clock delay
		asm("nop");
	for(i = 0; i < 16; i++){
		if(setFreq[i] == 1)
			PBOUT |= 0x04;	// set data bit
		else PBOUT &= 0xFB;
		for(j = 0; j <= 10; j++)	// set clock down delay
			asm("nop");
		PBOUT |= 0x02;		// turn clock on
		for(j = 0; j <= 10; j++)	// set up clock delay
			asm("nop");
		PBOUT &= 0xFD;	// turn clock off
	}
	PBOUT &= 0xFE;
}
```

Figure 12 C Code to Serially Program the BH1415F

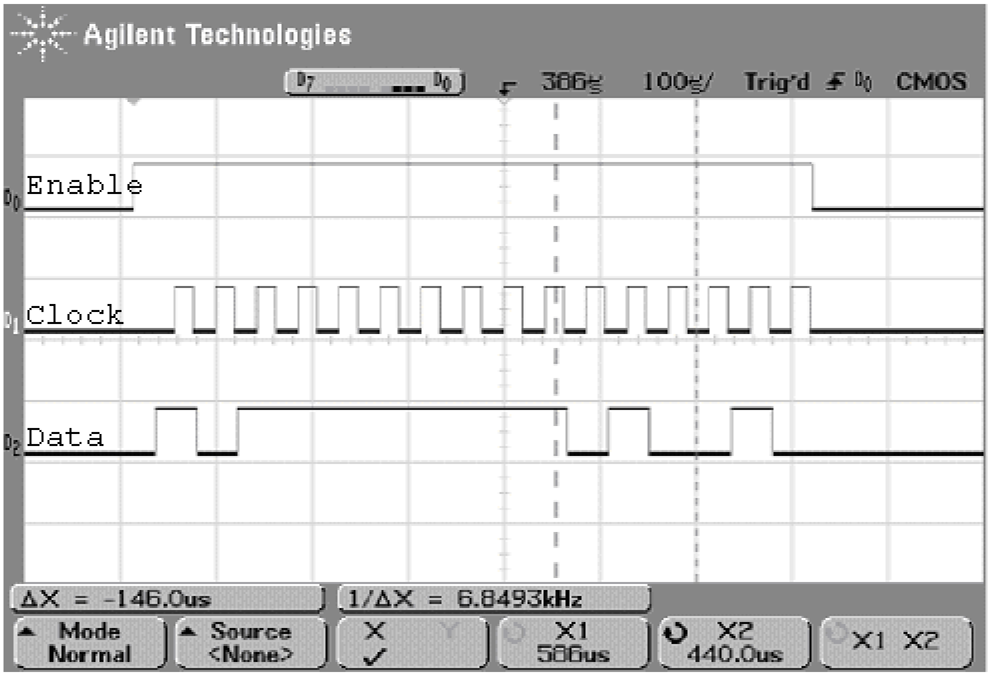


Figure 13 Microcontroller Output to Set BH1415F to 102.1MHz

Future Concerns: There are many issues that must be addressed dealing with the microcontroller. The current frequency selection should be stored when the power is turned off so the user does not have to reset it every time. The Z8Encore! documentation seems to suggest that flash memory can be directly accessed and if this is the case this would be the most feasible option. If that does not work then an external buffer may need to be investigated with a small battery or capacitor for backup.

The microcontroller must turn off the LCD display and backlight after a certain period of user inactivity to save power and prolong battery life. This feature will most likely be accomplished using timer interrupts that must be further investigated before implementation.

The low battery indicated must also be implemented in the code. The 'L' and 'B' characters are available in the code and when a low battery signal is detected these characters will be written to the first two positions on the LCD module. Due to the limited number of edge triggered interrupts, polling will most likely be used to detect the low batter signal from the power IC.

When the BH1415F support components have been received the entire system will have to be integrated. The code must be put together in one source file and debugged to ensure proper operation in all cases.

6 LCD Module Design and Test

The main purpose of the LCD module is to display the frequency of transmission. The frequency will range from 88.1 to 107.9 MHz. To display the value of the frequency, five characters are needed. In addition to the frequency of transmission, the LCD module displays a low-battery indicator when conditions are correct, which requires at most 2 extra characters. Therefore, to display both the transmission frequency and a low-battery indicator, the LCD module requires seven characters. The Everywhere Transmitter is a portable, handheld device, so the LCD module should be as small and lightweight as possible. This led to the decision to use an eight character by one line (8x1) LCD character module. To aid a user in viewing the display, an LCD module with an LED backlight is a necessity. After investigating manufacturers, the LUMEX LCM-S00801-DSF was selected.

Figure 14 LCD Module

		Symbol	Test Condition	Standard Value			Unit
				Min.	Typ.	Max.	
Supply Voltage for Logic		V_{DD}-V_{SS}	-	-	5.0	-	V
Supply Current for Logic		I_{DD}	V_{DD}=5V	-	2.0	3.0	mA
***LED Backlight**	**Voltage**	Vf	If=70mA	-	4.2	4.5	V
	Current	If	-	-	70	110	mA
	Power Consumption	PD	-	-	315	-	mW
	Luminous	L	If=70mA	70	-	-	cd/m^2
	Color	-	-	-	-	-	nm
*V_{DD}=4.7V to 5.3V, T_A=25°C							

Table 2 Electrical Characteristics of LUMEX LCM-S00801-DSF

Lumex Part Number	Overall Size with LED Backlight [mm]	Viewing Area (WxH) [mm]	Character Height (WxH) [mm]	Dot Size (WxH) [mm]	Font	Duty
LCM-S00801DSF	60x37.5x13	45x13.5	4.43x7.93	0.83x0.93	5x8	1/8

Table 3 Size Characteristics of LUMEX LCM-S00801-DSF

The standard driver for LCD modules is the HD44780. The HD44780 uses a 14 pin interface having eight data lines, three control lines, and three power lines. Pin 1, Vss, is connected to ground. Pin 2, Vdd, is connected to the positive power supply. The positive power supply may range from 4.5V to 6V, typical of 5V. Pin 3 is the contrast pin and is controlled by a potentiometer connected between pin 3 and ground. Pin 4 is the register select, RS, control line. When RS is low, data bytes transferred to the module are considered command instructions and data bytes read from the display indicate the status of the module. When high, data bytes transferred to the module are considered character instructions and can be transferred to and from the module. Pin 5 is the read/write, R/W, control line. A low R/W line indicates a write command or character instruction. A high R/W line indicates a read command or character instruction. Pin 6 is the enable, E, control line. The enable control initiates the actual data transfer of command or character data between the module and the data lines. When writing to the module, data is only transferred on the transition from high to low. When reading the module, data is available shortly after the low to high transition and is available until a falling edge. Pins 7 to 14 are the eight data bus lines, D0 to D7. A summary of the interface pin assignments can be seen in Table 1. An LCD module with LED backlight has two additional pins. Pin 15 is attached to +5V and pin 16 is attached to ground.

Pin number	Symbol	Function
1	Vss	Power supply (GND)
2	Vcc	Power supply (+5V)
3	Vee	Contrast adjust
4	RS	0 = Instruction input 1 = Data input
5	R/W	0 = Write to LCD module 1 = Read from LCD module
6	E	Enable signal
7	DB0	Data bus line 0 (LSB)
8	DB1	Data bus line 1
9	DB2	Data bus line 2
10	DB3	Data bus line 3
11	DB4	Data bus line 4
12	DB5	Data bus line 5
13	DB6	Data bus line 6
14	DB7	Data bus line 7 (MSB)
15	VB+	Backlight Power Supply (+5V)
16	VB-	Backlight Power Supply (GND)

Table 4 HD44780 Interface Pin Assignments

When first investigating with the LCD module, a test circuit was built using the schematic in Figure 15. The circuit used a 5V power supply for Vdd. The eight data bus lines were controlled using an eight-way dual in-line switch with 4.7kΩ pull-up resistors. The register select and enable control lines were connected to pushbuttons on the Digi-Designer with 4.7 kΩ pull-up resistors. The read/write control line was wired directly to ground for write commands only. For experimental purposes, a 5 kΩ potentiometer was connected between 5V and ground to control the contrast.

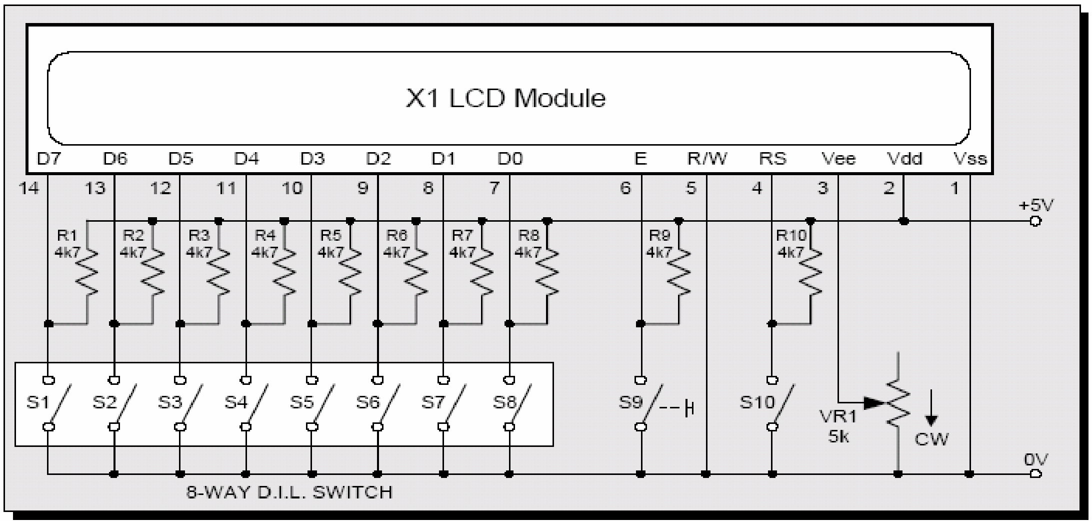


Figure 15 Experimental LCD Module Schematic

To begin using the LCD module, an initialization sequence must be done first. The display starts in an off state and must be switched on using the display ON/OFF & Cursor command from Figure 16. To use an instruction command, the register select control line must be low. From the display ON/OFF & Cursor command, D0-D3 were high and the rest of the data bus are low, the data bus line equals 0F in hexadecimal ($0F). When the enable control line pushbutton was toggled, the command turns on the display with the appearance of a blinking cursor.

While investigating the circuit, the potentiometer was adjusted and the contrast of the display changed. When the potentiometer was at the lowest resistance, the display had the greatest contrast.

Command	Binary D7	D6	D5	D4	D3	D2	D1	D0	Hex
Clear Display	0	0	0	0	0	0	0	1	01
Display & Cursor Home	0	0	0	0	0	0	1	x	02 or 03
Character Entry Mode	0	0	0	0	0	1	1 / D	S	04 to 07
Display On/Off & Cursor	0	0	0	0	1	D	U	B	08 to 0F
Display/Cursor Shift	0	0	0	1	D / C	R / L	x	x	10 to 1F
Function Set	0	0	1	8 / 4	2 / 1	10 / 7	x	x	20 to 3F
Set CGRAM Address	0	1	A	A	A	A	A	A	40 to 7F
Set Display Address	1	A	A	A	A	A	A	A	80 to FF

1 / D:	1=Increment*, 0=Decrement	R / L:	1=Right shift, 0=Left shift
S:	1=Display shift on, 0=Off*	8 / 4:	1=8-bit interface*, 0=4-bit interface
D:	1=Display on, 0=Off*	2 / 1:	1=2 line mode, 0=1 line mode*
U:	1=Cursor underline on, 0=Off*	10 / 7:	1=5x10 dot format, 0=5x7 dot format*
B:	1=Cursor blink on, 0=Off*		
D / C:	1=Display shift, 0=Cursor move	x = Don't care	* = Initialization settings

Figure 16 Command Instructions

After the display was turned on and initialized, characters were added to screen. In order to do this the register select control must be set high or to character mode. Next, the data bus must be set to the value for the appropriate character. The value of each character can be found in the standard LCD character table, Figure 17.

Figure 17 Standard LCD Character Table

To write the character “A”, the data bus would be set to $41. After the data bus was set, the enable button is toggled and an “A” appears on the screen. Figure 18 shows the result of the initial LCD module test.

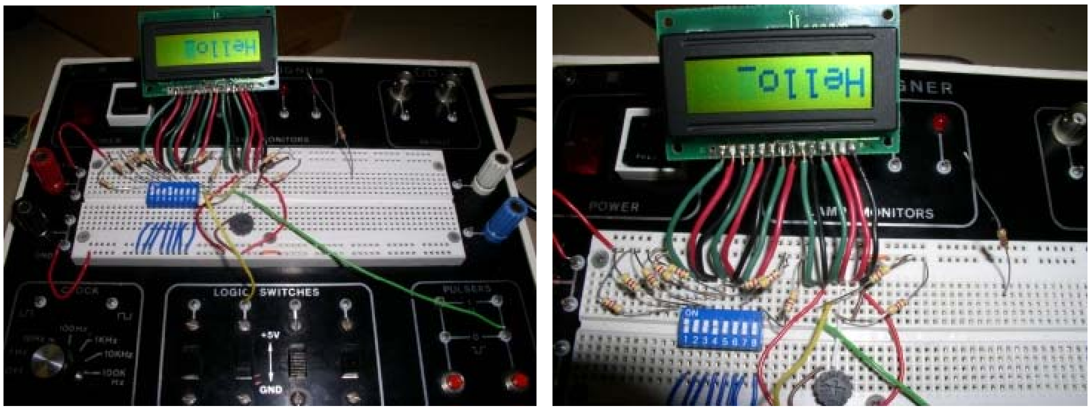


Figure 18 Pictures of LCD Module Display

After entering a character, the cursor moves to the next address making it easy to enter a string of characters. In order to write a character to a certain address location on the display, an address mode can be used. When testing the prototype circuit, addressing mode was experimented with. The register select control line was set to instruction mode. The data bus was then set to the address location where the character was to be written. After the data bus was set, the enable pushbutton was pressed and the cursor moved to the specified location. When writing to an address location outside of the first eight positions, the character cannot be seen unless the display is shifted. To shift the display, the display/cursor shift command can be used. To shift the display to the right, the command simplifies to a value of $1C on the data bus and the register select control line must be low. After experimenting with the prototype circuit, familiarity with the basics of an LCD module, initializing the display, writing characters, addressing mode, and shifting the display were achieved.

		Minimum	Maximum
High Level Input Voltage	V_{IH}	2.2 V	V_{CC}
Low Level Input Voltage	V_{IL}	-0.3 V	0.6 V
High Level Output Voltage	V_{OH}	2.4 V	-
Low Level Output Voltage	V_{OL}	-	0.4V

Table 5 LCD Module Logic Voltage Levels

The next step was to program a microcontroller to control the LCD module. Verification that the voltages output by the microcontroller would be high enough to meet the specifications of the LCD module was conducted. The microcontroller output high voltage level was measured between 3.2V and 3.3V. From Table 5, the LCD module's minimum for a high input voltage is 2.2V, well below the 3.3V from the microcontroller. The low level input voltage for the LCD module matches up with the microcontroller value of 0V. The output of the LCD module was ignored as it has no benefit to the design.

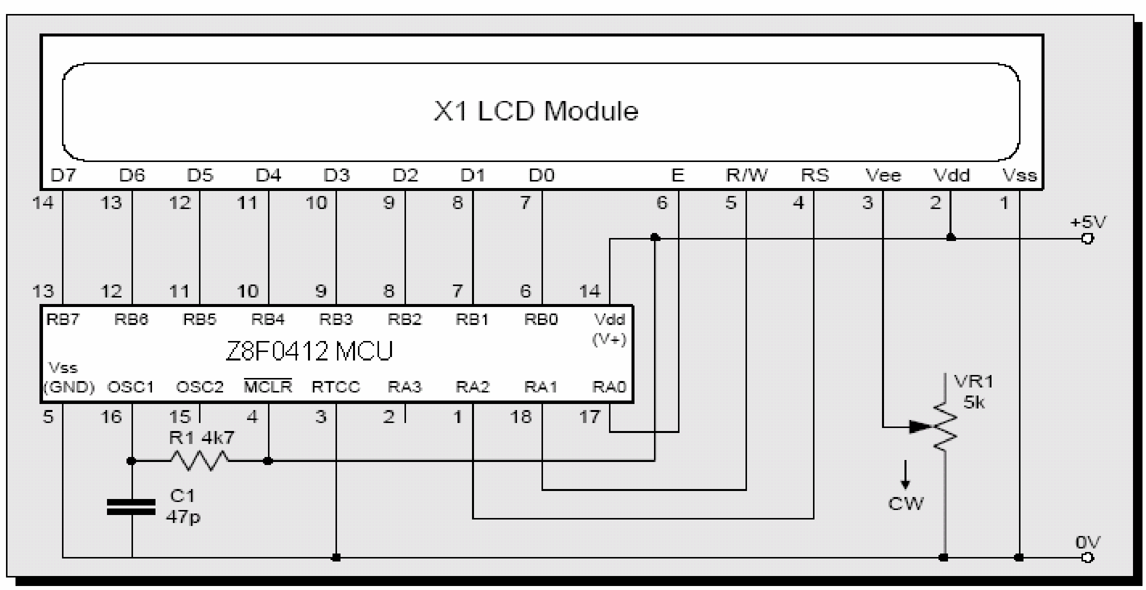


Figure 19 Circuit Diagram for Interfacing with Z8F0412 to an LCD Module

Once the voltage levels were test, the original prototyping circuit was re-wired to the microcontroller to match Figure 15. The pin assignments were wired according to Table 6. When programming the LCD module with the microcontroller the same procedure was followed. Using the C compiler, the microcontroller was programmed to initialize the LCD module by turning on the display and cursor. Functions were created to write characters to specific address locations. The function to write characters to specific address locations required the cursor to be shifted to the proper location. Once in the proper location, the character was written, Figure 28. The microcontroller was successfully interfaced with the LCD module: initializing display, writing character, addressing mode, and shifting the display.

Microcontroller		LCD Module	
A2	15	Enable	6
A3	16	Register Select	4
A4	17	D0	7
A5	18	D1	8
A6	2	D2	9
A7	3	D3	10
C0	1	D4	11
C1	19	D5	12
C2	12	D6	13
C3	11	D7	14
C4	10	Read/Write	5

Table 6 Interface Pin Assignments

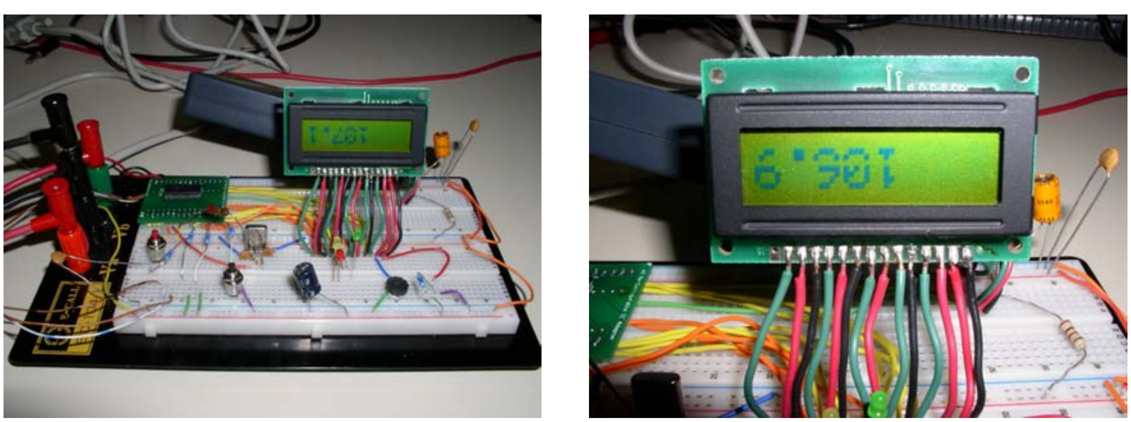


Figure 20 LCD Module Interfaced with Microcontroller

The LCD module and the LED backlight have very high power consumption. In order to increase the battery life of the transmitter, the decision to have both turn off when they are not in use was made. To accomplish this, the circuitry shown in Figure 21 will be implemented. The microcontroller will change the state of the MOSFET between ON and OFF.. When the MOSFET is in the ON state, the 5V from the supply will be across the resistor, which in turn will supply the LED backlight with the 5V. When the MOSFET is in the OFF state it will appear as an open circuit. No current will flow through the open circuit, therefore, there will be 0V applied to the LED backlight. The same schematic can also be used to turn the LCD module on and off. The LCD module may need to be reinitialized when it is turned back on.

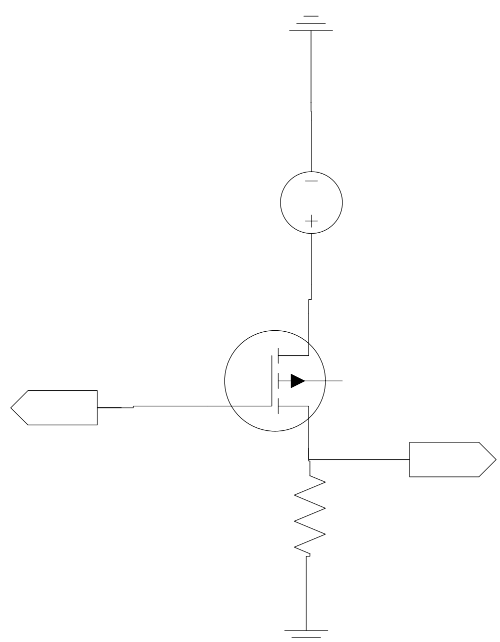


Figure 21 Schematic for LED Backlight Power Setup

To ensure that users know when their batteries are about to expire, a symbol will be displayed on the LCD module. The low-battery symbol will be a "LB" that can be seen at the far left of the module. The microcontroller will output to the module the character commands to display the letters when appropriate.

7 Audio Modulating/Transmitting Design and Test

The audio portion of the design required multiplexing left and right channel audio signals, creation of a pilot signal at 19kHz and frequency modulation. To accomplish this, the ROHM BH1415F integrated circuit was selected. Given audio input signals, serial input data and some external circuitry, it accomplishes all the specifications required. The input portion of the integrated circuit consists of a pre-emphasis circuit, a limiter circuit, a low pass filter and a multiplexer circuit. The transmitting section of the circuitry is made up of the serial data, another low pass filter, a voltage controlled oscillator and radio frequency output. A figure of the entire audio integrated circuit is shown below, Figure 22.

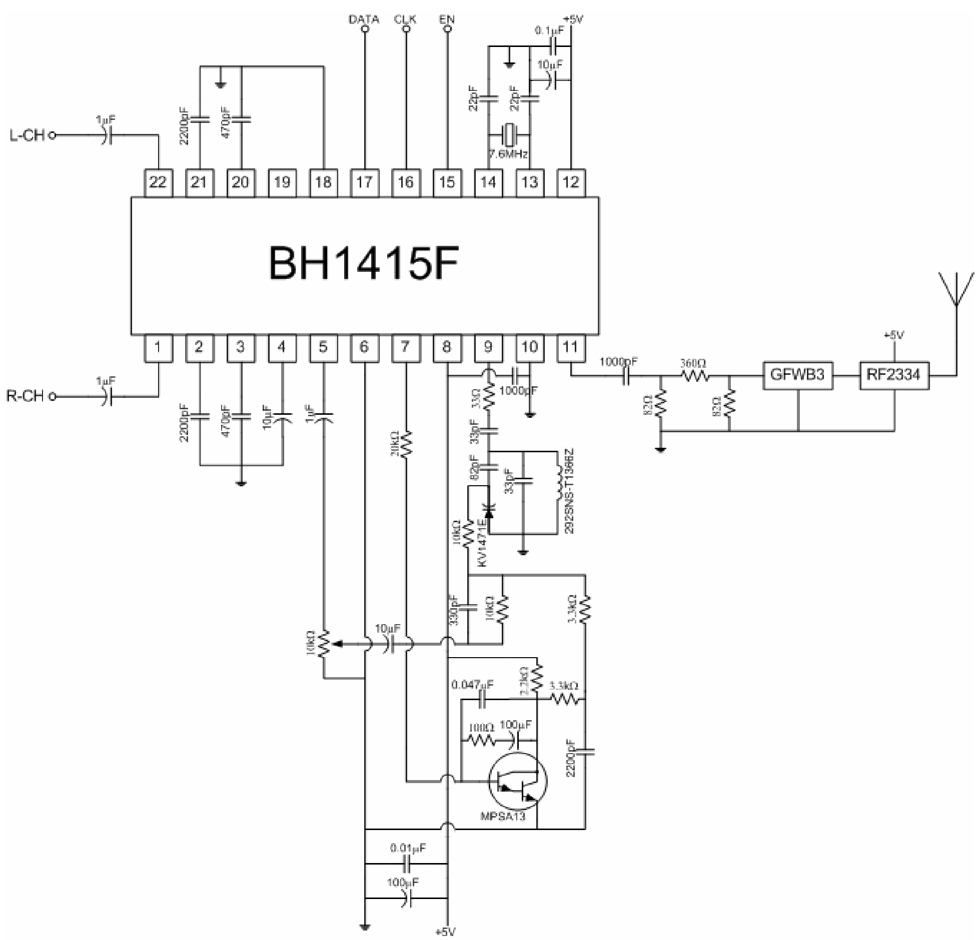


Figure 22 Audio Integrated Circuit

The pre-emphasis circuit (pins 2 and 21) is an audio amplifier that improves the circuit's frequency response over the audio range. The external component C_2 along with an internal resistance determines the time constant of the pre-emphasis circuit. The recommended value for C_2 is 2200pF, which is used in the design of the circuit.

The limiter circuit is completely internal and is located between the pre-emphasis circuit and the low pass filter. It consists of a diode amplifier and becomes active when the input level on pins 1 and 22 is –13dBV or more. This circuitry helps eliminate the potential for distortion whenever the input signals are too large.

The low pass filter (pins 3 and 20) consists of second-order low pass filters with Bessel characteristics that provide flat delay characteristics. The external capacitor, C_3, is used to set the cut-off frequency with a recommended value of 150pF so that it would pass frequencies between DC and 15kHz. A low pass filter measurement circuit was given in the datasheet to measure the cut-off frequency. The circuit was used to test the low pass filter's cut-off frequency using various capacitance values, Figure 23.

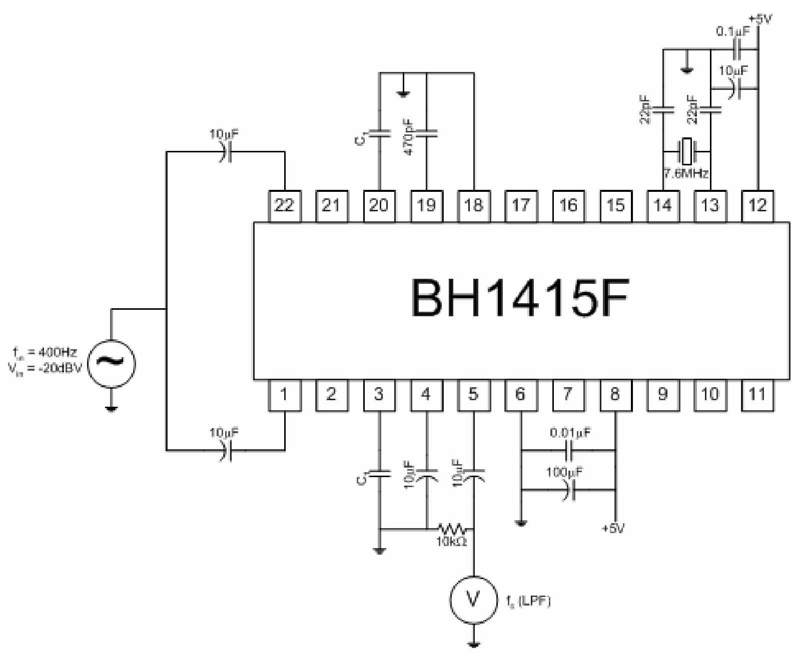


Figure 23 Low Pass Filter Test Circuit

Below, Table 7, is the capacitances used and the resulting cut-off frequencies measured from the test circuit.

C_1 (pF)	f_c(kHz)
150	19.1
300	17.7
470	16.1
620	14.8
2000	9.2

Table 7 Low Pass Filter Test Circuit Results

From the test circuit, it was determined that a 470pF capacitor would better suit the desired filter characteristics than the recommended 150pF capacitor.

The multiplexer circuit combines the left and right channel audio signals after the signals have passed through the pre-emphasis circuit, limiter circuit and low pass filter. The 7.6MHz crystal oscillator (pins 13 and 14) is used by internal circuitry to generate a 38kHz sub-carrier and a 19kHz pilot signal that are both multiplexed with the audio signals. The output is a composite signal (pin 5) that consists of a main, sub and pilot signal, Figure 24.

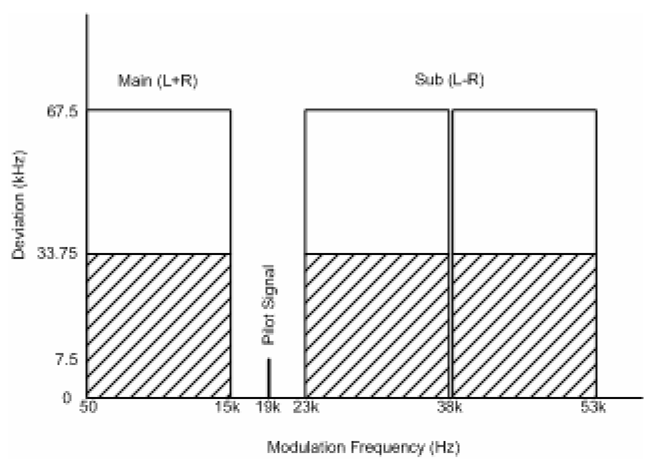


Figure 24 Main, Sub and Pilot Signal

A test circuit was also given to verify that the integrated circuit was functioning properly in its creation of the composite signal. The test circuit is shown below in Figure 25 followed by the expected result viewed on a spectrum analyzer, Figure 26.

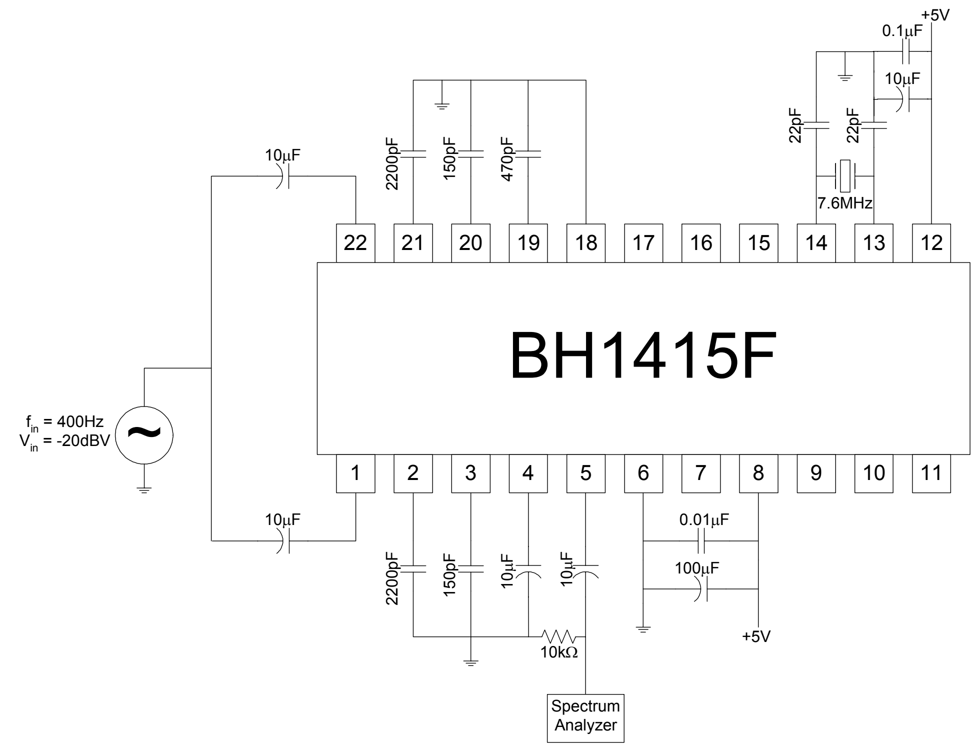


Figure 25 Composite Signal Test Circuit

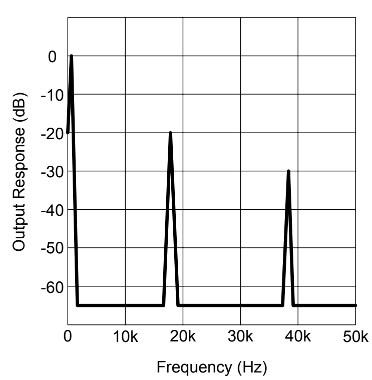


Figure 26 Expected Composite Signal Analysis Results

The result of the test circuit is shown below in Figure 27. The actual composite signal is displayed on the upper portion of the figure, with the presence of the 19kHz pilot signal riding on top of the 400Hz input. The lower portion displays the Fourier Transform analysis with the presence of all the expected frequency components (400Hz, 19kHz and 38kHz).

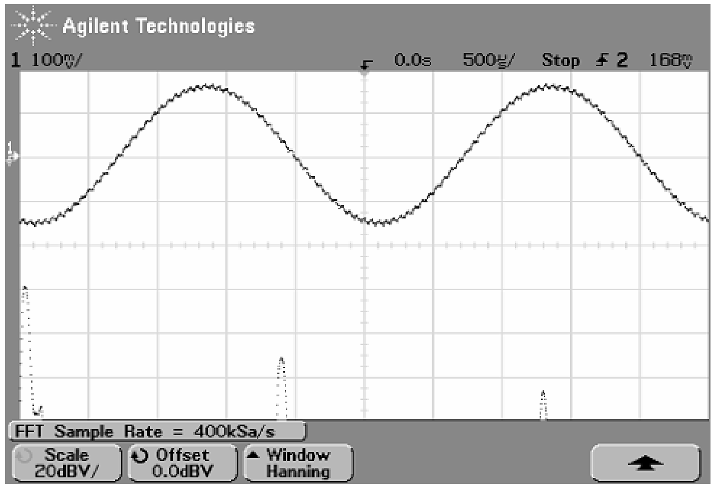


Figure 27 Composite Signal Analysis Results

The serial input data (pins 15-18) contains the following: chip enable, clock, data and muting. For the purposes of this project, the muting pin is unnecessary and will be fixed to ground. The chip enable, clock and data inputs will all come from the microcontroller. The timing diagram can be seen in the Microcontroller Design and Testing section of the report, Figure 11. The clock and data frequencies must not exceed 333.333kHz to meet timing requirements for the audio integrated circuit. Also, the data must transition before the clock's rising edge, due to the data being rising edge triggered. Below is the composition of the serial data, Figure 28.

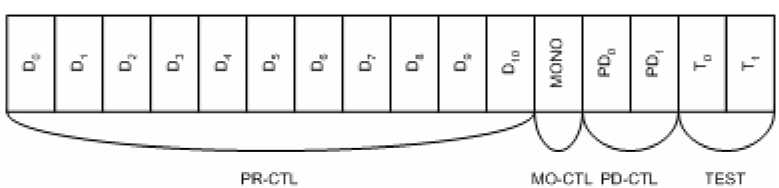


Figure 28 Composition of Serial Data

The program counter (PR-CTL) is the data that sets the transmission frequency and is a binary value with D_{10} being the most significant bit and D_0 being the least. Mono control (MO-CTL) determines whether the transmitted audio is in monaural (set to 0) or stereo operation (set to 1). The phase detector (PD-CTL) determines characteristics for the phase comparator in the circuit and will be always be set to normal operation, “00”. The test mode values will always be “1” for T_0 and “0” for T_1, which are used for internally for testing.

The second low pass filter and voltage controlled oscillator are an integral part of the phase-lock loop control that keeps the transmission frequency of the circuit stable. This stage along with the radio frequency output had various non-standard components that ROHM had recommended specific part numbers and their designated manufacturers. Some of the components were either no longer available or quantities were not readily in stock, so in some cases alternatives were investigated. The following table, Table 8, is a list of the recommended components from ROHM and the actual components that will be used in the design.

	Recommended		Actual	
Type	Manufacturer	Part Number	Manufacturer	Part Number
Darlington Transistor	ROHM	2SC2062S	Fairchild Semiconductor	MPSA13
Varactor Diode	TOKO	KV1471E	-	-
Band Pass Filter	Soshin	GFWB3	-	-
Variable Inductor	Sumida	FEM-10C-3F6	TOKO	292SNS-T1366Z
RF Amplifier	RF Micro Devices	RF2334	-	-

Table 8 Non-Standard Components
(a – in the right columns means the recommended was used)

Future testing will consist of measuring the control voltage of the voltage-controlled oscillator to insure that it is in the proper voltage and frequency range for operation. A frequency spectrum analysis of the radio frequency output will also be conducted. The final test will be an audio test consisting of listening to the modulated output on a radio.

8 Power Supply Design and test

The design of the power supply circuitry had to take into account many variables. First and foremost, it had to supply the voltage and current required to power the audio chip circuitry, the LCD module, and the microcontroller. Secondly, it had to allow for a relatively low input voltage because the device was to be battery powered. In addition, the power supply had to source voltage and current to the device for up to 8 hours of continuous use. Another requirement for the power supply was that it had to contain a low battery indicator.

Upon examining the specification sheets for the major components, it was determined that the microcontroller would need 125mA at 3.3V, the audio chip would require 90mA at 5V, and the LCD module would require 3mA at 5V to supply logic and 110mA at 5V for the backlight. Because of the two voltage levels needed, a dual output power supply would be needed. In addition, it had to produce 125mA at 3.3V (0.413W) and 203mA at 5V (1.02W). Therefore, it had to generate a total of 328mA (1.433W).

Due to size and portability constraints, 2 AA batteries were selected as the optimal power source. Because of this, the power supply had permit input voltages at or below 3V. Also, it had to detect if the battery power was below a specified threshold voltage and produce an output that could be relayed to the user to warn when the batteries were running out.

To determine if the 2AA batteries could act as a source, an equivalent test circuit was arranged. This was accomplished using 2AA batteries in series with a 9Ω resistor (3V/0.328A =9.2Ω). The voltage of the batteries was measured at various time intervals. Three trials were performed and the results are shown in Table 9.

	Voltage (V)		
Time (hrs)	Trial 1	Trial 2	Trial 3
0	3.03	3.01	2.54
3	2.54	2.67	2.07
6	2.10	2.18	1.57
7	1.95	2.09	1.20
7 ½	1.91	2.05	0.89
8	1.78	1.99	0.54
8 ½	1.59	1.76	0.32

Table 9 Preliminary Power Supply Testing

The results from this preliminary investigation were plotted to analyze the data, Figure 29.

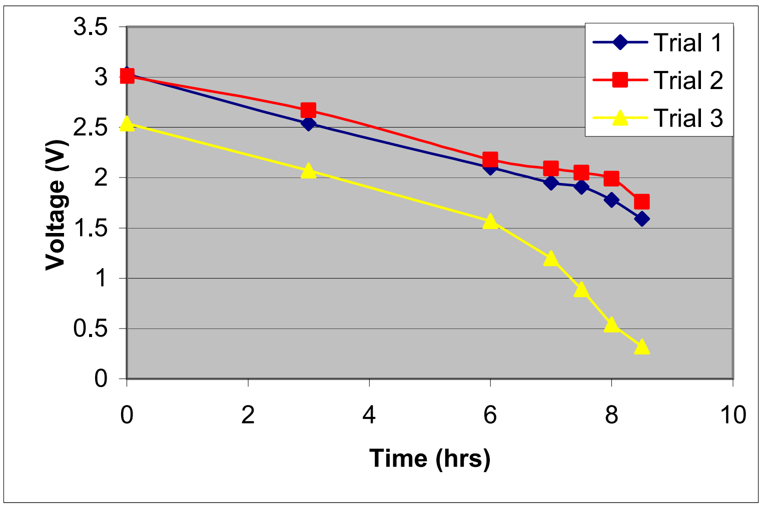


Figure 29 Voltage vs. Time

Figure 29 demonstrates that 2 AA batteries could act as a voltage source for the device. In Trials 1 and 2, the batteries were fully charged, and they supplied 328mA to the load for over eight hours while maintaining an input voltage above 1.5V. In Trial 3, used batteries selected as a power source and voltage above 1.5V was maintained for 6 hours. Therefore, 2 fully charged AA batteries will work as a power source for the device.

From these specifications, the MAX863 DC-DC Controller was selected. It is a dual output step-up converter that supplies up to 1A at both 3.3V and 5V. This power supply permits input voltages ranging from 1.5V and 3.3V, which allows for 2 AA batteries to act as a source. In addition, it has a low battery indicator that produces an output when the voltage of the source drops below 1.5V. It claims to have a 90% efficiency rating and also had an available development kit for testing and experimentation.

The MAX863 development kit was ordered to further examine the operation of the power supply. The development kit was a fully assembled and tested printed circuit board that demonstrates the capabilities of the MAX863. It had preset output voltages of 5V and 3.3V at currents of 700mA and 1.1A respectively. Various test points in the circuit were available so they could easily be measured. Also contained on the kit were jumpers that permit variation in the output voltages. While testing with the development kit, output voltages were measured at 5.0V and 3.3V as was specified. These outputs were maintained until the input voltage fell below the 1.5V threshold. Below 1.5V, the output voltages dropped down to the input voltage.

To begin the design of the power supply circuitry, a typical operating circuit for the MAX863 was created from the specification sheets for the power supply and the power supply development kit.

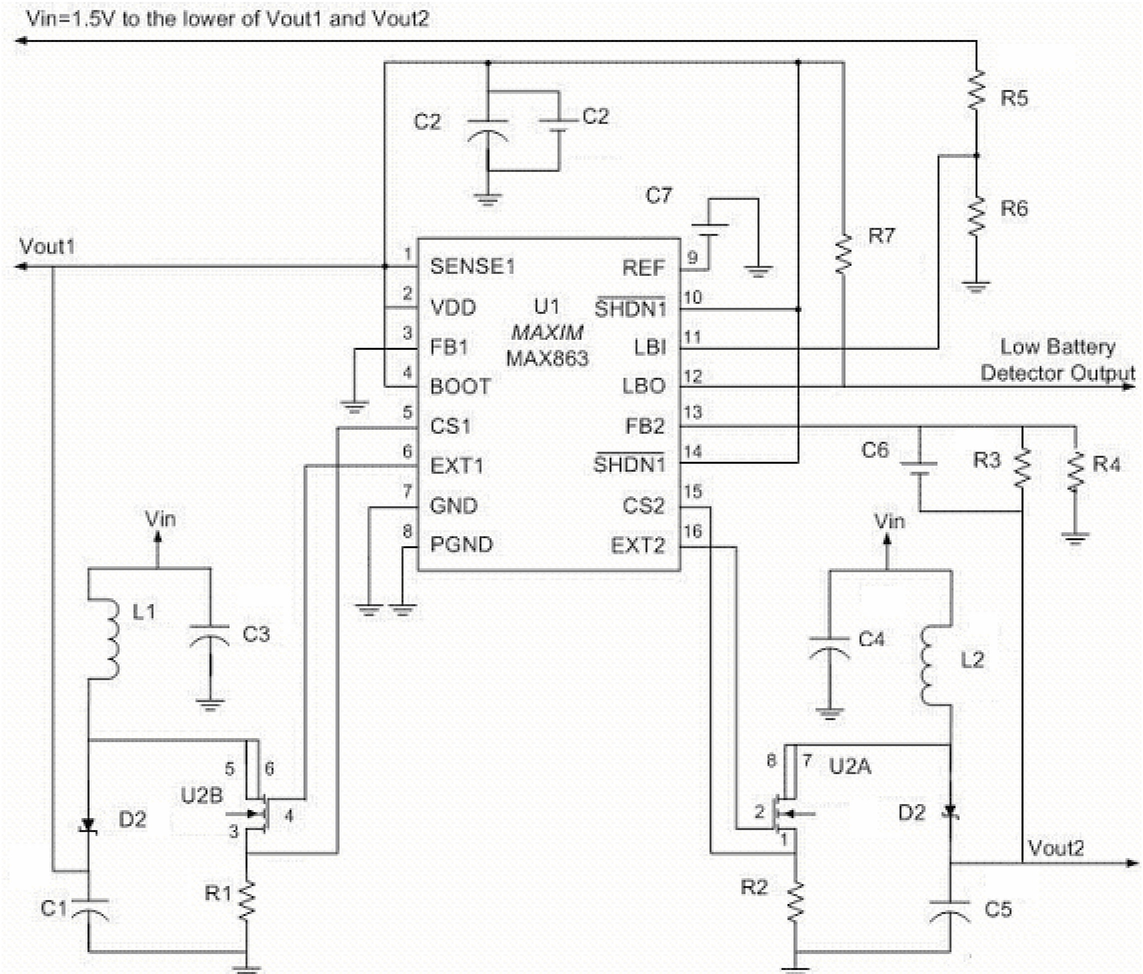


Figure 30 Basic Power Supply Circuit

To begin the design, certain parameters had to be specified.

$$V_{in1\max} = V_{in2\max} = 3.3V$$
$$V_{in1\min} = V_{in2\min} = 1.5V$$
$$V_{out1} = 3.3V$$
$$V_{out2} = 5.0V$$
$$I_{out1} = 203mA$$
$$I_{out2} = 125mA$$

First, the maximum input currents had to be determined:

$$I_{indc(\max)} = \frac{V_{out}(I_{out})}{0.8(V_{in\min})}$$

$$I_{in1dc(\max)} = \frac{5.0V(203mA)}{0.8(1.5V)} = 0.846A$$

$$I_{in2dc(\max)} = \frac{3.3V(0.125mA)}{0.8(1.5V)} = 0.344A$$

$$I_{intotal} = 0.846A + 0.344A = 1.193A$$

In order to calculate the peak switching current of the inductor the minimum allowable ratio of AC ripple current to peak current ($\varepsilon_{\min}$) had to be found.

$$\varepsilon_{\min} = \frac{t_{off\min}}{t_{on\min}}\left(\frac{V_{out} - V_{in\min}}{V_{in\min}}\right)$$

$$\varepsilon_{\min 1} = \frac{2\mu s}{17.5\mu s}\left(\frac{5V - 1.5V}{1.5V}\right) = 0.266$$

$$\varepsilon_{\min 2} = \frac{2\mu s}{17.5\mu s}\left(\frac{3.3V - 1.5V}{1.5V}\right) = 0.137$$

The value for ε could then be determined.

$$\varepsilon = \left(\frac{\varepsilon_{\min} + 1}{2}\right)$$

$$\varepsilon_1 = \left(\frac{0.266 + 1}{2}\right) = 0.633$$

$$\varepsilon_2 = \left(\frac{0.137 + 1}{2}\right) = 0.569$$

Now, the peak switching current in the inductor could be calculated.

$$I_{peak} = I_{indc}\left(\frac{2}{2 - \varepsilon}\right)$$

$$I_{peak1} = 0.846\left(\frac{2}{2 - 0.633}\right) = 1.234A$$

$$I_{peak2} = 0.344A\left(\frac{2}{2-0.569}\right) = 0.480A$$

The suggested value of the inductors (L_1, L_2) was:

$$L = \frac{\left(V_{out} - V_{in\min}\right)t_{off\min}}{I_{peak}(\varepsilon)}$$

$$L_1 = \frac{\left(5V - 1.5V\right)2\mu s}{1.234A(0.633)} = 8.93\mu H$$

$$L_2 = \frac{\left(3.3V - 1.5V\right)2\mu s}{0.480A(0.569)} = 13.2\mu H$$

The nearest standard inductor value was selected, therefore, $L_1 = L_2 = 10\mu H$. Next, the values for the sense resistors (R_1,R_2) were selected.

$$R_{sense} \le \frac{85mV}{I_{peak}}$$

$$R_{sense1} \le \frac{85mV}{1.234A} = 68.7m\Omega$$

$$R_{sense2} \le \frac{85mV}{0.480A} = 177m\Omega$$

In selecting the sense resistors, the values were rounded down to the nearest standard value. For the sake of simplification, R_{sense1} was made equal to R_{sense2} with both set at 50mΩ. Lastly, the power ratings for the sense resistors were determined.

$$P_{sense} = \frac{(115mV)^2}{R_{sense}}$$

$$P_{sense1} = P_{sense2} = \frac{(115mV)^2}{0.050\Omega} = 0.265W$$

The remainder of the components were listed in the specification sheets and assumed to be correct values for the purposes of the project.

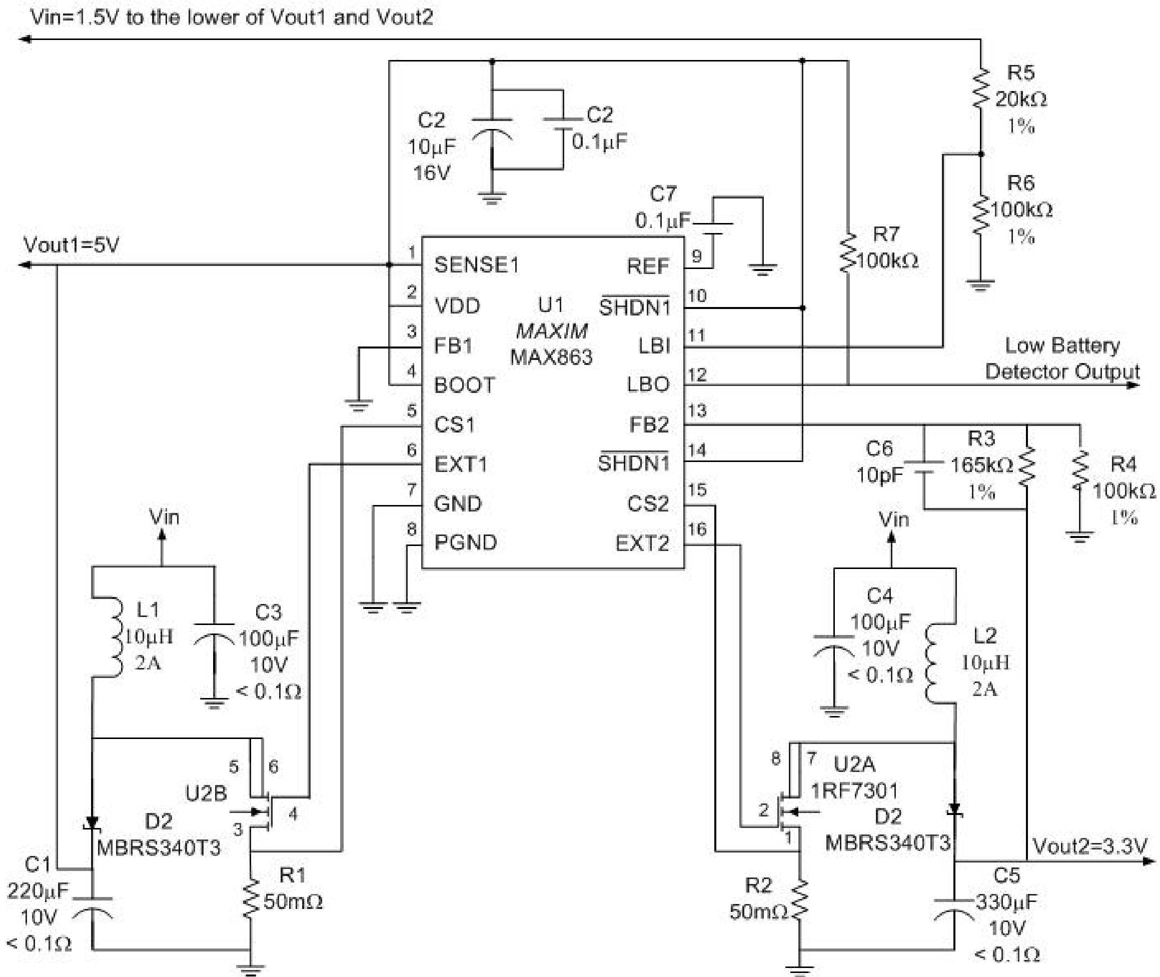


Figure 31 Designed Power Supply Circuit

It was decided that the addition of 12V and 120V power adaptors to the design of the power supply would be of benefit to the user. To design this, cords that convert the 12V and 120V to 3V were investigated. In addition to the 3V, they also had to source up to 1.25A. Many companies make universal adjustable power adaptors that meet the specifications from above. Most of these adaptors have adjustable output voltages anywhere from 1.5Vdc to 12Vdc, and many of them have 3Vdc as an option.

The last component to be selected for the 12V and 120V power adaptors was a DC power jack. The power jack had to be capable of internally switching between the batteries as the power source to either of the adaptors. Figure 32 shows the schematic for a DC power jack.

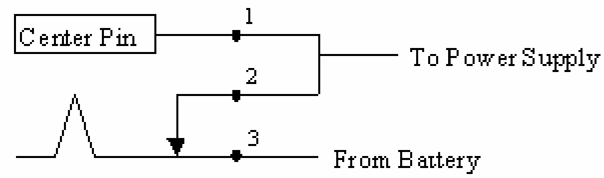


Figure 32 DC Power Jack Schematic

When the power adaptor is unplugged, pins 2 and 3 are connected internally and the battery is connected directly to the power supply. When the power adaptor is plugged in, the wire on pin 3 is pushed down, creating an open circuit between pins 2 and 3. The power adaptor slides over the center pin provides voltage to pin 1 and to the power supply.

9 Printed Circuit Board and Protective Shell

The printed circuit board will be designed using ExpressPCB's layout software. The printed circuit board will be 2-sided and be 3.8 inches by 2.5 inches. This will be well within the size specifications and also provide a nice, organized package for the circuitry.

Plans to design a protective shell will be made once the printed circuit board is laid out. Investigation into having Milwaukee School of Engineering's Rapid Prototyping Center build a custom shell will be done.

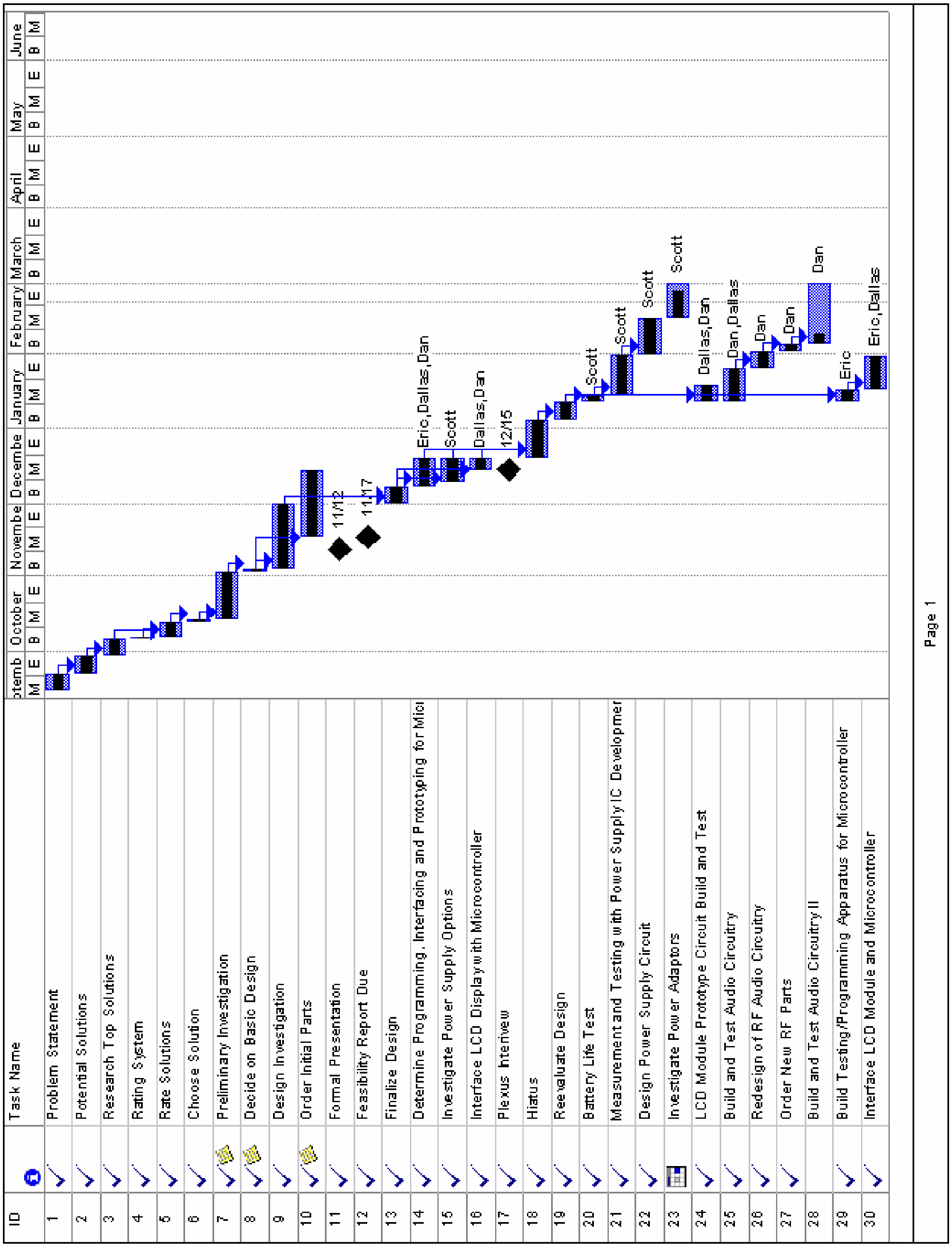
10 Legal Implications

The Federal Communications Commission, FCC, limits the broadcast of signals by unlicensed operators. The Code of Federal Regulations Title 47 Part 15 (CFR47) governs the use of unlicensed transmission devices. Sections 15.5 and 15.239 can be seen in the appendices. Section 15.5 states any unlicensed radiating devices must not interfere with licensed radiators such as radio stations and must accept interference from any other radiating sources. Section 15.239 states that the signal power of an unlicensed radiator "shall not exceed 250 microvolts/meter at 3 meters." This limits the effective range of unlicensed operation to less than 30 feet in many cases. The design of our solution is greatly affected by these radiation guidelines. Our design must not have a radiation power that will transmit out of the prescribed range. Problems occur when dealing with transmitters and receivers in line of sight or blocked by barriers, such as walls. Line of sight transmission needs a lot less power than a completely or partially blocked path. The transmitter is forced to have a line of sight transmission range of approximately 30 feet, which will greatly limit the range when the radiation path is blocked. The range for a blocked path will be limited to something less than half of the maximum range. The regulations instituted by the FCC have reduced the applications and added a small complication to the design of an FM transmitter.

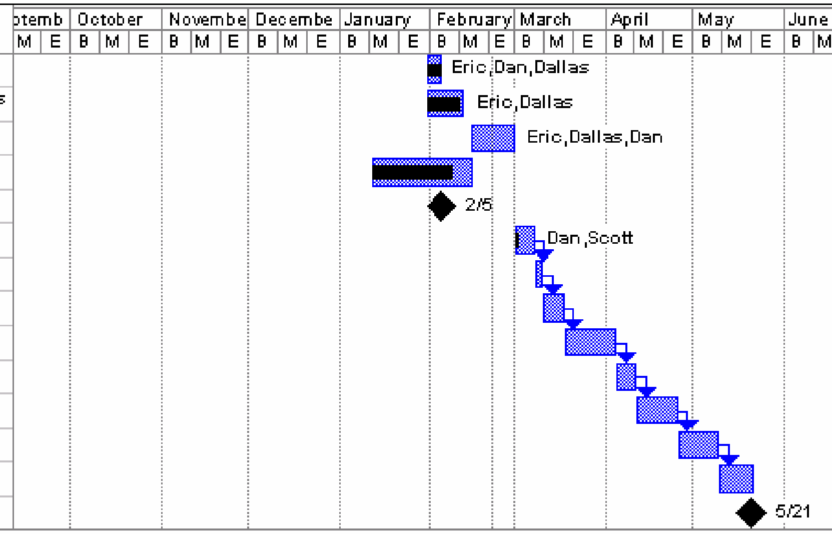
11 Conclusion

The design aspects of the main blocks of the Everywhere Transmitter are complete. Building and testing of each component is currently underway along with the integration of the various main blocks. Two design issues yet to be addressed are the printed circuit board and protective shell. The design of the printed circuit board is expected to be finished within the next two weeks. Once completed, the physical space required for the Everywhere Transmitter should be determined leading to the design of the protective shell.

12 Gantt Chart



ID	Task Name
31	Program Timing for Serial Output for Audio IC
32	Program Microcontroller Pushbuttons and Integral Functions
33	Interface Audio IC and Microcontroller
34	Order Parts
35	Formal Presentation
36	Design PCB
37	Order PCB
38	Initial Circuit Build
39	Test and Troubleshoot
40	Final Build
41	Final Test and Troubleshoot
42	Evaluate
43	SEED Show Preparation
44	SEED Show



13 Acknowledgments

Robles, Dr. Ted. 10 January 2004. Meeting with team member Scott Forbes concerning power sources.

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15 Appendices

16 Appendix A – CD-Rom Index

Microcontroller

Z8F0412 Source Code
/code *(folder)*

Zilog Z8 Encore! F08 Evaluation Kit User Manual UM0150
Z8 Encore! F08 Evaluation Kit User Manual UM0150.pdf

Zilog Z8F08_Product Specification_PS0197
Z8F08_Product Specification_PS0197.pdf

LCD Module

Hitachi HD44780U Dot Matrix Liquid Crystal Display Controller/Driver
hd44780u.pdf

Ilett, Julyan. How to Use Intelligent L.C.D.s Part One
LCD setup 1.pdf

Ilett, Julyan. How to Use Intelligent L.C.D.s Part Two
LCD setup 2.pdf

Audio Modulating/Transmitting

Fairchild Semiconductor NPN Darlington Transistor
MPSA13.pdf

RF Micro Devices General Purpose Amplifier
2334.pdf

ROHM BH1415F Audio Link IC
BH1415F.pdf

ROHM LSI Technical Note: Wireless Audio Link IC
bh1415.pdf

Soshin Electric Co. Ltd Band Pass Printed Filter
gfwb3.pdf

Toko Variable Capacitance Diode for Communication Equipment
kv1471.pdf

Toko Variable Coil Inductor
7kmm.pdf

Power Supply

CUI Inc. 2.0mm Surface Mount Power Jack
PJ-002AH-SMT.pdf

Maxim MAX863 Dual, High-Efficiency, PFM, Step-Up DC-DC Controller
MAX863.pdf

Maxim MAX863 Evaluation Kit
MAX863EVKIT.pdf

Memory Protection Devices, Inc. 2 Cell AA Holder With Cover and Switch
SBH321AS.pdf

Tamura Corporation AC Adaptor
830AS03175.pdf

17 Appendix B – FCC Regulations

[Code of Federal Regulations]
[Title 47, Volume 1]
[Revised as of October 1, 2002]
From the U.S. Government Printing Office via GPO Access
[CITE: 47CFR15.239]

[Page 737-738]

TITLE 47--TELECOMMUNICATION

CHAPTER I--FEDERAL COMMUNICATIONS COMMISSION

PART 15--RADIO FREQUENCY DEVICES--Table of Contents

Subpart C--Intentional Radiators

Sec. 15.239 Operation in the band 88-108 MHz.

(a) Emissions from the intentional radiator shall be confined within a band 200 kHz wide centered on the operating frequency. The 200 kHz band shall lie wholly within the frequency range of 88-108 MHz.
(b) The field strength of any emissions within the permitted 200 kHz band shall not exceed 250 microvolts/meter at 3 meters. The emission limit in this paragraph is based on measurement instrumentation employing an average detector. The provisions in Sec. 15.35 for limiting peak emissions apply.
(c) The field strength of any emissions radiated on any frequency outside of the specified 200 kHz band shall not exceed the general radiated emission limits in Sec. 15.209.
(d) A custom built telemetry intentional radiator operating in the frequency band 88-108 MHz and used for experimentation by an educational institute need not be certified provided

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the device complies with the standards in this part and the educational institution notifies the Engineer in Charge of the local FCC office, in writing, in advance of operation, providing the following information:
(1) The dates and places where the device will be operated;
(2) The purpose for which the device will be used;
(3) A description of the device, including the operating frequency, RF power output, and antenna; and,
(4) A statement that the device complies with the technical provisions of this part.

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TITLE 47--TELECOMMUNICATION

CHAPTER I--FEDERAL COMMUNICATIONS COMMISSION

PART 15--RADIO FREQUENCY DEVICES--Table of Contents

Subpart A--General

Sec. 15.5 General conditions of operation.

(a) Persons operating intentional or unintentional radiators shall not be deemed to have any vested or recognizable right to continued use of any

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given frequency by virtue of prior registration or certification of equipment, or, for power line carrier systems, on the basis of prior notification of use pursuant to Sec. 90.63(g) of this chapter.

(b) Operation of an intentional, unintentional, or incidental radiator is subject to the conditions that no harmful interference is caused and that interference must be accepted that may be caused by the operation of an authorized radio station, by another intentional or unintentional radiator, by industrial, scientific and medical (ISM) equipment, or by an incidental radiator.

(c) The operator of a radio frequency device shall be required to cease operating the device upon notification by a Commission representative that the device is causing harmful interference. Operation shall not resume until the condition causing the harmful interference has been corrected.

(d) Intentional radiators that produce Class B emissions (damped wave) are prohibited.