2007/04/15 ELEN 4314 Communications Circuits - Design Project

A Three Transistor Discrete FM Transmitter

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Abstract

This paper explains the design and construction of a simple FM transmitter. The transmitter is made from identical discrete bipolar junction transistors. Continuous tuning is achieved with a variable capacitor. The designed tuning range was 88MHz to 108MHz. The transmitter can transmit music on a 91.7MHz carrier over a distance of 50feet.

I. Introduction

Frequency modulation (FM) is a technique for wireless transmission of information where the frequency of a high frequency carrier is changed in proportion to message signal which contains the information. FM was invented and developed by Edwin Armstrong in the 1920's and 30's. Frequency modulation was demonstrated to the Federal Communications Commission (FCC) for the first time in 1940, and the first commercial FM radio station began broadcasting in 1945. FM is not a new concept. However, the concept of FM is essential to a wide gamut of radio frequency wireless devices and is therefore worth studying in 2007. [1]

The objective of this paper is to explain the design and construction of a simple FM transmitter. The salient specifications for the transmitter are as follows: one 9V supply, DC power consumption less than 80mW, transmit frequency at a vacant spot in FM band (88MHz ..108MHz), transmitted power not to exceed 10uW, and the only active device type allowed is the 2N2222A NPN BJT. In addition, a pre-emphasis filter is required with a 3dB corner frequency equal to 1 / 75us. A variable capacitor with value 4pF .. 30pF is used for tuning. The design has been simulated and constructed. The built transmitter can transmit music at a distance of 50 feet. This paper will explain the design decisions that were made in the process of design and construction.

II. System Design

A phase-locked loop (PLL) based approach to the FM transmitter was first considered. This approach has the advantage that the channel frequency spacing of 200kHz can be selected with accurate control. However, the complexity of the PLL based FM transmitter is high. It requires two oscillators, one of which is usually a reference crystal oscillator, which is not allowed in the requirements of this project. In addition, the common circuits used for the phase-frequency detector and divider use digital gates that would be cumbersome to build out of NPN transistors. For these reasons, I sought a much simpler system.

The simple system chosen is shown in Figure 1. The RF oscillator's bias point is directly modified by the audio input signal. First, the audio signal passes through the high pass pre-emphasis filter. Then a programmable gain amplifier amplifies it. The programmable gain stage ensures that the audio signal amplitude can be adjusted so that it modulates the oscillator; it also acts as a buffer between the audio source and the oscillator. The audio source can be a variety of devices each with its own output amplitude specification. An MP3 music player was used as the audio source in this design. The input signal amplitude was specified as 100mVpk; however, a signal source with a 100mVpk sinusoidal signal was not readily available. The MP3 player's output signal has a peak value of approximately 20mV as shown in Figure 2. Note that all of the frequencies present in the music appear as a mixture of different signals on the oscilloscope. The gain stage was designed to be programmable because it can compensate for audio sources with different output amplitudes. After the linear amplification, the audio signal changes the operating point of the oscillator and therefore modulates the frequency that the oscillator generates. An amplification stage after the oscillator was deliberately omitted for simplicity and to keep the amount of RF radiated power below the FCC limit of 10uW. If the goal was to build a transmitter that could transmit long distances, a power amplifier stage would have been added after the oscillator.

III. Circuit Design

The simple FM transmitter schematic is shown in Figure 3. The audio input is AC-coupled to the base of NPN Q2 through capacitor C4. The 3nF capacitor C4, NPN Q2, and its 100Ω emitter resistor R5 comprise the pre-emphasis filter. The input impedance looking into the base of Q2 is approximately β*Re which is 200*100Ω = 20kΩ. The product of the series capacitance, C4, and the resistance to ground is set equal to the desired audio pre-emphasis of 75μs (1 / 13.3kHz) giving a capacitance value of 3.75nF. In Figure 4, the simulation shows that a value of 3nF gives a f3dB of 11.2kHz which is closer to the desired 13.3kHz than the 7.5kHz simulated using the 3.75nF capacitor. The difference can be accounted for in the input capacitance of the NPN.

The NPN transistors Q2 and Q3 form a current mirror. The resistor RGAIN in the collector of Q3 sets the current through Q3. Since Q2 has the same base-emitter voltage as Q3, the same quiescent current will flow through Q2. As the value of resistance RGAIN increases from 0Ω to 5kΩ the voltage across the base-emitter junction of Q3 increases which in turn increases the collector current in Q3. Since the transconductance of a BJT equals I_C / V_T where V_T is the thermal voltage and the gain from base of Q2 to its collector is proportional to its transconductance, the gain of the stage is set by the resistor RGAIN. In Figure 5, the gain at 10kHz varies from –44dB to 28dB, a range of 72dB. This is sufficient to cover a wide range of input signal voltage magnitudes.

The audio signal, after being filtered, and amplified, is directly coupled to the base of transistor Q1, which is configured as a Colpitt's oscillator. Capacitor C3 shorts the base of Q1 to AC ground. The inductor is hand-wound with an air core. Using the empirical formula, $L = (an)^2 / (9a + 10b)$ [2] where a is the radius in inches, b the length in inches, and n the number of turns, the inductor's inductance value was calculated, 76nH. The variable capacitor CTUNE is used to tune the frequency as shown in Figure 8 from 81.6MHz to 120MHz; this covers the specifications. The AC response in Figure 8 uses a 1V AC source at the audio input to excite the circuit; the units on the y-axis are not to be interpreted literally; their relative value is what is important. From the plots, it is apparent that the circuit is excited at frequencies from 81.6MHz to 120MHz as the CTUNE is varied. A series parasitic resistance RPAR of 0.2Ω was added to the schematic for more realistic simulation; the value was measured after the circuit was built. A parasitic capacitance of 500fF was added between the oscillator output and ground to account for board trace inductances. Transient simulation shows the oscillator starts and oscillates at 94MHz with a magnitude of 16.5Vpp; this does not exceed the specified breakdown voltage from collector to emitter of 75V.

IV. Measured Results

The board was built on a perforated board with pre-made traces as shown in Figure 8. The board layout could be improved by placing the variable capacitor anywhere perpendicular to the magnetic field passing through the inductor. When a metallic screwdriver is brought in proximity to the inductor, it changes the oscillation frequency because the inductance value is changed. Furthermore, the variable capacitor is very sensitive and difficult to tune. Touching the tuning capacitor with a screwdriver changes the oscillation frequency as well. The 10pF fixed capacitor CFIX was added in parallel to the tunable capacitor to desensitize the oscillation frequency from the absolute value of the variable capacitor. An improvement would be to use a controllable voltage to set the capacitance of a reverse-biased PN junction which in turn sets the oscillator frequency.

The measured DC power consumption of the device is 46.5mW. Music was successfully transmitted and received at 90.5MHz and 91.7MHz. At these frequencies, the transmitter did not have to compete with more powerful received signals from radio stations. The music fidelity was good; its volume was audible but faint. The circuit is sensitive to its environment and is not designed to operate as the battery voltage drops or at extreme temperatures. A summary of the results is presented in Table 1.

V. Conclusions

A simple three transistor FM transmitter was designed and built. The circuit consumes 46.5mW and can transmit music at 90.5MHz and 91.7MHz.

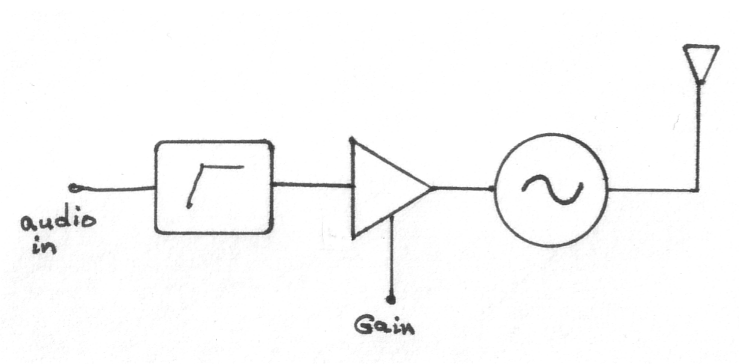

Figure 1. Simple FM transmitter system

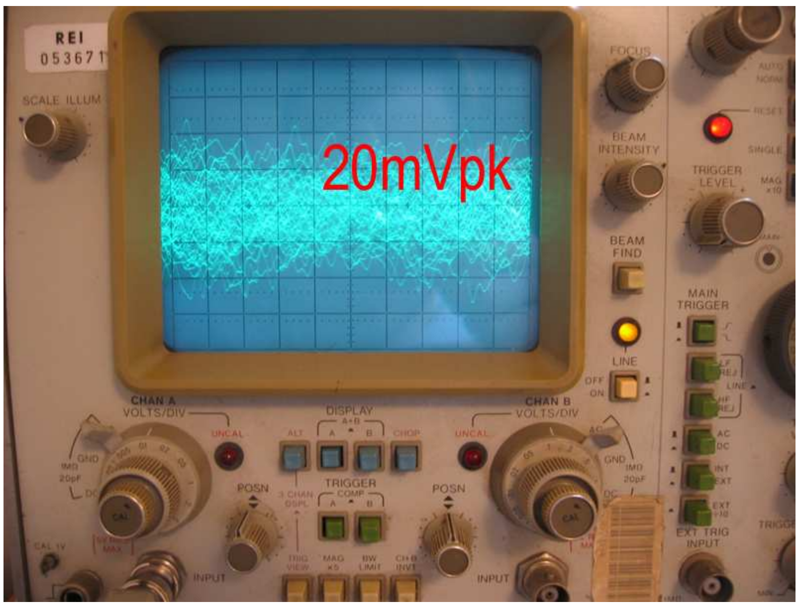

Figure 2. Audio signal amplitude ~ 20mVpk (iPod output)

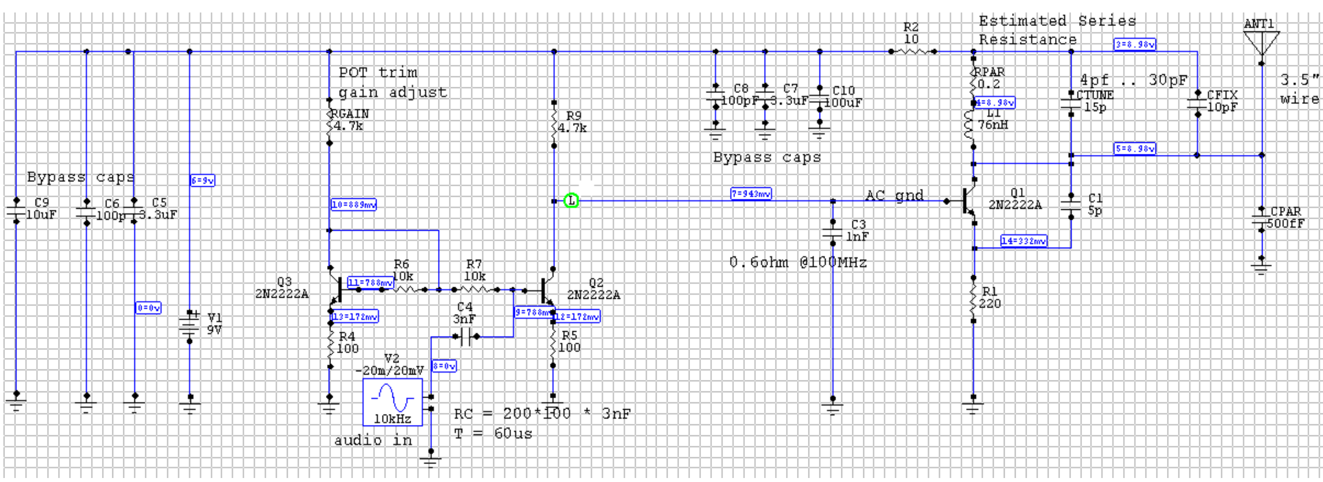

Figure 3. FM transmitter schematic with annotated DC voltages

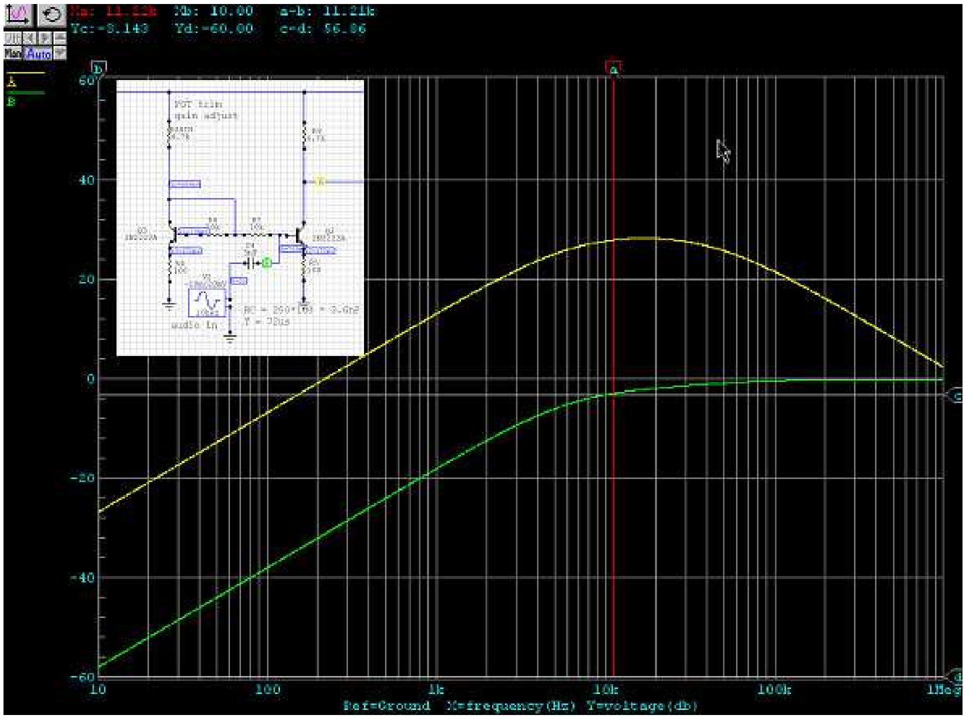

Figure 4. Pre-emphasis filter frequency response

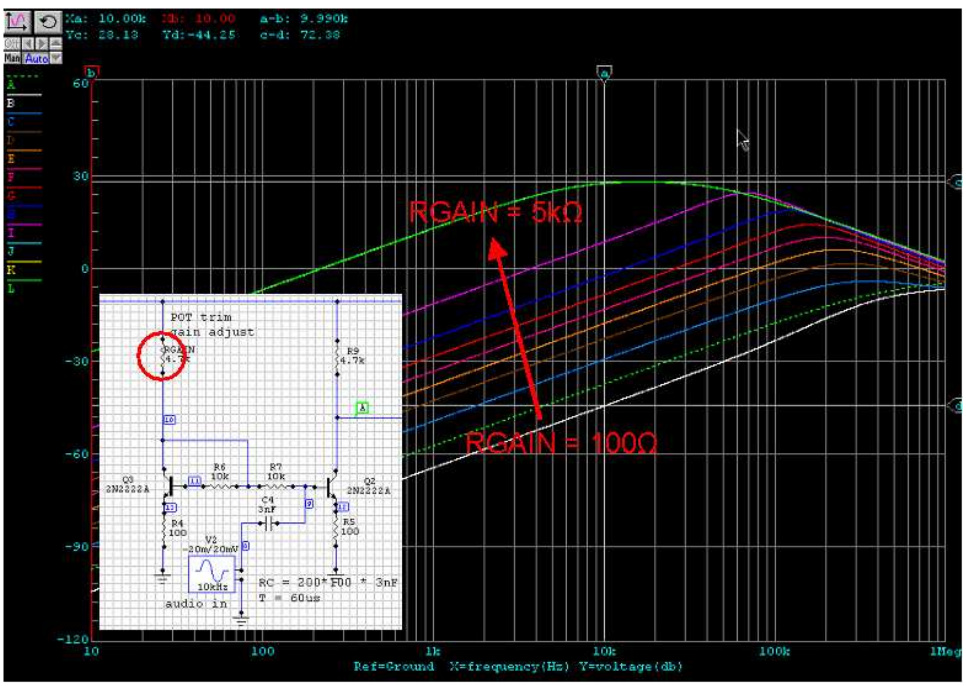

Figure 5. Programmable audio gain for RGAIN = 100Ω .. 5kΩ

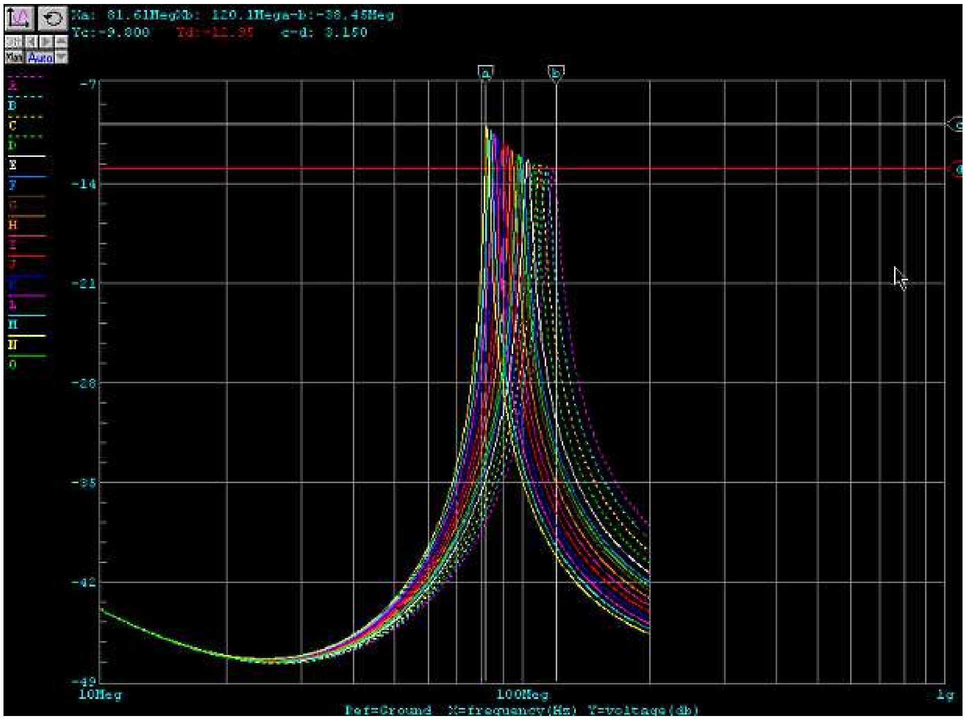

Figure 6. Frequency response at antenna as CTUNE varies from 4pF to 30pF

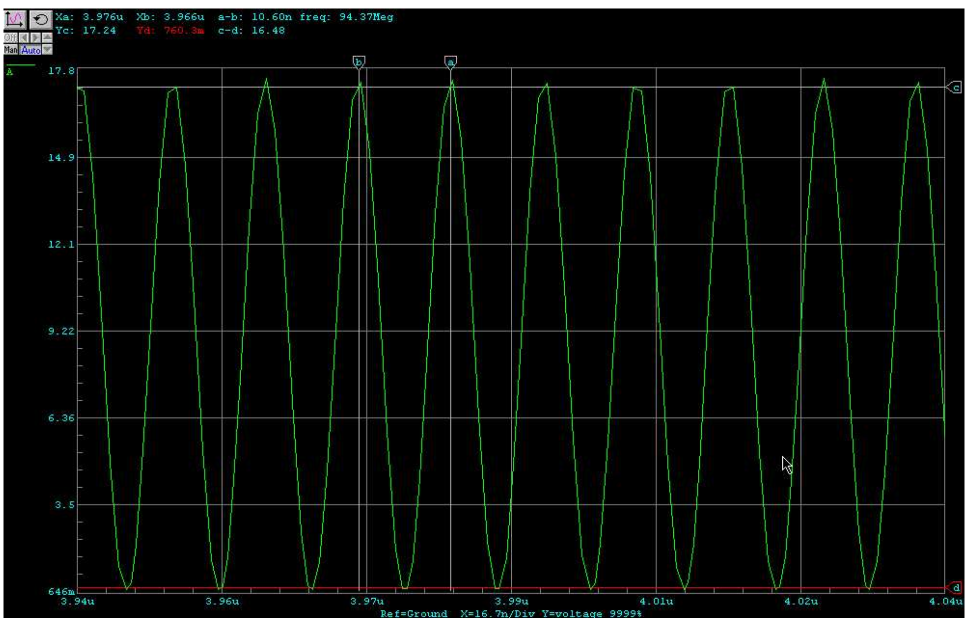

Figure 7. Simulated time-domain oscillator output, f = 94MHz

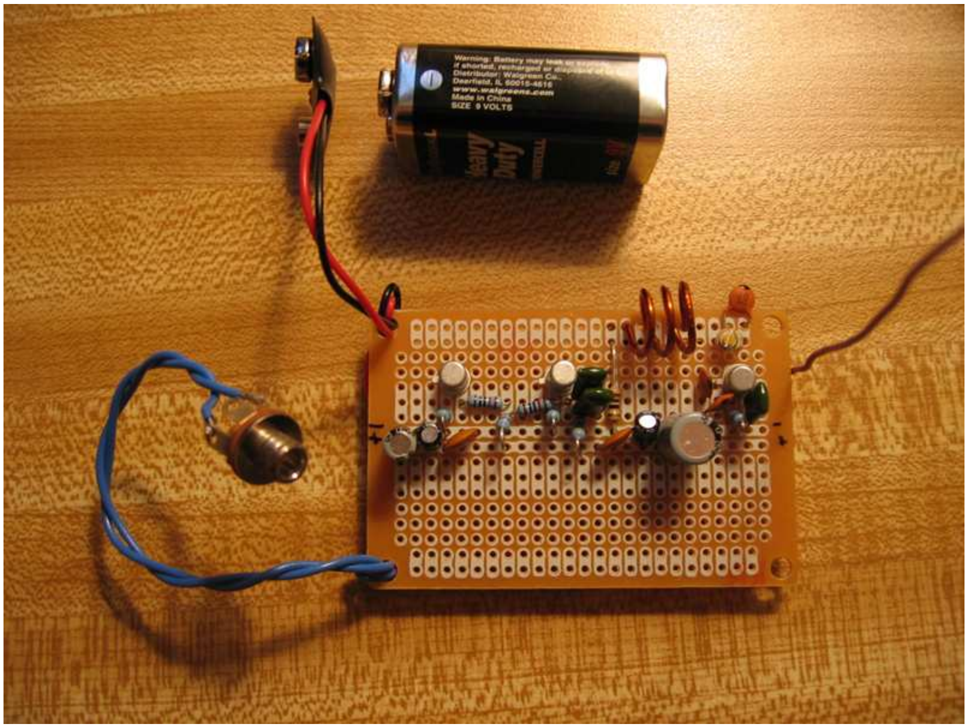

Figure 8. Functional prototype of simple FM transmitter

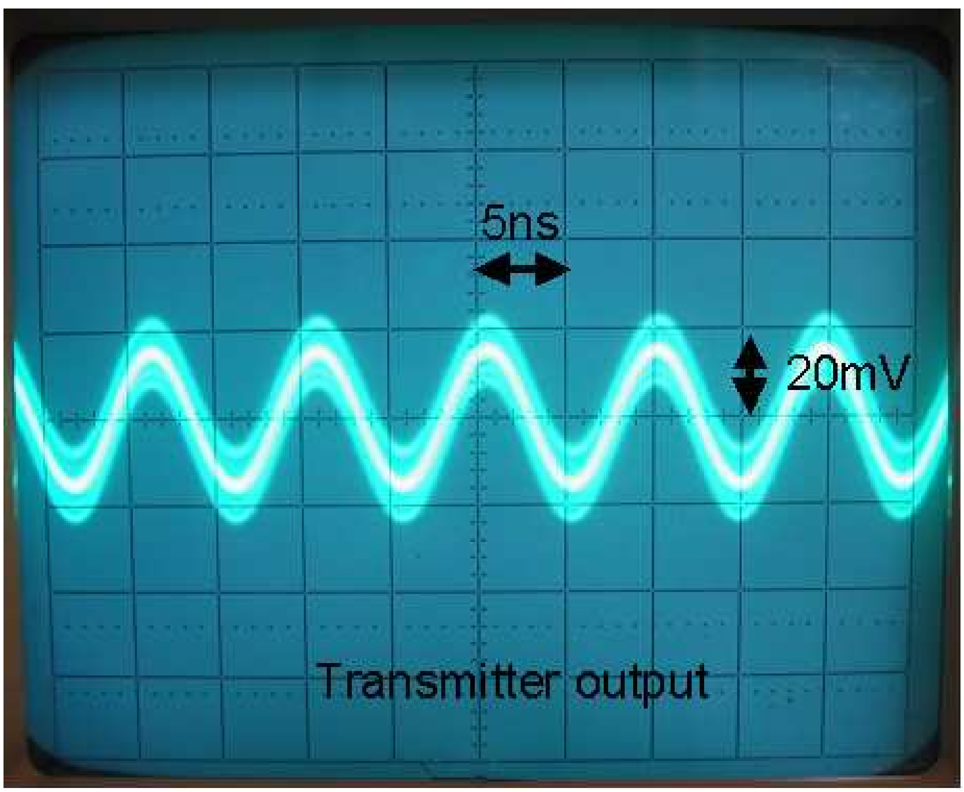

Figure 9. Measured output of FM transmitter

Figure 10. Transmitted signal received at 91.7MHz

Specification	Target	Measured	Units
Power supply	9	9	[V]
DC power consumption	< 80	46.5	[mW]
TX frequency	88 - 108	91.7	[MHz]
Frequency spacing	200	continuous	[kHz]
Audio pre-emphasis	75	90	[us]
Audio input magnitude	100	20	[mVpk]
Maximum RF power	< 10	TBD	[uW]
FM deviation	75	TBD	[kHz]

Table 1. Target and measured specifications of the FM transmitter

References

[1] Website: http://en.wikipedia.org/wiki/FM_broadcasting_in_the_USA

[2] Tsividis, Y. ELEN4314 Design Project, class assignment document, Project2007.pdf.