A Tunable AM Radio Receiver

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***Abstract*— The paper introduces a design of a simple AM radio receiver. The receiver is instructive in many of the fundamental concepts of communication circuits, among them basic transistor amplification, transformer applications, resonance, distortion, and power transfer. The design of this paper touches on all of these topics as a simple design topology is implemented to meet the provided specifications. The design consists of three basic stages: the RF selection, the demodulation, and the audio amplification stage, each of which are explained in detail in the sections to follow. The final design is physically implemented onto PCB board and tested on test bench for functionality.**

***Keywords*— AM, Receiver**

I. Introduction

AM modulation is a widely-used type of radio modulation. The receiver of it demodulates the information which contains two sideband frequency components with the center carrier frequency.

In this paper, we design a tunable radio frequency AM receiver, using both NMOS and bipolar transistors. Since bipolar transistors can provide good characteristics such as large amplification, large output impedance, relatively easy to bias etc., and NMOS benefits from its infinite impedance at the gate terminal, we can achieve corresponding specifications more proper by these attributes.

During the design, many problems are considered and solved, including matching the basic specifications provided and implementing many improvement aiming to get a better performance.

In terms of the differences between the theoretical design and realistic performance after build the design into real circuits, we try to optimize all the parameters to achieve a relatively robust receiver. Moreover, with two tunable control: RF and audio, as well as two potentiometers which can be adjusted to attain best performance, can enhance the robustness of the receiver.

The paper shows in details the design of the AM receiver, and the simulation results of it. The three main stages: RF amplifier, demodulator and audio amplifier are comprehensively introduced. At the end, we also provide an short conclusion and discussion of this design.

II. Specifications

Design specifications for the AM receiver are provided in Table I.

TABLE I
SPECIFICATIONS OF THE RECEIVER

Supply Voltage	9V
Number of transistors	≤5 transistors
Frequency range	520kHz~1710kHz
Controls	RF, Audio
Output power	>50mW
Frequency selectivity	±5 kHz
Audio -3dB frequency range	300Hz~5kHz
Distortion of audio circuits	<10%
Sensitivity	As high as possible

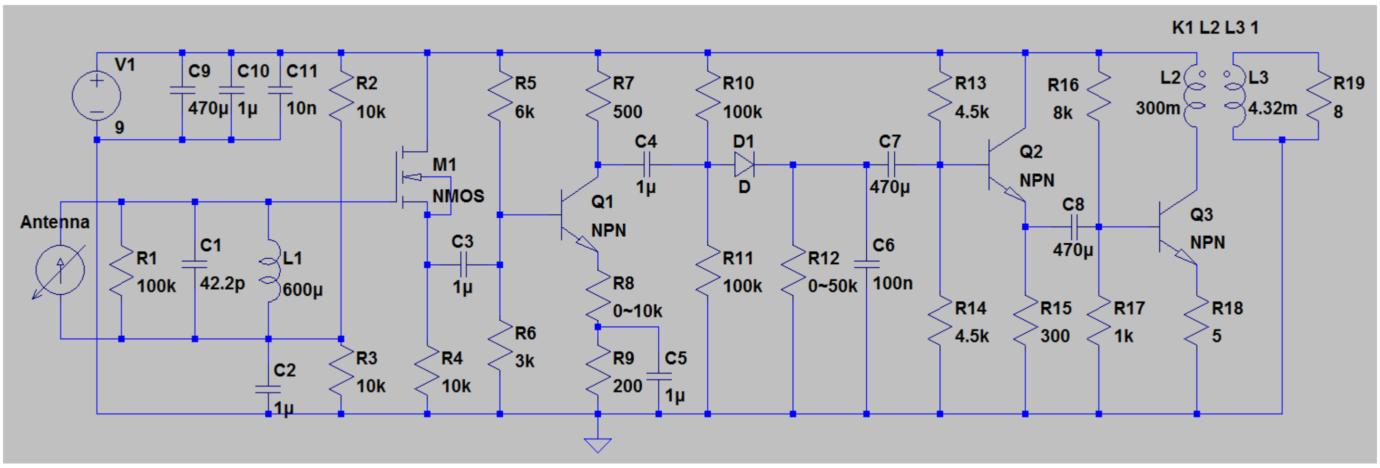

Fig. 1 Schematic of the TRF AM receiver

III. Design and Analysis

The schematic of our design of TRF AM receiver is shown in Fig.1.

A. RF Stage

The first stage in the signal path is the RF stage. The purpose of this circuit is to selectively capture an incoming Amplitude-Modulated signal, provide gain, and feed the signal into the demodulation stage. The basic topology is described in Fig.2.

The antenna is represented by a current source, which models the AM signal expressed in (1):

$$v_{in} = A(1+m\cos\omega_s t)\cos\omega_c t \tag{1}$$

where m is modulation index, ω_s is signal frequency, ω_c is carrier frequency. This signal has three frequency components: ω_c, $\omega_c+\omega_s$, $\omega_c-\omega_s$.

The signal is directly into the primary side of the RF Transformer, coupled with a variable capacitor C_1 which tunes the LC circuit to the appropriate frequency by (2):

$$f_{selected} = \frac{2\pi}{\sqrt{L_1 \cdot C_1}} \tag{2}$$

The signal is transferred across the transformer to the secondary to a NMOS source follower. Utilizing NMOS can we get infinite input impedance at its gate, so that the bandwidth control resistor R_1 is the only one determining the bandwidth as shown in (3):

$$f_{-3dB} = \frac{2\pi}{R_1 C_1} \tag{3}$$

Then we use a bipolar Q_1 amplifier to boost the signal. Q_1 provides main RF amplification.

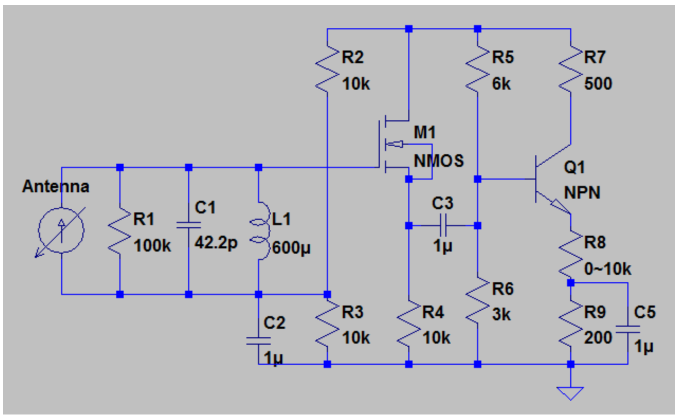

Fig. 2 RF Stage of the receiver

For DC biasing of NMOS, we use a smart method which conducts divided voltage for the gate through inductor L_1. This creative method provides us both the required DC bias and infinite impedance at the gate of M_1. For DC bias of bipolar common emitter amplifier, we use R_5 and R_6 to give a relatively stable voltage for the base. Considering distortion we use source degeneration by a tunable resistor R_8 which plays as RF tuning to control the RF amplification as shown in (4).

$$A_{RF} = \frac{g_{m,Q_1}}{1+g_{m,Q_1}R_8}R_7 \approx \frac{R_7}{R_8} \tag{4}$$

In order to maintain a proper DC current through emitter and collector we use R_9 with a AC bypass capacitor C_5.

B. Demodulator

The second stage of the design is demodulation stage shown in Fig.3, where the demodulated signal is recovered from the carrier. This stage of the design implements the basic diode envelope detector by D_1 seen below.

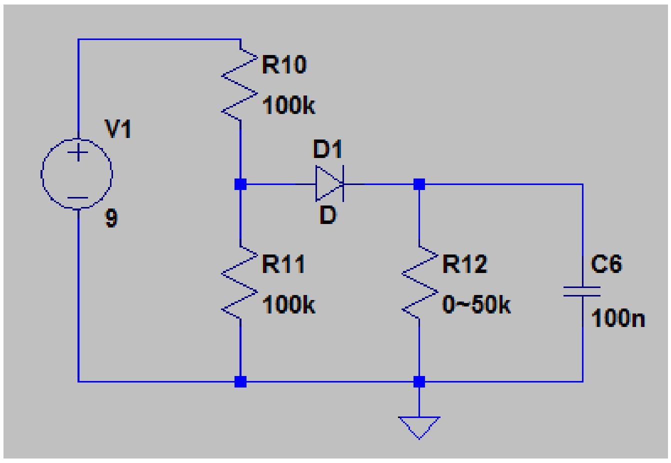

Fig. 3 Demodulator of the receiver

Two resistors R_{10} and R_{11} are used to bias the diode so that it does not turn off when the input AM signal goes low. The diode passes current in only the forward direction to the RC low pass filter, which filters out the high frequency behavior of the carrier, and outputs only the amplitude of the signal. The value of C_6 is chosen properly so that the capacitor does not discharge too quickly between peaks of the carrier, but does not discharge too slowly so that the envelope of the signal is not accurately captured by the response. One major consideration in this stage is the effect of loading. The input resistance of the Audio stage and the output resistance of the RF stage must be considered so that loading does not negatively affect any operation of the circuit.

R_{12} is a tunable resistor which provides voice control function.

C. Audio Amplifier

The audio amplifier stage, loading an 8 Ω loudspeaker, is shown in Fig.4.

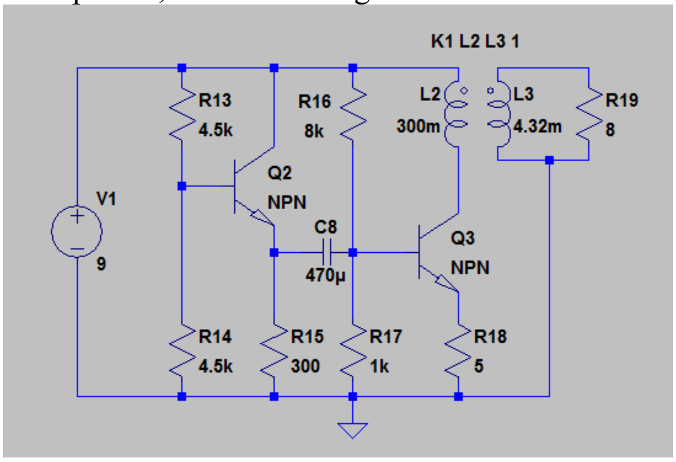

Fig. 4 Audio amplifier of the receiver

The audio amplifier consists of a emitter follower by Q_2 which provides a relatively large input impedance looking into base of Q_2 so that it won't affect the demodulation stage, and a source degeneration amplifier by Q_3 which is biased by R_{16} and R_{17} for a very low base voltage so that R_{18} can be very small to attain both a proper collector current for operation and a large amplification for the signal as shown in (5):

$$A_{Audio} = \frac{V_{loudspeaker}}{V_{audio,in}} \approx 1 \times \frac{g_{m3}\left[R_{19}\left(L_2 / L_3\right)\right]}{1 + g_{m3} R_{18}} \times \frac{1}{\sqrt{L_2 / L_3}} \approx \frac{R_{19}\sqrt{L_2 / L_3}}{R_{18}} \qquad (5)$$

At the collector of this amplifier stage is the primary side of our AC transformer, which steps down the amplified voltage. So we need to get as much amplification as we can at the primary side to complement this problem. It is important since the gain of this stage is proportional to the load resistance seen at the collector.

IV. Simulation, Test and Results

Using LT-Spice simulation workbench to do the simulation and building the physical circuits on PCB and test functionality, we get the specifications results in Table II.

TABLE II
Simulation and Test Results of the Receiver

Supply Voltage	9V
Number of transistors	3 bipolars and 1 NMOS
Frequency range	568kHz~1720kHz
Number of Station Received	14 stations
Controls	RF, Audio
Output power	38mW
Frequency selectivity	±4.5kHz at 1MHz
Audio -3dB frequency range	310Hz~∞
Distortion of audio circuits	1.7%
Distortion of RF Amplifier	9.3%
Sensitivity	8.9nA of antenna current

A. RF Frequency Response

Doing AC sweep and tuning the center frequency at 1MHz, we get the frequency response of RF stage in Fig5.

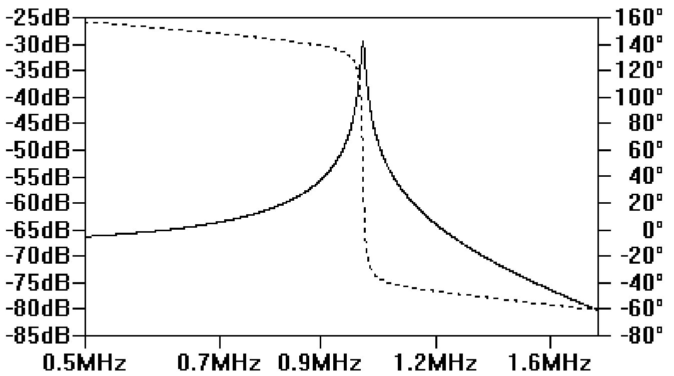

Fig. 5 RF stage frequency response of the receiver

Reading from the plot we get the -3dB bandwidth at 1MHz center frequency is 4kHz.

B. Audio Frequency Response

Doing AC sweep for the audio stage, we get the frequency response in Fig6.

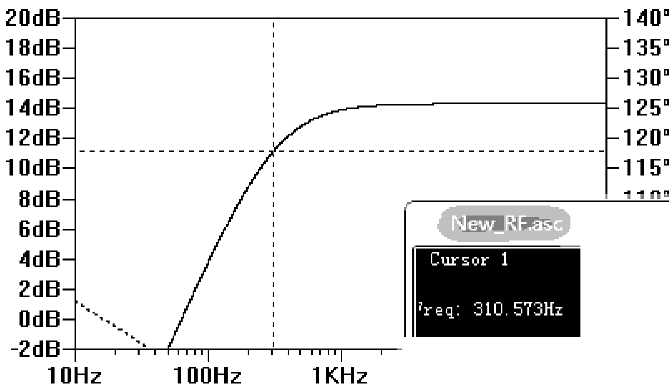

Fig. 6 Audio stage frequency response of the receiver

From the plot we measure the -3dB frequency of the audio stage is 304.5Hz~∞.

C. Audio Harmonic Distortion

Use a 1 kHz audio input to the audio amplifier, of such magnitude that the output power is 50 mW across an 8 Ω load. We get the frequency spectrum in Fig.7.

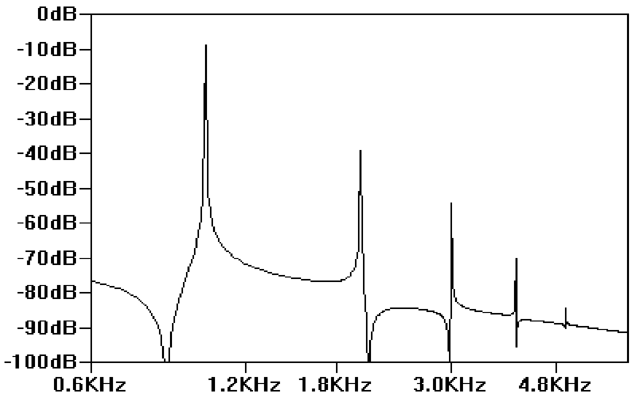

Fig. 7 Audio harmonic distortion of the receiver

Calculating the total harmonic distortion is 1.7%.

D. Maximum Signal Handled

The maximum unmodulated RF input signal current is 0.5 μA rms. We apply an input signal at 1 MHz, and it is 80% modulated with a 2 kHz audio signal, setting the volume controls are appropriately. Simulating the circuits and get the output at the loudspeaker as shown in Fig.8.

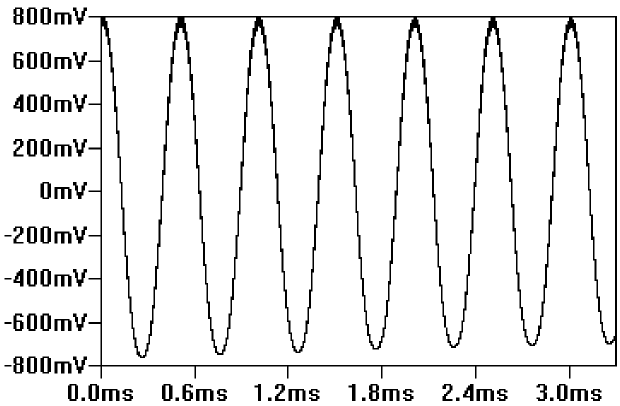

Fig. 8 Maximum signal handled

From the plot we can see the loudspeaker attains a clean and undistorted output waveform, which illustrates that the receiver can handle such maximum signal current.

E. Sensitivity

Assume that the minimum usable signal is defined as the rms value of the RF carrier, such that the audio output power is 1 mW when the signal is modulated at 80% with a 2 kHz audio signal.

We determine the minimum usable signal for our receiver by simulation, and we get the result is:

Minimum usable signal=8.9nA.

F. Receiver Harmonic Distortion

With an input RF carrier of 0.1 μ A rms, modulated at 80% with a 2 kHz audio signal and an output power as above, determine the THD at the output of the receiver as shown in Fig.9.

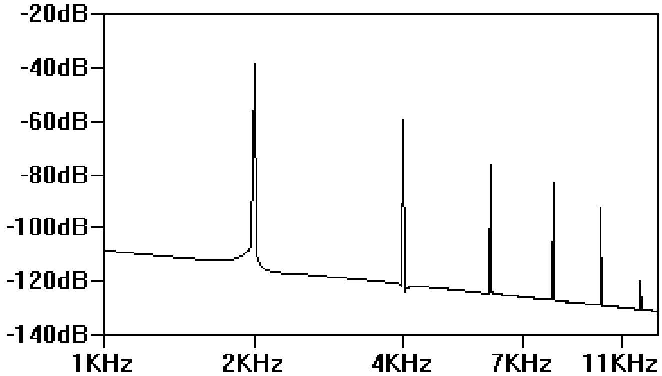

Fig. 9 Receiver harmonic distortion

The total harmonic distortion is 9.3%.

V. Conclusion And Discussion

Through the introduction and test results, we have designed a tunable AM radio frequency receiver. The receiver fulfills given specifications well. It is robust and sensitive to different signals and conditions. The design uses both bipolar and NMOS transistors for their respective special characteristics to achieve very good performance.

What we have to notice is that, building the real circuits using electronic components, has a lot of different effects from theoretical analysis. For example, the temperature will affect beta ratio of the BJT, and resistors, capacitors are also sensitive to temperature. Moreover, the parasitic capacitance of the transistors, as well as the parasitic inductance of the wire etc., will cause various kinds of undesired effects to the design. During the practical building circuit on PCB, we did some adjustment to compensate these problems in real environment. The decoupling capacitors are in various values so that it can bypass a wide bandwidth of noise. Soldering are also taken into consideration that, the components of a same function stage are soldered very near and grounded or powered in near spots on PCB. Although practical unideal problems exist, we did our best to weaken their influence to the circuits, and the final performance is very good.

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APPENDIX

Picture of completely-built AM radio receiver. (Voice control resistor and switch are added after shooting this photo)