Amplitude Modulation Transmitter Design

LAB 5

Introduction

The motivation behind this project is to design, implement, and test an Amplitude Modulation (AM) Transmitter. The Transmitter consists of a Balanced Modulator circuit which takes an audio signal stream from a Walkman and *mixes* it with a sinusoidal signal from a 1MHz oscillator. The resulting output is amplified by an output stage before being transmitted through a wire-antenna.

AM Transmitter Floorplan: Design Goals

Given the limited timeframe, we are providing you with the individual circuits that you need to design and construct. Fig. 1 shows the *floorplan* for the AM Transmitter. It consists of a Balanced Modulator which multiplies an audio frequency (20Hz to ~15kHz) signal with a 1MHz carrier frequency sinusoidal signal. The Balanced Modulator's output is amplified by an output stage which drives an antenna (in this experiment, the antenna is just a 3" copper wire).

The Balanced Modulator (Fig. 2) is essentially an *analog* multiplier: its time domain output signal, $V_{out}(t)$ is linearly related to the product of the time domain input signals $V_1(t)$ (called the modulation signal) and $V_2(t)$ (called the carrier signal). Its transfer function has the form:

$$V_{out}(t) = k \cdot V_1(t) \cdot V_2(t)$$

The Balanced Modulator uses the principle of the dependence of the BJT's transconductance, g_m, on the emitter current bias. In order to demonstrate the principle, consider the load currents I_{L1} and I_{L2}. From your knowledge of differential amplifier operation,

$$I_{L1} - I_{L2} = g_m \cdot V_{in} \approx \left(\frac{I_{L1}}{V_T}\right) \cdot \frac{V_1}{2}$$

Also, the bias current I_B in the differential amplifiers can be expressed as:

$$I_B \approx \frac{V_2 - 0.7}{R_E}$$

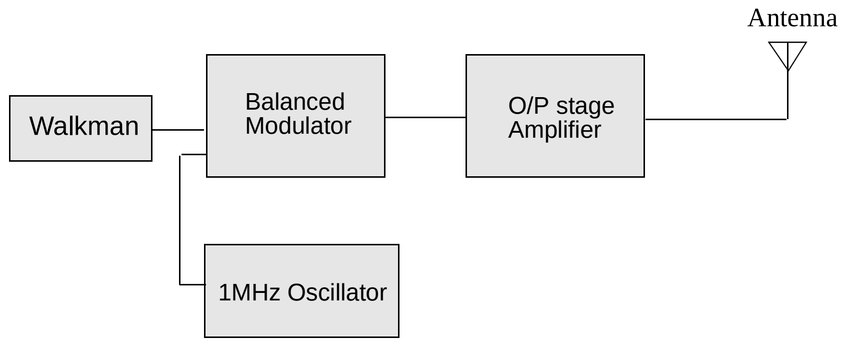

Figure 1 — Amplitude Modulation Transmitter floorplan.

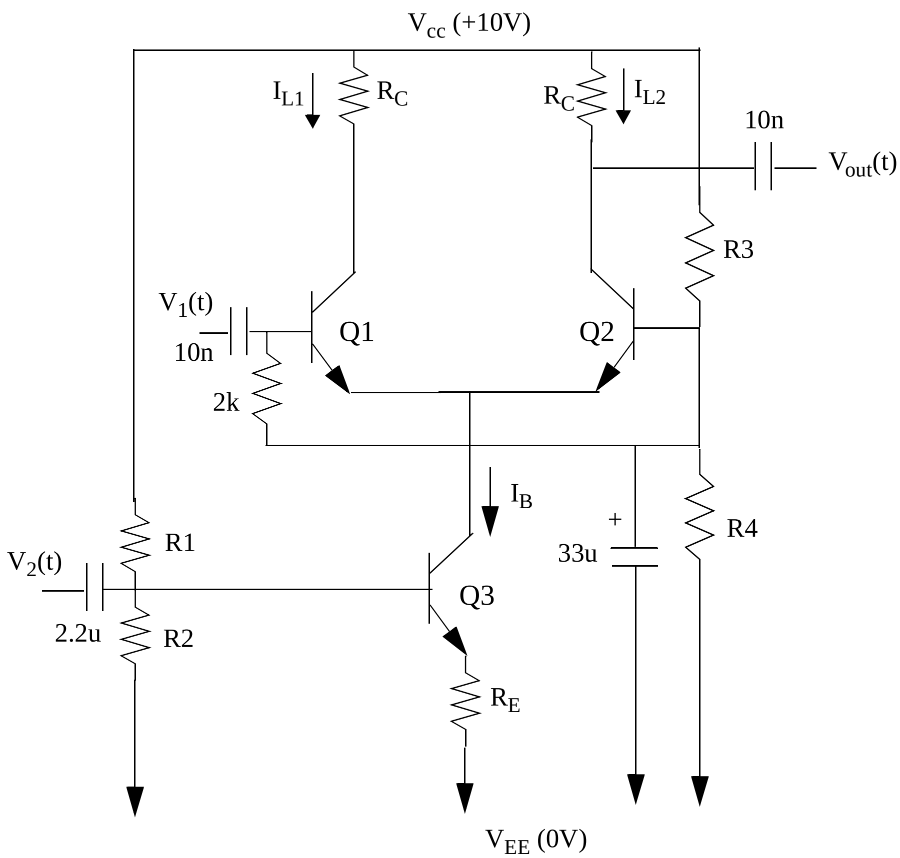

Figure 2 — Balanced Modulator circuit.

Therefore, $v_{out}(t)$ can be written as:

$$v_{out} = \frac{1}{2}\left(\frac{I_L}{V_T}\right)R_C V_1 = \frac{I_B}{4} \cdot \frac{R_C}{V_T} \cdot V_1$$

$$= \frac{R_C}{4V_T R_E} \cdot V_1 \cdot (-0.7 + V_2)$$

Thus, the output signal is proportional to the product of the carrier signal (V_1) and the moduating signal (V_2) with a DC offset. Notice however that the above expression is only valid with very small $V_1(t)$ due to the high gm values of Q1 and Q2 in the diff pair. For higher values of $v_1(t)$, the circuit response becomes non-linear with respect to $V_1(t)*V_2(t)$. Physically, this means that BJT's Q1-Q2 are driven into saturation mode and operate as switches. Then, $v_{out}(t)$ is given by:

$$v_{out} = \frac{R_C}{4V_T R_E} \cdot S_C \cdot (-0.7 + V_2)$$

where, S_c is the modulation signal "chopped" as shown in Fig. 3, for sinusoidal inputs. The corresponding "chopped" output signal is also shown in Fig. 3.

The output stage amplifier (Fig. 4) is essentially a common emitter amplifier that you have seen in class. Its purpose is to boost the power of the output signal being transmitted by the antenna. The output stage is usually designed for the highest power gain that you can achieve without output distortion.

Lab Timeframe

You goal is to design, implement, and test the complete AM Transmitter in 2 weeks, to be equally divided between the balanced modulator circuit (including oscillator circuit) and the output stage amplifier circuit. Here is a time schedule for you to use as a guide:

First Week: Balanced Modulator and Oscillator Design

Design the balanced modulator circuit in Fig. 2 (by choosing R1-R4, $R_{E,}$ and R_C) to achieve a gain of 20 (i.e., peak-to-peak $v_{out}(t)$ must be approximately $20*v_1(t)*v_2(t)$). Choose the smallest value of tail current I_B that will meet this goal.

Apply a 1MHz, 50mV peak-to-peak sinusoidal signal to $v_1(t)$ (this is in substitution of the oscillator circuit) and a 5kHz, 1V peak-to-peak sinusoidal signal to $v_2(t)$ (this is in substitution of the audio signal from the Walkman) to verify your Balanced Modulator circuit. Observe $v_{out}(t)$ and record the deviation between actual and expected differential outputs. Explain this deviation and your observations in your Lab Report. Next, increase the peak-to-peak amplitude of $v_1(t)$ from 50mV to 1V, and repeat the same experiment.

Next, replace the 50mV p-p 1MHz signal from the function generator with a 50mV p-p 1MHz sinusoidal oscillator circuit. You can either (i) design a transistor-level oscillator (perhaps as you did for Lab4) for an oscillation frequency of

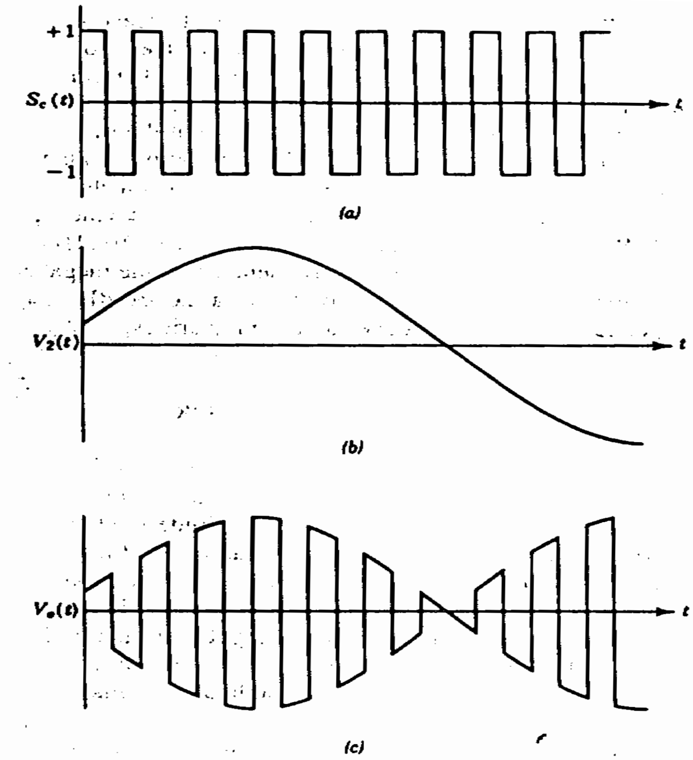

FIGURE 9.12. Modulated output waveform generated by high-level switching signal applied to balanced-modulator circuit of Figure 9.11: (*a*) Carrier signal; (*b*) modulating waveforms; (*c*) output waveform.

Figure 3 — Modulated output waveform for large signal inputs to the Balanced Modulator in Fig. 2.

1MHz, or, (ii) construct an astable multivibrator using a 555 Timer IC. For details on how to construct the oscillator using the 555 Timer, see Section 12.7 of your textbook. Again, observe $v_{out}(t)$ and record the deviation between actual and expected differential outputs.

Next, test your Balanced Modulator circuit with real audio output from the Walkman as the input $v_2(t)$. Set the audio level of the Walkman's output such that the peak-peak signal voltage swing is approximately 1V.

Second Week: Output Stage Amplifier Design

Design the output stage common emitter amplifier shown in Fig. 4 (by choosing R1-R4) to achieve a 5V peak-to-peak output voltage swing at the antenna. Verify that you can pick up this AM signal on an AM radio.

Parts List

The parts that will be made available to you for this project (datasheets are attached in the end of this document. Read them carefully while designing your circuit):

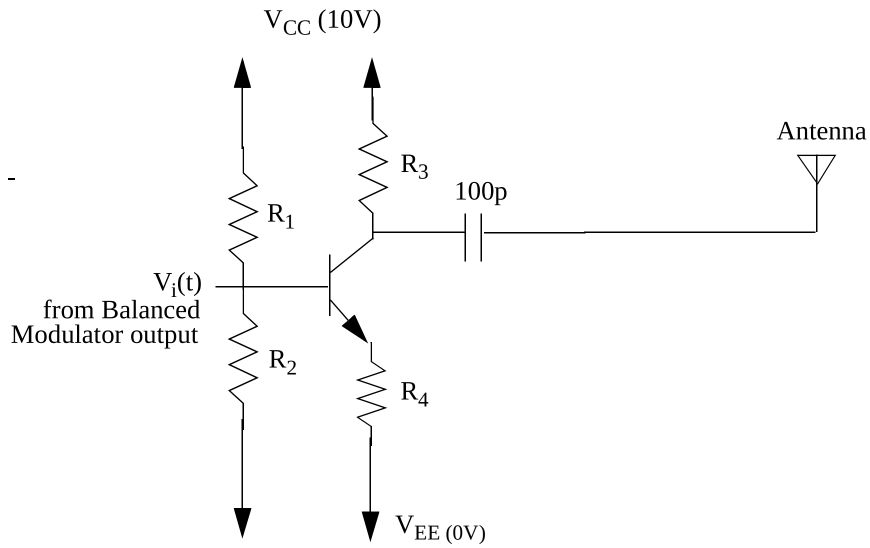

Figure 4 — Output Stage Amplifier circuit.

1. 555 Timer IC's.

2. NTE2321 Quad NPN Matched BJT's.

3. Transistors, etc., left over from lab 4.

Most R, L, and C elements you need will be made available. If you cannot find one that you want, you can either ask at Tech-Elec or use your ingenuity to construct the values you want.