EXPERIMENT #4
AM MODULATOR AND POWER AMPLIFIER

INTRODUCTION:

Being able to transmit a radio frequency carrier across space is of no use unless we can place information or intelligence upon it. This last transmitter stage will do just that; it is an *AM modulator.*

For a circuit to work as an AM modulator, it must be non-linear. This is very important. In a linear circuit, doubling the input voltage always doubles the output voltage; tripling the input voltage triples the output voltage; and so forth. However, in a non-linear circuit, this is not true. Doubling the input voltage may result in a tripled output voltage, while tripled input voltage may result in an output *much more* than triple the original! In other words, the input-output characteristic of the non-linear circuit isn't a straight line.

A transistor amplifier can easily be made non-linear by operating it in *large-signal* mode. OK, I see you remember now, and you're right: In large-signal mode, the transistor nearly approaches (or actually reaches) both cutoff and saturation on each cycle of the input signal. Which amplifier class is usually cut-off most of the time, and rarely turns on? Right, it's class C--and that's exactly the class the modulator stage in the transmitter will use. A class C amplifier is, in fact, highly non-linear!

A non-linear circuit will distort the input waveform. Normally this is undesirable; however, it's exactly what we want in this case. The input to the modulator will consist of the carrier (from the buffer amplifier and oscillator), and the intelligence (a 1 KHz sine wave from the benchtop signal generator.) Because of the non-linear distortion produced by the modulator, the output will consist of the two original output frequencies (f_c, f_m) , as well as NEW frequencies (f_{usb}--the upper sideband, and f_{lsb}--the lower sideband.)

CIRCUIT ANALYSIS

Figure 1 shows the modulator stage. The transistor is biased in class C by resistor R9 on its base. When there is no input signal, R9 is coupling the base of Q2 to ground. Since the base-emitter voltage would be zero under these conditions, the transistor will be cut-off with no signal. Sure enough, class C!

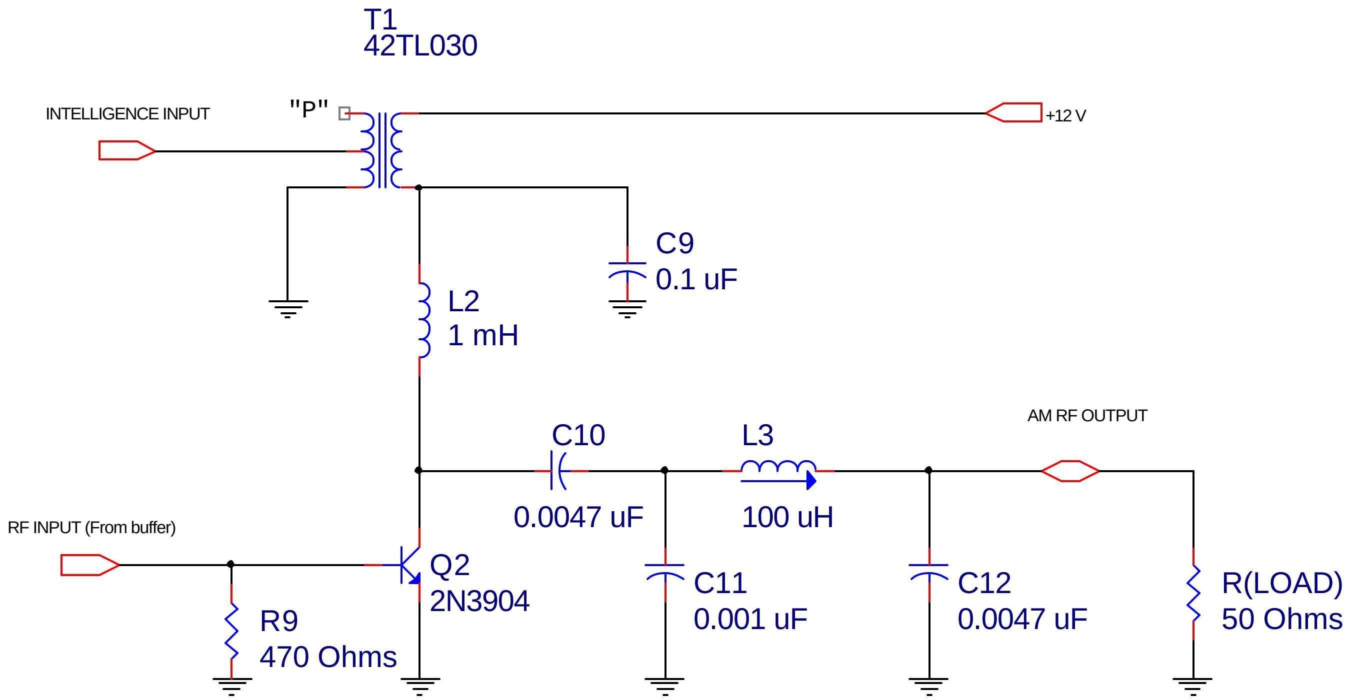


Figure 1: AM Modulator and Power Amplifier

C7 couples the buffer amplifier to Q2. It functions both as a DC blocking capacitor, and a signal coupling capacitor. C7 also works together with R9 and the base-emitter junction of Q2 to form a clamper network. You might recall that the effect of the base clamping network in a class-C amplifier is to allow the transistor to conduct only on the very tip of each positive peak of the input signal. This way, the transistor is off most of the time, giving just one "push" to the output tank circuit for each cycle of the signal.

Since the transistor conducts for only about 120 degrees of the input AC RF cycle, the waveform at the collector is highly distorted; it is, in fact, a series of *pulses*. These pulses have a peak amplitude of approximately *Vcc* (remember, the transistor is going all the way between cutoff and saturation). The load needs to see a clean sine wave. How can we convert the pulses back into a sine wave?

A *resonant tank circuit* will do the job. C11, L3, and C12 form this tank circuit. Huh? Take a look at the circuit. This surely must be a misprint; that circuit doesn't look *anything* like the resonant circuits from fundamentals!

C11, L3, and C12 in fact form a *PI network antenna coupler*, which acts as a resonant circuit (two capacitors and an inductor, of course) in the *time domain*, and a low-pass filter in the *frequency domain*.

In the time domain, the flywheel action of C11, L3, and C12 converts the pulse train at the collector of Q2 back into a sine wave. As a free bonus, these components also impedance match the 50 ohm load to the 2200 ohm collector resistance of Q2.

The antenna coupler can also be explained in the frequency domain. The pulse train at the collector of Q2 consists of a DC level, a fundamental sine wave frequency, and an almost infinite number of harmonics. Capacitor C10 eliminates the DC level, while the low-pass filter formed from C11, L3, and C12 eliminates most of the harmonic energies, producing a relatively pure sine wave at the *AM RF OUTPUT* terminal.

A class C amplifier can be emitter, base, or collector modulated. This circuit uses *collector injection* of the information signal. The secondary of audio transformer T1 is placed in series with the *Vcc* power supply of Q2. When audio energy from the signal generator is coupled into T1's primary, this AC energy becomes superimposed upon the *Vcc* power supply at the collector of Q2. Therefore, the instantaneous DC voltage at the collector of Q2 rides up and down in step with the information signal. This causes the peak voltage at Q2's collector to also rise up and down (since we're varying the power supply). The result is that the total AC output compliance (maximum p-p signal output) of Q2 rises and falls in step with the information. In other words, *amplitude modulation* occurs.

Inductor L2 is an *RF choke.* An RF choke prevents radio frequency currents from passing through. In this case, L2 forces the AC RF currents to stay "below" in the Q2 circuit, while allowing the low-frequency audio energy from T1 to pass, creating amplitude modulation. C9 is an additional RF bypass capacitor, whose job is to clean up any residual RF that happens to sneak through L2.

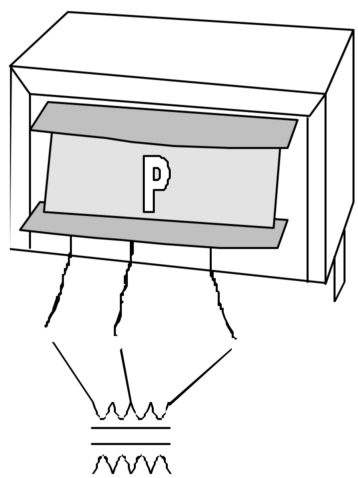
LABORATORY PROCEDURE:

Name _______________ Sign-off _________

In this experiment, you'll align the tuned circuits of the transmitter, then observe the resulting AM waveform at the output of the unit. You will learn how to compute the percentage of modulation of an AM signal by measuring the modulated carrier waveform with an oscilloscope.

1. Add the AM modulator stage to your existing transmitter circuitry.

   NOTE: The transformer T1 has three leads on each side, and one side is marked "P" (for Primary). Be careful to insert T1 in the correct direction. Don't force T1's leads into the breadboard; they're easily damaged.



2. Connect the analog output of the AF signal generator to the INTELLIGENCE INPUT of the modulator stage. Leave the generator off. This ensures that no intelligence is being fed into the modulator.

3. Connect channel #1 of the scope to the AM RF OUTPUT of the circuit. Trigger off this channel.

4. Apply power to the circuit, and make the following adjustments:

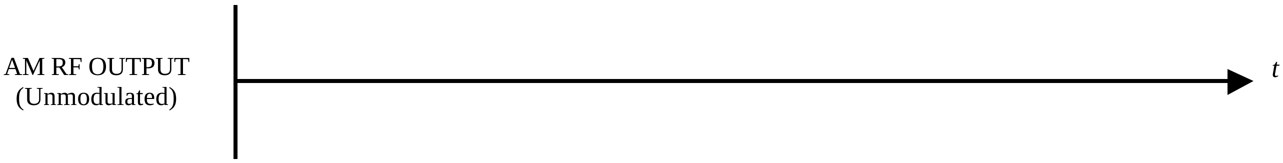
   L1 (Oscillator): Adjust for desired carrier frequency, between 450 KHz and 700 KHz. (You may want to make sure you're using a different frequency than others in the lab.)

   R4 (RF Level): Adjust for maximum output *without clipping* at the AM RF OUTPUT test point.

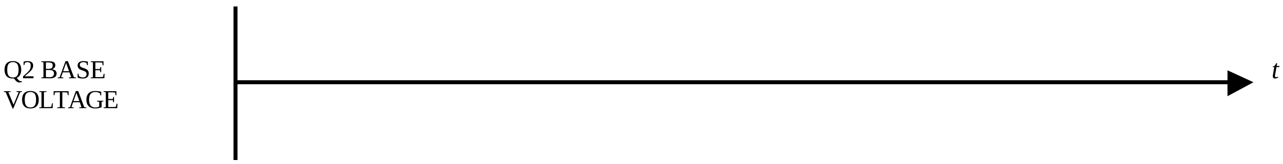
   L3 (Antenna Coupler): Adjust for maximum output at the AM RF OUTPUT.

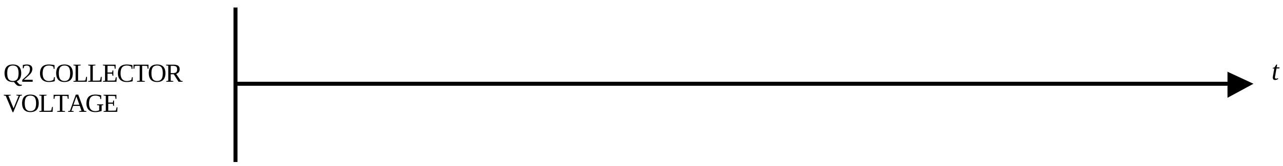
   TIP: If everything is working correctly, you'll get a clean sine wave of 5 Vpp or better at the AM RF OUTPUT. This corresponds to the design RF output power level of approximately 60 mW.

5. The wave obtained in step 4 is the unmodulated carrier wave. Draw it below. Don't forget to show time and voltage!



6. What do the base and collector voltages in the class C circuit look like? Let's find out! Leave channel #1 of the scope connected, and connect channel #2 of the scope to the base of Q2. Use DC coupling! Draw a detailed graph of the Q2 base voltage below:





7. We would now like to view some AM waveforms. On the scope, the channel #1 trace should display the INTELLIGENCE, and the channel #2 trace should show the MODULATED WAVE. We should also trigger off the INTELLIGENCE. Reconnect the scope leads to the proper points, please!

8. Turn on the AF signal generator, and set its frequency to 1 KHz. This is the intelligence frequency. Set the amplitude of the information signal to 6 Vpp.

9. Adjust the scope until you see one cycle of the intelligence displayed across the screen. (Channel 1)

Note: You'll find it helpful to use CHOP mode, so that you can see channel 1 and 2 at the same time.

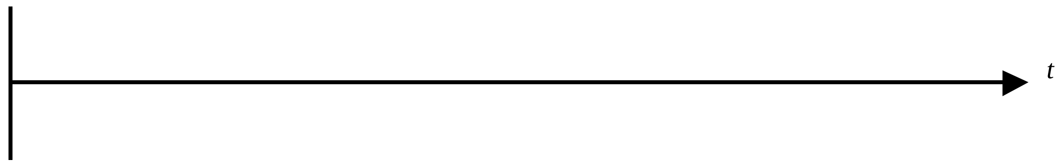
10. Remember how to calculate percentage of modulation from the envelope dimensions of a waveform? We used the formula:

$$m = \frac{V_{\max} - V_{\min}}{V_{\max} + V_{\min}}$$

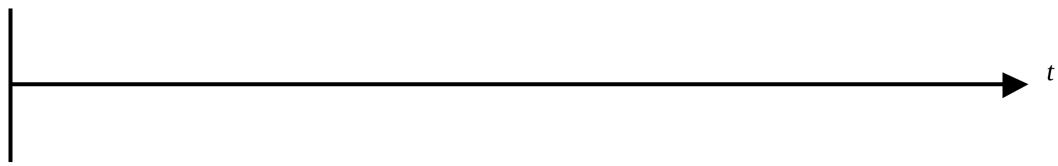
Where *Vmax* is the maximum peak-to-peak envelope size, and *Vmin* is the minimum peak-to-peak envelope size.

Adjust the intelligence amplitude (Wavetek) until there is approximately 50% modulation, then draw the following waveforms:

INTELLIGENCE VOLTAGE



AM RF OUTPUT (50% mod)



11. Record your measured Vmax and Vmin values in the table below; then repeat step 10 for the rest of the values in the table. (You do not have to redraw the waveforms).

% Modulation	*Vmax*	*Vmin*
50%		
25%		
0%		
100%		

12. From what you did in steps 10 and 11, can you tell me an easy way (no calculations) to determine when the oscilloscope-displayed AM waveform reaches 100% modulation?

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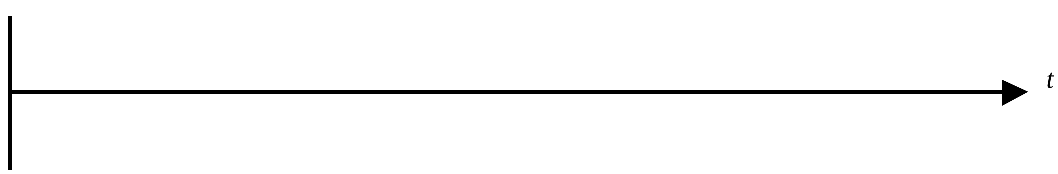
13. What happens if we try to exceed 100% modulation? Well, try it and find out! Draw the resultant AM OUTPUT waveform below:

AM RF OUTPUT (> 100%)



14. Can you explain to me how I can identify an OVERMODULATED AM waveform on the scope, given your results from step 13?

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Outstanding! I think you're ready for the next experiment!

QUESTIONS

1. What purpose is acheived in the modulator stage of a transmitter?

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2. Why does the AM modulator output Fusb and Flsb, in addition to the the carrier frequency? (In other words, what property of the circuit makes it useful as a modulator?)

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3. Why is a class C amplifier a good choice for a modulator stage?

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