Amplitude modulator

fall 2020

1 Task

Your task is to build and test this amplitude modulator on a breadboard.

2 What is amplitude modulation

In the transmitter we generate a *carrier* that is just a sine wave or other periodic signal at 18 MHz. Then we modulate its *amplitude*. The signal *frequency* remains constant (more exactly 18.432 MHz) but its amplitude is going to be non-constant. We want to vary the amplitude according to an information signal. The instantaneous amplitude or *envelope* [1] of the 18-MHz signal is supposed to be a copy of the information. For more comprehensive discussion, see article Amplitude modulation in Wikipedia.

In the final transmitter, the information signal is the signal from the microphone, once amplified in the audio amplifier. Why the microphone signal must be amplified, will be discussed in Chapter 6. Note that the signal frequency from the microphone is much lower than the carrier frequency. We can expect the audio frequency band to stretch form around 100 Hz to around 10 kHz.

If the envelope of the 18-MHz output signal follows the waveform of the information signal, then, the output signal has been amplitude-modulated. That is our target.

3 Operation of the amplitude modulator

3.1 General idea

The operation of this amplitude modulator (Figure 1) is based on the 18-MHz *amplifier* that was was build and tested previously. The only significant difference is that there is an extra input, called AF in, audio-frequency input.

The potentiometer allows you to choose the base current I_b and thereby also the collector current I_c, since collector $I_c = \beta I_b$ where β, the DC current gain, is constant; typically $\beta \approx 100 \ldots 120$ for bipolar junction transistors. The voltage gain

[1] By definition, *envelope* is the curve that is tangent to every one of a family of curves. It is not exactly a correct term for us, but its commonly used.

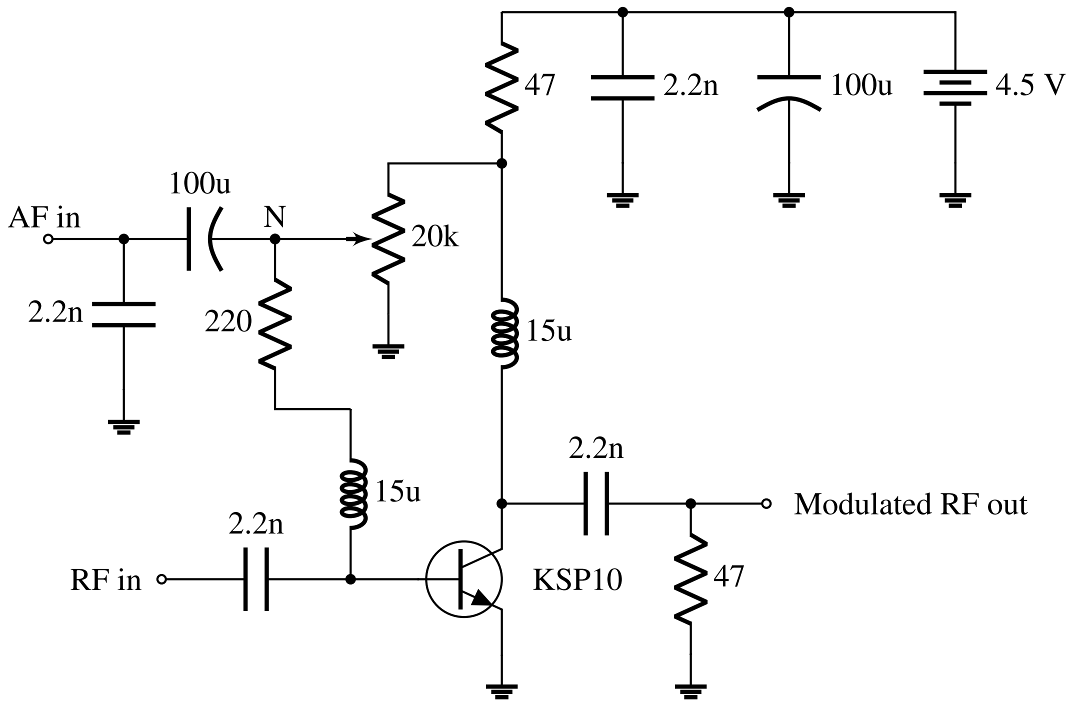

Figure 1: The modulator. Try to identify the DC, AF and RF paths when (1) the 15-μH chokes impede only the RF current, (2) the 2.2-nF capacitors impede DC and AF currents, but not RF, and (3) the 100-μF capacitors impede DC, only. The resistors impede currents at all frequencies, equally, according to their resistance.

of the transistor is dependent on the these DC currents. When you turn the potentiometer, you actually adjust the voltage gain. In that sense this circuit is also a “variable-gain amplifier”. The gain can be varied by turning the potentiometer knob. In this application you should set the collector current to about 4 mA, because at that current: (1) transistor is operating in active mode (2) the gain is strongly dependent on the current.

The information current that comes form the AF input sums up with the DC current at node N, see Figure 1. The consequence is that both the amplifier gain and the output amplitude will vary according to the information current. Note that the information current is AC. This means that the net current to the transistor base is sinked and sourced at the audio frequency rate, making the gain alternate about the average value.

3.2 Numerical values for our case

- Average voltage gain 1. . . 1.2.
- Input voltage 1.8 V$_{pp}$.
- Output voltage 1.8. . . 2.2 V$_{pp}$.
- DC collector current $I_c \approx 4$ mA.
- DC collector-to-emitter voltage $V_{ce} \approx 4.3$ V.

- DC base-to-emitter voltage $V_{be} \approx 0.76$ V.
- Desired modulation depth $m \approx 0.5$.
- Corresponding maximum gain $(1+0.5)|1.1| \approx 1.65$,
- Corresponding minimum gain $(1-0.5)|1.1| \approx 0.55$.
- Needed audio drive 100...500 mV.

3.3 DC blocks and RF chokes

Notice that we need two kinds of DC blocks. The 2.2-nF capacitors work as DC blocks for 18 MHz and the 100-μF capacitors for the audio frequencies. The 2.2 nF capacitor reactance is only $\frac{1}{\omega C} = 4\ \Omega$ at 18 MHz[2] but as much as 70 kΩ at 1 kHz. As a consequence, the 2.2-nF DC block is passing hardly any of the the audio signal to the RF signal source or antenna load, where internal impedances are low, in the order of 50 ohms.

The 100-μF audio frequency DC block provides very low impedance for 1 kHz: $\frac{1}{\omega C} = 1.6\ \Omega$. It is uncertain which impedance it provides for 18 MHz: probably low but not an ideal zero. The parasitic elements of such a large capacitor could be significant at 18 MHz.

The 15-μH inductors work as RF chokes. According to ωL, their reactance is at least 1.7 kΩ at 18 MHz[3] but just 0.1 Ω at 1 kHz. The RF choke stops the RF current but passes the DC and audio frequency currents.

3.4 Stability resistors

An apt student might ask about the reason for having the 220-ohm and 47-ohm resistors. The answer is, these resistors keep the transistor stable. The fact is that RF transistors typically have high gain, especially at lower frequencies. High forward gain together with certain feedback mechanisms can make a transistor potentially unstable. Potential instability means the transistor has tendency to oscillate on its own. The resistors somewhat damp down the gain.

The stability issues are crucial in professional design. The topic has been largely excluded from the scope of this introductory course. However students are welcome to *ELT-41206 Basics of RF Engineering* on 4th period to learn more!

4 Construction

Before you start placing components, plan with paper and pen paper how they should be laid out. Some hints:

- Make the circuit compact.
- Minimize the amount of jumper wires.

[2]The actual reactance at 18 MHz may be much lower due to the parasitic series inductance.
[3]The actual reactance at 18 MHz may be much higher due to the parasitic shunt capacitance.

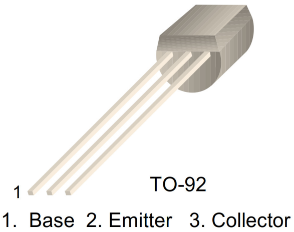

Figure 2: KSP10 pinout.

Table 1: Components needed to construct the modulator

component	value	purpose/description/type	amount
C	2.2 nF	DC block for RF	4
C	100 μF	DC block for AF	2
L	15 μH	RF choke	2
R	47 Ω	for stability	2
R	220 Ω	for stability	1
potentiometer	20 kΩ	for adjusting gain	1
transistor		KSP10	1
connector		SMB	1
breadboard			1
jumper wires			many

- Minimize the wire lengths, especially those used for grounding.
- Do not make the signal go back and forth, all over place on the breadboard. Keep the layout simple. Otherwise possible debugging may be difficult...
- Do not splay out the leads of components if not absolutely necessary. Respect the intended assembly pitch, typically multiples of 2.5 mm. Breadboard holes are 5 mm apart.

5 Testing

You should test the modulator as follows: First test that DC operation is ok. Then test the modulator *without an audio signal*, merely as an RF amplifier. Finally test it with two inputs; RF *and* audio.

5.1 Testing DC operation

- Connect 4.5 V from the Virtual Bench (VB) DC power power supply.
- Check with the VB multimeter that the transistor gets biased properly: measure the voltage across the upper 47-Ω resistor, and, using Ohm's law, determine the DC current consumption of the modulator. Alternatively you may just read the current from the DC power supply. If the DC operation is not

Table 2: Equipment needed to test the modulator

equipment	purpose
Virtual Bench	As an oscilloscope, RF generator, and DC supply.
5.6-μH inductor	Suppresses RF at the oscilloscope probe tip.
	Use only for to measure AF, see Figure 3.
SMB-SMB cable	Incident RF.
BNC-BNC	Incident RF.
SMB male-BNC female adapter	To connect the cables.
MyDAQ	As an audio generator.
Windows computer	To control Virtual Bench and MyDAQ.

satisfactory, see what happens if you turn the potentiometer knob. The current probably changes between zero and about 60 mA. (The transistor will not damage even if the knob is at either extreme, as long as the circuit is correctly constructed.)

- Measure the emitter-to-base voltage V_{be}. Notice how it changes when you adjust the potentiometer from one extreme to the other. The base to emitter voltage probably varies between zero and about 0.9 V.

- Adjust the potentiometer until the DC current consumption is about 4 mA. In case you use a potentiometer with a knob, keep in mind the arrow direction. At this current, the base-to-emitter voltage V_{be} should be close to 0.76 V.

5.2 Testing RF gain of the modulator

- Feed an 18.4-MHz the signal from the Virtual Bench to the RF input.

- Monitor the RF signal both at the at the RF input (v_{in}) and at the RF output (v_{out}) with the Virtual Bench oscilloscope. Use a time scale on the horizontal axis such that you are able to see a sine wave with several periods. The period length is $\tau = 1/(18.4\text{MHz}) = 54$ ns. For the vertical scale, you might use something like 200 mV/div.

- Set the VB function generator amplitude to 0.08 V_{pp}.

- Observe how the voltage gain $G_v = |v_{out}|/|v_{in}|$ changes as you adjust the potentiometer, allowing V_{be} to range from zero to about 0.9 V. You may notice that the gain increases rapidly for increasing current, up to about 8 mA.

- Turn the knob to find how high the gain can go. You can expect that at maximum $G_v \approx 10$ at about 15 mA.

- Set the potentiometer then to the position that allows a 4-mA current.

- Adjust the amplitude to 1.8V_{pp} and determine the voltage gain. In the final transmitter input voltage will be about 1.8 V_{pp}.

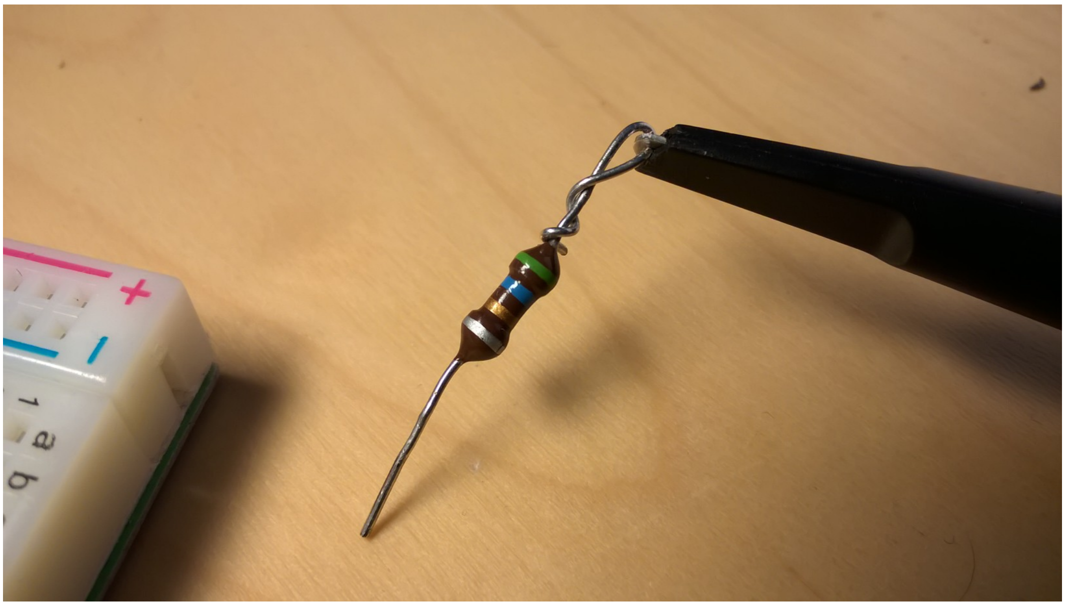

Figure 3: A 5.6-μH choke at the hook of an oscilloscope probe.

5.3 Testing the actual modulator operation

- Keep the RF signal applied to the RF input.
- Preferred: Feed a 1-kHz, 100...500-mV$_{pp}$ signal from MyDAQ Function Generator to your modulator AF input. Use the analog outputs of myDAQ (AO0 or AO1)
- Measure simultaneously the voltages at the AF input and at the RF output using the oscilloscope channels 1 and 2. Use such a time scale that allows you to to see several periods of the audio waveform, e.g., 500 μs/div.
- Hint: Connect a 5.6 μH inductor to the oscilloscope probe hook that you use for monitoring the AF input as shown in Figure 3. This way you can filter out the RF ripple from the measurement and your audio signal *looks* nice and clean.
- Once previous test is completed, you may use other kinds of audio signal sources, such as the headset connector (3.5 mm) of your laptop, mobile phone, or MP3 player. Just make sure you are able to turn down the audio volume to about 200 mV$_{pp}$. Ask teachers for a special cable to connect to your device, if needed.

6 The modulator in the final transmitter

This amplitude modulator is going to be part of the final transmitter as such. The output connects directly to the antenna.

Input RF signal originates in the crystal oscillator. It is attenuated to the fraction of about $47/(47+220) = 18\%$ before applying it to the modulator input. Without

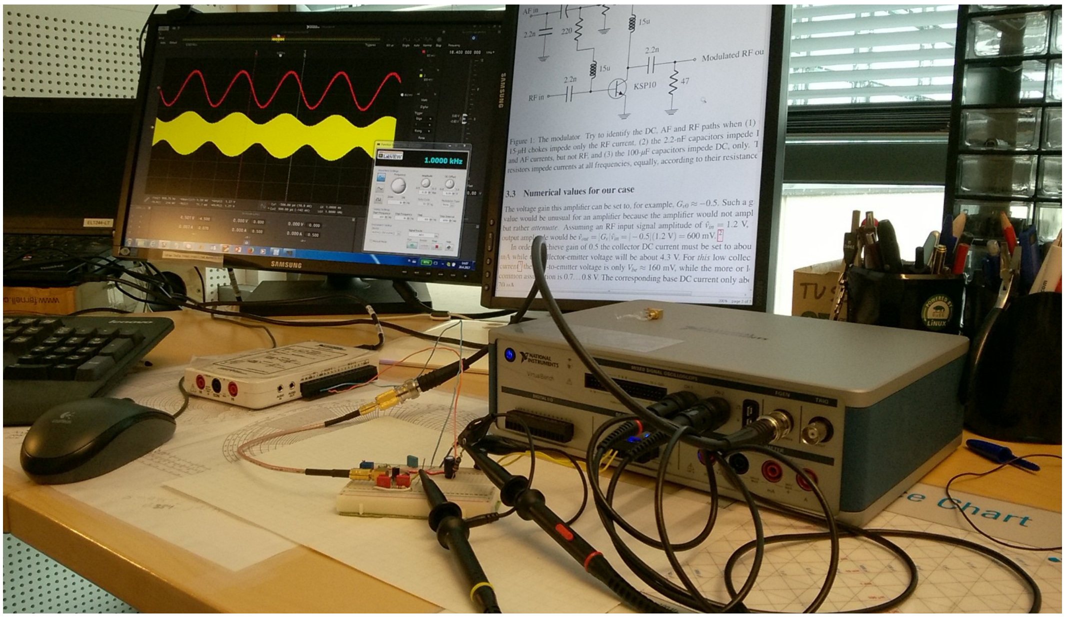

Figure 4: Measurement of the amplitude modulator using NI Virtual Bench and MyDAQ. The red curve is audio signal and the yellow "curve" is the amplitude modulated RF signal.

the attenuator, the signal would be too strong for good modulation. The crystal oscillator can put out a signal that can be as strong as 10 V_{pp}. This is attenuated down to about $(0.18)(10\ V_{pp}) = 1.8\ V_{pp}$.

The audio frequency signal originates in the electret microphone. Although the microphone is quite sensitive, its output signal is very low. It is typically as low as some few millivolts peak-to-peak. The signal must be amplified in the audio amplifier to about $50 \ldots 100\ mV_{pp}$ to be able to control the gain of the modulator. The signal voltage at the microphone output is quite low, typically just $5 \ldots 10\ mV_{pp}$. Such a low signal may be difficult to monitor directly with the Virtual Bench, because of the noise generated in the VB power supply.

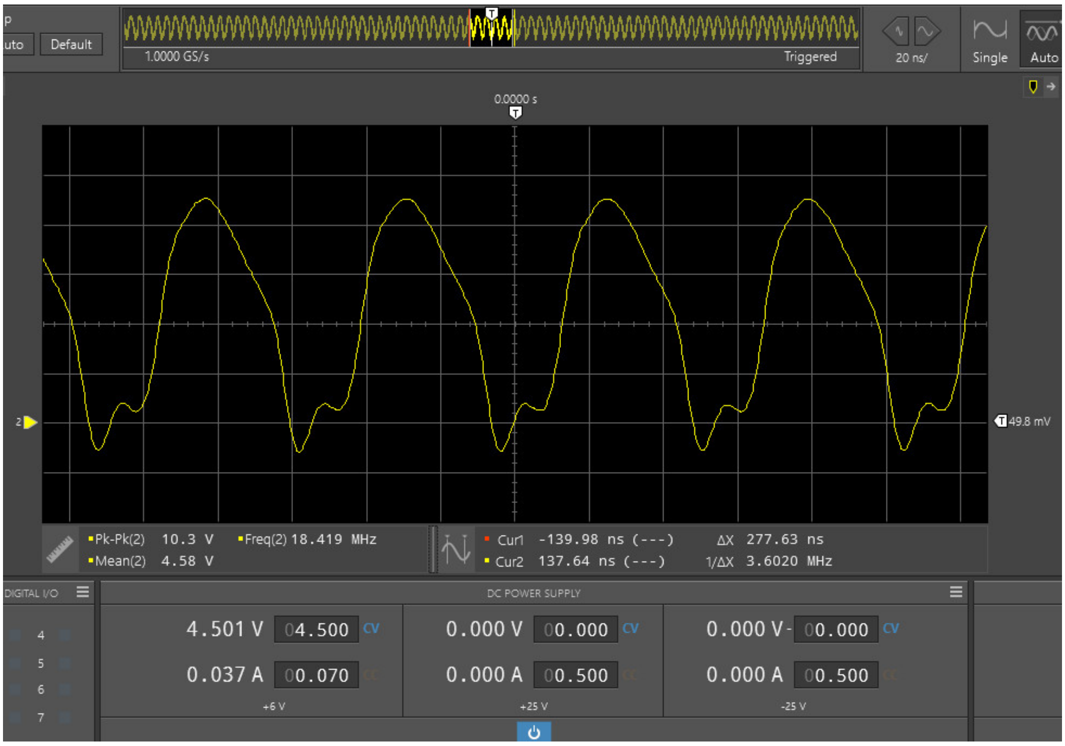

Figure 5: Crystal oscillator output voltage is 10.3 V peak to peak.