An 18-MHz amplifier

Fall 2021

1 Task

Your task is to build and test an 18-MHz amplifier on solderless breadboard. Fig. 1 shows a built amplifier and Table 2 lists the components needed.

2 Operation of the amplifier

2.1 General idea

The circuit is a single-transistor common-emitter amplifier. The amplifier works, if the transistor is biased properly and if the signal is routed properly in and out of the transistor.

One can think of the DC operation and the RF operation of the transistor separately. The first thing to worry about is DC. There has to be a DC power supply and a proper arrangement of resistors to make the collector-to-emitter voltage settle somewhere in the active region of IV-characteristics: see this image in Wikimedia. Several resistor configurations can be used for to implement a common-emitter amplifier. One is shown in Figure 2

V_BE=0.8V
DC gain:100..200

When a typical small-signal transistor is operating in the active mode and biased to the active region, its collector DC current is usually more than 1 mA but less than 50 mA. The collector-to-emitter voltage is a few volts and the base-to-emitter voltage is 0.7...0.8 V. The base current is typically $1/200 \ldots 1/100$ of the collector current; in other words, the DC current gain is typically 100...200. Figure 3 shows the DC current gain of KSP10.

The second thing to worry about is how the signal is routed in and out. The operation of the amplifier is based on the fact that a small change in the base current causes a large change in collector current. This small change of the base current is achieved by summing a low-amplitude signal current on top of the base bias current. Consequently, the much higher collector current will experience a corresponding change.

2.2 DC blocks

The 2.2-nF capacitors work as DC blocks. Theoretically the reactance of such capacitor is only $\frac{1}{\omega C} = 4\ \Omega$ at 18 MHz. However in practice, the impedance is even lower, close to zero which is due to the series inductance associated with the component leads and other physical dimension.

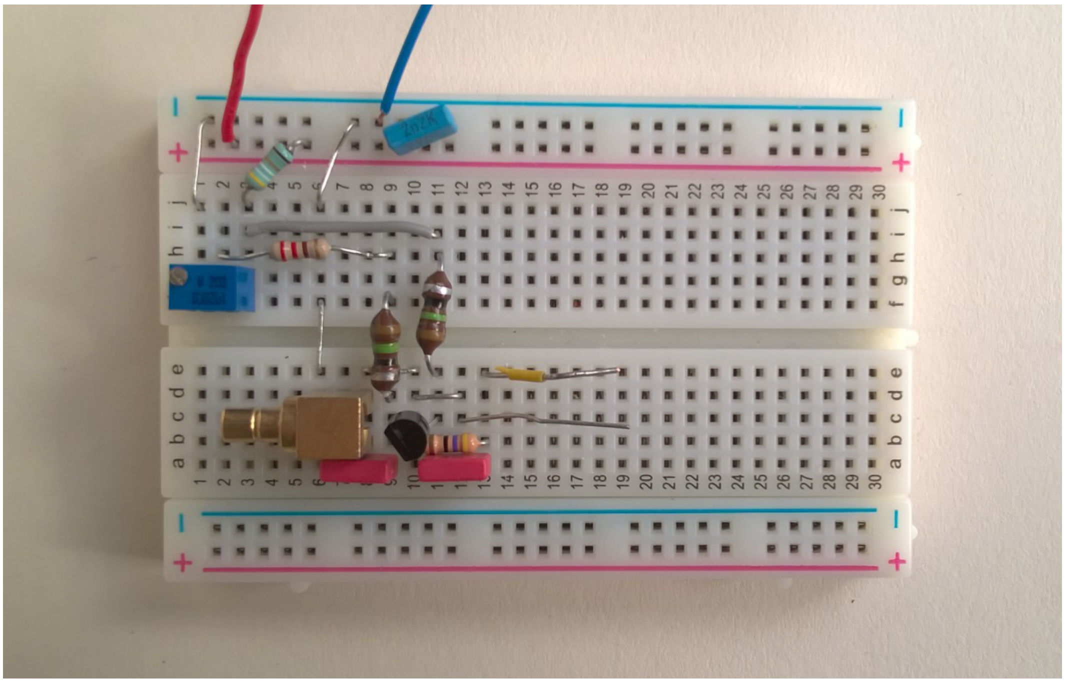

Figure 1: The SMB connector is the input The yellow jumper wire is the output. The big brown components with stripes are the 15-μH RF chokes. The red and blue capacitors are the 2.2-nF DC blocks.

The input DC block allows the signal current, which is always AC, to pass on from a signal source towards the base-emitter-junction. The output DC block allows the signal "component" of the collector current to flow back and forth between the collector and the load. The second obvious job of the DC blocks is to block the operating DC currents from being conducted to the signal source or to the load circuit. The third use of a DC-block-size capacitor is in filtering the DC supply voltage, or in other words, to keep the V_{cc} steady at 4.5 V.

2.3 RF chokes

The 15-μH inductors work as RF chokes. According to simple theory, the reactance of such inductor is $X = \omega L = 1.7\ \mathrm{k\Omega}$ at 18 MHz, which is quite high. However, due the parallel capacitance associated with the neighboring wire windings and other parasitics, the true reactance is probably even higher.

The purpose of having the RF chokes is to increase the amplifier gain. The input side RF choke prevents almost completely the signal current form being passed on to the biasing resistors. The less current is passed on to the 220-ohm resistor, the more there is current to drive the transistor, and consequently, more there is current change at the collector. The same logic applies to the output side. The less there is AC component flowing ("upwards") to the 47-ohm resistor (see Figure 5), the more there is AC into the load.

Now that the output side RF choke is connected between the collector and the 47-ohm resistor, the 47-ohm resistor could actually be removed and replaced with a short circuit. The transistor would stay biased properly and RF routing in and out would not change. By doing this we could actually increase the gain and linearity. However the resistor may be crucial for stability purposes as discussed next.

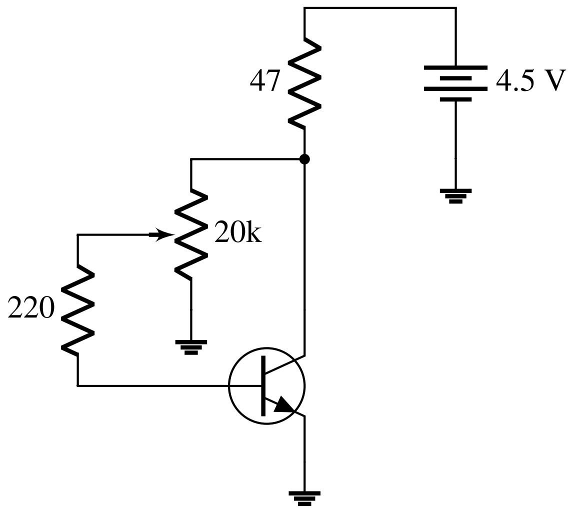

Figure 2: One possibility to bias an NPN transistor to active mode.

2.4 Resistors for stability

Besides setting the desired operating point, the 220-ohm and 47-ohm resistors have a second purpose: stability. RF transistors typically have high gain at lower frequencies. High forward gain together with certain undesirable feedback mechanisms tend to make RF amplifiers oscillate on their own. The resistors somewhat damp down the gain and stabilize the device. Another 47 ohm resistor should be connected as a load resistor to further ensure stability. This arrangement ensures there is a lowish resistive path from the collector to the ground at all frequencies. Fig. 6 shows the complete amplifier schematic.

3 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.
- Minimize the wire lengths, especially those used for grounding.
- Do not splay 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.
- Do not make the signal go “back and forth, all over place” on the breadboard. Keep the layout simple.
- Use the side rail, marked blue for ground and the other side rail marked red for V_{cc}.
- Debugging is going to be easier if you follow these rules!

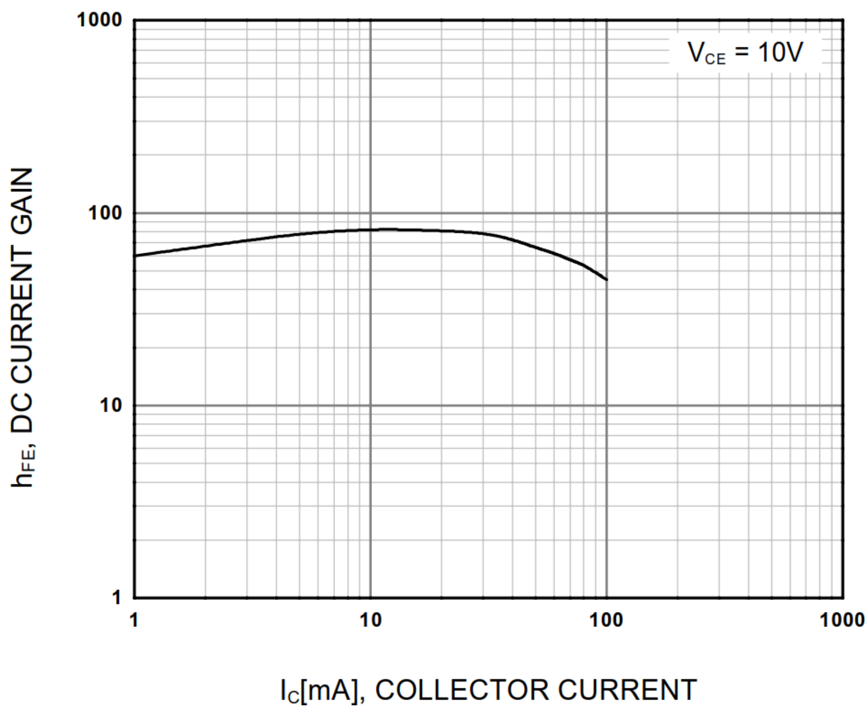

Figure 3: Typical DC current gain h_{fe} of KSP10 as a function of collector DC current, while collector-to-emitter voltage is kept to 10 V [?]. Current gain varies between 40 and 80.

Table 1: Equipment needed to test the amplifier

equipment	purpose
Virtual Bench	As an oscilloscope, RF generator, and DC supply.
SMB-SMB cable	Incident RF.
BNC-BNC	Incident RF.
SMB male-BNC female adapter	To connect the cables.
Windows computer	To control Virtual Bench.

4 Testing

Connect the 18 MHz RF signal from the function generator of the Virtual Bench. Measure input and output voltages using the VB oscilloscope channels one and two.

4.1 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 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.)

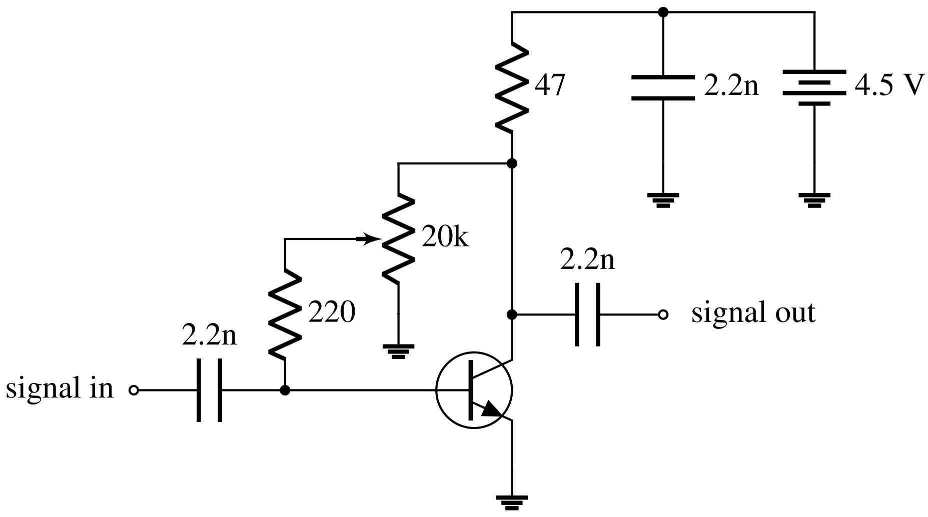

Figure 4: DC blocks added.

- 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.

4.2 Testing the voltage gain

- Feed an 18.4-MHz 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 50 mV_{pp}.
- Observe how the voltage gain $G_v = |v_{\text{out}}|/|v_{\text{in}}|$ changes as you adjust the potentiometer.
- Turn the knob to find how high the gain can go.

4.3 Testing the linearity

- Keep feed the 18-MHz signal from the Virtual Bench to the RF input.
- Increase the input amplitude from 50 mV_{pp} up to 100 mV_{pp} and beyond and observe how the output waveform gets more and more distorted.
- When does the waveform start to be seemingly non-sinusoidal? How high are the input then amplitudes then? Compare the AC and DC voltages. When can you say that signal is a "small signal".

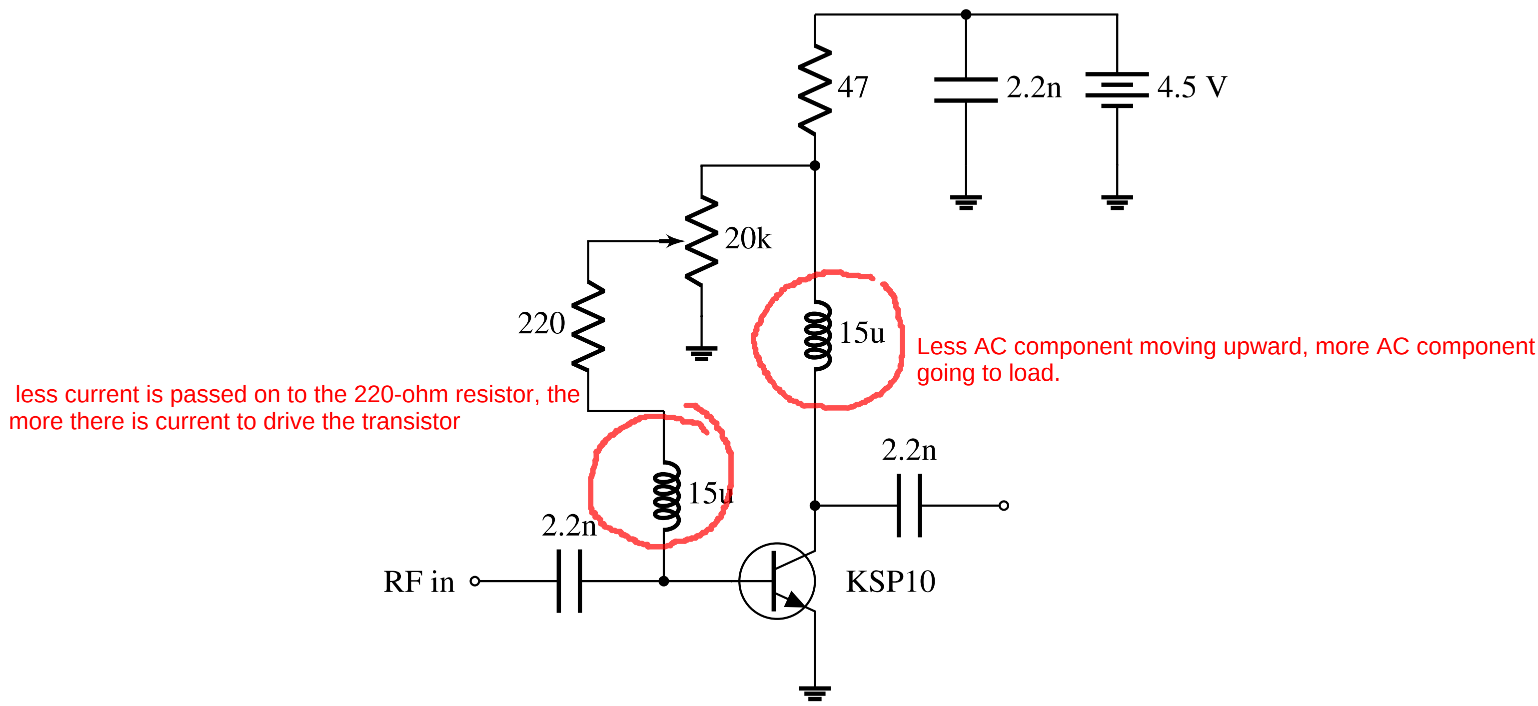

Figure 5: RF chokes added.

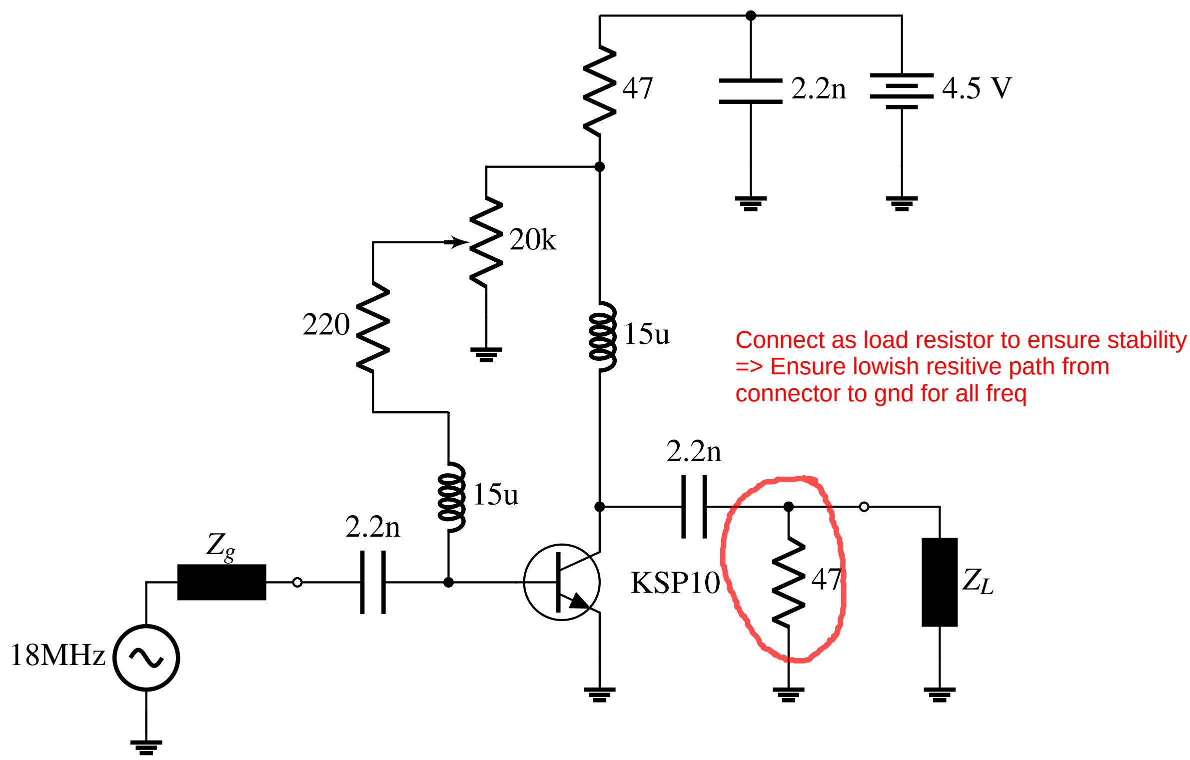

Figure 6: Completed amplifier with the load side stability resistor added. An external signal source and load also shown.

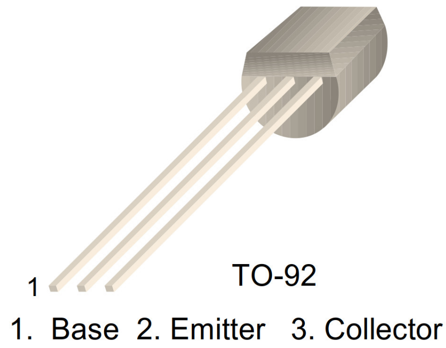

Figure 7: KSP10 pinout [1].

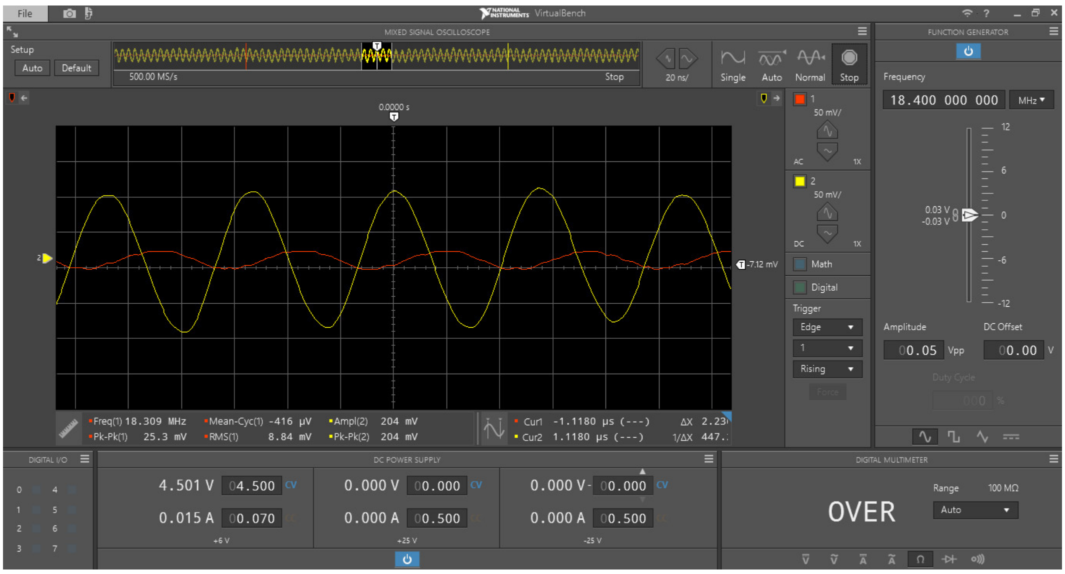

Figure 8: Input (red) and output (yellow) waveforms. Voltage gain is $204/25.3 \approx 8$. Input voltage ($25.3 mV_{pp}$) is about one half of the electromotive force of the generator ($50\ mV_{pp}$). Therefore we may assume that input impedance of the amplifier is of the same order of magnitude as the internal impedance of the generator, 50 Ω.

5 Further applications

Later on, in this course, this amplifier circuit shall be developed and used as part of an LC oscillator, crystal oscillator, and an amplitude modulator.

Table 2: Components needed to construct the amplifier

component	value	purpose/description/type	amount
C	2.2 nF	DC block for RF	3
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
RF connector		SMB	1
breadboard			1
jumper wires			many

References

[1] "‘KSP10 datasheet,"’ 1999, Fairchild Semiconductor.