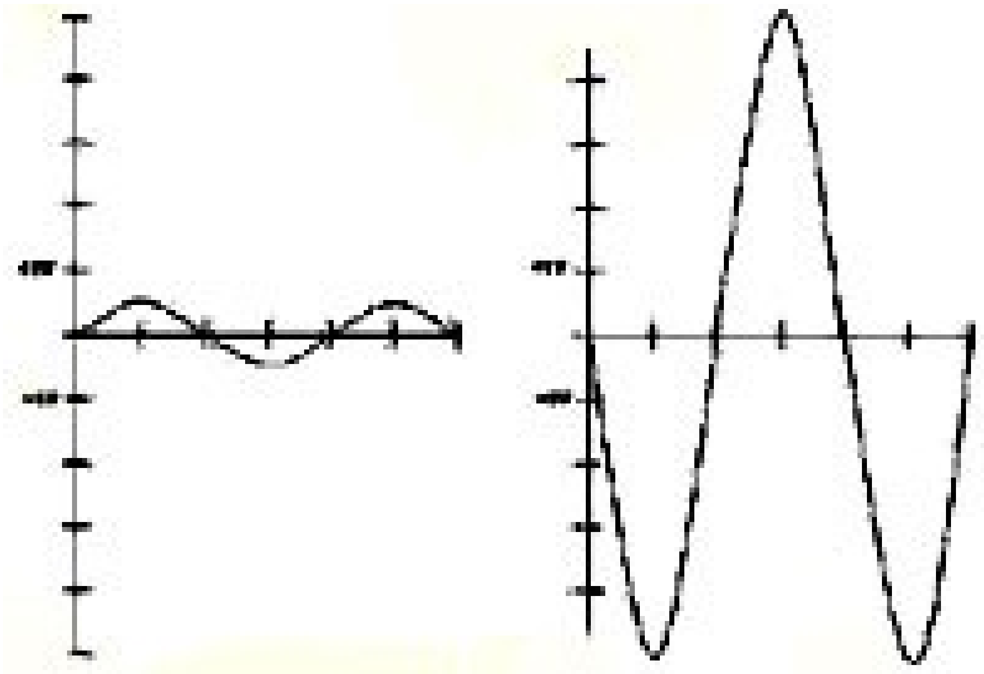
The New England Radio Discussion Society electronics course (Phase 3 cont'd)



Amplifier gain

AI2Q – January 2017

We know the ratio of an amplifier's input to its output is called *gain*, and gain is indicated by the upper-case letter A.

Gain **can be expressed as a function of voltage ratios.**

$$A_V = \frac{V_{\text{out}}}{V_{\text{in}}} = \text{voltage gain}$$

Voltage gain is usually used for what are dubbed *small-signal* amplifiers.

Ratios can also be expressed as current *gain*.

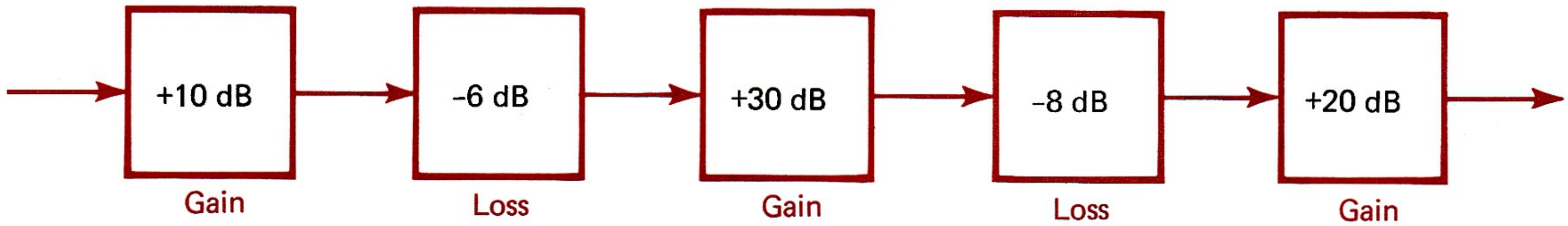
$$A_I = \frac{I_{\text{out}}}{I_{\text{in}}} = \text{current gain}$$

Gain can also be expressed for power (W).

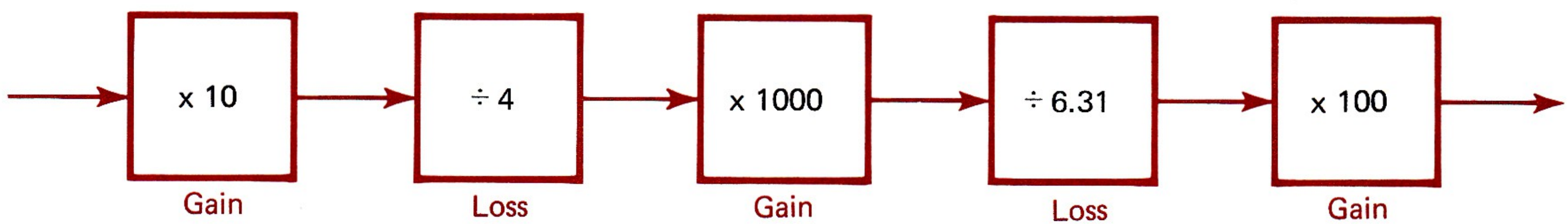
In this example the output power is 8 watts and the input is 500-mW.

$$A_P = \frac{P_{out}}{P_{in}} = \frac{8\ \text{W}}{0.5\ \text{W}} = 16$$

The dB is a useful unit when comparing *gain* and *loss* in various electronics "stages"

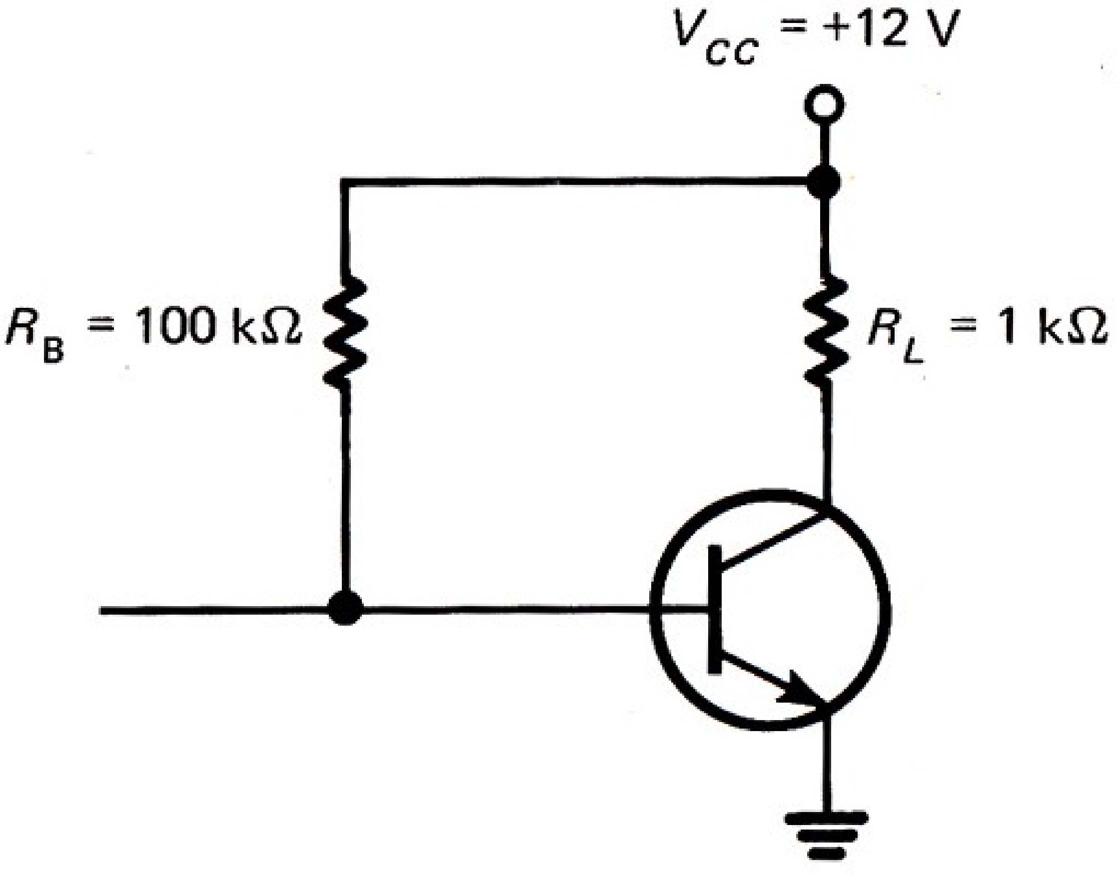


Gain and loss in decibels

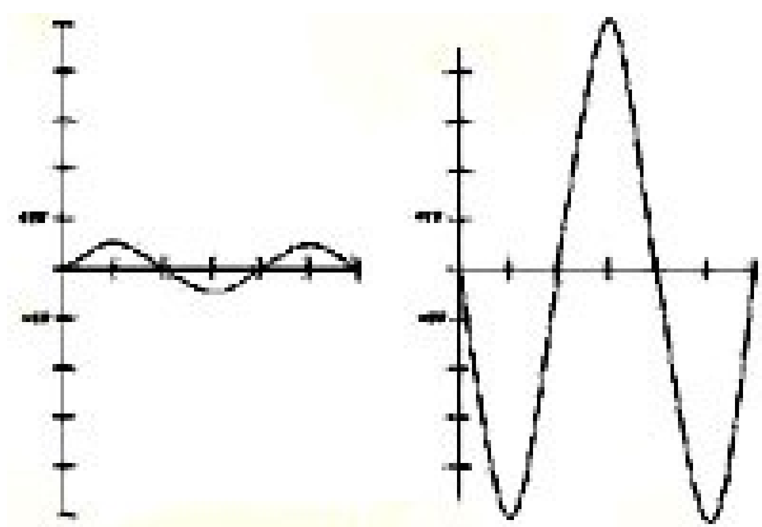


Gain and loss in ratios.

Here's the simplest NPN xstr amplifier set up as a *common-emitter* amplifier.



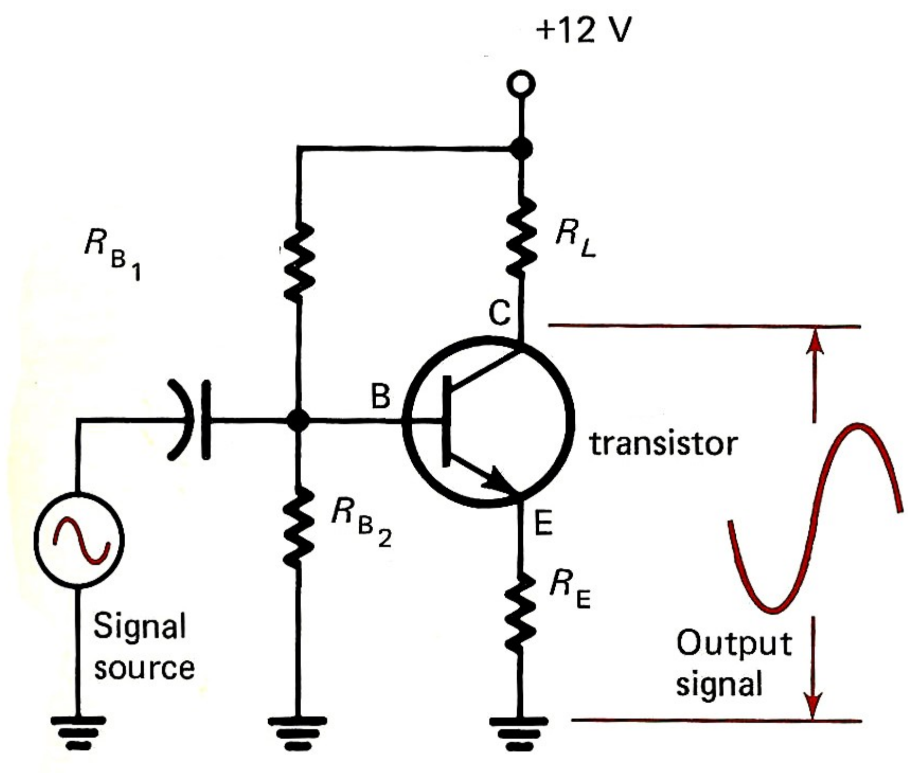
The gain of a transistor is dubbed *beta*, or *hFe*. The *hFe* multiplied by the base current reveals how much collector current can flow in the simple common-emitter circuit.



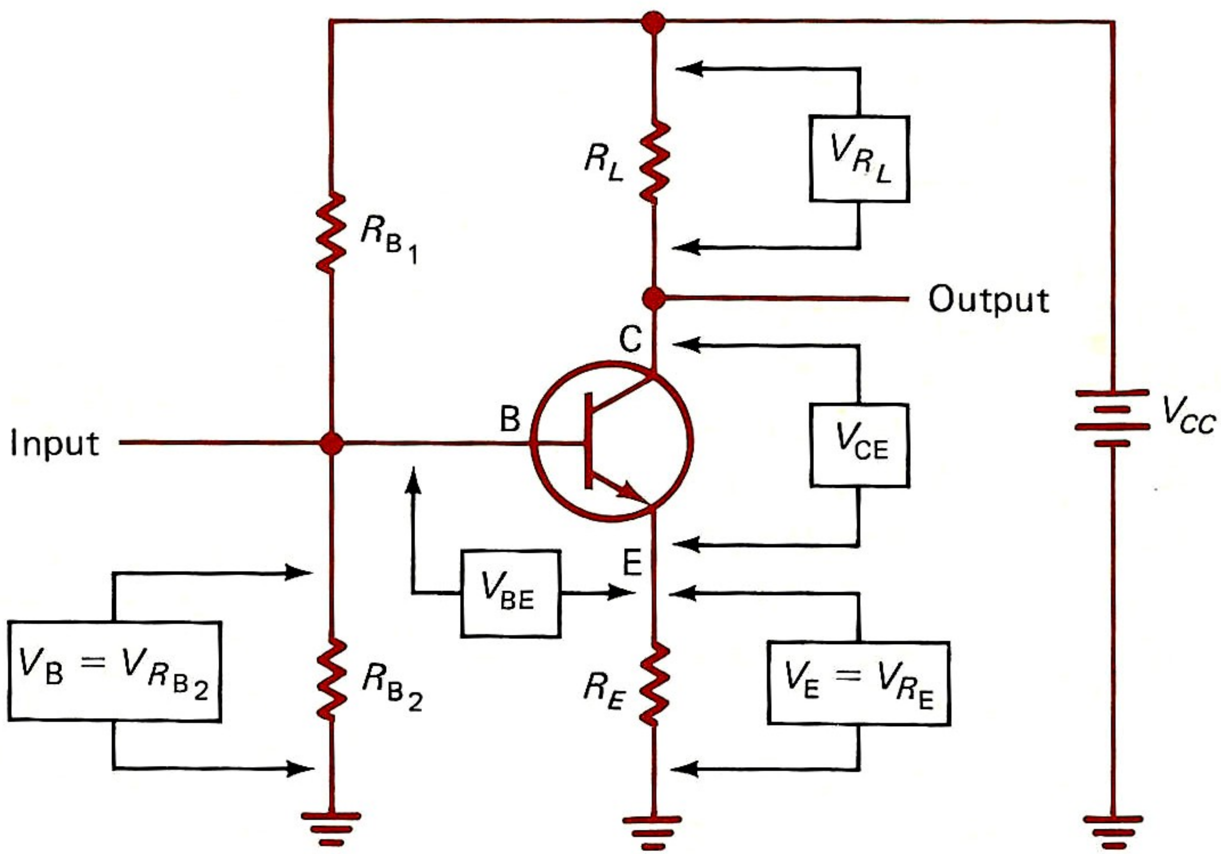
But the *beta* of a BJT varies from transistor to transistor, even for the same part number. That makes the simplest amplifier suitable only for the most basic applications, as it's sensitive to variations in beta as well as temperature.

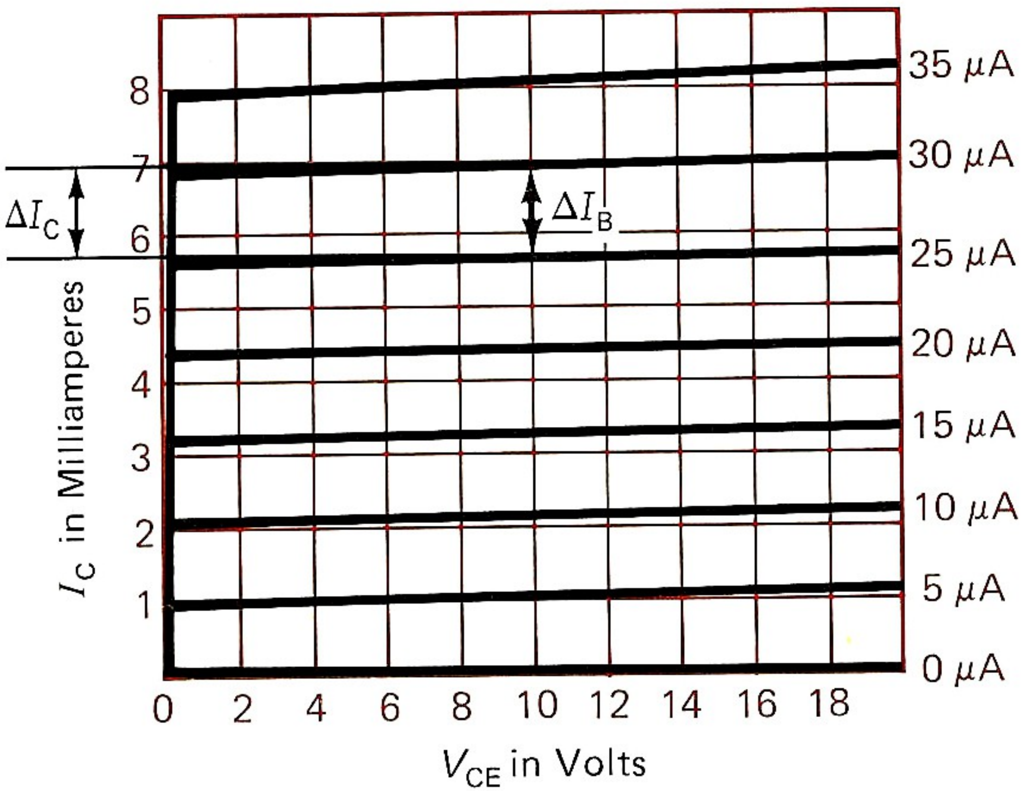
Here's an improved circuit, also showing an AC coupled input. The cap at the input prevents the signal generator's output-impedance from upsetting the bias.

Note the addition of a resistor in the emitter.



These are the designated voltage drops in our common-emitter circuit example



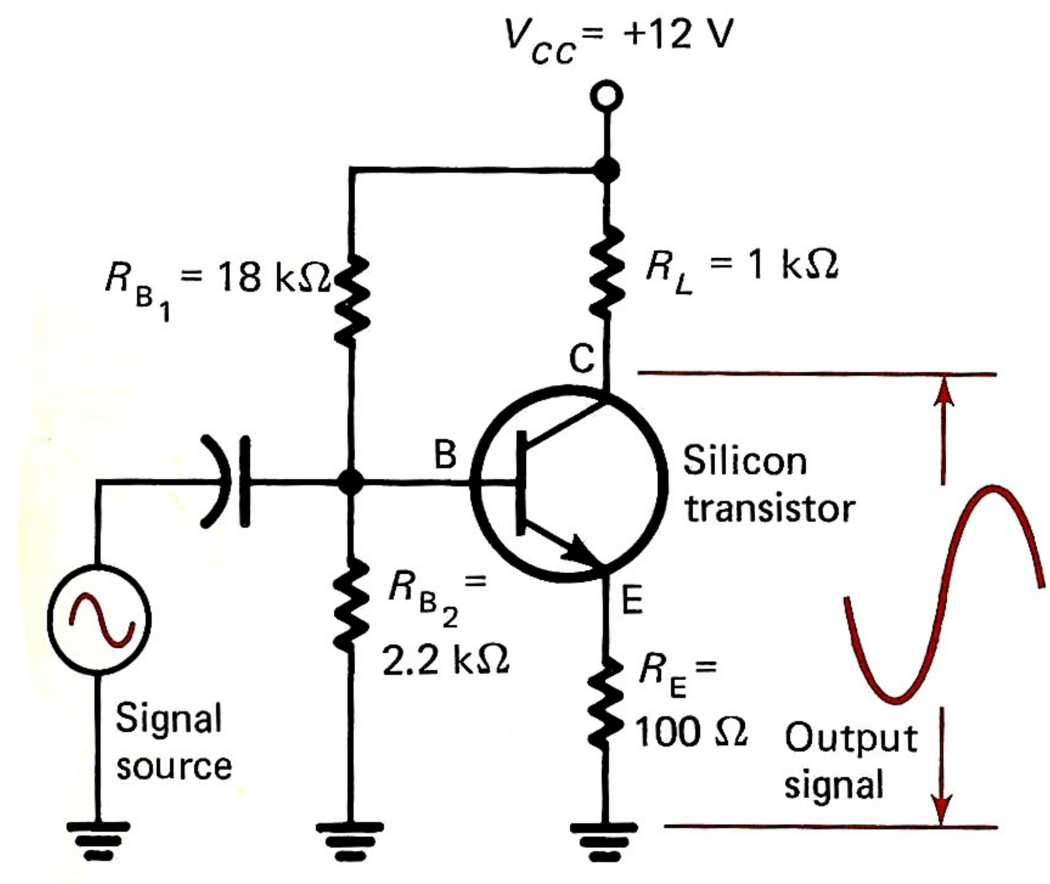


$$\beta_{ac} = h_{fe} = \frac{\Delta I_C}{\Delta I_B} = \frac{1.3\ \text{mA}}{5\ \mu\text{A}} = 260$$

Generating a family of curves in the lab for a device can then be used to determine gain. In this example the gain is *260.*

Here's a common-emitter BJT circuit using typical values of resistors, and an input coupling cap to block the DC bias from getting to the signal generator.

Blocking cap ->>



In this circuit using an emitter-resistor, if the supply voltage V_{cc} increases, the transistor's collector current would also increase.

If the collector current increases, the emitter current will also increase, causing the voltage drop across the emitter-resistor to increase. That causes an increase in base voltage because $V_B = V_E + V_{BE}$.

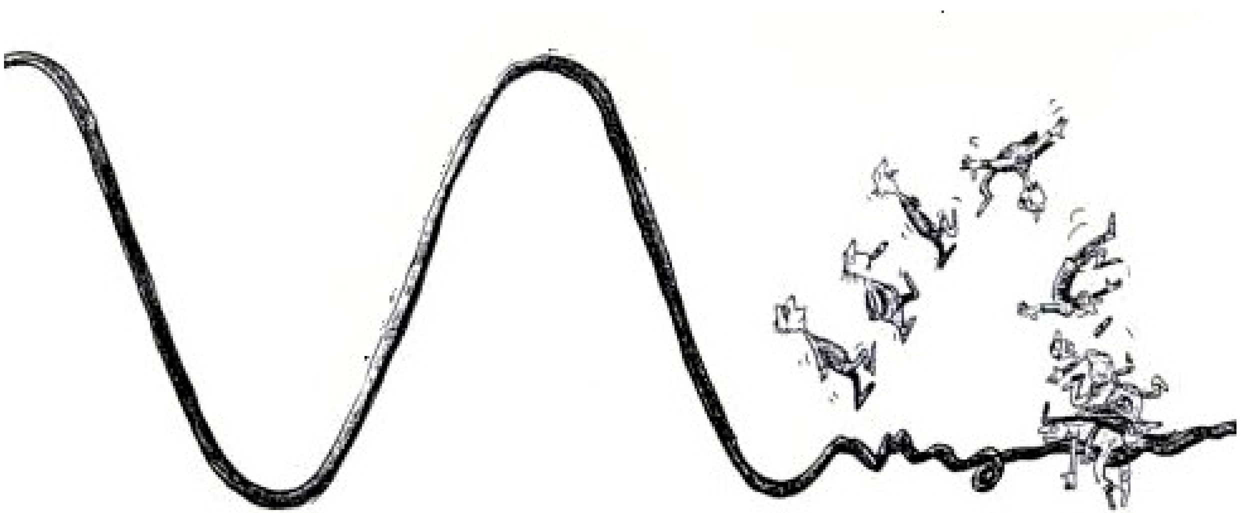
But, since the base is held constant by the base divider resistors, the DC voltage on the base <u>relative</u> to the emitter voltage is *lowered*.

That reduces the already low base current, which in turn, keeps the collector current from increasing!

A similar action occurs if the supply voltage and collector current try to decrease.

The result:

The addition of the emitter-resistor helps control the transistor' base-bias using what's called *negative feedback.* The negative feedback negates any attempted change in collector current with an opposing change in the base bias voltage.

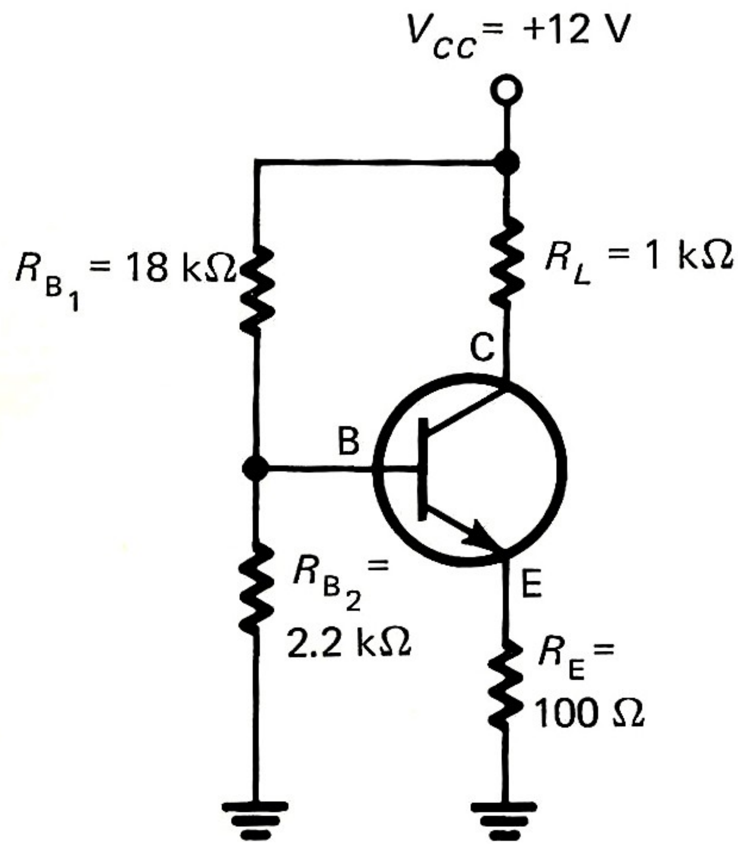


The circuit tends to be stabilized at a fixed level!

The amplifier's bias voltage is stabilized by placing the resistor in the transistor's emitter circuit.

The addition of the *emitter resistor* means the transistor's emitter is no longer grounded at zero volts. It now sits at a small potential above ground.

Once again, here's our example NPN BJT circuit, with DC components only, and no coupling caps at input or output



Using Ohm's Law:

$R_{b1} + R_{b2}$ = 18 kohms + 2.2 kohms = 20.2 kohms

Then I = E/R = 12V/20.2 kohms = 594 uA

Then E_b = I x R_{b2} = 594 uA x 2.2 kohms = 1.307V

It's close enough to say that 1.3V is firmly established at the base of the XSTR with respect to ground.

Now, the base voltage establishes the emitter voltage

The base to emitter "diode" drop is 0.7V, so the emitter voltage is

$1.3V – 0.7V = 0.6V = V_e$

Knowing that, you can determine the emitter resistor's current flow.

$I_e = V_e / R_e = 0.6V / 100$ ohms $= 6$ mA.

Remember, the collector current is essentially the same as the emitter current, as the the emitter-to-base current is *very* low.

The collector current in our common-emitter example is 6 mA.

Keep that value in mind for a moment.

Multiplying the collector current and the collector load resistor values reveals the IR drop across the collector resistor.

So, 6 mA x 1000 ohms = 6V. This is half the applied voltage (V_{cc}). Therefore you can safely say the transistor is operating in the middle of its range of output swing.

The XSTR's collector voltage can swing from 0V to 6V. It's a Class A amplifier, with a Q point near the middle of the load line.

Voltage gain can also be determined by estimating what's called the *ac resistance* of the emitter of the BJT.

The *ac resistance* is partially determined by the dc emitter current.

Semiconductor engineers refer to the so-called *ac resistance* as r_E

Semiconductor engineers also tell us that

$$r_E = \frac{25\ \text{mV}}{I_E}$$

So, in our example common-emitter circuit we can establish the *ac resistance* using this textbook formula.

Recall the 6 mA (actually 6.07 mA) of emitter/collector current derived earlier.

$$r_E = \frac{25\ \text{mV}}{6.07\ \text{mA}} = 4.12\ \Omega$$

Next, the voltage gain (A_V) can now be found. --- >>

Using this relationship:

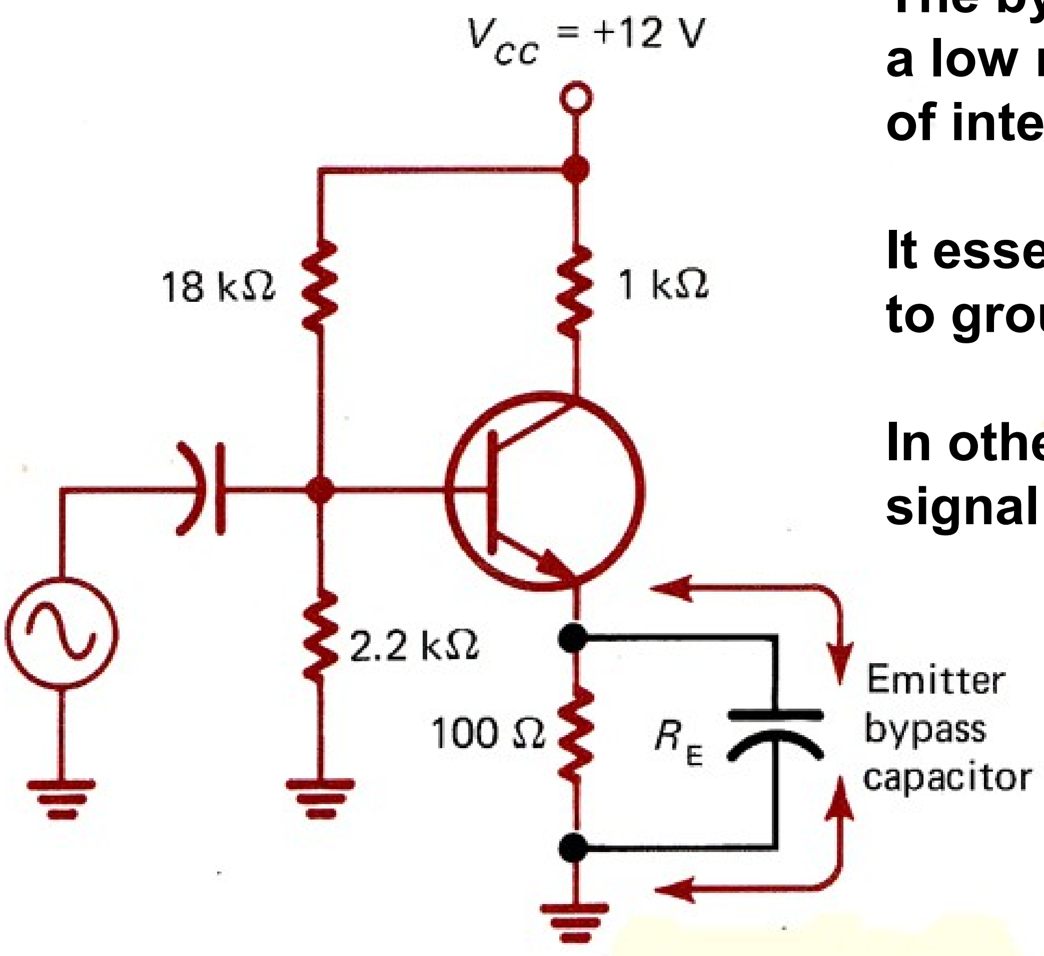
$$A_V = \frac{R_L}{R_E + r_E}$$

In our example common-emitter BJT circuit the gain is therefore 9.6.

$$A_V = \frac{1000\ \Omega}{100\ \Omega + 4.12\ \Omega} = 9.6$$

i.e. **if the input voltage is 1V peak-to-peak, then the output voltage will be 9.6V p-p**

How about a higher gain figure? Gain can be increased by adding an *emitter bypass* capacitor.



The bypass cap is chosen to have a low reactance at the frequency of interest.

It essentially shorts the ac signal to ground.

In other words, it bypasses the signal around the emitter resistor.

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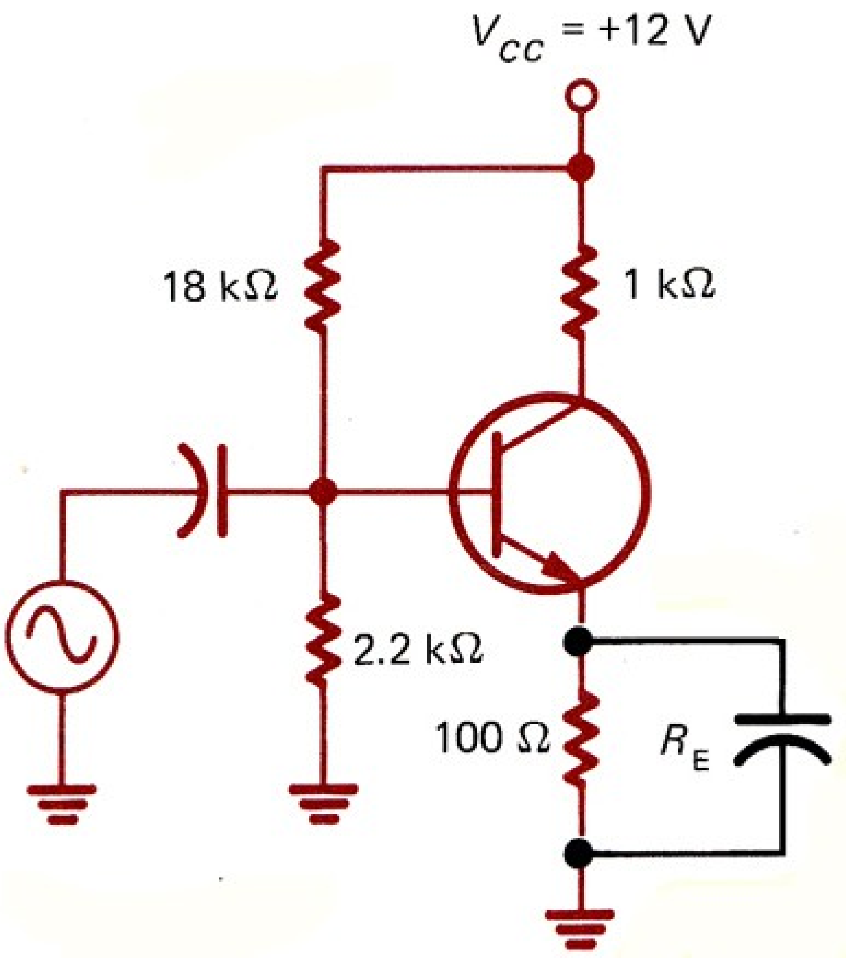
Now, recall that

$$A_V = \frac{R_L}{r_E}$$



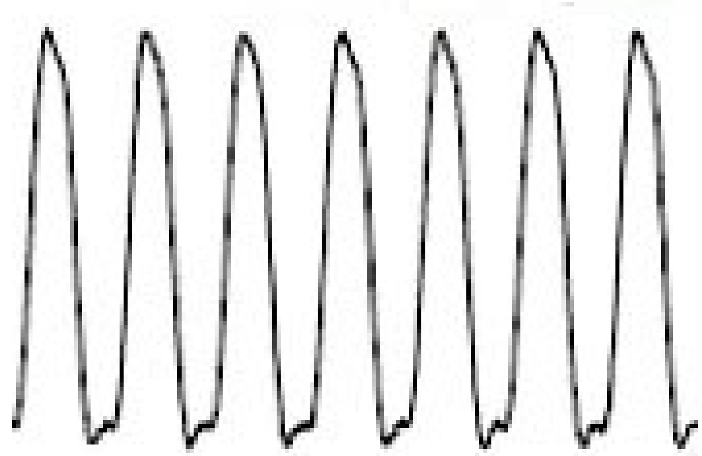
So,

$$A_V = \frac{1000\ \Omega}{4.12\ \Omega} = 243$$

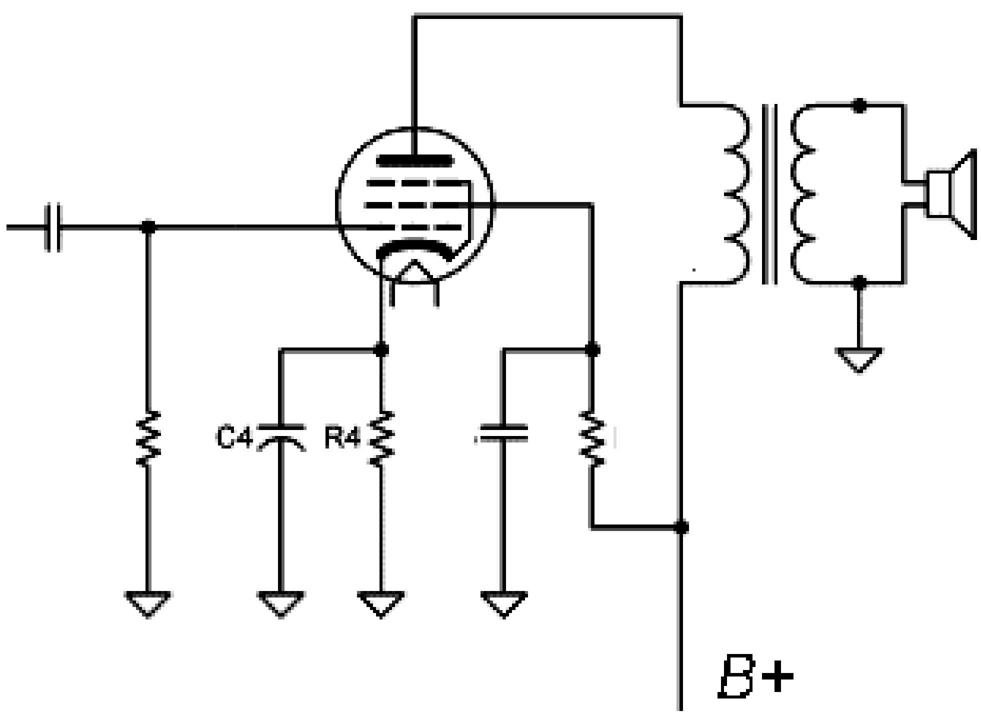
Not a bad gain increase just for adding a cap, eh?

The trade-offs

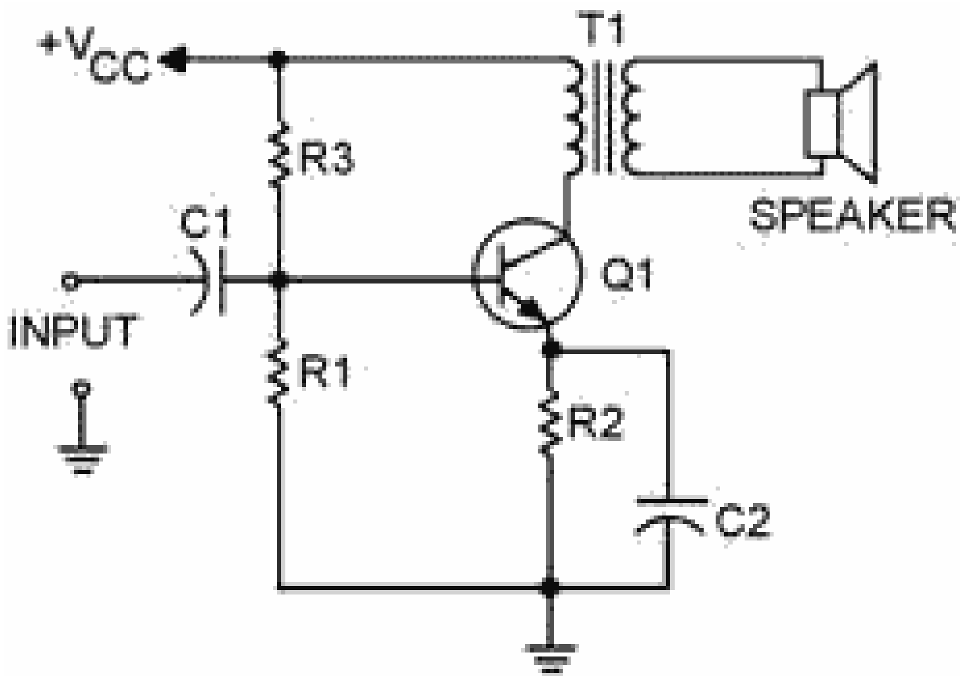
(1) The bypass cap is an additional component; and cost
(2) the cap affects the input-impedance of the amplifier
(3) the cap limits the amp's frequency range of operation
(4) The cap may distort the output signal



Here's a schematic of a vacuum tube audio amplifier stage driving a loudspeaker. The input signal is coupled to the control grid of the pentode tube through a capacitor. Note the cathode bypass capacitor C4 across cathode resistor R4.

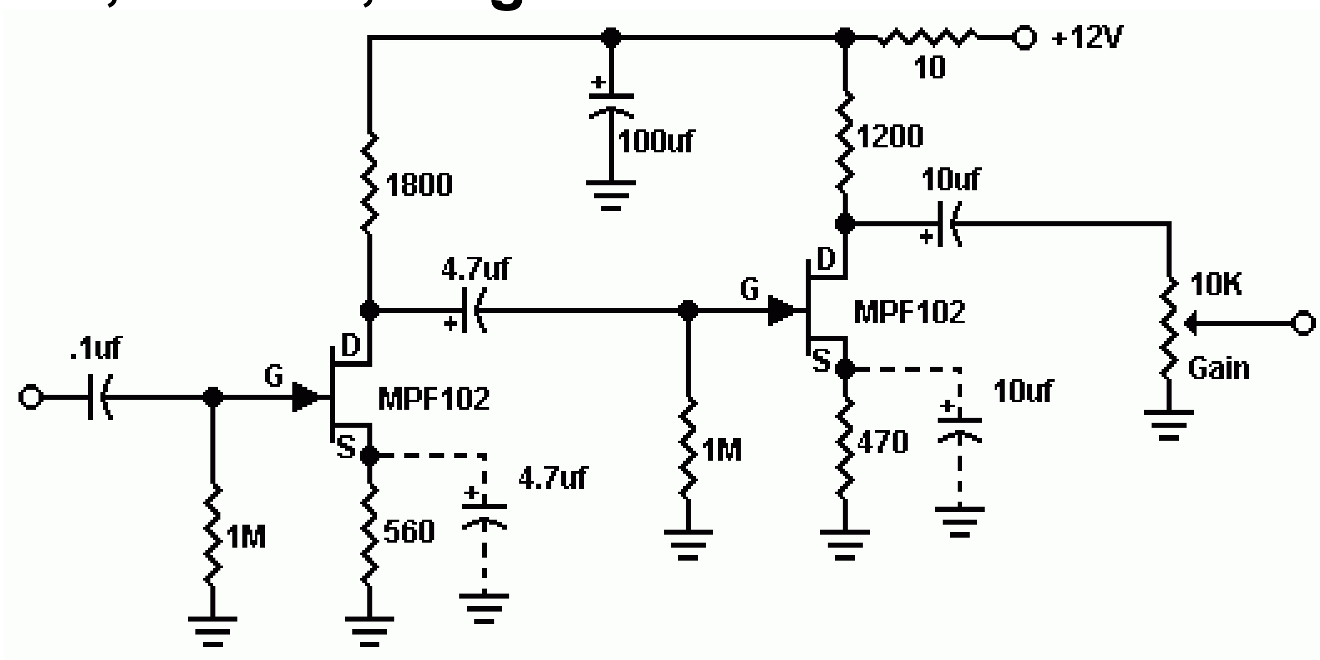


Here's a schematic of a single xstr audio amplifier stage driving a loudspeaker. The input signal is coupled to the base of the NPN device through capacitor C1. Note the emitter bypass capacitor C2 across emitter resistor R2.



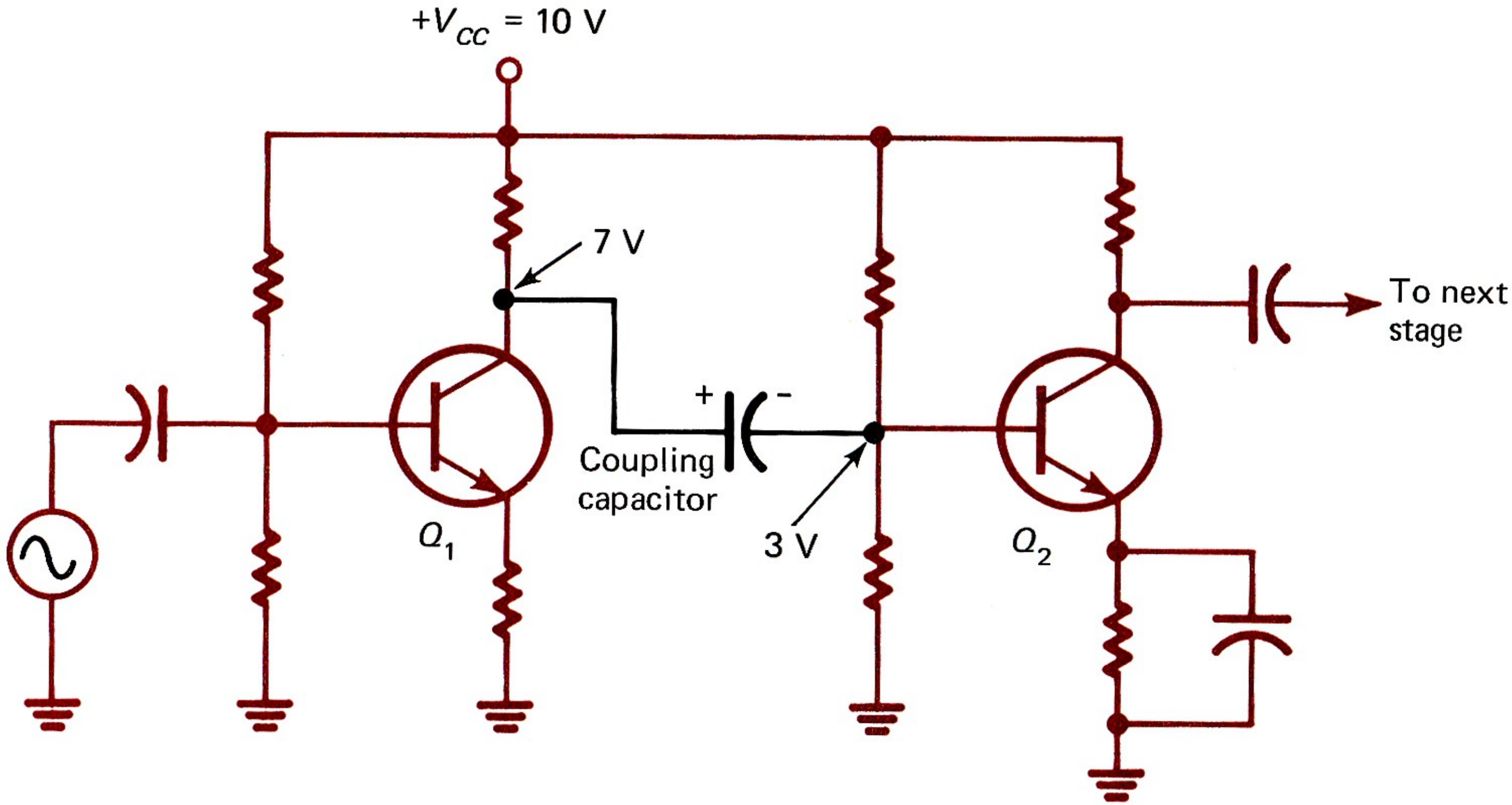
This schematic shows two N-channel field effect xstrs (FETs) in an audio amplifier (perhaps used as a pre-amp ahead of a power amplifier driving a loudspeaker).

The input signal is coupled to the gate of the first FET through a 0.1 uF cap. The dotted lines show how source bypass caps can be added to increase gain of one, or both, stages.



The 4.7 uF cap has about 17 ohms of reactance at 2 kHz. The 10 uF cap has about 8 ohms of capacitive reactance.

Overcoming disadvantages



Until next time, 73 de AI2Q