Lecture 30: Audio Amplifiers

Once the audio signal leaves the Product Detector, there are two more stages it passes through before being output to the speaker (ref. Fig. 1.13):

1. Audio amplification,
2. Automatic gain control (AGC).

We'll discuss each of these separately, beginning with audio amplification in this lecture.

In the NorCal 40A, the Audio Amplifier is the LM386N-1 integrated circuit. The LM38x amplifier series is quite popular.

A simplified equivalent circuit for the LM386 is shown in Fig. 13.1 and in the data sheet beginning on p. 399 of the text:
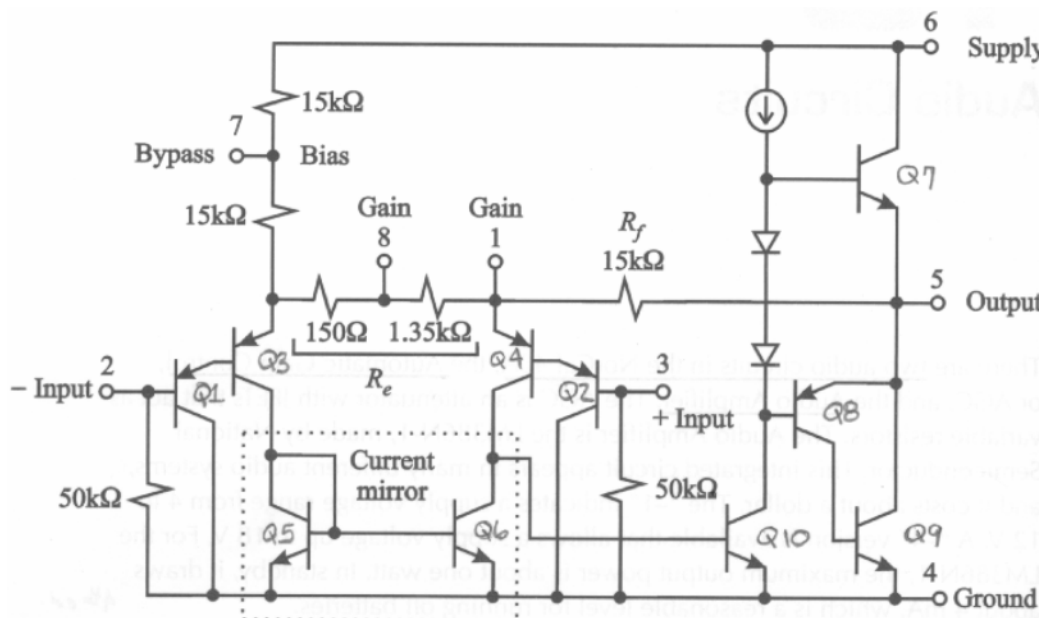

Figure 13.1. Schematic for the LM386N-1 Audio Power Amplifier, from the National Semiconductor data sheet in Appendix D.

We'll describe the operation of this circuit beginning near the input. (Note that Sedra and Smith, 5th edition, Sec. 14.8 has a nice description of a closely related circuit: the LM380 IC.)

There are three stages of amplification in the LM386:
    1. *pnp* common-emitter amplifiers (Q1 and Q2),
    2. *pnp* differential amplifier (Q3 and Q4),
    3. Class AB power amplifier (Q7 and Q8+Q9).

For the remainder of this lecture, we'll step through the LM386 equivalent circuit and explain the operation of each part.

• Q1 and Q2:
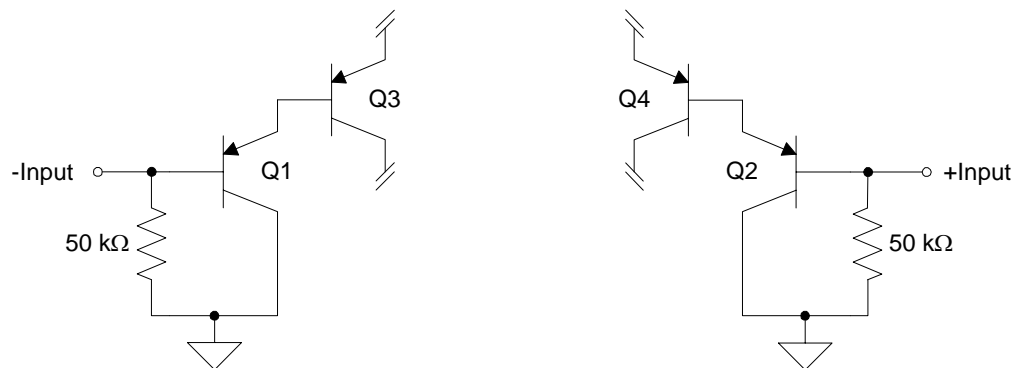
Q1 and Q2 are *pnp* emitter follower amplifiers. These provide buffering of the input to the LM386.

The 50-kΩ resistors provide dc paths to ground for the base currents of Q1 and Q2. Consequently, the input should be capacitively coupled so to not disturb this internal biasing.

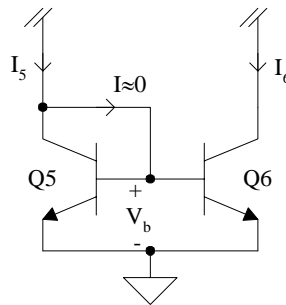Because of these resistors, the input impedance will be dominated by these 50-kΩ resistors.

*   Q3 and Q4 with R$_e$:
    Q3 and Q4 form a *pnp* differential amplifier:
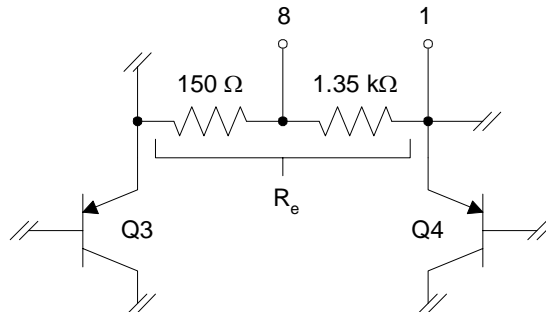
*   Q5 and Q6:
    The differential amplifier is biased by the current mirror formed by Q5 and Q6:

In the current mirror, $\boxed{I_6 \approx I_5}$. To see this, notice that $V_{be} = V_b$ for both transistors. With

$$I_c = I_{cs} e^{V_b / V_t} \tag{13.1}$$

and V_b the same for both transistors, then

$$I_{c5} = I_{c6}$$

provided the two transistors are matched. This implies that $I_5 \approx I_6$, if we neglect the base currents wrt the collector currents. This is valid if the β's are large.

This current-source biasing provides a reliable bias and considerably simplifies the analysis of amplifier circuits.

Signal Gain of the LM386

We're now in a position to compute the signal gain provided by the LM386. We'll see that the Audio Amplifier is providing much of the total gain in the NorCal 40A receiver.

The current mirror forces the currents on both halves of the differential amplifier to be equal: both dc and ac components.

Consequently, the currents i at the emitters of Q3 and Q4 must be the same, as shown in Fig. 13.2(c):
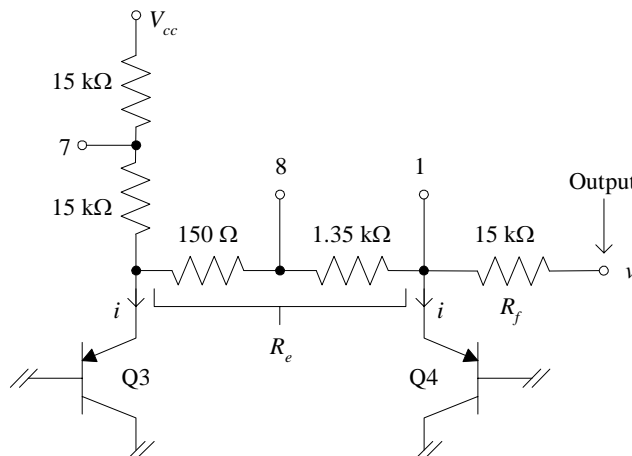
From this circuit, the small signal ac model is:
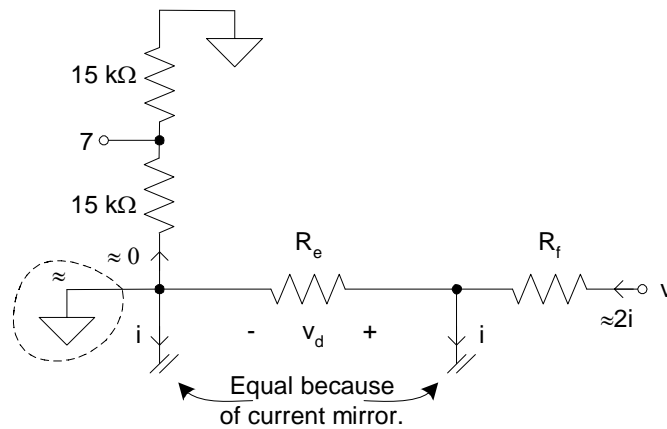
Notice that the voltage across R_e is simply the differential input voltage v_d. Why? Because the base-emitter voltage drops in the *pnp* transistors are the same on each side of the diff amp! Therefore, the voltage across R_e is v_d. Tricky.
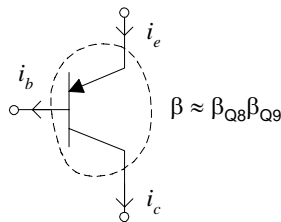
Due to the mirror, the current through $R_f \approx 2i$, neglecting the current in the two 15-kΩ resistors (which are large impedances relative to the other parts of the circuit). Therefore,

$$\frac{v - v_d}{R_f} \approx 2i \tag{1}$$

Now, the output voltage *v* is produced by a so-called "class AB" power amplifier:
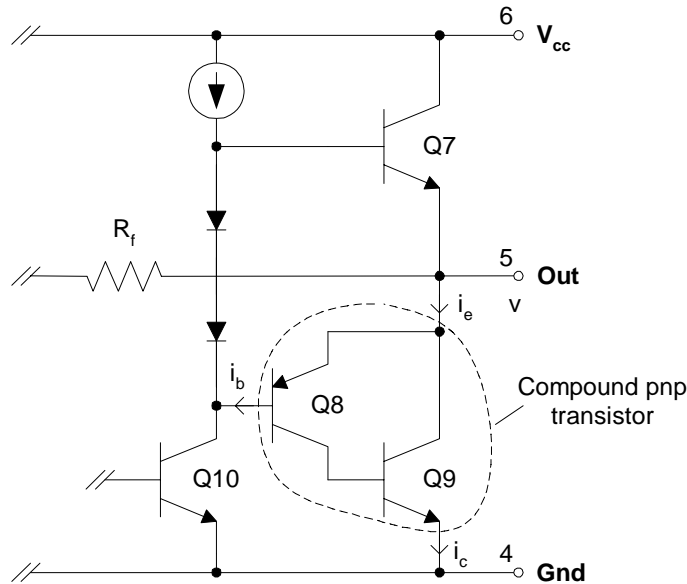
The combination of Q8 and Q9 is called a "compound *pnp* transistor":

Notice that $\beta \approx \beta_{Q8}\beta_{Q9}$, which is easy to show starting with $i_{c8} = \beta_{Q8}i_{b8}$ and $i_{c9} = \beta_{Q9}i_{b9}$. Compounding *pnp*'s was done in early IC's to improve the traditionally poor performance of *pnp* transistors wrt frequency response, etc. That's not much of a problem today.

Section 10.6 of the text has a discussion on class AB (and class B) power amplifiers. The result, in any event, is that the output voltage *v* will be much larger than v_d. Therefore, from (1)

$$\frac{v}{R_f} \approx 2i \tag{13.4}$$

Also, from the small-signal model shown above, we can see that

$$i = \frac{v_d}{R_e} \tag{13.5}$$

Combining these last two results, we find that
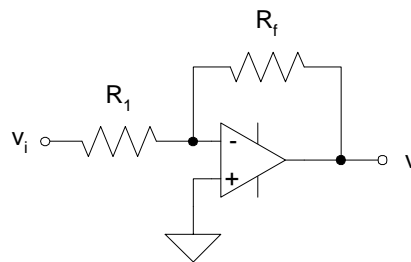
$$\frac{v}{R_f} = \frac{2v_d}{R_e}$$

or

$$G_v = \frac{v}{v_d} = 2\frac{R_f}{R_e} \tag{13.6}$$

This is the differential voltage gain of the LM386 audio amplifier.

Notice that this gain does not involve internal device parameters (such as the transistor β's) other than R_f and R_e. Nice.

Have you ever seen such a result as (13.6) before? Sure, with simple operational amplifier circuits such as:

The voltage gain is

$$\frac{v}{v_i} = -\frac{R_f}{R_1}.$$

Similar to an op amp, the LM386 has incorporated feedback *internally* through R_f and R_e, in a fashion similar to this inverting op amp circuit that is using *external* components.

Now, using (13.6), the gain of the LM386 shown in Fig. 13.1 (i.e., no other components attached between pins 1 and 8) is:

$$G_v = \frac{2R_f}{R_e} = 2\frac{15\times10^3}{1.5\times10^3} = 20$$

As you'll discover in Prob. 31, a capacitor can be placed (externally) across pins 1 and 8 of the LM386 to bypass R_e at "high" frequencies [$X_c = (\omega C)^{-1}$]. In such a case,

$$G_v = \frac{2R_f}{R_e} = 2\frac{15\times10^3}{150} = 200$$

This is a sizeable gain at "high" frequencies.

LM386 Connection in the NorCal 40A

The NorCal 40A Audio Amplifier is built in stages in Prob. 31. The first stage of this construction is shown in Fig. 13.6:
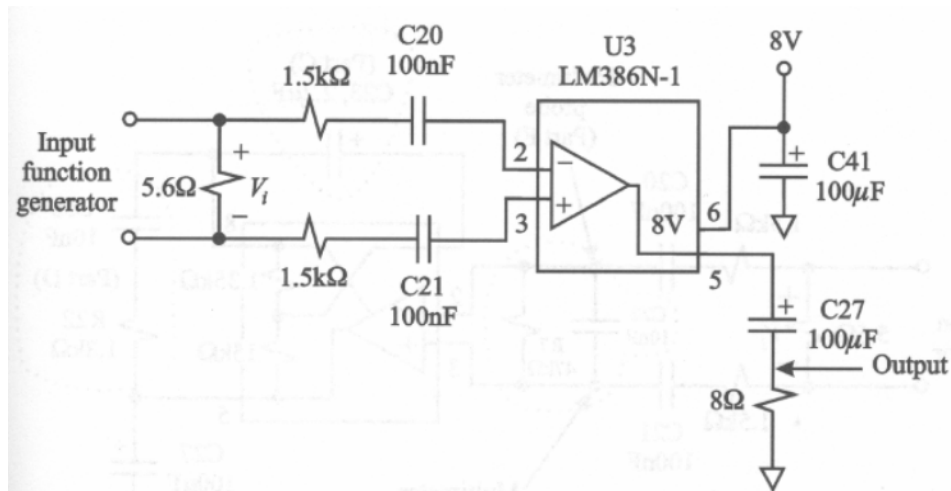
Figure 13.6. Measuring the frequency response of the output network of the Audio Amplifier.

The input is taken differentially, as shown, and is capacitively coupled by C20 and C21 for reasons we discussed on p. 2. Note that with the polarity of V_i shown above, we will expect the gain of this audio amplifier to be the negative of (13.6).

The output is also capacitively coupled. Why? It can be shown that the dc output voltage is $V_{cc}/2$ at pin 5 of the LM386. So once again, we need to capacitively couple in order not to disturb this internal biasing.