

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:

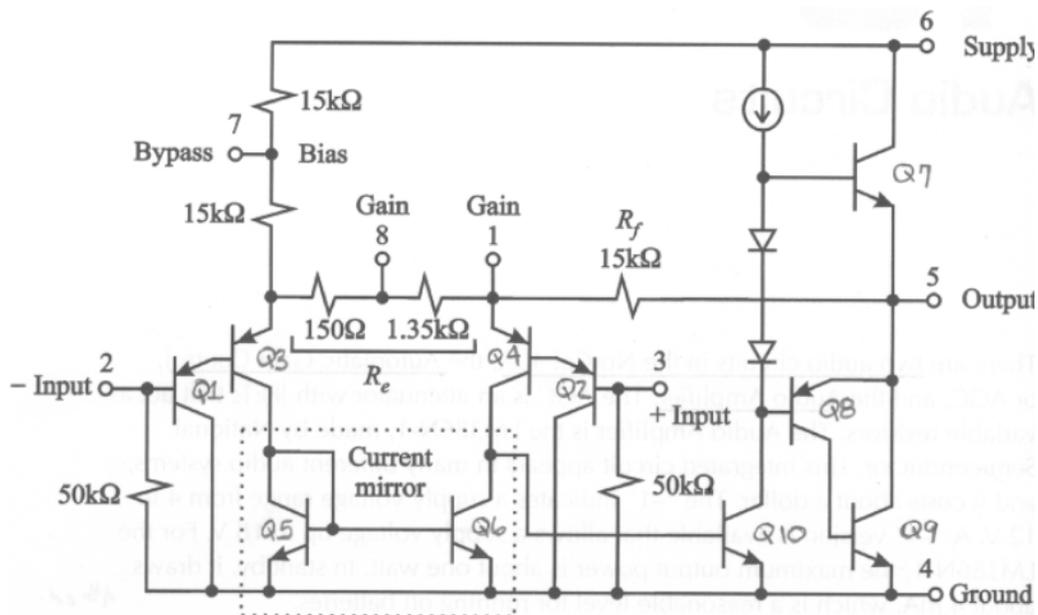


Figure 13.1. Schematic for the LM386N-1 Audio Power Amplifier, from the National Semiconductor data sheet in Appendix D.

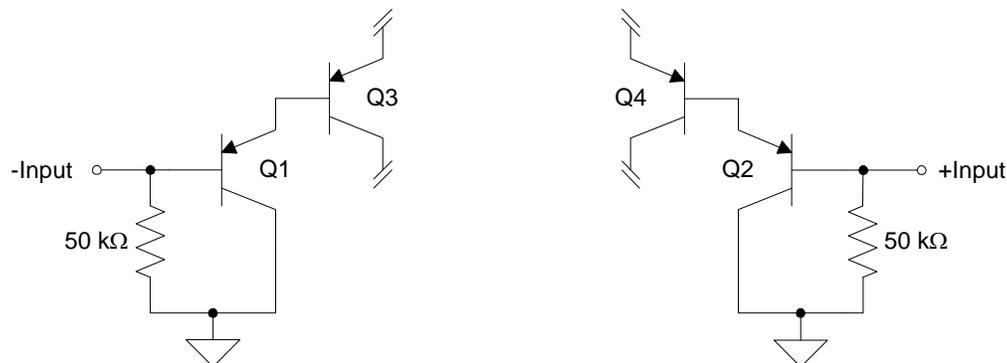
We'll describe the operation of this circuit beginning near the input. (Note that Sedra and Smith, 7th edition, Sec. 12.8.1 has a nice description of a closely related circuit: the LM380 IC.)

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:



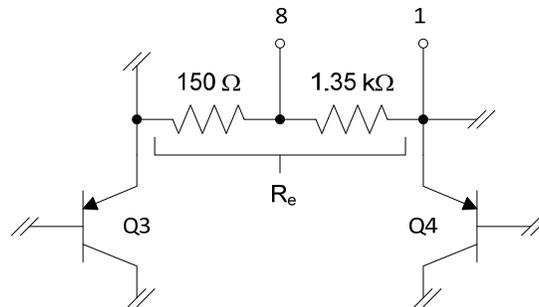
Q1 and Q2 are ***pnp emitter follower*** amplifiers. These provide buffering of the input to the LM386.

The 50-k Ω 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 dc biasing.

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

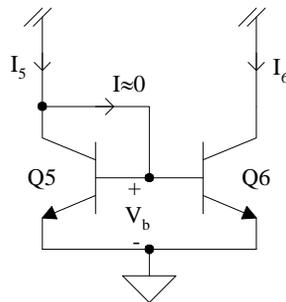
- Q3 and Q4 with R_e:

Q3 and Q4 form a *pn*p differential amplifier:



- Q5 and Q6:

Strictly speaking, the differential amplifier is biased from the Supply (pin 6). However, the **current mirror** formed by Q5 and Q6 does play a role in the biasing by forcing the currents $I_6 \approx I_5$.



To see this, notice that $V_{be} = V_b$ for both transistors. With

$$I_c = I_{cs} e^{V_b/V_t} \quad (13.1)$$

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.

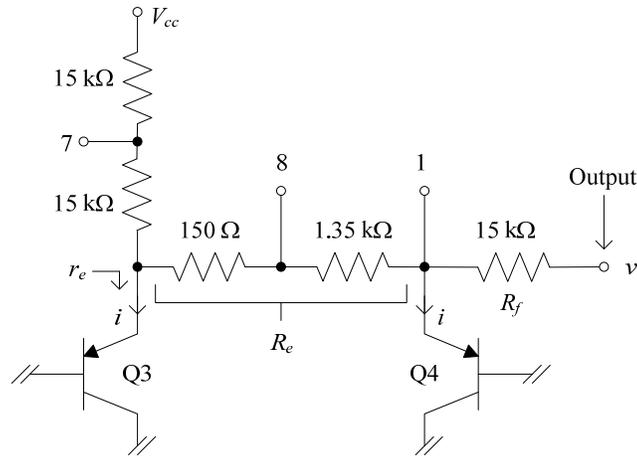
Forcing $I_5 \approx I_6$ is a critical component in the proper operation of this audio amplifier. It also considerably simplifies the analysis of the circuit, as we'll see next.

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:

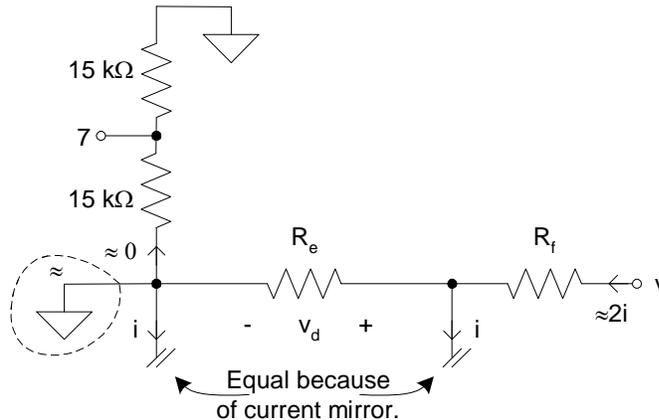


Fig. 1

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.

Note that this *pnp* differential amplifier in the LM386 is **quite different** from the *npn* diff amp we discussed earlier in Lecture 20. For one thing, v_d was the differential output voltage for the

npn diff amp while here for the *pnp* diff amp it's a differential input voltage.

Further, the “gain” from base to emitter is **approximately one** for the *pnp* diff amp, whereas the gain from base to collector could be appreciable for the *npn* diff amp.

Referring back to Fig. 13.2(c), the current through the two 15-k Ω resistors **will be small** relative to i . This is because r_e for an active-mode biased BJT is (See EE 320 *Electronics I* Lecture 14 notes)

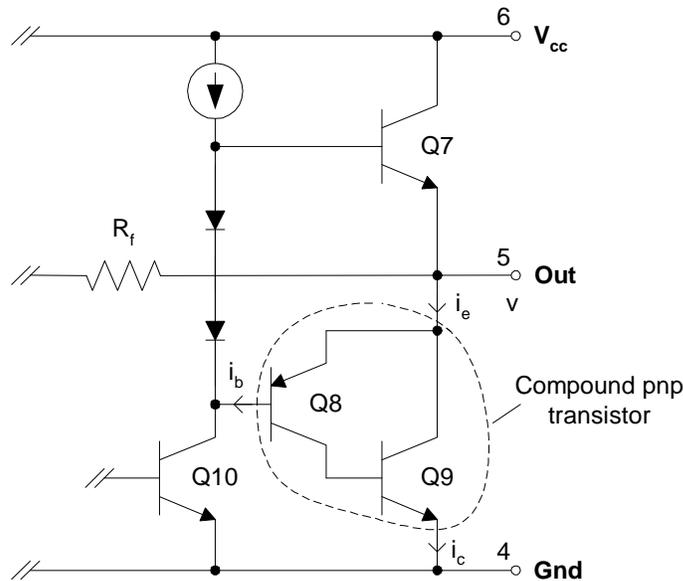
$$r_e = \frac{\alpha}{g_m} \approx \frac{1}{g_m} = \frac{V_t}{I_C} \text{ } [\Omega]$$

and will likely be **on the order of hundreds of Ohms**, which is much smaller than the 30-k Ω presented by the two series 15-k Ω resistors.

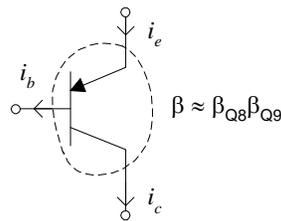
Because of this and because of the current mirror, the current through $R_f \approx 2i$. Therefore, referring to Fig. 1 and the “virtual ac ground” due to the small current in the series 15-k Ω resistors

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

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)

$$\frac{v}{R_f} \approx 2i \quad (13.4)$$

Also, from the small-signal model shown above in Fig. 1, we can see that

$$i = \frac{v_d}{R_e} \quad (13.5)$$

Combining these last two results, we find that

$$\frac{v}{R_f} = \frac{2v_d}{R_e}$$

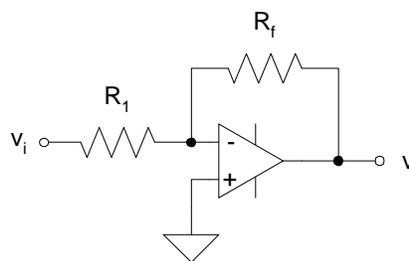
or

$$G_v = \frac{v}{v_d} = 2 \frac{R_f}{R_e} \quad (13.6)$$

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:

$$G_v = \frac{2R_f}{R_e} = 2 \frac{15 \times 10^3}{1.5 \times 10^3} = 20$$

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,

$$G_v = \frac{2R_f}{R_e} = 2 \frac{15 \times 10^3}{150} = 200$$

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:

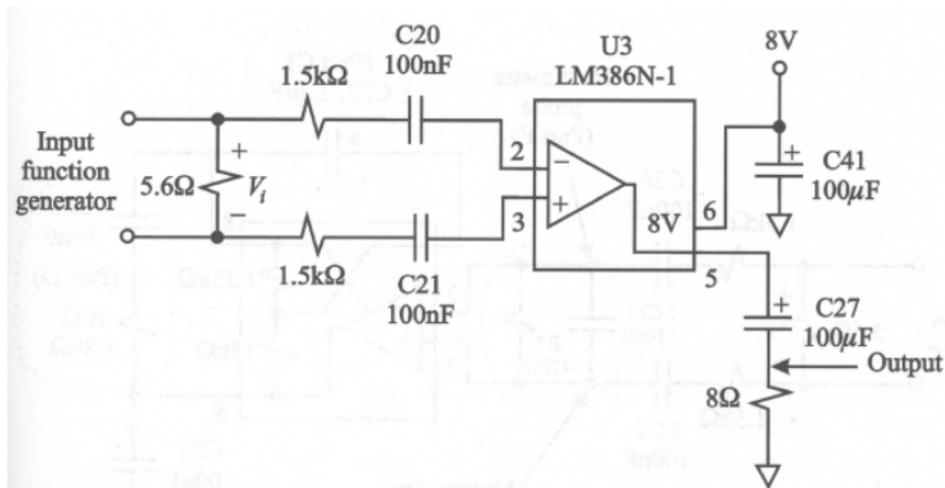


Figure 13.6. Measuring the frequency response of the output network of the Audio Amplifier.

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.