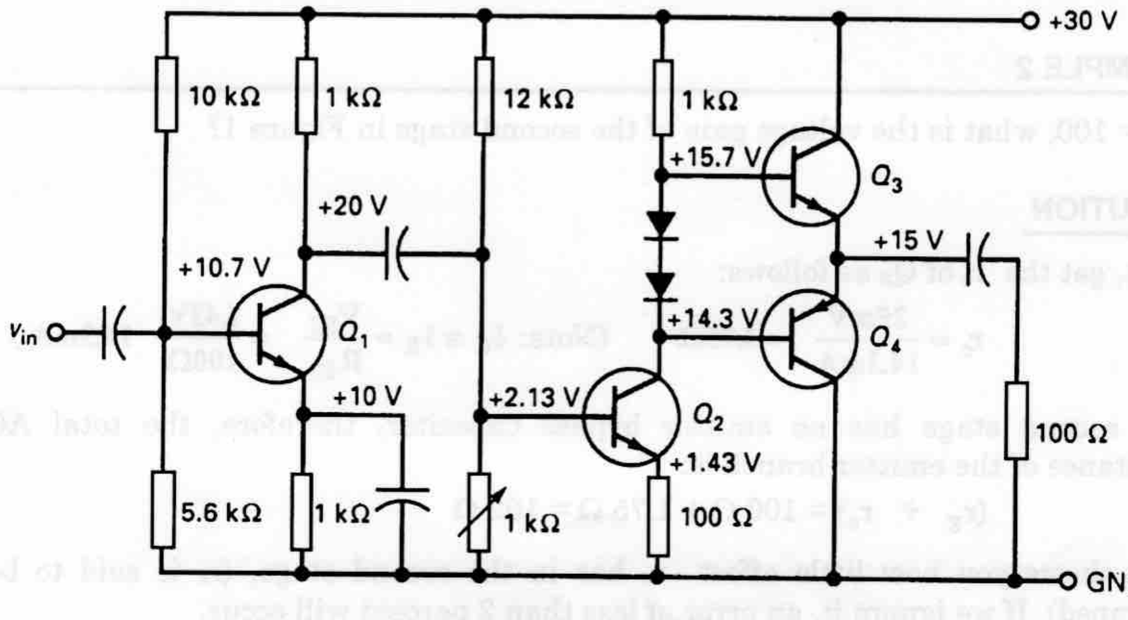
POWER AMPLIFIERS — 1

COMPLETE AMPLIFIER — ANALYSIS

CALCULATING THE GAINS

The three-stage amplifier shown in Figure 1 is fairly complicated, but can be analysed if sensible approximations are used. Stage 1 is a small-signal amplifier, (Q_1), Stage 2 is a large-signal Class A amplifier, (Q_2), acting as a direct-coupled driver to Stage 3 which is a Class B push-pull emitter follower power amplifier, (Q_3,Q_4).



Complete amplifier.

Figure 1 — Complete three-stage amplifier.

The following worked examples, used in conjunction with previous worked examples (on biasing, frequency response and power/efficiency), should help you to consolidate the analysis of a complete amplifier system.

EXAMPLE 1

What is the voltage gain of the first stage in Figure 1? Assume all β's are equal to 100.

SOLUTION

First, get the r_e of Q_1 as follows:

$$r_e = \frac{25\text{mV}}{10\text{mA}} = 2.5\Omega \qquad \left(\text{Note: } I_C \cong I_E = \frac{V_{E1}}{R_{E1}} \frac{10\text{V}}{1\text{k}\Omega} = 10\text{mA}\right)$$

Second, let us work out the input impedance of the second stage. Looking into the base of the second stage, the AC signal sees an impedance of approximately

$$z_{in(base)} = \beta(R_E), = 100(100\ \Omega) = 10\ \text{k}\Omega$$

Notice that we are ignoring the r_e of the second stage. (Note: it is only 1.75 ohm, which is much smaller than the 100 ohm.) The input impedance of the second stage includes the biasing resistors:

$$z_{in} = 12\ k\Omega \parallel 1\ k\Omega \parallel 10\ k\Omega = 844\ \Omega.$$

Third, work out the AC collector resistance of the first stage and the voltage gain. The AC collector resistance is:

$$r_c = R_{C1} \parallel z_{in2}, = 1k\Omega \parallel 844\ \Omega = 458\ \Omega$$

and the voltage gain is:

$$A = \frac{r_c}{r_e} = \frac{458\Omega}{2.5\Omega} = 183$$

EXAMPLE 2

If $\beta = 100$, what is the voltage gain of the second stage in Figure 1?

SOLUTION

First, get the r_e of Q_2 as follows:

$$r_e = \frac{25mV}{14.3mA} = 1.75\Omega \qquad \text{(Note: } I_C \cong I_E = \frac{V_{E2}}{R_{E2}} = \frac{1.43V}{100\Omega} \quad 14.3mA\text{)}$$

The second stage has no emitter bypass capacitor, therefore, the total AC resistance of the emitter branch is:

$$(r_E + r_e) = 100\ \Omega + 1.75\ \Omega = 102\ \Omega$$

This shows you how little effect r_e has in the second stage, (r_e is said to be swamped). If we ignore it, an error of less than 2 percent will occur.

Second, let us work out the input impedance of the third stage.
The third stage operates class B. This means that only one of the transistors is conducting at a time. No matter which is conducting, the input impedance looking into its base is:

$$z_{in(base)} = \beta(r_{EQ3,4}), = 100(100\ \Omega) = 10\ k\Omega$$

Third, work out the AC collector resistance of the second stage.
The collector of Q_2 sees two conducting diodes in series with 1 kΩ. The DC current through these diodes is approximately equal to the DC current through the emitter resistor of the second stage, which is 14.3 mA. Therefore, each diode has an AC resistance of:

$$r_{ac} = \frac{25mV}{14.3mA} = 1.75\Omega$$

This AC resistance is much smaller than the 1 kΩ collector resistor of the second stage. Therefore, in the AC equivalent circuit we can ignore the AC resistance of the two diodes.

This is why it is valid to say that the AC collector resistance of the second stage is approximately:

$$r_c = 1\ \text{k}\Omega \,\|\, 10\ \text{k}\Omega = 909\ \Omega.$$

This is the parallel equivalent of the 1 kΩ in the second stage and the 10 kΩ of input impedance for the third stage.

Now, we can calculate the voltage gain of the second stage:

$$\mathbf{A} = \frac{r_{c2}}{r_{e2}} = \frac{909\,\Omega}{102\,\Omega} = 8.91$$

Because of the swamping effect of the unbypassed resistor in the emitter of the second stage, most people would ignore the r_e and calculate a voltage gain of:

$$\mathbf{A} = \frac{909\,\Omega}{100\,\Omega} = 9.09$$

In fact, a troubleshooter looking at the second stage of Figure 1 would think along these lines:

> The input impedance of the third stage is much larger than 1 kΩ so I can ignore it. The AC resistance of the two diodes is much smaller than 1 kΩ so I can ignore the diodes. That means that the collector of the second stage sees only 1 kΩ. Since the second stage has a swamping resistor of 100 Ω, the voltage gain is approximately:
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> $$\mathbf{A} = \frac{1\,\text{k}\Omega}{100\,\Omega} = 10$$

A designer probably would prefer the first or second answer, because the additional accuracy improves one's confidence in the design. But a troubleshooter doesn't need much accuracy because troubles cause large changes from normal values.

Remember, there is never only one right answer to a real-life situation. There is only a best answer selected from several right answers.
The best answer depends on your goal and the reason for analysing the circuit. Don't accept the idea that there is only one correct way to do anything. There are many ways to solve problems. The goal determines which way is the best way.
If your goal is to design a circuit, the goal will shape your thinking and control the level of approximation you use. If your goal is to find out why a circuit is not working, this goal will change your approach and the desire for accurate answers. Therefore, stay flexible in every situation, use your head as much as possible, and do it your way at all times.

EXAMPLE 3

What is the voltage gain of the three-stage amplifier in Fig. 1? What is the value of compliance (MPP) for the output stage? What is the approximate input voltage that produces the MPP?

SOLUTION

The third stage is an emitter follower. Each bias compensating diode has 14.3 mA flowing through it. Therefore, each emitter diode in the final stage has 14.3 mA, (due to the "current mirror"), which is equivalent to an r_e of 1.75 Ω. This means the third stage has a voltage gain of:

$$A = \frac{R_L}{(r_{E2} + r_e)} = \frac{100\Omega}{100\Omega + 1.75\Omega} = 0.983\ \Omega$$

In previous examples, we found that the first stage had a gain of 183 and the second stage had a gain of 8.91. The total gain of the amplifier is the product of the three stage gains:

$$A_T = (183)(8.91)(0.983) = 1603$$

Here is how you get the compliance (MPP) of the third stage.
The supply voltage is 30 V, so each transistor in the third stage has a quiescent collector-emitter voltage of:

$$V_{CEQ} = 0.5V_{CC}, = 15\text{ V}$$

You learned previously that compliance (MPP) is two times the value of V_{CEQ}:

$$MPP = 2(15\text{ V}) = 30\text{ V}$$

This is approximately the largest peak-to-peak output voltage without clipping.
The approximate input voltage that produces the MPP is:

$$v_{in} = \frac{V_{out}}{A_v} = \frac{V_{PP}}{A_T} \cong \frac{30}{1600} \cong 18.8\text{ mV}$$

In other words, when the input voltage to the three-stage amplifier is approximately 18.8 mV peak-to-peak, the output voltage is approximately 30 V peak-to-peak. Any further increase in the input voltage will produce clipping of the output signal.