

# EEE225: Analogue and Digital Electronics

## Lecture V

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# This Lecture

- 1 Problems with the Basic Opamp
  - Differential Stage
  - VAS and OPS
  - Voltage amplification stage load resistance
  - The Output Stage's Input Resistance
  - The Output Stage's Output resistance
  - Crossover Distortion and the “amplified diode”
  - An Improved Opamp Design
  - Cascode
  
- 2 A Real Opamp
  - Texas Instruments LM741
  
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## Differential Stage Problems

Problems with the input (differential) stage

- 1 Half of the differential signal is wasted. The collector of  $T_2$  is connected to the negative supply. The output from the differential stage is  $\Delta I$  for a given  $\Delta V$  input (see lecture 3 slide 5) but we can do better...
- 2 The balance of collector current in  $T_1$  and  $T_2$  is difficult to maintain due to loading effect of  $T_3$  - this leads to DC offset at the output.
- 3 The current flowing into the base of  $T_1$  and  $T_2$  is quite high. This input current has to be supplied by the signal source. The basic opamp has a low input resistance compared to a commercial opamp.
- 4 The effective load resistance of the differential stage (approximately // combination of  $R_1$  and  $r_{be3}$ ) is very low so the differential stage has low gain.

## VAS and OPS Problems

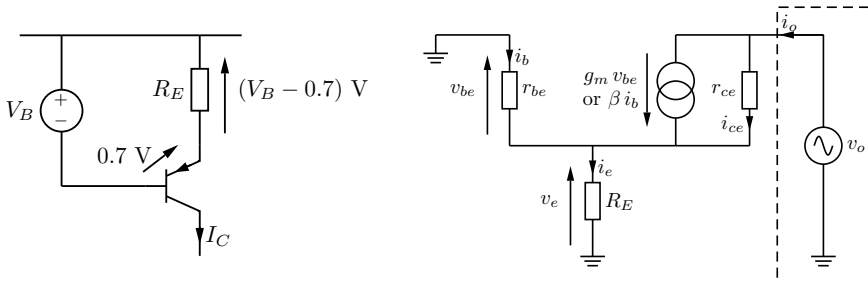
### Problems with the voltage amplification stage

- 1  $R_{VA}$  needs to be quite small to maintain correct DC (quiescent) conditions – the quiescent current of  $T_3$  flows through  $R_{VA}$  – but the gain of the VAS is proportional to  $R_{VA}$  so a very large value is desirable which the DC current does not permit.

### Problems with the output stage

- 1 The input resistance of  $T_4$  and  $T_5$  depends on the external opamp load resistance, this affects the effective load resistance of the VAS altering its gain.
- 2 The output resistance of the emitter follower is dependent on the source resistance driving it.
- 3 Without OPS biasing  $T_4$  and  $T_5$  will give rise to severe **crossover distortion** (as per Amplifier Lab).

From lecture 3, the resistance looking out of  $T_3$ 's collector is  $\approx R_{VA}$ . Increasing the value of  $R_{VA}$  is desirable as it increases gain. However  $T_3$ 's quiescent collector current has to flow through  $R_{VA}$  limiting its value.  $R_{VA}$  can be replaced by a current source (left) and its small signal model (right).



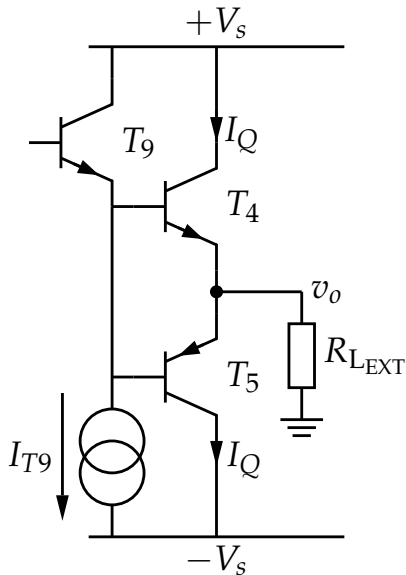
The effective resistance looking into the current source output – its output resistance – will become the new  $R_{VA}$ . For analysis see handout “Small Signal Output Resistance of a Simple Current Source”. In brief  $r_o \approx r_{ce} (1 + \beta)$ .

The output stage's input resistance (looking into  $T_4$  and  $T_5$ ) is affected by the external load resistance  $R_{L_{EXT}}$ . The VAS gain is affected as  $R_{VA}$  is now not so low as to be dominant.  $T_9$  can be added to partially overcome this loading effect.  $T_9$  forms a Darlington pair with whichever of  $T_4$  or  $T_5$  is conducting. The input resistance of  $T_4$  is

$$r_{i4} = r_{be4} + (\beta_4 + 1) R_{L_{EXT}} \quad (1)$$

The input resistance of  $T_9$  is,

$$r_{i9} = r_{be9} + (\beta_9 + 1) r_{i4} \quad (2)$$

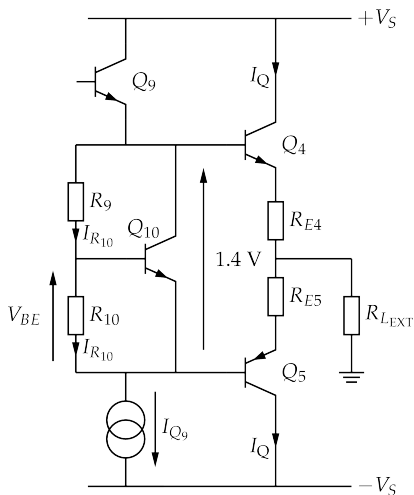


The now higher resistance looking towards  $T_3$ 's collector acts to increase the output resistance of the amplifier as well. The output resistance of an emitter follower is

$$r_o = \frac{r_{be}}{\beta} + \frac{R_S}{\beta} \quad (3)$$

Without  $T_9$  the  $R_S$  for  $T_4$  is the collector load resistance of  $T_3$  which has been made very large to maximise the VAS gain. This increases the OPS output resistance. Including  $T_9$  allows the input resistance of the OPS ( $T_9$ ,  $T_4$  and  $T_5$ ) to be large and the output resistance of the OPS to be small.

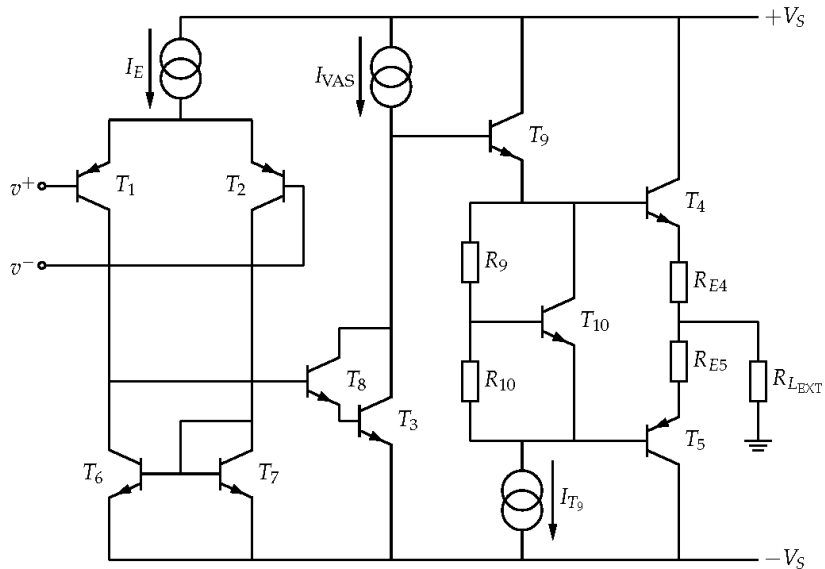
These two problems (firstly the low input resistance of the OPS, and secondly, having increased the source resistance driving the OPS, the OPS output resistance increases) unveil the true nature of the transistor – an imperfect impedance transformer. The ideal OPS would present infinite input resistance to its source and present zero output resistance to its load. Adding  $T_9$  improves the resistance transforming property.



$T_4$  and  $T_5$  don't conduct until  $|V_{BE}| > 0.7 \text{ V}$ .

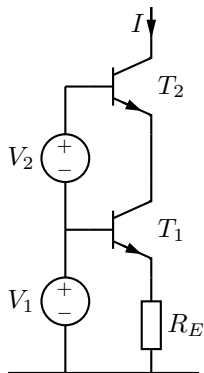
When the bases of  $T_4$  and  $T_5$  are connected together there is a region in which the signal is permanently lost. A circuit to spread the bases by approximately  $2 V_{BE}$  is inserted between them. This is sometimes called an amplified diode. The  $V_{BE}$  of  $T_{10}$  appears across  $R_{10}$  causing a current  $I_{R_{10}}$ . Assume  $I_{B(T_{10})} = 0$  so  $I_{R_{10}}$  must flow in  $R_9$  also. Reducing  $R_{10}$  increases the current through it (voltage is very nearly fixed). The voltage across  $R_9$  must increase...  $I_{R_{10}}$  should be a fraction of  $I_{T_9}$ .



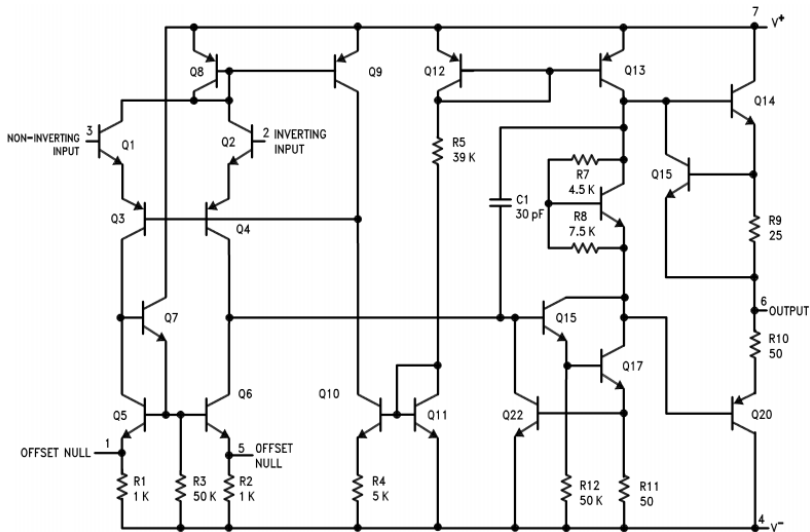


- $I_E$ ,  $I_{VAS}$  and  $I_{T_9}$  set up the DC or quiescent conditions by defining currents.
- Current sources are normally current mirror circuits with one or two additional components to set the DC conditions. The simple current source tends not to see much use.
- The current mirrors can be connected together to allow the ratio of supplied currents to be set. The simple current source has no similar advantage.
- $I_E$  is typically  $10 - 50 \mu\text{A}$ .  $I_{VAS}$  is typically  $100 - 200 \mu\text{A}$  and  $I_{T_9}$  is typically  $1 - 5 \text{ mA}$
- This improved circuit reduces all of the problems. However it is one possible implementation of a simple opamp. Real opamps tend to be somewhat more complicated.
- Notice the general lack of resistors - transistors are easy to produce in ICs, resistors (especially precise values) are difficult and expensive. Designers will always use one or more transistors if possible.

- A common emitter amplifier ( $T_1$ ) connected to the input of a common base amplifier ( $T_2$ ).
- Prevents voltage swing on the collector of ( $T_1$ ) by making the resistance looking into  $T_2$ 's emitter small.



- Enhances the bandwidth of the CE stage by reducing the “Miller effect”.
- Depletion capacitance of  $T_1$ 's reverse biased CB junction couples signal voltages from the collector to the base developing undesirable negative feedback effect – overcome by preventing significant voltage swing on this node.
- The voltage swing on  $T_2$ 's collector is OK because  $T_2$ 's base is a fixed voltage - it does not have the input signal on it and is a low resistance path to ground for signals.



## Review

- Introduced a one transistor current source
- Re-iterated concept of transistor as an active component for transforming resistances (a transfer-resistor) by looking at the OPS input and output impedances
- Introduced the amplified diode, and cascode circuit
- Briefly discussed a simplified schematic of a real opamp (circa 1968).

The key points about these integrated circuit building blocks are,

- 1 To understand the bigger circuits one must first be confident with all their various circuit blocks.
- 2 To put the circuit blocks together one must appreciate how they are likely to interact.
- 3 Reducing the problem to the components which are dominant is one key to an easy analogue life...
- 4 ...the other is practice, and reading!

