

EEE225: Analogue and Digital Electronics

Lecture III

James E. Green

Department of Electronic Engineering
University of Sheffield
j.e.green@sheffield.ac.uk

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This Lecture

- 1 Problems with the Basic Opamp
 - Differential Stage
 - VAS and OPS
 - Problems with the Output Stage
- 2 Solutions...
 - Input Stage Balance and Gain
 - Voltage amplification stage biasing current and input resistance
 - Voltage amplification stage load resistance
- 3 Review
- 4 Bear

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Problems with the Basic Opamp
Differential Stage

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 ΔI for a given ΔV 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.

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Problems with the Basic Opamp
VAS and OPS

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).

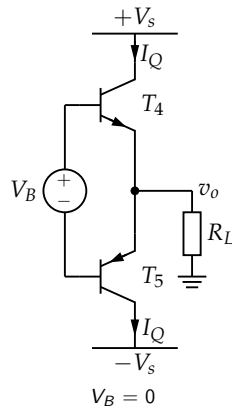
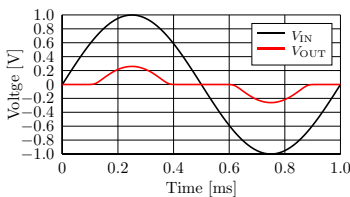
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Problems with the Basic Opamp
Problems with the Output Stage

Briefly discussed in Lecture 3, where OPS biasing was considered,

- 1 In terms of the magnitude of the signal current compared to the quiescent current.
- 2 In terms of the **angle of conduction** of T_4 and T_5 as a fraction of one cycle (360°)



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Solutions...
Input Stage Balance and Gain

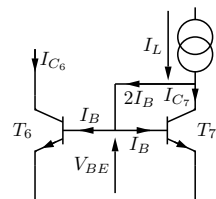
Input Stage Balance and Gain - Current Mirrors

- Assume T_6 and T_7 are identical
- Circuit tries to make $I_{C6} = I_L$
- Collector and base of T_7 connected together
- Base of T_6 and T_7 connected together
- Emitters of T_6 and T_7 connected together
- V_{BE} identical for both transistors

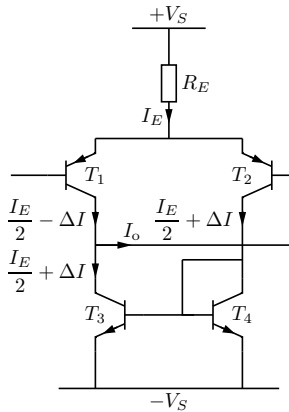
I_L develops a V_{BE} sufficient to make T_7 conduct a current $I_{C7} = I_L - 2I_B$

$$I_L = I_{C7} \left(1 + \frac{2}{h_{FE}} \right) \quad (1)$$

$$I_{C7} = I_L \frac{h_{FE}}{2 + h_{FE}} \quad (2)$$



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Suppose T_1 's base is slightly positive with respect to T_2 's. Considering the action of the current mirror we can sum currents at the collector of T_3 .

$$I_o = \frac{I_E}{2} - \Delta I - \left(\frac{I_E}{2} + \Delta I \right) \quad (3)$$

$$I_o = -2\Delta I \quad (4)$$

The output signal current from the differential stage has been doubled. And the quiescent currents in T_1 and T_2 are now nearly identical.

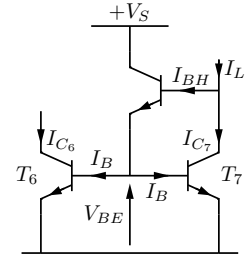
- The mirror is not perfect however as the mirroring depends on h_{FE} .
- In reality the transistors will not be identical.
- The error due to finite h_{FE} can be reduced by using a "β helper" transistor.

Assuming all transistors have the same h_{FE}

$$I_{BH} = \frac{2 I_B}{h_{FE}} \quad (5)$$

$$I_L = I_{C7} + I_{BH} \quad (6)$$

$$= I_{C7} \left(\frac{h_{FE}^2 + 2}{h_{FE}} \right) \quad (7)$$



For small signals, h_{FE} becomes β and the small signal Early resistance of T_7 , r_{ce} conducts a small part of i_L into the negative rail.

The main cause of imbalance of current in the differential pair collectors is the base current flowing into the VAS. A second transistor can be added to the VAS to form a Darlington pair.

$$I_{E3} = I_{C3} + I_{B3} \quad (8)$$

$$I_{E3} = h_{FE3} I_{B3} + I_{B3} \quad (9)$$

$$I_{E3} = I_{E8} (h_{FE3} + 1) \quad (10)$$

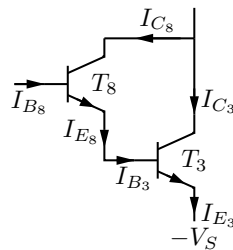
similarly

$$I_{E8} = I_{B8} (h_{FE8} + 1) \quad (11)$$

Eliminating I_{E8} ...

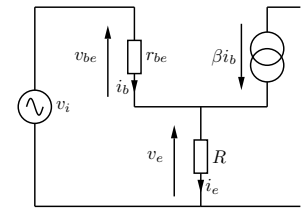
$$I_{E3} = I_{B8} (h_{FE8} + 1) (h_{FE3} + 1) \quad (12)$$

If h_{FE3} & $h_{FE8} \gg 1$, $I_{E3} = I_{C3}$ and $\frac{I_{C3}}{I_{B8}}$ is very large.



For small signals,

- Assume that the input resistance of T_3 is "R".
- Draw a small signal diagram.
- Sum currents at the emitter.
- Sum voltages round the input loop.

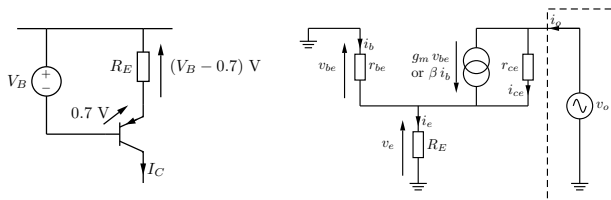


See handout "Small Signal Input Resistance of a Darlington Pair" for a possible solution. But in brief,

$$r_i = r_{be8} + \beta_8 r_{be3} \quad (13)$$

r_i is increased by the β of the (new) upper transistor multiplied by the input resistance of the lower transistor. Remember quiescent currents in T_3 and T_8 will be different and so their g_m 's will be different as a consequence $r_{be8} \neq r_{be3}$, more precisely $r_{be8} \gg r_{be3}$.

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 $r_o \approx r_{ce} (1 + \beta)$.

Review

- Considered problems related to input stage, voltage amplification stage and output stage of the simple opamp.
- Introduced current mirrors (two kinds)
- Introduced the Darlington pair
- Introduced a one transistor current source

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.

