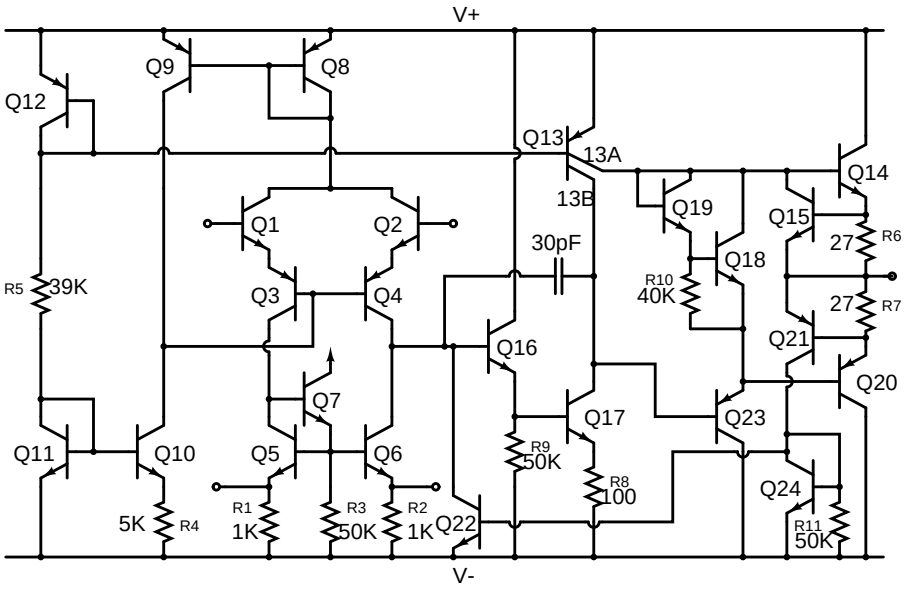
The bipolar opearation amplifier uA741

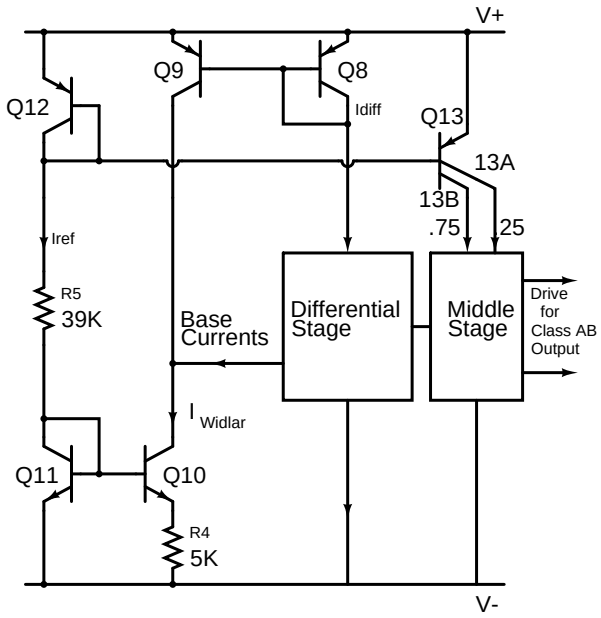
The 741 is a 3 stage bipolar opamp. The differential input signal is first amplified and converted to a single ended output by a pnp differential amplifier. The single ended output is further amplified by a common emitter amplifier and then given to the final push-pull output stage which includes short circuit protection. A bias generator provides bias currents to all stages of the opamp.



This circuit looks quite complicated. It is much easier to understand if we look at various functional blocks of this circuit individually.

1 Bias Generator

The purpose of the this circuit is to provide a reference current for various current mirrors used by the amplifier stages. The circuit is based on a Widlar current mirror circuit.



R5 sets up a reference current I_{ref} which flows through the diode connected transistor Q11.

$$I_{\text{ref}} = \frac{V_+ - V_- - 2V_{BE}}{R5}$$

With a nominal supply voltage of ±15V, $V_{BE} = 0.65$V and R5=39KΩ, this gives a value of 736μA for I_{ref}. This is mirrored by Q10 which is connected in Widlar configuration with a resistor R4 in its emitter. Equating voltages at the base of Q10 and Q11,

$$V_T \ln\left(\frac{I_{\text{ref}}}{I_s}\right) = V_T \ln\left(\frac{I_{\text{Widlar}}}{I_s}\right) + R4 \cdot I_{\text{Widlar}}$$

where I_s is the reverse saturation current of identical transistors Q10 and Q11, and V_T is the thermal voltage KT/q.

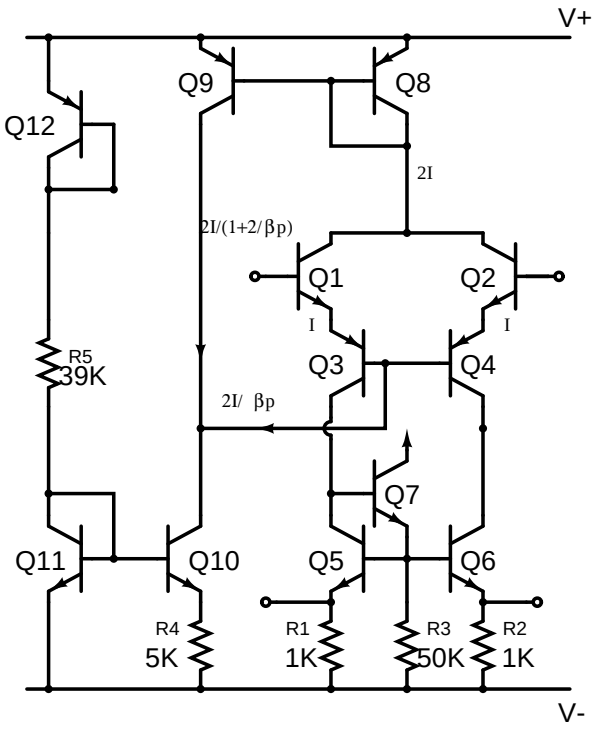
$$\text{This gives} \qquad I_{\text{Widlar}} = \frac{V_T}{R4} \ln\left(\frac{I_{\text{ref}}}{I_{\text{Widlar}}}\right)$$

This can be solved iteratively to get I_{Widlar}.

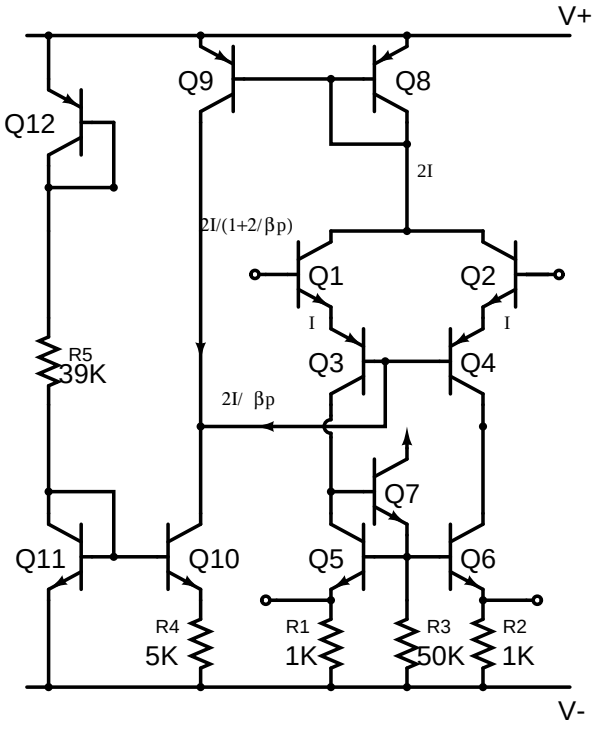
Suppose we start with a guess value of 500 μA for I_{Widlar}, The next few values which are calculated are: (in μA) 2, 30.6, 16.5,19.7, 18.7, 19, 18.9 etc. Thus, I_{Widlar} is nearly 19 uA. This current source is connected to another pnp current source, which mirrors the total current of the differential stage. Suppose the current through each arm of the differential stage is I. Then a current 2I flows through the reference transistor Q8. This means that Q9 sources a current which is 2I minus the base current of two pnp transistors. The base currents of the pnp transistors in the differential stage are added to this. The base voltage of the differential transistors now adjusts till the current through Q9 plus the base current of two pnps equals the current through Q10. Since the base current of pnp transistors is cancelled out, each arm of the diffential amplifier will get half the current through Q10. Thus, each arm of the differentila amplifier gets 9.5μA in our example.

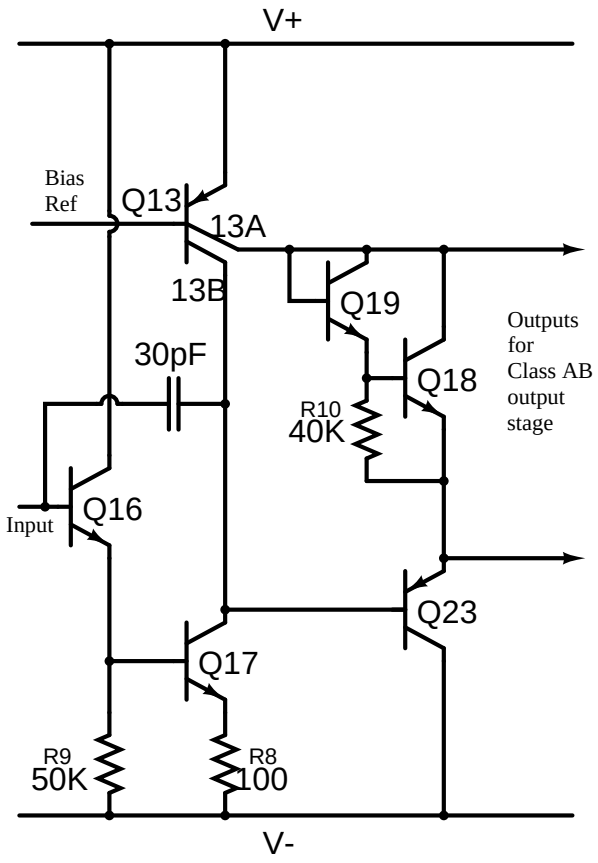
2 The differential stage

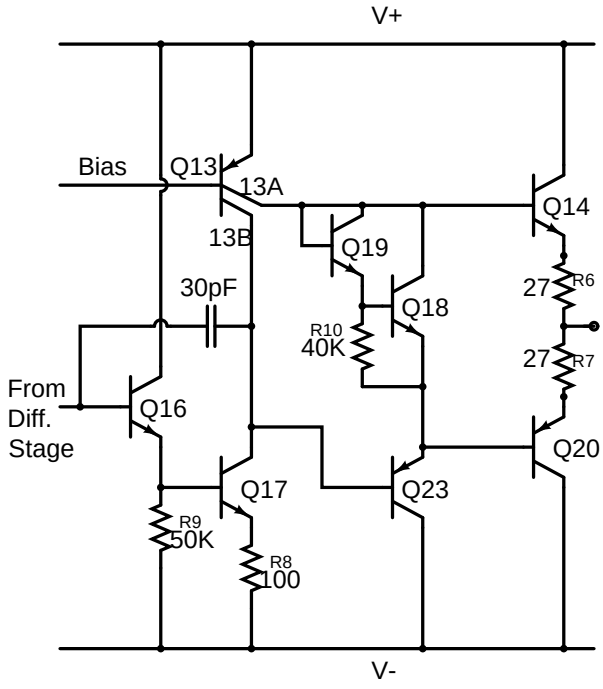
The differential stage is the first gain stage seen by the inputs. Since a high input impedence is required, each arm of the diffential amplifier uses an npn emitter follower, which feeds a pnp common base amplifier.

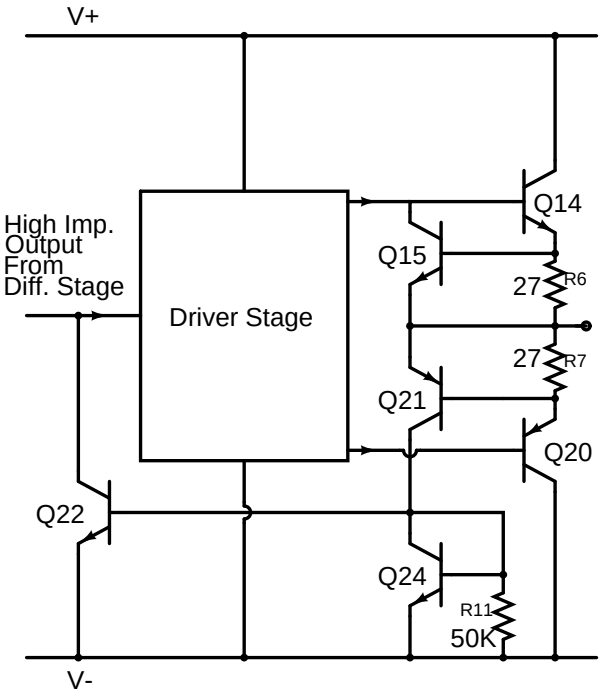


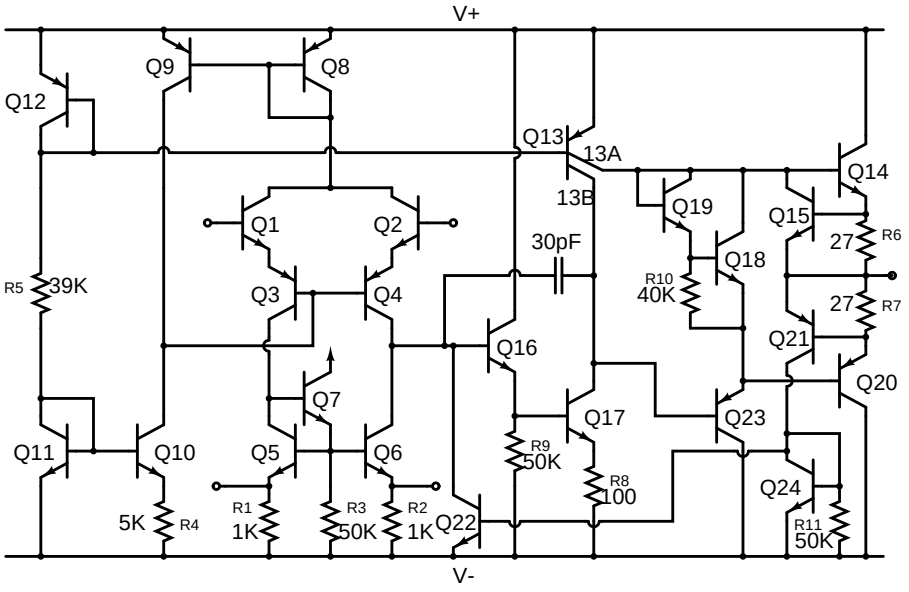
A common base pnp stage allows us to take out the base current of the two pnp transistors for compensating the mismatch in the current mirror Q8-Q9. The differential stage is loaded by a current mirror which also does differential to single ended conversion. The npn current mirror load Q5-Q6 uses the transistor Q7 to supply the base current of Q5,Q6.




V+
Bias
Ref
Q13
13A
13B
Q19
Outputs
for
Class AB
output
stage
30pF
Q18
R10
40K
Input
Q16
Q23
Q17
R9
50K
R8
100
V-


V+
Bias
Q13
13A
Q14
13B
Q19
30pF
27
R6
Q18
R10
40K
27
R7
From
Diff.
Stage
Q16
Q20
Q17
Q23
R9
50K
R8
100
V-


V+
High Imp.
Output
From
Diff. Stage
Driver Stage
Q14
Q15
27
R6
27
R7
Q21
Q20
Q22
Q24
R11
50K
V-


V+
Q9
Q8
Q12
Q13
13A
13B
Q14
Q19
Q15
27
R6
Q1
Q2
30pF
Q18
R10
40K
27
R7
R5
39K
Q3
Q4
Q16
Q21
Q20
Q7
Q17
Q23
Q11
Q10
Q5
Q6
R9
50K
R8
100
Q24
5K
R4
R1
1K
R3
50K
R2
1K
Q22
R11
50K
V-