Negative Feedback
Physics 623

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1 Introduction

We will consider the use of a difference amplifier. We will assume that this difference amplifier has some common attributes.

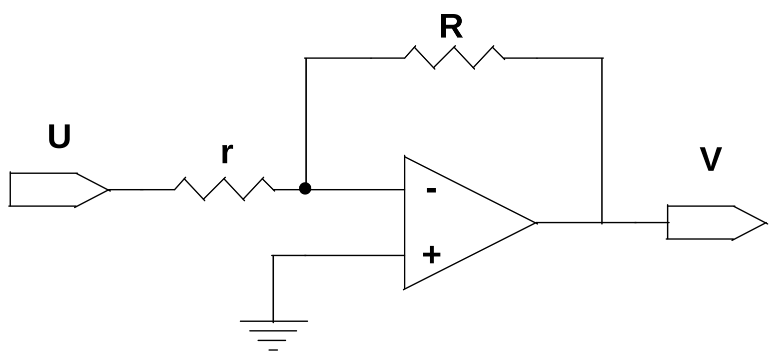
- relatively large negative voltage gain A
- relatively high input impedances
- relatively low output impedance

An operational amplifier is similar but has extreme values. An operational amplifier has

- extremely large negative voltage gain A
- extremely high input impedances
- very low output impedance

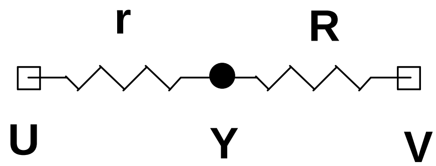
2 Negative Feedback with a Difference Amplifier

Place two resistors r and R about a difference amplifier and consider the overall characteristics of the combination.



Consider the current i in the feedback resistor R. Because the input impedance of the difference is very high, the current in the series resistor r will be the same as that in the feedback resistor, namely i. Give i the polarity of flowing from input with U to the output with V.

Since the inverting input has an extremely high input impedance, it can take no current. Thus the combination of r and R acts as a potential divider generating a voltage Y from voltages U and V and the voltage Y at the inverting input is that of the join in the symmetric form;



$i = \frac{U-V}{r+R}$

$Y = V + iR$

$Y = V + \frac{U-V}{r+R}R$

$Y = \frac{Vr+VR+UR-VR}{r+R}$

$Y = \frac{UR}{r+R} + \frac{Vr}{r+R}$

But if the amplifier gives an output V due to an input Y and large gain A then

$V = -A(Y - 0)$

$Y = -\frac{V}{A}$

Substituting this formula for Y into the earlier equation for Y;

$-\frac{V}{A} = \frac{UR}{r+R} + \frac{Vr}{r+R}$

$V \ (-\frac{1}{A} - \frac{r}{r+R}) = \frac{UR}{r+R}$

$-V \ (r + R + rA) = UAR$

$V = -U \ (\frac{AR}{r+R+rA})$

$V = -U \ (\frac{R}{\frac{r}{A}+\frac{R}{A}+r})$

Since we have assumed that the voltage gain A of the difference amplifier is relatively large, this formula can be simplified.

$V \approx -U \ (\frac{R}{r})$

By choosing a high gain difference amplifier, we gain three clear advantages.

1. We can make the amplification of the overall system be nearly fully dependent on the resistors and nearly independent of the amplifier gain. For example, if the gain A of the difference amplifier were $A = 2000$ for small signals and $A = 1000$ for large signals, the choice of $r = 1k\ ohm$ and $R = 30k\ ohm$ would give an overall combination with a gain of $\frac{V}{U} = -\frac{30k}{1k} = -30$ for signals of all sizes.

2. The voltage gain of the combination is independent of production variations, temperature variations and DC power levels in the transistors and is dependent only upon the ratio of two resistances. It is easy to make integrated circuits with resistances if we are not concerned with precise resistances but want to control only the ratios of resistance values.

3. The calculation of the voltage gain of the combination is made to be really simple.

3 Negative Feedback with an Operational Amplifier

Now consider the use of an Operational Amplifier in this mode with, typically, $A = 10,000,000$ or more) and an extremely high input impedance at the inverting and non-inverting inputs, typically $Z_{in} = 10^9$ *ohms* to 10^{12} *ohms*.. We can consider the limit of the formulae for V and Y as $A \to \infty$.

$V = -U\ (\frac{R}{r})$

We can also consider the voltage at the inverting input of an Operational Amplifier. From above

$Y = \frac{uR}{r+R} + \frac{Vr}{r+R}$

In the same limit as $A \to \infty$, we get;

$Y = \frac{uR}{r+R} + \frac{[-U\ (\frac{R}{r})r]}{r+R}$

$Y = \frac{uR}{r+R} + \frac{[-U\ R]}{r+R}$

$Y = 0$

Thus the negative feedback and grounded non-inverting input causes the inverted input to act as a "virtual ground"!

4 Summary

For a combination using an Operational Amplifier, the following effects (including the 3 mentioned above) are given by negative feedback. Any difference amplifier, with negative feedback, gains these effects to a lesser degree.

1. The amplification of the combination is less than one might expect from the raw transistors.
2. The voltage gain becomes a very stable $\frac{V}{U} = -\frac{R}{r}$ and is dependent only upon the ratio of two resistances. The fabrication has been made simple.
3. Both Operational Amplifiers and resistors are cheap.
4. It does not matter if the operational amplifier (or general difference amplifier) has been designed with a number of approximations (such as "assume β is large" or "neglect the internal resistances r_e and r_b". The voltage gain of the combination will still be $\frac{V}{U} = -\frac{R}{r}$.
5. We can make the amplification of the overall system be nearly fully dependent on the resistors and nearly independent of the amplifier gain. It is relatively easy to select or adjust resistors and so gain a desired amplification.

   Thus the negative feedback overcomes an imperfection such as that due to β being dependent upon the signal size. In other words, negative feedback can make the amplifying combination amplify with good linearity.

6. The voltage gain of the combination is independent of temperature variations in the transistors.

7. The voltage gain of the combination is independent of production variations in the transistors.

8. The voltage gain of the combination is independent of DC power levels in the transistors.

9. The voltage gain of the combination is independent of noise and other fluctuations upon the DC power levels in the transistors.

10. The voltage gain of the combination is independent of variations in any voltage offsets in the transistors.

11. It is easy to integrate a amplifier with negative feedback since in such a circuit, we are not concerned with precise resistances but want to control only the ratios of resistance values.

12. The calculation of the voltage gain of the combination is made to be really simple.

13. We can use the "virtual ground" for a number of other purposes in electronic systems. It can be shown that this "virtual ground" has a relatively low impedance.

14. An Operational Amplifier combination can amplify DC signals with a precise gain.

15. In an AC or voltage transient system, the full analysis with complex impedances gives the very simple form; $\frac{V}{U} = -\frac{Z_{feedback}}{Z_{series}}$. It is practical to add capacitances and inductances so that the input signal is integrated or differentiated precisely making it possible to make analog computers.

16. The high gain operational amplifier must not use any internal coupling capacitors.

17. If the non-inverting input is tied to a point with voltage V_{point}, then the inverting input becomes a "virtual voltage level with voltage V_{point}" It can be shown that this "virtual V_{point}" has a relatively low impedance.

18. It can be shown that the ouput impedance of the combination with negative feedback gives an output impedance which is lower than that of the operational amplifier by itself.

19. Beware of positive feedback!