

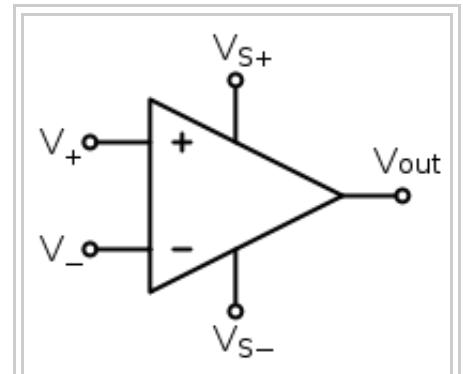
Differential amplifier

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A **differential amplifier** is a type of electronic amplifier that multiplies the difference between two inputs by some constant factor (the differential gain).

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Differential amplifier symbol
The inverting and non-inverting inputs are distinguished by "-" and "+" symbols (respectively) placed in the amplifier triangle. V_{s+} and V_{s-} are the power supply voltages; they are often omitted from the diagram for simplicity, but of course must be present in the actual circuit.

Theory

Many electronic devices use differential amplifiers internally. The output of an ideal differential amplifier is given by:

$$V_{\text{out}} = A_d(V_{\text{in}}^+ - V_{\text{in}}^-)$$

Where V_{in}^+ and V_{in}^- are the input voltages and A_d is the differential gain.

In practice, however, the gain is not quite equal for the two inputs. This means, for instance, that if V_{in}^+ and V_{in}^- are equal, the output will not be zero, as it would be in the ideal case. A more realistic expression for the output of a differential amplifier thus includes a second term.

$$V_{\text{out}} = A_d(V_{\text{in}}^+ - V_{\text{in}}^-) + A_c \left(\frac{V_{\text{in}}^+ + V_{\text{in}}^-}{2} \right)$$

A_c is called the common-mode gain of the amplifier.

As differential amplifiers are often used when it is desired to null out noise or bias-voltages that appear at both inputs, a low common-mode gain is usually considered good.

The common-mode rejection ratio, usually defined as the ratio between differential-mode gain and common-mode gain, indicates the ability of the amplifier to accurately cancel voltages that are common to both inputs. Common-mode rejection ratio (CMRR):

$$\text{CMRR} \triangleq \frac{A_d}{A_c}$$

In a perfectly symmetrical differential amplifier, A_c is zero and the CMRR is infinite. Note that a differential amplifier is a more general form of amplifier than one with a single input; by grounding one input of a differential amplifier, a single-ended amplifier results. An operational amplifier, or op-amp, is a differential amplifier with very high differential-mode gain, very high input impedances, and a low output impedance. Some kinds of differential amplifier usually include several simpler differential amplifiers. For example, an instrumentation amplifier, a fully differential amplifier, an instrument amplifier, or an isolation amplifier are often built from several op-amps.

Differential amplifiers are found in many systems that utilise negative feedback, where one input is used for the input signal, the other for the feedback signal. A common application is for the control of motors or servos, as well as for signal amplification applications. In discrete electronics, a common arrangement for implementing a differential amplifier is the long-tailed pair, which is also usually found as the differential element in most op-amp integrated circuits. A differential amplifier is used as the input stage emitter coupled logic gates.

Examples

Long-tailed pair

A differential pair amplifier is formed from two transistors, or vacuum tubes (valves) – normally triodes, where their emitters (for BJT transistors; cathodes for triodes, sources for FETs) are connected together. A long-tailed pair (LTP), or emitter-coupled pair, is a differential pair where the shared emitter (or cathode or source) node is fed from something approximating a constant current source/sink, such as a relatively large value resistor to the negative supply (or positive for PNP or P-Channel devices) that develops a large voltage drop relative to the amplitude of the input signal... the "long tail". Therefore the summation of the two collector (or anode/plate or drain) currents is almost constant with signal.

The two bases (or grids or gates) can be fed with a differential (balanced) input signal and the two outputs from the collectors (etc) remain balanced, or one input could be grounded to form a phase splitter circuit.

The higher the resistance of the current source R_e , the lower A_c is, and the better the CMRR. In more sophisticated designs, a true (active) constant current source may be substituted for the long tail.

With two inputs and two outputs, this forms a differential amplifier stage. The two bases (or grids or gates) are inputs which are differentially amplified (subtracted and multiplied) by the pair; they can be fed with a differential (balanced) input signal, or one input could be grounded to form a phase splitter circuit. The output may be single-ended (taken from just one of the collectors (or anodes or drains), or differential depending on the needs of the subsequent circuitry.

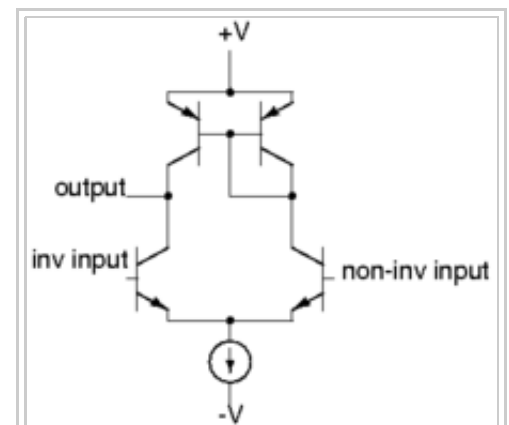


Figure 2: A long-tailed pair with current-mirror load and constant-current biasing

In a long-tailed pair formed using BJTs, the emitters are connected together, and then through the current source to ground or to a negative supply (for an LTP using NPN transistors). In this form, one of the transistors can be thought of as an amplifier operating in common emitter configuration, and the other as an emitter follower, feeding the other input signal into the emitter of the first stage. Since a transistor will amplify the current flowing between base and emitter, it follows that the current flowing in the collector circuit of the first transistor is proportional to the difference between the two inputs. However since the circuit is totally symmetrical, either element can be viewed as an amplifier or as an emitter follower, understanding does not depend on which role you assign to which device.

The output from a differential amplifier is itself often differential. If this is not desired, then only one output can be used, disregarding the other output. Or to avoid sacrificing gain, a differential to single-ended converter can be utilized. This is often implemented as a current source.

Long-tailed pairs are frequently used in circuits that implement linear amplifiers with feedback, in operational amplifiers, and in other circuits that require a differential amplifier.

When used as a switch, the "left" base/grid is used as signal input and the "right" base/grid is grounded; output is taken from the right collector/plate. When the input is zero or negative, the output is close to zero; when the input is positive, the output is most-positive, dynamic operation being the same as the amplifier use described above.

Bias stability and independence from variations in device parameters can be improved by negative feedback introduced via cathode/emitter resistors.

Historical background

The long-tailed pair was originally a pair of vacuum tubes, about 20 years before transistors would be practically available. The circuit works the same way for all three-terminal devices with current gain.

The long-tailed pair circuit was designed and patented by Alan Blumlein in 1936 as an amplifier for small signals, and later applied to switching functions in radar and television. Today, its main feature is mostly vestigial, by virtue of the fact that long-tail resistor circuit bias points are largely determined by Ohm's Law and less so by active component characteristics.

The long-tailed pair was very successfully used in early British computing, most notably the Pilot ACE Model and descendants,^[nb 1] Wilkes' EDSAC, and probably others designed by people who worked with Blumlein or his peers. The long-tailed pair has many attributes as a switch: largely immune to tube (transistor) variations (of great importance when machines contained 1,000 or more tubes), high gain, gain stability, high input impedance, medium/low output impedance, good clipper (with not-too-long tail), non-inverting (EDSAC contained no inverters!) and large output voltage swings. One disadvantage is that the output voltage swing (typically ± 10 – 20 V) was imposed upon a high DC voltage (200 V or so), requiring care in signal coupling, usually some form of wide-band DC coupling. Many computers of this time tried to avoid this problem by using only AC-coupled pulse logic, which made them very large and overly complex (ENIAC: 18,000 tubes for a 20 digit calculator) or unreliable. DC-coupled circuitry became the norm after the first generation of vacuum tube computers.

Footnotes

- [^] Details of the long-tailed pair circuitry used in early computing can be found in "Alan Turing's Automatic Computing Engine" (Oxford University Press, 2005, ISBN 0 19 856593 3) in Part IV, 'ELECTRONICS'

References

See also

- Instrumentation amplifier
- Op-amp differential configuration
- Emitter-coupled logic

External links

- BJT Differential Amplifier (http://www.ecircuitcenter.com/Circuits/BJT_Diffamp1/BJT_Diffamp1.htm) — Circuit and explanation
- A testbench for differential circuits (<http://www.designers-guide.org/Analysis/diff.pdf>)
- A discrete OpAmp with complimentary differential amplifier (http://gaedtke.name/SubMenu_Verstaerker/KompDiffAmp.html) (in german)

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