A COMPACT A–Z OF ANALOGUE SEMICONDUCTORS

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STACK IN THE BOX

Analogue circuits have held the fort against the digital invasion by jumping on the ic bandwagon – from single-function devices, to matched transistor pairs to whole circuits, all on a single chip.

Before the 1960s, analogue techniques were dominant in the world of electronics. Digital methods played a minor role simply because of the complexity and expense of making logic circuits from discrete components; just one logic gate required a handful of transistors, diodes and resistors. Advancing and cheaper integrated circuit technology has created a vast range of applications for digital electronics, now seemingly dominating analogue.

But this increase in digital techniques is not to the exclusion of analogue. Look in any supplier catalogue and you will find that many of the time-honoured analogue circuits and some new ones are now available in ic form. They are cheaper, simpler to include in a design and often more efficient than using discrete components. They have opened up a new world of applications.

This A–Z guide gives a general coverage of the many types of circuits available, the terms and jargon used. It should be useful as a refresher for the experienced or as an overview introduction for the newcomer.

ANALOGUE SWITCH

An electronically controlled switch, based on a semiconductor device such as a fet, which exhibits a low on resistance when the switch is 'closed' and a high off or 'open' resistance. Being a semiconductor device, it exhibits low transient switching compared with the bounce of mechanical switches.

Analogue switches are available in dual-in-line ic packages (see Fig.1), containing a variety of switches. Typical device numbers are:

4051BE & 74HC4051	(1-pole 8-way)
4052BE & 74HC4052	(2-pole 4-way)
4053BE & 74HC4053	(3-pole 2-way)
HI200-5	(dual spst)
HT201-5	(quad spst)

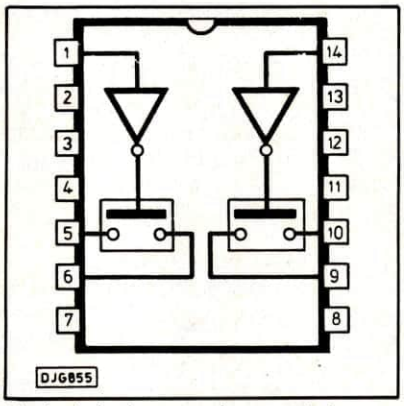

Fig.1. *A dual spst analogue switch*

ANALOGUE-TO-DIGITAL CONVERTER (ADC OR A/D)

A device which outputs a digital code which is proportional to an analogue signal present at its input. For example, a 3-bit converter as shown in Fig.2, will give all 1s (111) when the input is a maximum voltage, all 0s (000) when the input is zero, and a binary mixture of 1s and 0s for voltages between zero and maximum.

There are many types of adc, each requiring a *conversion time* from nanoseconds to microseconds depending on the method of conversion. The *resolution* of a converter is the minimum difference in input voltage which causes a binary change of 1 in the digital output.

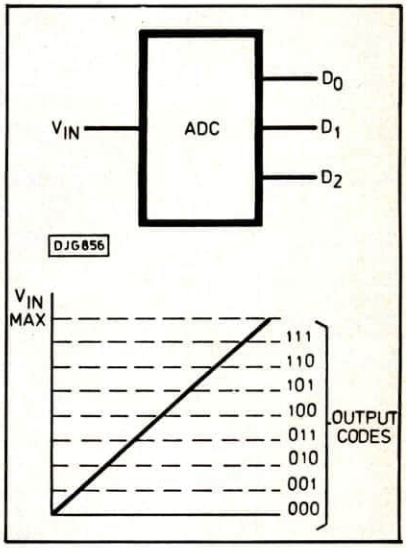

Fig.2. *A 3-bit adc showing output codes*

A more detailed description of adcs will be given in a future A–Z feature on converters. Typical device numbers are:

ADC0804 8-bit A/D
ADC820CCN 8-bit high-speed A/D
ADC0831CCN 8-bit with serial in/out
ZN448E 8-bit tri-state parallel

AUDIO ATTENUATOR

An amplifier with a gain less than one, controlled by an external voltage or resistance (see Fig.3).

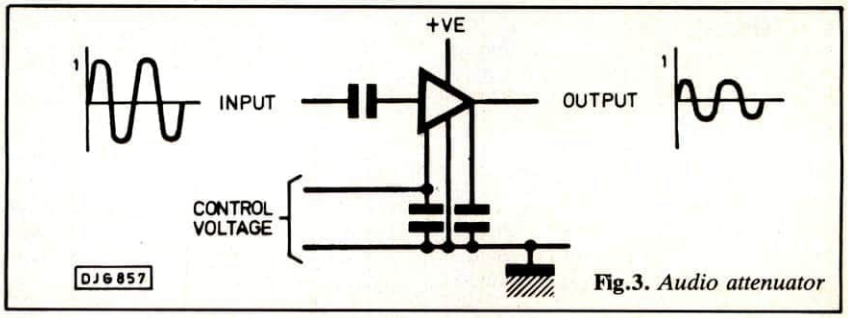

Fig.3. *Audio attenuator*

BI-POLAR DEVICE

Semiconductor device which operates using both types of charge carriers: electrons (negative charge carriers) and holes (positive charge carriers). The junction transistor is a bipolar device, whereas the fet is uni-polar because only one charge carrier flows through the channel.

COMPARATOR

A device for detecting when a varying voltage signal reaches a threshold value. An analogue comparator compares an input voltage against a reference level or against another input, and the output switches state when the input voltage exceeds the other (see Fig.4).

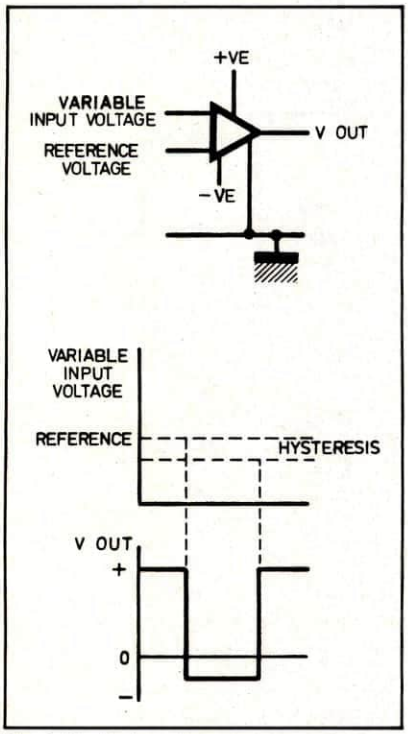

Fig.4. *Typical analogue comparator*

Operational amplifiers can be used as analogue comparators but special purpose comparators are available. These have quicker switching times and low *hysteresis* which is the difference between the switch-on threshold input voltage and the value to which the input voltage must fall below the threshold for the device to switch off.

The 710, a popular high-speed voltage comparator in a 14-pin ic package, can switch in nanoseconds and has a hysteresis of 2mV. The 319 is a dual comparator in one package, requiring a single supply rail.

COMPLEMENTARY TRANSISTORS

These are pairs of transistors, one npn and the other pnp with closely matched performance characteristics. They are used for applications such as push-pull amplifiers (Fig.5) where one transistor amplifies the positive half cycles of the signal waveform and the other amplifies the negative half cycles for greater efficiency.

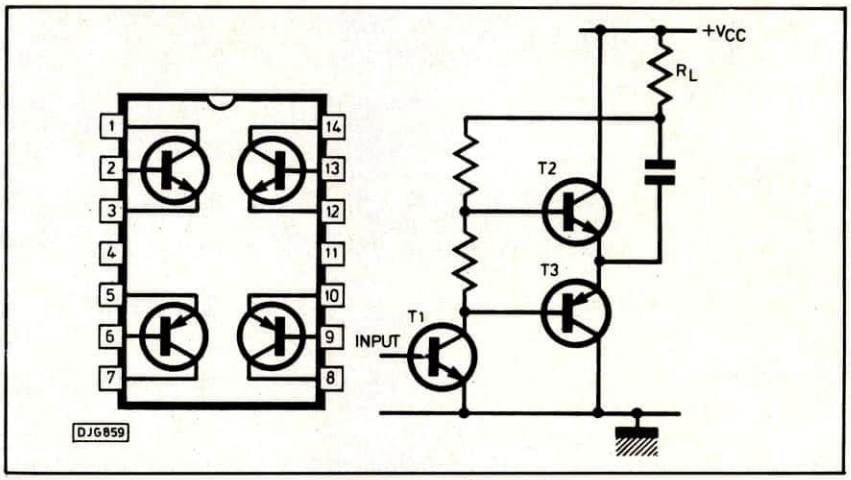

Fig.5. *Complementary transistors and push-pull amplifier*

Complementary transistors are now available as single packages, sometimes containing multiple complementary pairs with some thermal matching which means their performance characteristics change by the same degree as a result of change in temperature.

DARLINGTON DRIVERS

Two transistors connected as a Darlington pair can achieve a much greater current gain than one transistor. They are often used to drive loads such as relay coils (Fig.6) and in series voltage regulars. Quad (four) and octal (eight) Darlington drivers are available in a single ic package, including inbuilt protection diodes.

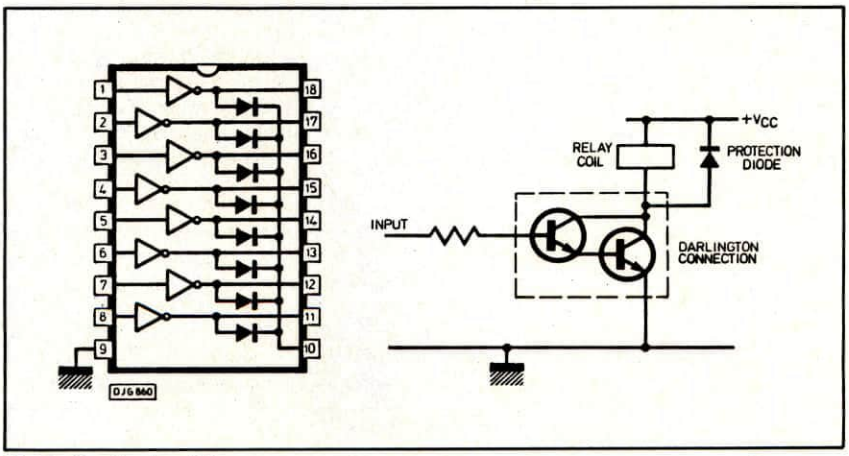

Fig.6. *Darlington drivers*

A protection diode is reverse-biased when the Darlington pair conducts and current passes through the relay coil. Yet when the driver switches off, the diode allows current, caused by back-emf as the magnetic field of the coil collapses, to circulate. Protection diodes speed up the switch-off of the coil and protect the Darlington drivers from back-emf.

DELAY LINE

A means of creating a delay in the transmission of an analogue signal for a fixed time interval. Typical applications are for electronic musical effects such as artificial reverberation and introducing delays into public address systems so that the audio signal reaches each speaker simultaneously.

The bucket brigade delay (bbd) principle (Fig.7) is often used where you can imagine the analogy of buckets being passed along a line of people where the contents of each bucket represents a sample of the analogue waveform.

Very simply, analogue switches are opened and closed alternately so that the charge on a line of capacitors is passed along the line, where each charge is a sample of the analogue input. A two-phase clock controls the opening and closing of alternate switches. The result at the output is a series of delayed, chopped amplitude samples of the input waveform.

The chopping of the waveform introduces many unwanted frequency components which can be removed from the output by filters.

Practical devices include the MN 3044 which is a mos monolithic ic with 512 stages (buckets!) providing delays from

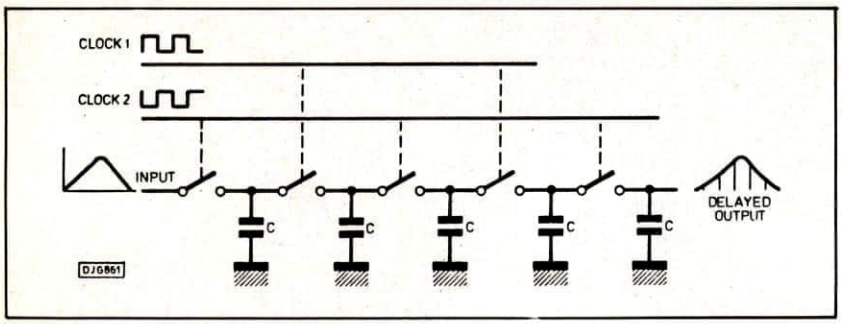

Fig.7. *Bucket brigade delay line*

2.65ms to 25.6ms. The MN 3011 has 3328 stages with six output taps and having a full delay range of 16.64ms to 166.4ms.

There are many short delay lines available, such as the 63 microsecond delay lines for television receivers, which are not suitable for audio use. The reason for this is that delays in the range of several milliseconds are required for the effects to be audible. As each stage of a delay line introduces its own errors, cascading a number of short delay lines would increase the distortion for audio to an unacceptable level.

DIGITAL-TO-ANALOGUE CONVERTER (DAC OR D/A)

A device which converts a digital code into a proportional analogue voltage (Fig.8). For example, a 3-bit converter can generate eight levels of voltage, each level representing one of the binary combinations possible with 3-bits.

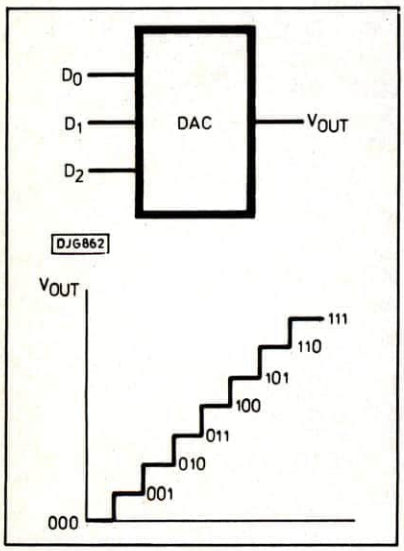

Fig.8. *Digital to analogue converter*

The output voltage is not true analogue but is in discrete steps, called *quantisation levels*, and no voltages can be output between these levels. This is the source of error in dacs, called *quantisation error.*

Dacs are used for waveform generators, industrial control applications and now in compact disc players to reconstruct the analogue music from digital codes. An A–Z feature is planned dealing specifically with dac and adc. Typical device numbers:

DAC0801 8-bit d/a
AD7581 8-bit 8-channel d/a
ZN428 8-bit d/a
DAC703JP 16-bit d/a

FIELD EFFECT TRANSISTOR (FET)

A semiconductor device which can amplify voltage signals or act as a switch. The fet has certain advantages over the bipolar transistor it is not as susceptible to temperature variations, having high input resistance and low noise which makes it suited for the early stages of amplification.

Very simply, the fet operation is as follows: an input voltage signal applied to the gate terminal creates an electrical field which controls the flow of current from an external source in a channel between *drain* and *source* terminals.

There are three main types of fet. The *junction gate* fet (jfet), the *metal-oxide-semiconductor* fet (mosfet or most) and the vmos power fet which has a V-shaped channel for switching high currents (typically 2A) very quickly (tens of nanoseconds).

HYBRID INTEGRATED CIRCUITS

These have a ceramic support often called a substrate, upon which is mounted several other types of circuit such as silicon chips, power transistors and film resistors. The advantage is that one hybrid package can mix component types which would be difficult to manufacture as a *monolithic* ic.

INSTRUMENTATION AMPLIFIER

A high performance operational amplifier having substantially lower drift characteristics than standard operational amplifiers.

MATCHED PAIR

Two transistors manufactured in one piece of semiconductor to exacting tolerances so that their performance characteristics are almost identical. Any change in operating conditions such as temperature or humidity change affects each of the matched pair equally.

MONOLITHIC IC

A complete circuit manufactured on a single piece of silicon. The word monolithic literally means "single stone". The term monolithic can also be used for other devices, eg monolithic ceramic capacitors.

MULTIPLEXER

An analogue multiplexer (Fig.9) contains a number of switches which when selected to "close" one at a time connects the signal path from one input channel to a common output, rather like an electronic version of a multi-way switch. The channel is selected by a code applied to address inputs (A0 and A1 in diagram). Analogue multiplexers are used extensively for data acquisition systems, audio and video switching.

Multiplexers can be built around discrete fets, but are now available as complete ics, such as the LF13508, but are now available as complete ics, such as the LF13508, 8-channel multiplexer or the 16-channel LF13526. Other device numbers:

74153 4-line to 1-line
74151 and 4512 8-line to 1-line
74150 16-line to 1-line

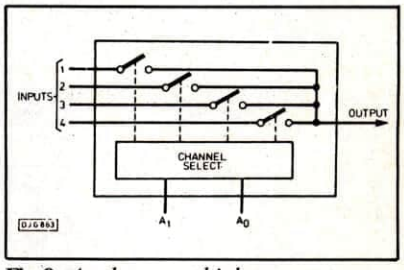

Fig.9. *Analogue multiplexer*

OPERATIONAL AMPLIFIER (OP AMP)

A high gain voltage amplifier which is direct coupled (no capacitors) so it is suitable for amplifying dc or ac signals. Operational amplifiers have *differential* inputs, one inverting (−) and one non-inverting (+) and exhibit very high input impedance and very low output impedance. They are used extensively for industrial instrumentation, small signal processing, general purpose amplifiers and summing amplifiers.

Bipolar operational amplifiers have low output impedance and high slew rates (rapid change of output measured in volts per microsecond). Cmos operational amplifiers exhibit very high input impedance and have low power consumption but with lower slew rates.

An A–Z feature is planned dealing exclusively with operational amplifiers and their applications.

Typical device numbers:

Bipolar: LM301A 709
LM308 741
LM324 NE531

cmos/fet: LF441, 442, 443
LF351, 353, 347
CA3130

RMS TO DC CONVERTER

A device which will output a direct current which represents the true rms value of the input signal. The rms value is different for different types of waveforms and ic devices are available which compute for sinewaves, squarewaves or any complex waveform containing ac into the mega-hertz region or both dc and ac components.

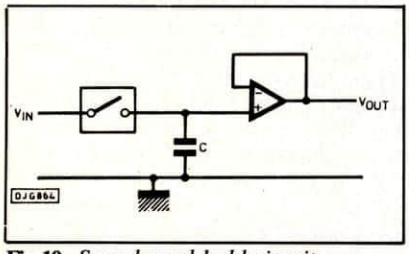

Fig.10. *Sample and hold circuit*

SAMPLE AND HOLD (S/H)

For many data acquisition applications, a rapidly changing analogue voltage must be frozen at a particular instant in order that an analogue-to-digital conversion can take place accurately.

The s/h circuitry (Fig.10) includes a fet switch which when closed (sampling) allows the voltage on capacitor C to change with the varying input voltage, Vin. When the switch is opened (hold state), the voltage across C is held constant which appears as Vout through the buffer. The buffer is an operational amplifier with high input impedance to prevent the capacitor discharging.

Acquisition time is the time required to change from one holding voltage to new voltage level with a step of 10V.

Droop rate is a measure of the holding voltage fall-off in millivolts per millisecond, and depends on the quality of the capacitor and the high input impedance of the buffer.

TRANSISTOR ARRAY

A number of transistors in one ic package (Fig.11). Used in applications where space saving or close thermal matching (ie changes in performance due to temperature changes) are important.

A typical device is the CA 3046 which consists of five npn transistors.

VOLTAGE-CONTROLLED OSCILLATOR

A device which converts a variable analogue input voltage to an output voltage whose frequency is directly proportional to the input voltage. Ics are

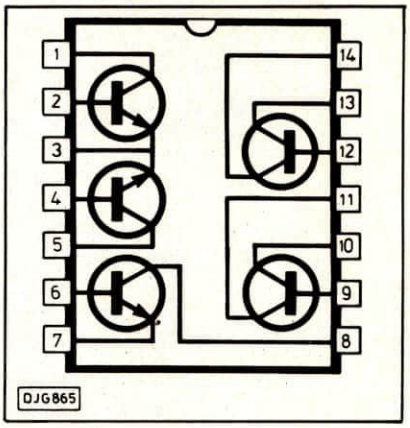

Fig.11. *Transistor array*

available which output pulses at a frequency proportional to the input voltage and some devices can work in reverse, giving a voltage proportional to the frequency of the input. One frequently used device is the cmos 4046.

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