

Using Circuits, Signals and Instruments

To be ignorant of one's ignorance is the malady of the ignorant.

A. B. Alcott (1799-1888)

Some knowledge of electrical and electronic technology is essential for work in most modern areas of physics and engineering. These notes are intended to help you apply your abstract knowledge of electricity and magnetism to the practical problems of circuit construction, signal propagation and electrical measurement.

CIRCUITS

An electrical circuit is a collection of components connected together with wires to perform a desired function. The physical realization of the circuit can vary enormously, as long as the connections between components are correct. For this reason, circuits are usually represented by schematic diagrams whose geometry need not resemble that of the physical circuit at all. An amplifier, for example, might equally well be assembled from several centimeter-sized components connected by pieces of solid copper wire, or from a micron-scale pattern of thin metal and semiconductor films on the surface of a silicon wafer. Details of the geometry only become important when the wavelength of the signals becomes comparable to the circuit size, typically at frequencies of a few gigahertz. A successful design must then manipulate propagating electromagnetic waves, rather than currents and voltages in discrete components.

Figure 1 shows the conventional schematic symbols for a number of components, some of which you will use in the laboratory. A typical schematic diagram is shown in Fig. 2, and there are other examples in your text. If you wanted to construct a circuit you would first identify the various components and their connection points, using the manufacturers' data sheets if needed. You would then use wires to systematically join each component to the others according to the lines in the schematic drawing. The relative positions of the components need not resemble the schematic layout, but the circuit will work if the connections are correct.

In discussing circuits, there are two general arrangements that are referred to by name, as drawn in Fig. 3 using resistors. In the series circuit the currents I_{AB} and I_{CD} must always be the same, since charge cannot accumulate between the components. The electric potential difference between A and B, V_{AB} , will not be the same as V_{CD} unless the elements are identical. For the parallel connection, the reverse is true: $V_{AB} = V_{CD}$ because they are connected by a resistanceless wire, but the currents I_{AB} and I_{CD} are generally different. The distinction is useful if, for example, you want the same current to flow in two coils to generate a magnetic field. Connecting them in

	wires, connected		diode
	wires, not connected		bipolar transistor, NPN
	zero reference or earth ground (ambiguous)		bipolar transistor, PNP
	resistor		field effect transistor
	variable resistor		battery or DC source
	variable capacitor		AC source
	inductor		ammeter
	transformer, with core		voltmeter
	switch, DPDT		

Fig. 1 Some symbols and wiring conventions used in electronic diagrams.

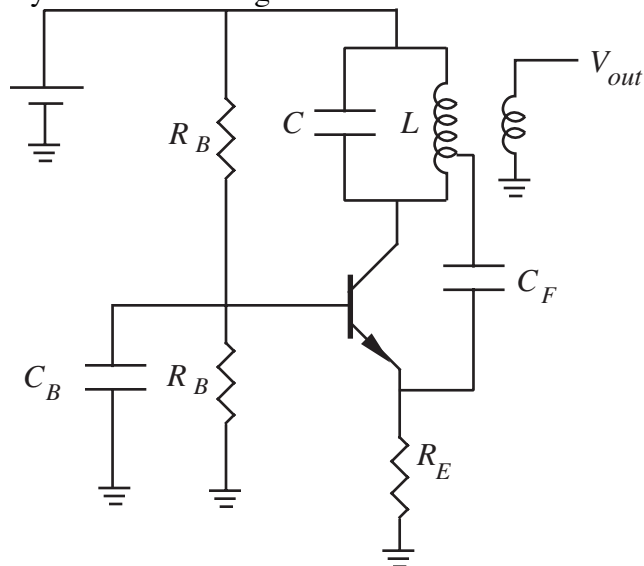


Fig. 2 Schematic diagram of an oscillator circuit.

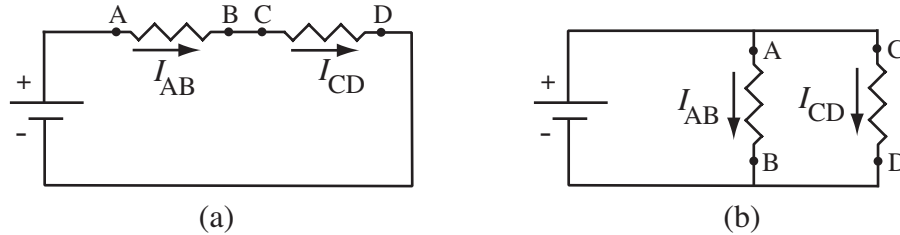


Fig. 3 (a) Series connection of DC supply and two resistors. Here $I_{AB} = I_{CD}$, but $V_{AB} \neq V_{CD}$ unless the resistances are equal. (b) Parallel connection of two resistors across a DC supply. Now $V_{AB} = V_{CD}$, but $I_{AB} \neq I_{CD}$ unless the resistances are equal.

series guarantees that this will occur, regardless of the characteristics of the individual coils. Conversely, a group of devices which require the same voltage, such as light bulbs, would be connected in parallel with the power source.

SIGNALS

Various voltages and currents will be present in an operating circuit. It is customary to distinguish between the currents from a power source, which supply energy to the circuit, and signals, which determine the function of the circuit. The power supply is usually a steady voltage of one polarity, capable of supplying whatever magnitude of current the circuit needs to operate. Signals are more varied, with a variety of time dependences that are conventionally designated by various names.

DC is an abbreviation for direct current, although in common usage it means either a current or voltage of fixed magnitude and polarity. This is sometimes extended to refer to a slowly varying current or voltage as quasi-DC.

AC stands for alternating current. In practice, it is any current or voltage which reverses polarity, whether or not it is sinusoidal. The term is sometimes extended to refer to any time-varying signal, even if it does not actually change from positive to negative.

Pulse signals consist of a pattern of short periods at a defined current or voltage level, with intervals of zero voltage or current in between. Information may be encoded in the pattern of pulse times, the times at which fixed-length pulses occur, the polarity of the pulses, or some combination. Since the pulse amplitude is fixed within a specified range, it does not carry additional information.

Digital systems commonly use pulse signals, since they operate on binary logical states. Some feature of the pulse signal encodes the logical true/false information that the system uses. Analog systems, in contrast, use the amplitude of an AC signal to represent some other physical quantity, such as sound pressure in an audio application.

The terms AF and RF are sometimes used in communications electronics. Audio frequency, AF, signals are in the range from about 10 Hz to about 20 kHz, which somewhat more than spans the range of human hearing if converted to sound. Radio frequency signals, above about 500 kHz, are associated with electromagnetic transmission.

INSTRUMENTS

There are a variety of instruments used in electrical systems. Basic functions include supplying energy to the circuit, measuring voltage and current, and supplying signals for testing. There are also numerous devices made for more specialized functions in particular applications such as television, computer design, and communications.

Power supply

In portable equipment, necessary operating voltages can be supplied by a battery. For fixed use or extended operation, most equipment also has power supply circuitry to convert 60 Hz 120 V AC power (in the US) to the needed voltages. Depending on circuit requirements, the power supply may provide one or more fixed voltages with appropriate current capability. In supplies intended for laboratory use the outputs may be adjustable, and may have protective features such as definite output current limits.

For safety reasons, one of the output terminals and/or the metal case of a power supply may be connected to earth ground via the third prong of the AC power cord. This prevents the user from receiving an electric shock if an internal malfunction effectively connects the AC power line to a terminal or to the case. (The resulting short circuit current within the grounded supply then blows a fuse or completely destroys the unit, removing the hazard.) In a floating or isolated supply neither terminal is connected to earth ground. With careful design these can be reasonably safe.

Since many other instruments will also have one terminal connected to earth ground, it is important to make connections carefully. If an ungrounded signal input or output terminal on one instrument is connected to a grounded terminal on another device, the signal will be lost and the circuit will not operate as intended.

Electrical meters

The potential difference between two points in a circuit can be measured with a voltmeter connected in parallel between the points, as shown in Fig. 4. An ideal voltmeter would have infinite resistance so that current flow in the circuit will not be affected by the additional path between the measuring points. Practical voltmeters, or the voltage input to a computer interface

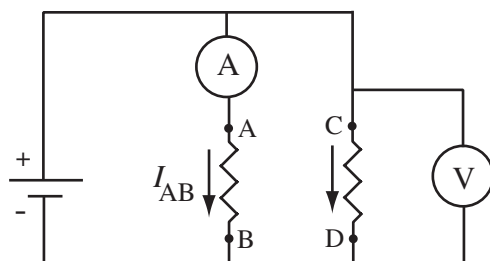


Fig. 4 Resistors connected in parallel across a DC supply. The ammeter is placed in series with one resistor to measure I_{AB} , while the voltmeter is placed in parallel with the other resistor to measure V_{CD} .

or an oscilloscope, have resistances of 1 - 10 $M\Omega$, which may affect measurements in some circuits.

Current flow through a specified part of the circuit is measured by inserting an ammeter in series at the desired location, as shown in Fig. 4. An ideal ammeter would have zero resistance so the circuit would not be affected by insertion of the meter. Depending on their design and sensitivity, practical ammeters will add their internal resistance of 1 -10 Ω into the circuit.

Meters are also available to determine DC resistance. They typically apply a known voltage to the component to be tested and measure the resulting current, displaying the ratio as the resistance in ohms. The component must be disconnected from the rest of the circuit to avoid interference from currents or voltages not supplied by the meter.

Digital multimeter

Voltage, current, and other measurement capabilities are often combined into a single general-purpose instrument called a digital multimeter or DMM. The various models available are sufficiently similar that basic measurements can usually be completed without reference to the manufacturer's instructions. Most DMMs are battery operated, so their inputs are not grounded and can be connected anywhere in a circuit.

Figure 5 illustrates the style of DMM used in the lab, with important features labeled. The function dial is used to select the type of measurement and sometimes the range, although many DMMs select the scale automatically. An input terminal usually labeled COM or Common is the reference for most measurements. The other terminals may be labeled with various combinations of V, A and Ω , indicating their use for measuring voltage, current and resistance respectively. Wires from these terminals are connected into the circuit as needed for each function. Additional labels on the same or other terminals may be used to denote the inputs for other functions such as high current, high voltage, capacitance or frequency ranges when those

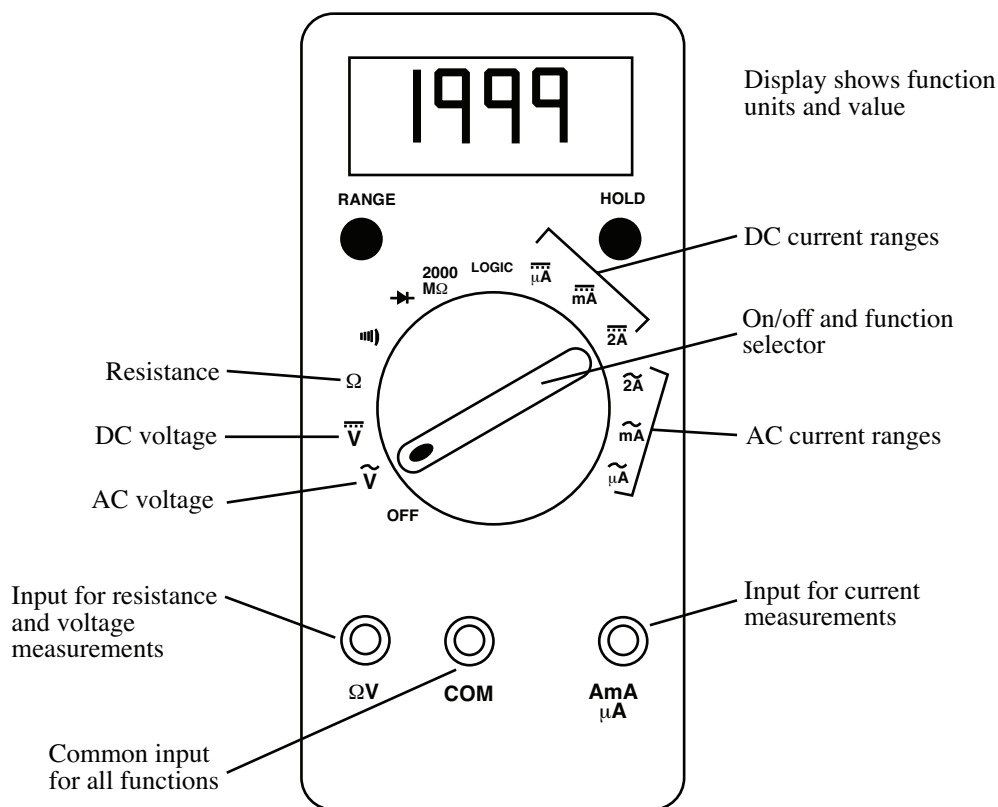


Fig. 5 Controls and inputs for a general-purpose DMM typical of those used in the lab.

are present. Other controls may be provided to select a specific measurement range or to hold a previous reading.

Practical limitations of the DMM may be important in some measuring situations. Input resistance of most units is $10M\Omega$ on voltage ranges, which can cause errors if circuit resistances are comparable. The effective resistance on current ranges is about 5Ω , which could disrupt current paths with low internal resistances. AC current and voltage functions are usable only for frequencies of a few tens of Hz to perhaps 1 kHz, and are correctly calibrated only for sine waves. Voltages above a few hundred volts or currents above a few amps may damage the meter and create hazards for the operator.

Signal generator

Signal generators are used to produce AC signals for various purposes. The simplest signal generators produce only a sinusoidal output at a selected frequency and amplitude. Function generators are often used as general-purpose test instruments to produce a choice of sine, square and triangle waves, and perhaps other synchronized pulses or waveforms at frequencies of a few Hz to a few MHz. Arbitrary function generators can be programmed to

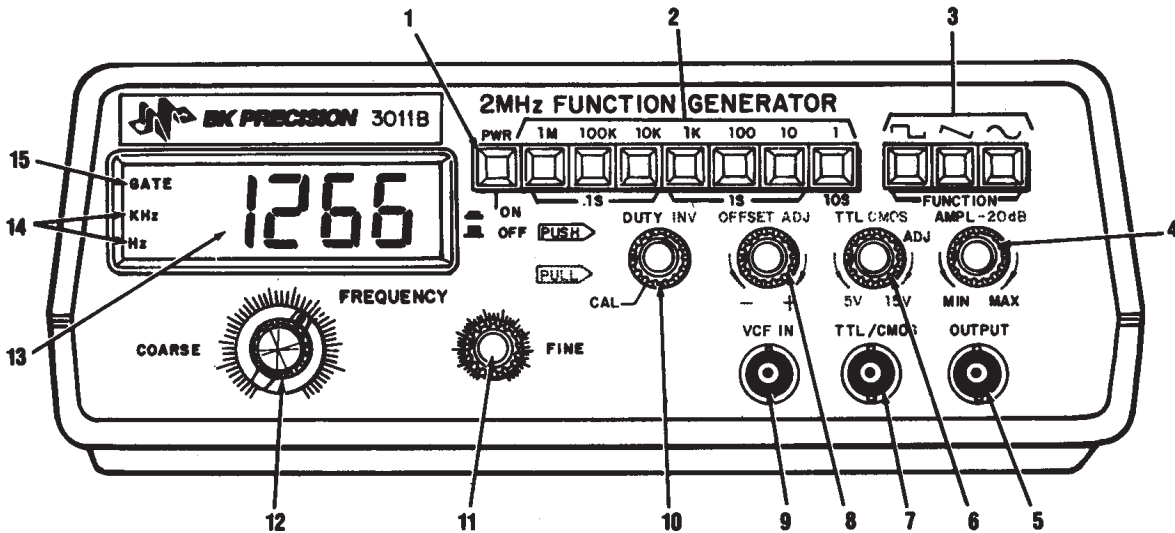


Fig. 6 The front panel of the function generator, with controls marked.

produce almost any waveform at repetition rates up to a few MHz. RF generators are used to produce higher frequencies, ranging up to a GHz or so, for testing communications equipment. These may also include provisions for AM, FM or other modulation of the basic waveform, depending on the intended use. Even more specialized units are available to produce pulse trains for use in digital systems.

Figure 6 shows the control panel of the function generator most often used in this lab. The instrument is turned on with the power switch, item (1) in the figure. A sine, square or triangle waveform is selected with the buttons labeled FUNCTION (3). The frequency range is determined by pushbuttons (2), and the exact frequency is then set using the coarse and fine FREQUENCY knobs (12, 11). The output amplitude is determined by the AMPL knob (4). Pulling gently on the AMPL knob decreases the output amplitude by a factor of 10. The display (13) shows the output frequency numerically in Hz or kHz, according to the indicator (14) and decimal point on the display. The selected output appears as a voltage at OUTPUT (5).

Other features are more specialized. The knob labeled DUTY (10) changes the shape of the output wave at (5). It is generally left in the CAL position to obtain an almost-ideal sine wave. The OFFSET ADJ (8), when pulled out, will add a positive or negative DC component to the output at (5). The TTL/CMOS output (7) produces a positive pulse train which is synchronized with the main output. The TTL/CMOS pulse output amplitude can be adjusted from 5 to 15 V with the TTL CMOS ADJ knob (6). The VCF IN connector (9) accepts an external control voltage to vary the output frequency of the generator.