

A BEGINNER'S GUIDE TO MAKING  
ELECTRONIC GADGETS

BY R. J. VARRING

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# A BEGINNER'S GUIDE TO MAKING ELECTRONIC GADGETS

BY R. H. WARRING



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## Preface

This is intended as a mainly practical book on interesting—and useful—electronic circuits, simple to construct and get working. Most of these working circuits—and there are some hundred described in all—are based on semiconductor devices (mostly transistors) and standard miniature components, all of which should be readily obtainable from shops or mail order houses specializing in the supply of amateur radio or electronic experimenter components.

The manner in which many of the circuits work, and can be modified, is explained in practical terms so the reader can acquire a sound background knowledge of practical electronics as he progresses through the book.

No previous knowledge of electronics—or even of electronic components—is needed to get started, for essential basic information on this particular subject is given in the first three chapters. It is assumed, however, that the builder of these circuits can use an electric soldering iron and has some familiarity with laying out and wiring up physical circuits.

The chapters on Coupling, Amplifiers, Oscillators and Outputs have been included to broaden further the reader's background knowledge of practical electronics, again with many working circuits illustrating the principles involved.

These represent the building blocks on which many more complicated circuits are constructed.

The remainder of the book is devoted to descriptions of individual circuits which come under the general category of electronic gadgets. A number of these have been inspired by, or are based on, original circuit designs which have been published elsewhere; i.e., the author has experimented with these circuits and adapted them or variations for this book.

A number of circuits are also based on original Mullard designs—circuits which have become virtually standard electronic practice and widely used both by amateur and professional constructors. True originality in simple electronic circuitry is now comparatively rare—the basic factors of such circuits being established by the characteristics of semiconductor devices themselves.

R. H. Warring

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# Transistors

Let's begin by learning what transistors are and what they can do. (Readers who already know how transistors work and how to connect them can skip this chapter, but they may still find it useful for reference from time to time.)

*Transistor* is the name given to a whole variety of semiconductor or solid-state electronic components (usually called devices), with characteristics more like the old-fashioned triode radio tubes than similar electronic components like resistors and capacitors. While transistors form the *working* part of electronic circuits, resistors and capacitors usually adjust working *levels* in a particular circuit. This is rather like the transistor being an *engine*, and the resistors and capacitors in the circuit the *control* for the engine.

Common types of transistors are distinguished by having three terminals connected to the semiconductor material from which they are made. This distinguishes them from a *diode*, which is another semiconductor device with two terminals, and more complex semiconductor circuits or ICs (Integrated Circuits). However, some transistors apparently have only two terminals. In such cases, the third is inside connecting to a metallic case. The type used in simple circuits, with three



terminals (usually thin wires), show these emerging from the bottom of the transistor case. Inside they connect to internal parts of the transistor known as the *emitter*, *base* and *collector* shown in symbolic form in Fig. 1-1. This forms the picture of a transistor used in circuit diagrams.

It will be noticed that two different types of transistors are shown—a PNP type and a NPN type. This is really a difference in the *polarity* of the transistor and indicates the way it has to be connected in a circuit. The arrow on the emitter (in the transistor symbol) points from a positive to a negative polarity in a circuit where the transistor is normally conducting.

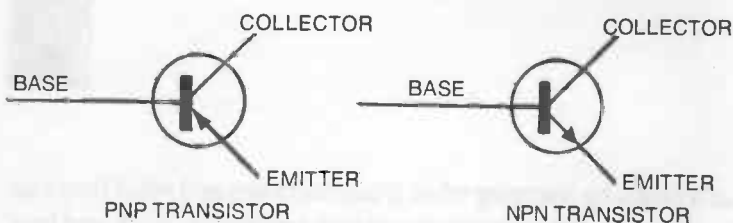


Fig. 1-1. Symbols and terminal connections of PNP and NPN transistors.

The basic rules to remember when connecting a transistor to a circuit or designing a transistor circuit are:

1. The base must be one terminal of the *input* circuit.
2. The collector must be one terminal of the *output* circuit.
3. With a PNP transistor, the polarity must always be such that the *collector* is **Negative** relative to the connection to the emitter.
4. With an NPN transistor the polarity of connection must always be such that the *collector* is **Positive** relative to the connection to the emitter.

It is important to get these connections right, for if a transistor is connected the wrong way in a circuit it can be "blown" and permanently damaged.

What can be a little confusing at first is the variety of shapes and sizes of transistor bodies, plus the fact that the three terminal wires do not always emerge from the bottom of

the body, or case, in the same way. Some common arrangements are shown in Fig. 1-2. These cover nearly all transistor types most likely to be used in simple circuits except power transistors.

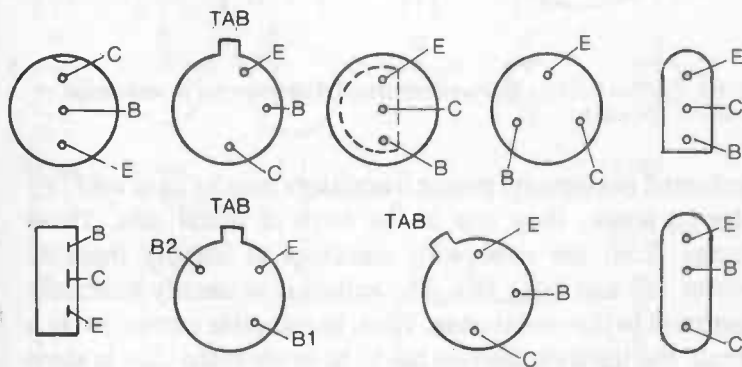


Fig. 1-2. Common arrangements of transistor leads: E = emitter, B = base, C = collector.

If the three wire leads emerge *in line*, these may be evenly spaced (usually from a circular shape), or unevenly spaced (usually from a rectangular shape). If they are *evenly* spaced then there will be a colored or white dot marked on the side of the transistor opposite one of the end leads. This identifies that lead as the *collector*. The center lead is the *base* and the other end lead the *emitter*.

With uneven spacing the end lead most widely spaced is the *collector*. The center lead is the *base* again and the other end lead the *emitter*.

The other alternative is a triangular arrangement of the leads usually found on a circular shaped transistor body with a flange on the bottom. Here two leads will be opposite one another in line with the center. The third will be at the apex of the triangle. This third wire is the *base*. Viewing the transistor from the bottom, the right-hand lead is then the *collector* and the left-hand lead the *emitter*.

The common form of *power transistor* is larger than other transistors and commonly has the shape shown in Fig. 1-3. This shape has been standardized by most manufacturers. As

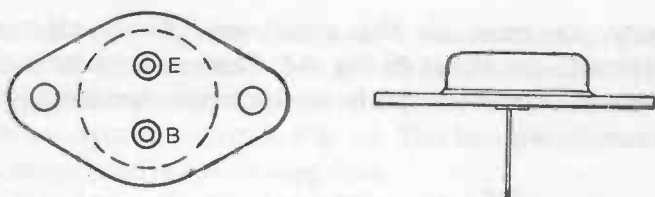


Fig. 1-3. Typical form of a power transistor. The collector is connected internally to the case.

mentioned previously, power transistors usually have only two external leads; they are in the form of metal pins. These emerge from the case with markings to identify them as *emitter* (e) and *base* (b). The collector is usually internally connected to the metal case. Thus, to complete connection in a circuit, the third connection has to be made to the case in some suitable way (e.g. to one of the screws used to mount the transistor in position).

Transistor specifications in manufacturers' or suppliers' catalogues normally state the outline as a TO number; common Transistor Outlines and their numbers are shown in Fig. 1-4. By knowing the TO number you can, from these diagrams, determine both the physical size of transistor specified and the lead configuration. It's a useful reference.

To complete our general picture of transistors, all are made from either germanium or silicon semiconductor material. These are known as germanium transistors or silicon transistors. Germanium transistors are generally cheaper, but this type of material is more readily damaged by heat. Thus germanium transistors cannot be used at working temperatures in excess of 100° C. Silicon transistors can be operated at working temperatures of 150° C. or more, if necessary, without damage.

There are electrical differences, too. Germanium transistors have lower voltage losses, but higher leakage currents. Silicon transistors have very much lower leakage currents, can accommodate higher voltages without damage, and are particularly advantageous where higher output powers are required.

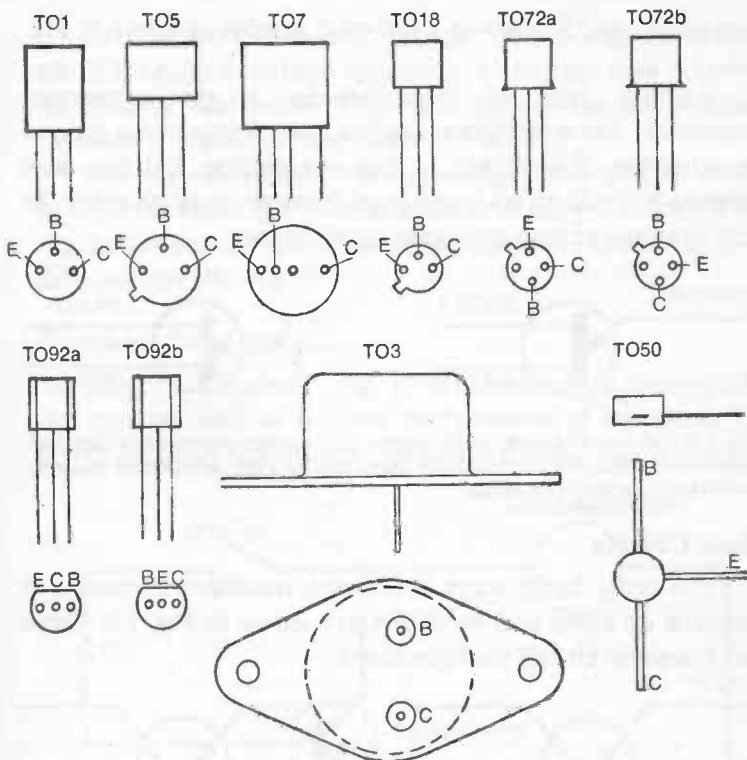


Fig. 1-4. Common transistor shapes, shown actual size, with lead identification.

Silicon transistors are usually made by the planar process and are often referred to as *silicon planar transistors*. Germanium transistors are made by either the alloy-junction or alloy-diffusion process. All three are basically junction type transistors where the construction produces definite junctions between the base, emitter and collector elements. Today, the advantages of silicon transistors have long since made them the most popular type.

*Field effect transistor*, or FETs, are a later development, and here the construction is quite different. It may still end up looking like an ordinary transistor, but its electronic characteristics are quite different. Its elements are known as the *source*, *gate* and *drain* (equivalent only vaguely to the emitter, base and collector, respectively, of a conventional

transistor) and it is given a different symbol as shown in Fig. 1-5.

Another type of semiconductor is the *unijunction* transistor; the description applies specifically to the type of construction. Effectively, it has one emitter and two base terminals. Field effect transistors, however, may be either the junction type or insulated-gate construction.

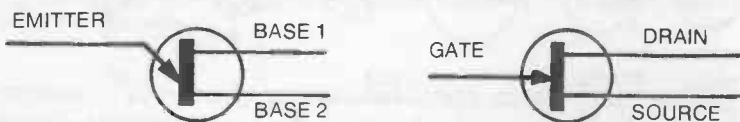


Fig. 1-5. Symbol and lead identification for unijunction transistor (left) and field effect transistor (right). Both types can be PNP (arrowhead inwards) or NPN (arrowhead outwards).

### Basic Circuits

The three basic ways in which a transistor is connected between an input and an output are shown in Fig. 1-6. These are known as circuit configurations.

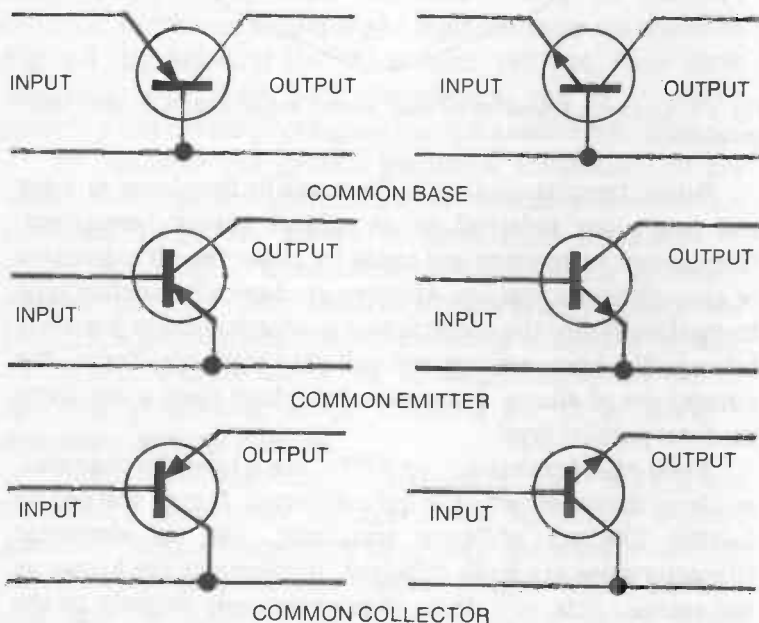


Fig. 1-6. Basic transistor circuit configuration. PNP transistors left; NPN transistors right.

To function, a transistor also has to be provided with bias, which is really a voltage applied to, or current flow between, the emitter and base. This bias determines the working characteristics of the transistor.

The common-emitter circuit configuration is most widely favored for transistors since a single battery will supply the bias in the emitter circuit and also the power in the output or collector circuit.

### Transistor Test Circuit

The circuit shown in Fig. 1-7 is an example of *current* bias, and can be used to test the performance of individual low power junction transistors. Although simple, this is actually

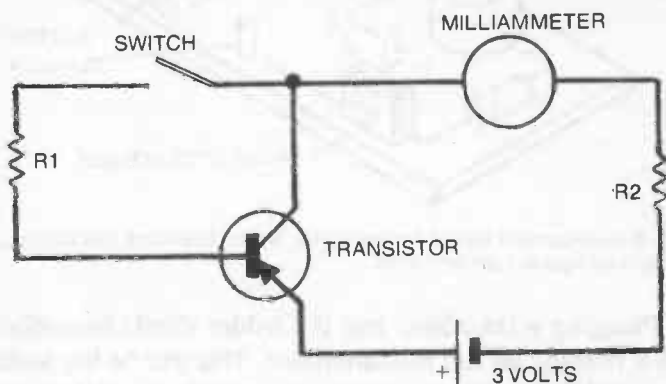


Fig. 1-7. Simple current bias circuit which can be used for testing transistors  $R1 = 60,000$  ohms,  $R2 = 1000$  ohms.

quite a clever bias circuit for it provides automatic DC compensation for transistor variations. The current flowing is determined by the value of  $R1$  and the battery voltage. Any increase in collector current will lower the voltage at the collector because of the increased voltage drop across  $R2$ . This will reduce the bias to automatically adjust the collector current to a lower level.

This circuit can be built on a simple board as shown in Fig. 1-8. Transistor connections are made not to the transistor, but to a transistor socket; this enables different transistors to be plugged in for testing and easy removal. The ammeter shown

has a 0.25 or 0.5 milliamp range. Resistor values are:  $R_1 = 60K$  (60,000 ohms) and  $R_2 = 100K$  (100,000 ohms). A switch (preferably a push button) is connected on the emitter circuit. A 3-volt battery connects to the + and - terminals for testing PNP transistors. For testing NPN transistors *the battery connections must be made the other way* (battery + to circuit - and battery - to circuit +).

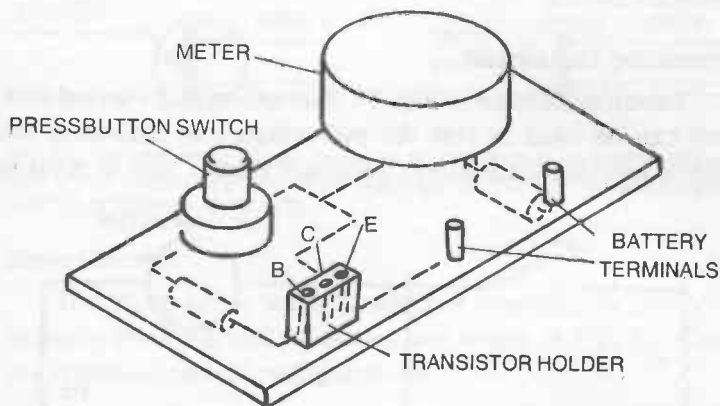


Fig. 1-8. Component layout for transistor tester. Resistors and wiring connections completed under panel.

Plugging a transistor into the holder should immediately give a reading on the milliammeter. This will be the *leakage current* of the transistor. Closing the switch should then give a higher current reading, indicating that the transistor is working. A faulty transistor will indicate the following:

1. open circuit transistors—no reading when plugged in and no reading when switch is depressed.
2. isolated transistors—high reading when plugged in.

The component values for this circuit have been chosen so that the current gain of the transistor can also be measured; this is expressed as  $h_{fe}$  on transistor specifications. Simply make a note of the actual reading in milliamps when switch is depressed and multiply by 20. This will be the  $h_{fe}$  figure for that transistor.

Since leakage currents are generally minute—especially with silicon transistors—and small differences in meter needle

position are difficult to read, it would be better to use an 0 to 100 microammeter in the circuit for leakage current measurement. The performance of individual transistors of the same or similar type can then be compared, and the best transistor can be selected for a particular circuit. Remember to replace the microammeter with the milliammeter for measuring gain as the current with the switch depressed will be much higher than the microammeter can safely take.

To make the test circuit goof proof, terminate the wires connecting to the meter in a 2-pin socket. Microammeter and milliammeter are then each wired to a 2-pin plug. This makes it easier to change from one meter to the other.



## 2

# Equivalent Transistors

Transistors of specific type number, produced by individual manufacturers, have individual characteristics, although these may vary even within one type. Circuits commonly specify a particular type of transistor or equivalent. This is really a matter of availability. A particular transistor type specified may not be obtainable when wanted, so an equivalent must be used to work with the other components and component values given in the original circuit design. The circuit could also work with quite a different type of transistor, but this would normally mean altering most, or all, the component values.

Transistors of one make may not have an exact equivalent in another make, so quoted equivalents are normally near-equivalents, implying that they should work with the same circuit component values. Since literally thousands of different types of transistors have been produced, a list of equivalents could (and does) fill a whole book. In fact, there are reference books devoted exclusively to listing transistor equivalents; the serious electronic experimenter will find it useful to add one to his library. TAB book 970 is one such reference. Book 1010 is another.

As a general guide, the following section lists common transistor types according to usual application. The list is

restricted to transistor types readily available in the U.S. and Great Britain and is by no means complete. But by keeping the listings short, and confining them to good quality transistors, there is less possibility of confusion in deciding on an equivalent type. Basically, all transistors in the same group can be regarded as equivalents when functioning in the *same type of circuits*. It does not follow that their performance will be the same in such circuits, however, nor that the same circuit component values can be used. Suitable equivalents are therefore also given, where practicable. Equivalents listed should be a satisfactory direct substitute in the same circuit. Coding given in brackets designates the transistor package style.

**Germanium PNP—low power general duty:**

TYPE	EQUIVALENT(S)
OC41 (TO1)	CV7042, ASY56, ASY57, OC72, 2N65, 2N104, 2N109, 2N111, 2N112, 2N113, 2N114, 2N123.
OC42 (TO1)	CV8252, ASY57, ASY58, OC72, 2N65, 2N104, 2N109, 2N111, 2N112, 2N114.
OC72 (TO1)	CV5713, CV7006, CV8440, OC308, OC604, NKT 121, 2N281, 2N1305, 2SB89, AC128, AC131, AC132, AC151, AC153, ACY36.
OC75 (TO1)	CV5439, OC304, OC604, NKT213, 2N41, 2N1303, 2SB77, 2SB89, AC122, AC125, AC126, AC131
OC81 (TO1)	AC151, AC163, ACY30, ASY58, ASY59. NKT271, 2N1305, AC128.
OC81D (TO1)	AC128.
AC128 (TO1)	CV9779, OC74, OC318, NKT281, 2N467, 2SB222, 2SB415, AC117, AC124, AC153, GET110.

**Germanium PNP—radio frequency amplifiers and oscillators:**

<b>TYPE</b>	<b>EQUIVALENT(S)</b>
2N3325 (TO18)	
NKT603F (TO7)	
NKT613F (TO7)	
NKT674F (TO7)	
OC44 (TO1)	CV5710, CV7003, OC170, OC171, OC410, OC613, 2N1303, 2SA15, AF101, AF117, AF126, ASY55.
OC45 (TO1)	CV5105, CV7004, OC390, OC612, 2N218, 2N1303, 2SA12, 2SA49, AF101, AF116, AF126, AF127, ASY54.
AF118 (TO7)	CV10276, 2SA76, 2N327, 2N328, 2N329, 2N935, 2N936, 2N945, 2N1035, 2N1232.
AF139 (TO72a)	AF148, AF239, 2N502, 2N700, 2N1158, 2N1727, 2N1728, 2N1790, 2N2363, 2SA54, 2SA256, 2SA257.
AF200U (TO72b)	
AF239 (TO72a)	
AF279 (TO50)	

**Germanium PNP—low power audio frequency amplifiers:**

<b>TYPE</b>	<b>EQUIVALENT(S)</b>
NKT214 (TO1)	2N1305, AC115, AC128, ASY63, ACY34, ACY35.
NKT217 (TO1)	ASY13, ASY51, ASY52.
NKT274 (TO1)	2N1303, AC128.
NKT211 (TO1)	ACY18, AC128, ASY82, ASY84.
NKT212 (TO1)	2N1305, AC127, AC128, AC131, AC132, AC166, AC167, AC177, ACY36.
NKT213 (TO1)	2N1309, ACY23, ACY31, AC122, AC128, AC138, AC156, AC165.

AC126 (TO1)	OC71, OC81, OC303, OC304, KNT219, 2N506, 2SB219, 2SB415, AC122, AC151, AC163.
AC107 (TO1)	CV7008, OC303, OC304, 2N1305, NKT216, AC117, AC122, AC128, AC151, ACY32, 2SB178.
AC128 (TO1)	CV9779, OC74, OC318, NKT281, 2N467, 2SB222, 2SB415, AC117, AC124, AC153, GET110.
OC71 (TO1)	KNT214, 2N280, 2N1305, 2SB77, AC122, Ac125, AC151, AC163, ACY35.

**Germanium PNP—medium power AF amplifiers, medium current suitability:**

TYPE	EQUIVALENT(S)
ACY17 (TO5)	CV7376, CV9482, NKT237, 2SB218.
ACY18 (TO5)	CV7436, CV8130, KNT238.
ACT19 (TO5)	CV7436, CV10183, NKT239.
ACY20 (TO5)	CV7438, CV9483, KNT240, 2N524, 2N525, 2N526, 2N527, 2N597.
ACY21 (TO5)	CV7439, CV8259, NKT241, 2N524, 2N525, 2N597, 2N650.
ACY22 (TO5)	CV10550, NKT242, ACY33, 2N315, 2N317, 2N598, 2N1204, 2N1384, 2N1478, 2N1495.
ACY39 (TO5)	NKT244.
ACY41 (TO5)	NKT245.
ACT44 (TO5)	
2N1303 (TO5)	CV7352, NKT135, ASY26, ASY57, ASY63, ASY64, 2N1997, 2N1998.
2N1305 (TO5)	CV353, CV9536, ASY54, ASY58, ASY63, NKT135, 2N466, 2N1309, 2N1997, 2N1998.
2N1307 (TO5)	CV7354, NKT137, ACY29, ACY30, ASY27, ASY55, ASY59, ASY63, 2N1309, 2N1997, 2N1998.

2N1309 (TO5)	CV7355, CV9481, ASY59, ASY60, ASY63, 2N1997, 2N1998.
ASY26 (TO5)	CV9730, OC390, NKT135, 2N799, 2SA155, ASY24, ASY48, ASY56, ASY64, ACY20, BSY24.
ASY27 (TO5)	CV10275, OC304, NKT135, 2N36, 2SB101, AC163, ASY30, ASY48, ASY54, ASY57, ASY66.
OC83 (TO1)	CV8724, CV9259, NKT223, AC128, AC152, ACY30, ASY58, ASY59.
OC84 (TO1)	CV5416, NKT211, AC128, ASY59.
AC188K (XO)	
AC151 (TO1)	OC303, OC304, NKT216, 2N238, 2SB101, 2SB415, AC122, AC125.
AC151R (TO1)	
AC152 (TO1)	OC303, OC304, KNT281, 2N238, 2SB101, 2SB415, AC117, AC124, AC125, AC132, ASY48, GET110.
AC153	OC318, NKT281, 2N467, 2SB222, 2SB415, AC117, AC124, AC128, GET110.

**Germanium NPN—AF amplifiers, medium current suitability:**

TYPE	EQUIVALENT(S)
2N1302 (TO5)	NKT34, 2N634, 2N635, 2N636, 2N1304, 2N1306 2N1308, 2N1891, 2N1993, 2N1994, 2N1995.
2N1304 (TO5)	CV7349, CV9261, NKT734, 2N634, 2N635, 2N636, 2N1302, 2N1306, 2N1891, 2N1993, 2N1994, 2N1995.
2N1306 (TO5)	CV7350, CB10686, NKT736, 2N634, 2N635, 2N636, 2N1891, 2N1993, 2N1994, 2N1995.

2N1308 (TO5)	2N1302, 2N1304, 2N1306, 2N1891, 2N1993, 2N1994, 2N1995.
ASY28 (TO5)	
ASY29 (TO5)	CV9040, OC400, NKT734, 2N211, 2SA255, AF101.
NKT713	ASY86, ASY88, AC127, AC128, AC132, AC168, AC172, AC175.
NKT773	AC130, AC157.
AC127 (TO1)	CV9778, NKT713, 2SD100, 2SD104, 2SD105, 2N59, 2N60, 2N61, 2N402, 2N403, 2N611, 2N726, 2N1221, 2N1280.
AC176 (TO1)	CV10675, NKT781
AC176K (X9a)	
AC187K (X9a)	

#### Germanium PNP—high power

TYPE	EQUIVALENT(S)
OC19 (TO3)	AD140, AD149.
OC25 (TO3)	CV7085, CV8982, AD149, OC28, 2N297, 2N418, 2N420, 2N443, 2N458, 2N463.
OC28 (TO3)	CB7085, CV8342, NKT401, 2N456, 2S42, 2SB424, AD148, ASZ15, AUY22.
OC29 (TO3)	CV7083, CV8356, NKT402, 2N457, 2N457, 2SB86, 2SB425, AD150, ASZ16, AUY21, OC28, OC35.
OC35 (TO3)	CV7084, CV9264, NKT404, 2N352, 2SB86, 2SB425, ASZ17, AUY21, OC28, OC29, OC36.
OC36 (TO3)	CV7086, CV8480, NKT403, 2N157, 2N157, 2N1666, 3N1668, 2N2526, 2SB87, 2SB424, AD132, ASY18, ASZ18, AUY22, OC28, OC29, OC35.

NKT403 (TO3)	AD105, AU103, AUY32, ADY23, ADY24, ASZ18, 2N458, 2N574, 2N677, 2N678, 2N1021, 2N1022, 2N1029.
NKT404 (TO3)	AD104, AD131, AD140, AD152, ASZ16, ASZ17, AUY33, AU103, OC29, 2N443, 2N458, 2N574, 2N677.
NKT405 (TO3)	AU103.
AL102 (TO3)	
AD133 (TO3)	2N1146, 2SB236, ADZ11, ADZ12.
AD136 (TO3)	AD138, ADZ11, 2N278, 2N442, 2N443, 2N511, 2N512, 2N513.
AD140 (TO3)	NKT404, AD149.
AD142 (TO3)	OC26, OC27, 2N301A, AD133, ADZ12.
AD149 (TO3)	OC28, OC36, 2N456, 2S42, 2SB426, C138, AD148.
AD150 (TO3)	OC28, OC36, 2N456, 2S42, 2SB426, AC138, AD140, AD149.
AD161 (MD17c)	CV9777.
AD162 (MD17c)	CB9777, 2SB426.

**Silicon NPN, general purpose, small signal:**

TYPE	EQUIVALENT(S)
2N3708 (TO92a)	BC107.
2N3709 (TO92a)	BC107.
2N3710 (TO92a)	BC107.
2N3711 (TO92a)	
2N3904 (TO92b)	CV11041.
2N4124 (TO92b)	

**Silicon NPN—radio frequency amplifiers and oscillators:**

BF115 (TO72b)	CV10243.
BF167 (TO72b)	

BF173 (TO72b)	
BFY90 (TO72a)	CV10533.
BF194 (MM10b)	
BF195 (MM10b)	
BF254 (TO92za)	
BF255 (TO92za)	
2N3663 (TO98a)	BF173.
2N4292 (u29)	

### Silicon NPN—audio frequency amplifiers:

TYPE	EQUIVALENT(S)
2N3707 (TO92a)	BC107.
2N930 (TO18)	CV7493, CV8467, CV10416, BC107, 2N243, 2N244, 2N560, 2N698.
2N2484 (TO18)	CV7738, CV9133, CV9368, 2N930, BCY66, BFY26.
2N2924 (TO98a)	CV11046, BC107.
2N2926 (TO98a)	BC107.
2N3391A (TO98a)	
2N4286 (u29)	BC107.
2N5088 (TO92b)	
BC109 (TO18)	CV10769, CV10806.
BC149 (MM10)	
BC169 (TO92a)	BC109.
BC184L (TO92a)	
BC269 (TO18)	
PN109 (RO97Aa)	
PN109 (RO97Aa)	
PN930 (R097Aa)	

### Silicon NPN—general purpose switching:

TYPE	EQUIVALENT(S)
BSX20 (TO18)	
BSX60 (TO5)	
BSX61 (TO5)	
P346A (TO18)	



2N706 (TO18)	CV9211, BSY20, BSY62, BSY70, 2N703, 2N708, 2N743, 2N744, 2N753, 2N756, 2N757, 2N1199.
2N2369A (TO18)	CV7555, CV9564.
2N3702 (TO92a)	CV10564.
2N3703 (TO92a)	CV10682.
2N4036 (TO5)	CV10548.
2N4291 (u29)	
BC126 (RO97)	
BCY30 (TO9)	CV7344, CV9430, BCY29.
BCY31 (TO5)	CV7344, CV8760, CV9247, BCY27, BCY28.
BC160 (TO5)	
BC303 (TO5)	
BFX29 (TO5)	
BFX87 (TO5)	
BFX88 (TO5)	CV10629.
40362 (TO5)	
40406 (TO5)	

### Field Effect Transistors

TYPE	EQUIVALENT(S)
2N3819 (TO92c)	CV10684.
2N3823 (RO97Ab)	CV10832, CV11004.
2N4303 (RO97Ab)	
2N5163 (RO97Ab)	
2N5457 (RO97Ab)	
2N5458 (RO97Ab)	
2N5459 (RO97Ab)	

### Unijunction Transistors

TYPE	EQUIVALENT(S)
2N2646 (TO72d)	CV9695.
T1543 (TO92e)	

## Other Circuit Components

Resistors used in transistor circuits are invariably of sub-miniature or miniature type, usually of carbon film construction. Such resistors have high stability and little self-generated noise, both characteristics are highly valued in transistor circuits. Typical shapes and sizes are shown in Fig. 3-1.

Resistance values normally follow a standard series: 1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, and 8.2. There is a very good reason for this. Preferred values are based on a *logarithmic* scale, so that the next number up, or down, represents an approximately constant *percentage* change in resistance value.

Actual resistance values in ohms thus follow the series 10, 12, 15, 18, 22, etc. up to 1000. A value of 1000 ohms is usually described as 1 kilohm, written 1K. Values in kilohms then run 1, 1.2, 1.5, 1.8, 2.2 and so on up to 1000 kilohm, or 1 megohm, written 1 Meg. Values in megohms then follow in the same way—1.0, 1.2, 1.5, etc.

*The physical size of a resistor is no indication of its resistance value.* All values of similar make and type are usually the same size. The actual resistance value is marked

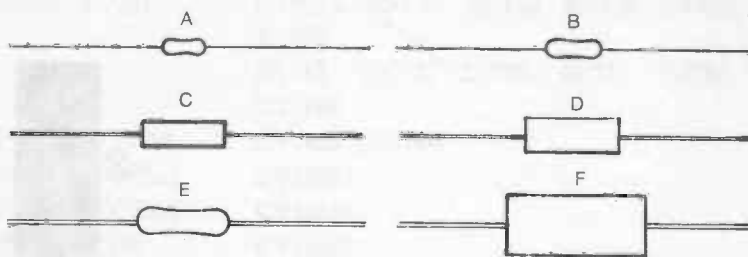


Fig. 3-1. Examples of sub-miniature and miniature resistors actual size. A, B, C & D are carbon film. E is metal oxide. F is carbon film.

by a color code consisting of four colored rings around the body of the resistor. See Fig. 3-2. These colors are read starting from the ring nearest to the end of the resistor.

The complete color code is:

Color	Value	Color	Value
black	0	green	5
brown	1	blue	6
red	2	violet	7
orange	3	grey	8
yellow	4	white	9

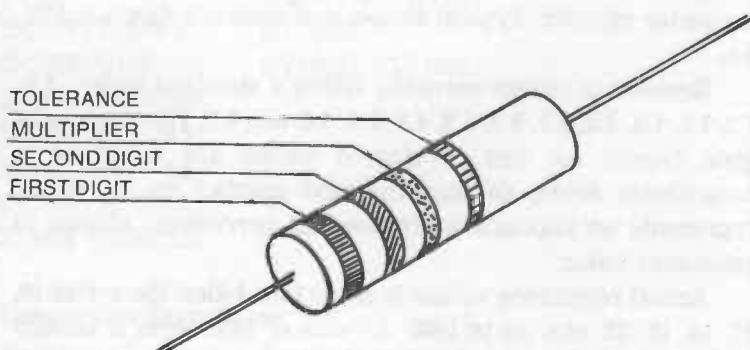


Fig. 3-2. Resistor color coding

The number corresponding to the *first* color (first ring) gives the *first* digit of the value. The number corresponding to the second color (second ring) gives the second digit of the value. The number corresponding to the third color (third ring) gives the number of zeros to be added to the value.

For example: if the color is green, blue, orange—

First color: green = 5 = first digit  
Second color: blue = 6 = second digit  
so we have 56  
Third color: orange = 3 = number of zeros to be added  
Finally giving 56,000 ohms or 56 K ohms as the resistor's resistance value.

So far the fourth color band has been disregarded. This gives the tolerance of the resistor and so can be ignored for most purposes. The tolerance code is as follows:

brown  $\pm 1$  percent  
red  $\pm 2$  percent  
gold  $\pm 5$  percent  
silver  $\pm 10$  percent

Thus, if the previous example—green, blue, orange—was followed by a silver band, this would indicate a 56K ohm resistor with a tolerance of  $\pm 10$  percent.

The only other important thing about a resistor is its power rating. This is given in watts, e.g. 1/10 watt, 1/4 watt, 1/2 watt, 1 watt, etc. Again this is only significant in circuits when the wattage rating of the resistors used is at least as great as the value of circuit voltage multiplied by maximum current (in amps) flowing in that circuit. Average *electronic gadget* circuits use 1/2 watt resistors throughout. If not, there is a danger of the resistor becoming overheated and permanently damaged.

*Variable* resistors are generally known as potentiometers and have quite a different construction and physical appearance. The two main types used in simple circuits are carbon elements and "skeleton" types—see Fig. 3-3. Carbon

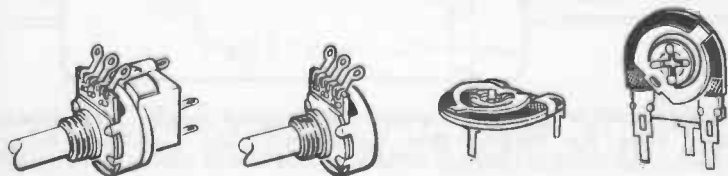


Fig. 3-3. Conventional potentiometer (left) with carbon or wire-wound element. Skeleton potentiometers (right) are designed to connect directly into circuit panels or circuit boards.

potentiometers are adjustable by a knob fitted to the spindle. With a skeleton type potentiometer, adjustment of the setting is made by screwdriver adjustment in the central slot.

Resistance values with potentiometers again usually follow the preferred series, but not so closely spaced, e.g. 1K, 2.2K, 4.7K, 10K, 22K, 47K, 100K, etc. They are commonly referred to as nominal values in circuits, e.g. 1K, 2K, 5K, 10K, etc.

Capacitors are made in a wide range of sizes, shapes and materials. Ceramic capacitors are widely favored for transistor circuits because of their small size. They are usually *plate* shape for pF values from 22 to above 6800, and *disc* shape for values from 1000 pF up to  $0.1 \mu\text{F}$  (i.e.  $0.001 \mu\text{F}$  to  $0.1 \mu\text{F}$ ). Molded mica types are also used for  $\mu\text{F}$  values. For large values,  $0.1 \mu\text{F}$  up, electrolytic capacitors are normally used. These are larger and readily identified by their metallic casing (see Fig. 3-4). Electrolytic capacitors are *polarized*;

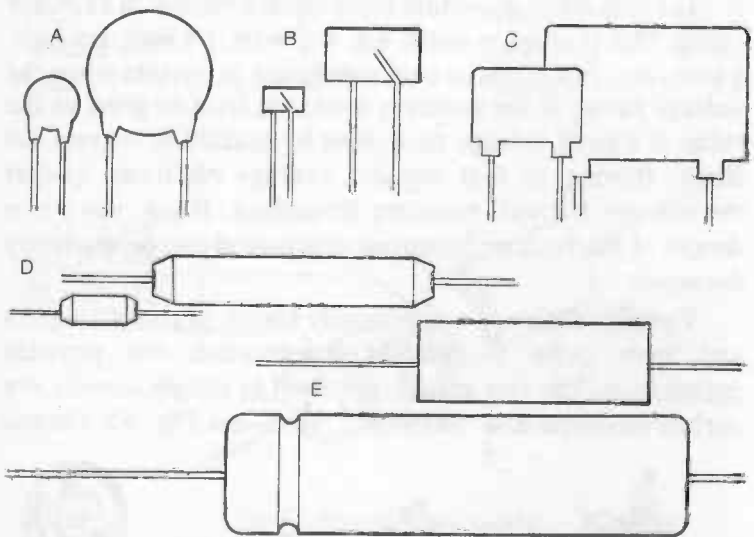


Fig. 3-4. Capacitor types and approximate range of physical sizes (shown actual size). A = ceramic disc. B = ceramic plate. C = silvered mica. D = polyester. E = electrolytic.

this means they must be connected with the + end marked on the capacitor body to circuit positive.

Capacity values are usually marked on the capacitor body; a color code is also sometimes used. The color code used today is:

- black = 1
- brown = 10
- red = 100
- orange = 1000
- yellow = 10000

Other colors can be usually ignored as these refer to tolerance and/or temperature characteristics.

The colors are then read similarly to the resistor color code, as:

first digit }  
 second digit } see Fig. 3-5.  
 multiplier }

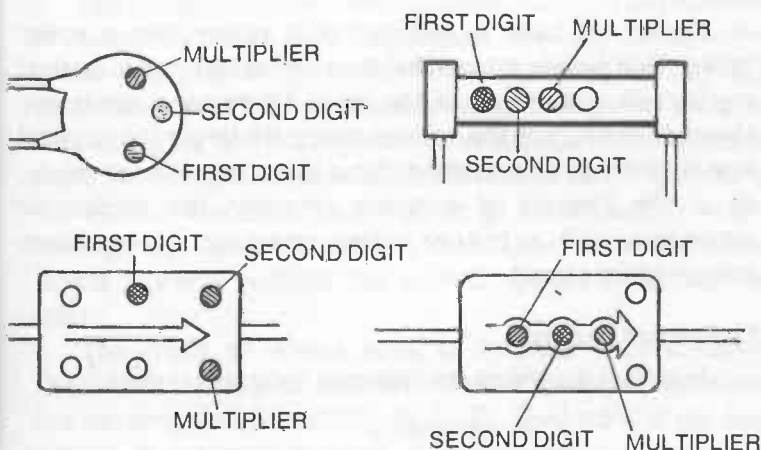


Fig. 3-5. Capacitor color codes.

Miniature *variable capacitors* suitable for simple transistor circuits are usually plastic dielectric where the size is about 1 inch square by 1/2 inch thick (typical values up to 500 pF), with spindle and knob adjustment. Even smaller mica-dielectric trimmer capacitors may be used, adjustable

by screwdriver. Typical capacity values extend to 500 pF. Miniature air-spaced variable capacitors are also available, although maximum capacity is usually of the order of 150–200 pF. The latter type are often fitted with trimmer capacitance as standard.

Alternative types, where size is not important, are solid dielectric tuning capacitors (up to 500 pF), and larger air-spaced tuning capacitors, single, double and triple ganged. Values again usually extend up to 500 pF (Fig. 3-6).

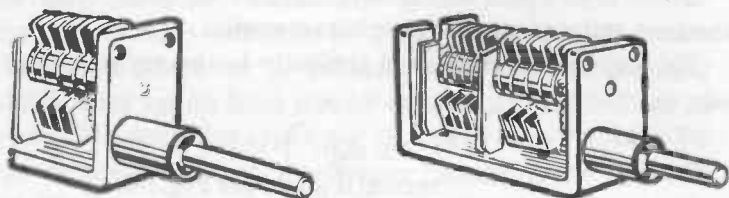


Fig. 3-6. Examples of variable capacitors, single and twin-gang. Variable capacitors sometimes have reduction gearing between the operating spindle and vane movement.

Capacitors have a *voltage* rating rather than a power rating. This simply means that they are constructed to work at *any* circuit voltage up to the rated figure as a maximum. However the higher the voltage rating the larger the physical size of electrolytic capacitor (for a given capacitance value), so in the interest of compact circuitry, use electrolytic capacitors with a voltage rating matching the maximum voltage of the circuit.

### Component Symbols

In circuit diagrams the following symbols are used:

C for capacitors

D for diodes

L for coils (inductances)

R for resistors

RFC for radio frequency chokes

### 'Microfarads' and 'Picofarads'

Confusion can often arise when capacitor values are quoted in both microfarads ( $\mu\text{F}$ ) and picofarads (pF) on the

same circuit diagram, especially as sometimes the actual unit symbol is omitted. The basic rule in this case is to remember that a picofarad is one *millionth* of a microfarad:

$$1 \text{ pF} = \frac{\mu\text{F}}{1,000,000}$$

It therefore follows as a general rule that where *whole number* values are given for capacitors with no symbol following, then the value is specified in picofarads (pF). For example if 250 is marked against a capacitor then its value is probably 250 pF. This, of course, is the same as 0.00025  $\mu\text{F}$ .

Capacitor values in microfarads ( $\mu\text{F}$ ) are generally—but not invariably—decimal fractions e.g. 0.01, 0.005, etc. So if a decimal fraction value appears without a symbol this will certainly be microfarads.

For example, if 0.02 is quoted against a capacitor, then its most likely value is 0.02  $\mu\text{F}$ .

The exception is that whole number values of capacitance in microfarads can also be quoted. Electrolytic capacitor values may even range up to 10,000  $\mu\text{F}$ , although really high values like these are not found on simple low power circuits. Single number and double number values are more common, e.g. 2.2 or 10—and could be confused with pF in the absence of any symbol. Normally, however, large whole number values usually refer to picofarads and are unlikely to be given in a circuit drawing without the correct symbol following, i.e. (pF).

The prefix m means milli, or 1/1000th while  $\mu$  means micro, or 1/1,000,000th. However, even large capacitor values are never quoted in millifarads (mF). So if mF (or m) does appear on a circuit drawing, it almost certainly means  $\mu\text{F}$  (microfarads).

In the circuit diagrams in this book, where capacitor values are given in a drawing, a capacitor value (number) *without* a following symbol should be read as microfarads ( $\mu\text{F}$ ). Where capacitor values are in picofarads the numerical value is followed by pF.



# 4

## What a Single Transistor Can Do

The variety of working circuits which can be produced around a single transistor is virtually endless. One could start with a 'complete' radio receiver, for instance, which requires no battery power at all. This, of course, is the well-known *crystal receiver*, normally based on a germanium diode detector.

The classic circuit is shown in Fig. 4-1. L1 is a proprietary antenna tuning coil wound on a ferrite slab, and C1 is a matching variable capacitor (either 400 or 500 pF). Virtually any diode will do, and the only other circuit component is capacitor C2 connected across the output. Phones must be of high impedance type (headphones or earpiece). An external aerial and a good physical ground connection are essential for satisfactory working.

The same circuit will work as well, or even better, using nearly any RF germanium transistor. Suggested types are 2N370, 2N371, and 2N3325 or equivalents. Only the base and emitter leads of the transistor are connected into the circuit (replacing the diode). The collector lead of the transistor is ignored. Also it does not matter which way round the transistor is connected. However, this is wasting the full potential of the transistor. It can be made to act as a detector

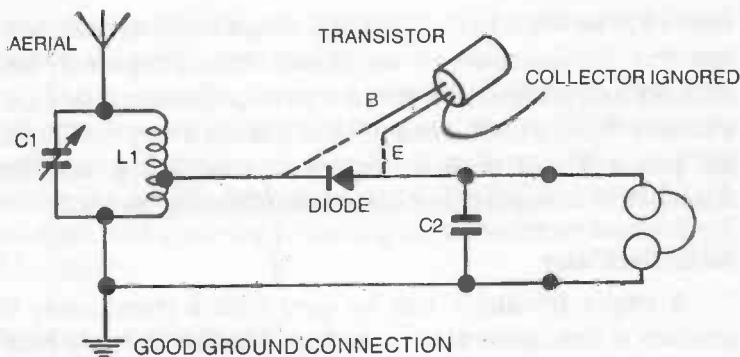


Fig. 4-1. Basic crystal set works without a battery and can use either a diode or a transistor as a detector.

and amplifier in the simple circuit shown in Fig. 4-2. This time a battery is required (which can be anything from 1.5 to 9 volts), and the connections of the transistor are important. Those shown are for any PNP type.

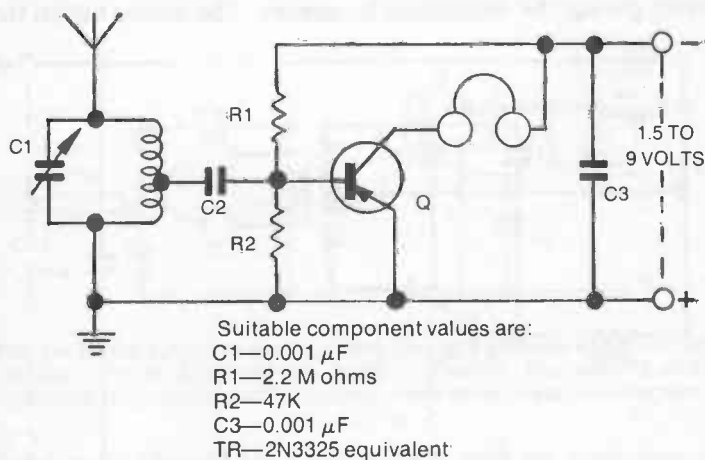


Fig. 4-2. Modified crystal set employing a transistor both as detector and amplifier.

It may be possible to get working results with even fewer components. Capacitor C3 may well be omitted for instance (try the receiver with and without). Try also shorting out capacitor C2. If this has no appreciable effect, then C2 can be

omitted. You may, in fact, get this simple radio working with just five components—an aerial coil, tuning capacitor, two resistors and a transistor, plus a high impedance earpiece and a battery. Such a circuit can be built down to a very small size, but you will still need an external aerial and ground for satisfactory reception and reasonable 'listening' strength.

### Audio Oscillator

A single transistor can be used with a transformer to produce a tone generator or audio oscillator—the only other components needed being a couple of resistors and three capacitors. The transformer is a typical transistor radio output transformer. The tone produced can be heard in low impedance phones connected across the output of the transformer using a 3-volt battery; or in a miniature loudspeaker of 16 ohms resistance using a 9-volt battery.

The circuit design is shown in Fig. 4-3. The primary winding of the transformer and capacitor C2 form the tuned circuit giving the oscillation frequency. The center tap on the

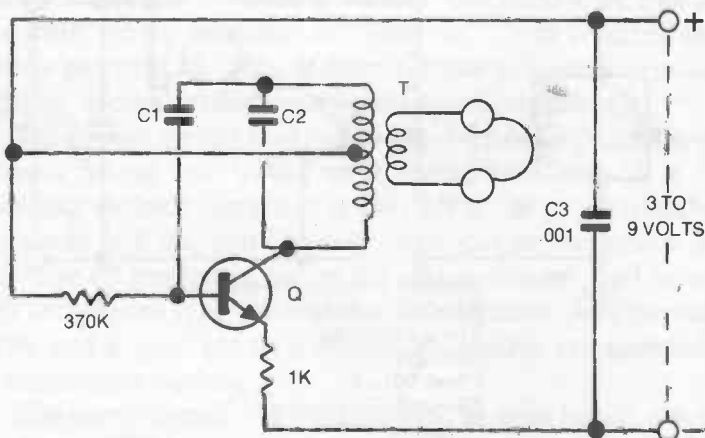


Fig. 4-3. Audio oscillator circuit based on a Motorola HEP S0015 transistor or equivalent. Try  $0.01 \mu\text{F}$  for C1 and  $0.02 \mu\text{F}$  for C2. Resistor values are shown on the diagram. Phones are low impedance type.

primary connects to the base of the transistor via the 370K ohm resistor. Using different values for C2 will alter the tone—higher pitched tone with a lower value of C2, and vice

versa. Capacitors C1 and C3 are merely blocking capacitors for direct current in the circuit.

If the circuit does not oscillate, remove the end connections to the primary of the transformer. If this does not produce an audible tone, then the circuit may be oscillating outside the audible frequency range. Try higher values for C2 to adjust, and again try removing the transformer connections if necessary.

### Transistor Radio Booster

Small, inexpensive transistor radios often have low listening volume, particularly on weaker stations, even when listening via a plug-in earpiece. This simple single-transistor circuit will boost earpiece listening levels considerably, so much so, in fact, that a separate volume control is essential.

The circuit is based around an FET transistor—see Fig. 4-4. One side of the circuit is wired to a plug matching the earpiece socket on the transistor radio. This is the input side of

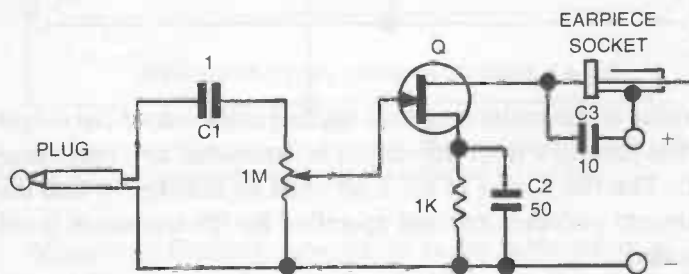


Fig. 4-4. Radio output booster for plugging into earpiece socket on small transistor radios. Earpiece now plugs into socket. Transistor is an FET type 2N3823 or equivalent. Other component values shown on diagram.

the circuit, coupled via capacitor C1, with the potentiometer R1 acting as a potential divider and volume control. An earpiece socket is wired into the output side of the circuit, and a separate 6- or 9-volt battery is required for this circuit, rather than tapping on to the receiver battery. This enables the amplifier to be unplugged from the radio when not required without having also to disconnect leads taken to the receiver battery.

Capacitors C2 and C3 may or may not be required. Try first with C2 connected, then without. If there is no appreciable difference in performance, omit C2. Capacitor C3 should improve the tonal quality of the signal, but since this is usually poor to start with in the case of a miniature transistor radio, it may be an unnecessary elaboration.

### DC Amplifiers

Transistors can also amplify direct current. A basic DC amplifier circuit is shown in Fig. 4-5 which provides *current gain* (i.e. works as a current amplifier). The actual current gain is dependent on the 'beta' value of the transistor used, and

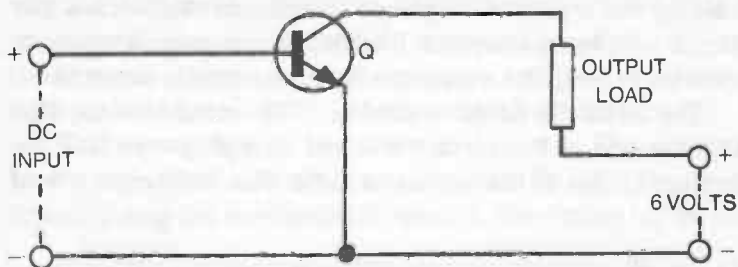


Fig. 4-5. Basic DC amplifier using NPN transistor.

the value of the resistance load applied to the output (no output current can flow until the output is connected to a resistance load). The resistance of the load must be selected so that the maximum collector current specified for the transistor is not exceeded.

Fig. 4-6 shows another type DC amplifier, using an FET. In this case the circuit works as a *voltage amplifier*. The

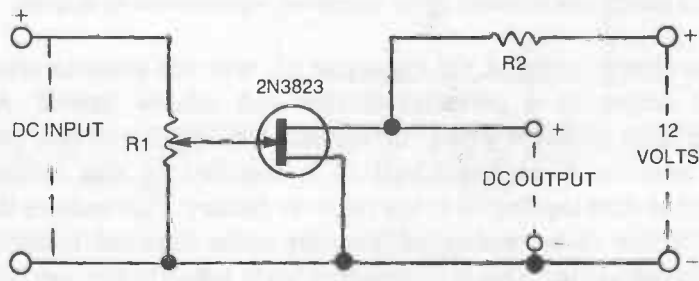


Fig. 4-6. Voltage amplifier based on an FET.

potentiometer R1 acts as a gain control. The value of R2 is chosen so that the maximum drain-to-source voltage of the transistor is not exceeded. Have a look also at the chapter on Amplifiers for other practical amplifier circuits.

### Simple Stroboscope

Using an ordinary flashlight bulb for a stroboscope (Fig. 4-7), instead of a special neon, is quite practical, provided it is accepted that the flashing rate is limited by the inability of a filament to go out and on at high repetition rates. (If it had that ability then electric light bulbs would flicker continuously.)

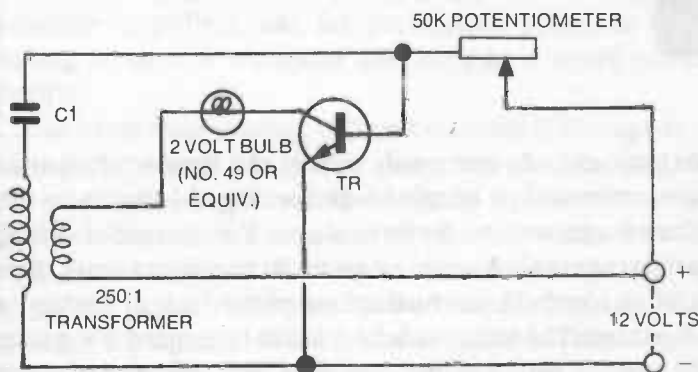


Fig. 4-7. Simple stroboscope using an NPN transistor type BC107 or 2N2712. A suitable value for the blocking capacitor C1 is 50  $\mu$ F.

Maximum flashing rate likely to be achieved is of the order of 20 per second, equivalent to 1200 rpm. If any job calls for a simple low frequency strobe of this order, then this simple circuit will suffice.

It consists of a blocking oscillator with a variable oscillation frequency from about 1 to 25 Hz. The only components involved are one NPN transistor, a miniature 250:1 transformer, a 50K potentiometer and a blocking capacitor (C1). The bulb is a 2-volt pilot light of the type that draws about 50 milliamps current.

Adjustment of the potentiometer controls the flashing rate. If the circuit does not work as originally connected, reverse the connections to one side of the transformer.

# 5

## Coupling

Electronic circuits commonly consist of a number of separate stages connected or coupled together. Fig. 5-1 illustrates this in block diagram form for three stages. For the sake of making this diagram real, A could be an audio oscillator circuit, B an amplifier, and C a further amplifier stage feeding a loudspeaker. The output side of A has to be coupled to the input of B, and the output of B to the input of C. The output of C is then connected to the loudspeaker.

There are three different ways in which one stage can be coupled to another: direct (i.e. output direct to input), direct, but with a capacitor in the connecting lead, and indirect, through a transformer.

Choice of the type of coupling used is influenced by the characteristics of the circuits involved, as well as the circuit designer's ideas on what is the best method to use in a particular case. Where any of three methods would work, the main thing to remember is that the first will pass both AC and DC, whereas the second and third methods pass only AC from input to output.

Direct coupling is the simplest, and most obvious method. It also eliminates the need for a coupling capacitor or coupling transformer. Besides saving on components, this can also be an advantage from the performance point of view in the case

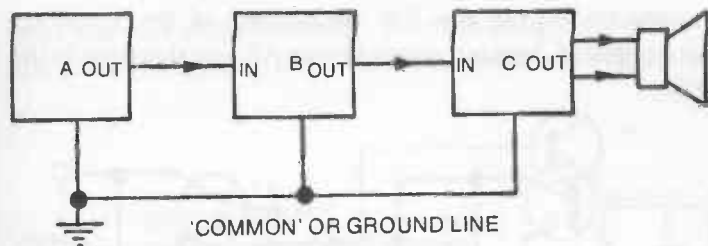


Fig. 5-1. Diagrammatic illustration of 'coupling'.

of amplifiers, since any capacitor or inductance in the circuit path will tend to limit the frequency response of the amplifier. Transistor amplifiers, too, are particularly suited for direct coupling because a transistor can work as a direct current amplifier.

The basic disadvantage of direct coupling (DC coupling as it is often termed) is, in this case, the problem that the transistor in one stage must be biased by a proportion, or the whole, of the output current of another transistor. In other words, each stage controls the bias of the following stage and any change in the transistor characteristics brought about by heating effects, etc., will also be amplified. This effect is aggravated by the fact that high amplification is already a feature of a DC coupled amplifier. Thus the higher the gain, the more important it is to introduce some satisfactory method of compensating for temperature changes. This can be done by 'stabilizing' the transistor circuit, e.g. resistor or capacitor in parallel connection to the emitter in a common-emitter configuration; or the use of a little trick circuitry aimed at the same end.

Figure 5-2 shows the audio end of a simple transistor receiver. Q1 is an NPN transistor forming the amplifier stage. Q2 is a PNP transistor forming the output stage. Q1 is biased to near cut-off point so that there is only a small current in the collector, forming the bias for Q2.

Potentiometer R1 is the volume control, but it also acts as a potential divider controlling the bias current. Thus signal and bias increase, or decrease, simultaneously and in step. In the complete circuit, capacitors C1, C2 and C3 are also



necessary to bypass the RF components of the amplified signal to ground, leaving only a strong AF signal passed to the output.

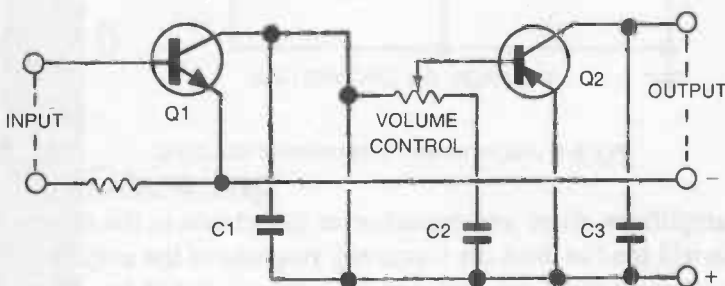


Fig. 5-2. Simple directly coupled 'audio' end of a radio receiver.

Direct coupling of amplifier stages like this is commonly employed with transformer coupling at each end, i.e. the input to Q1 is provided by transformer coupling to the preceding stage; and the output from Q2 is transformer-coupled to the loudspeaker. Alternatively, the input side may be capacitor-coupled and the output transformer-coupled.

A capacitor is smaller and cheaper than a transformer and so is commonly preferred for input (or inter-stage) coupling where it is necessary (or desirable) to block the DC voltage from a previous stage. Transistors normally represent a low impedance input and so in order to pass audio frequencies quite high values of capacitance are necessary, e.g. 1 to 100  $\mu\text{F}$ . If only RF is to be passed, lower capacitance values can be used.

The main significance here is that high values of capacitance usually are an indication that it is better to use electrolytic capacitors which are polarized, i.e. it is important that they be connected in the circuit the right way round. If not, they will be destroyed.

Capacitor coupling is known as RC coupling since both resistance (R) and capacitance (C) are involved. In amplifier stages the same necessity for stabilizing the transistor in the following stage applies. Again a potentiometer can be used both as a volume control and current divider to change signal

level and bias simultaneously, but stabilizing components are also usually employed in the emitter circuit—see Fig. 5-3.

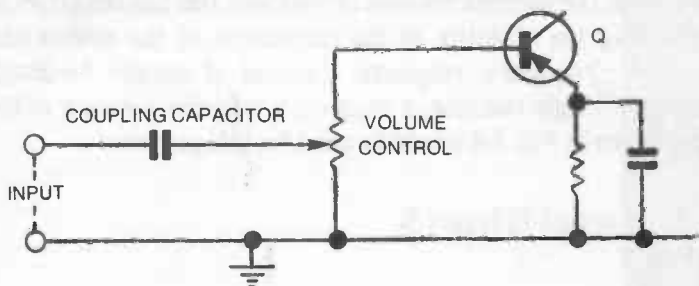


Fig. 5-3. Capacitor or R-C coupling.

Transformer coupling has the advantage that it can readily provide a proper impedance match, and thus work with high efficiency. In certain cases only a transformer will provide the necessary impedance match, such as coupling a high impedance output to a low impedance input. A typical example is the use of transformer coupling between a transistor output stage and a low impedance speaker.

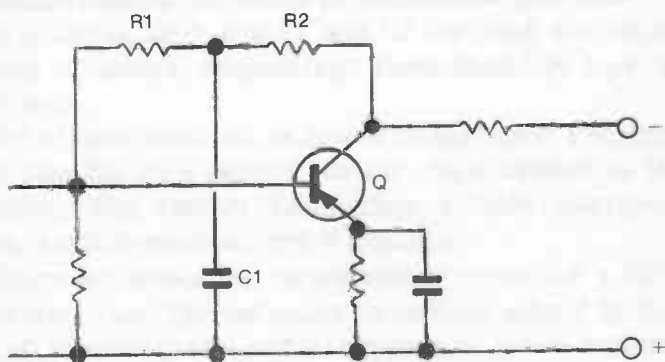


Fig. 5-4. Frequency selective network of the type used in better quality radios. R1, R2 and C1 are three components forming the network.

The main disadvantage of transformer coupling in an audio circuit is that the impedance will rise with higher frequencies, which can affect the quality of the output. This

can be compensated by feeding back a proportion of the collector current from the transistor output to the transistor base. With the correct amount of feedback this has the effect of controlling the stability of the impedance of the circuit and thus the frequency response. Instead of simple feedback through a single resistor, a frequency-selective network of the type shown in Fig. 5-4 would be used for this purpose.

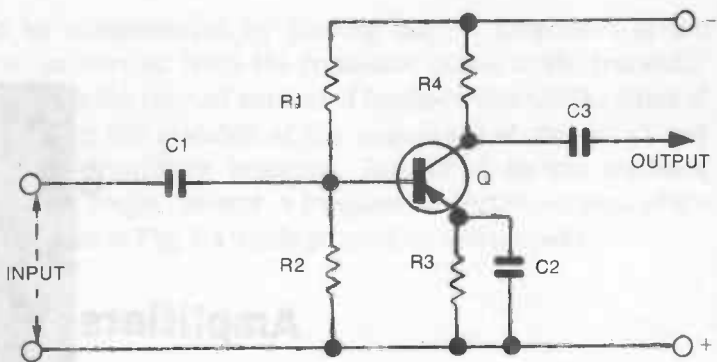
## Amplifiers

Basic circuit for a PNP transistor AF amplifier is shown in Fig. 6-1. This would normally be RC coupled at the input and output (see previous chapter on Coupling). The DC base bias is produced by the potential divider formed by R1 and R2, and the emitter resistor R3. R3 and C2 also stabilize the circuit. R4 is the collector load; and C1 and C3 the input and output coupling capacitors, respectively. These should be  $1 \mu\text{F}$  or larger value.

Actual component values depend on the type of transistor used; also the gain depends on the characteristics of the transistor. The caption summarizes suitable component values to match common types of transistor.

Figure 6-2 shows the corresponding circuit for a NPN silicon transistor. The particular advantages offered by this type of transistor are higher impedance, lower collector current, better frequency response and less susceptibility to temperature (see also Chapter 1 on transistors). Again typical matching component values are given in the caption. Coupling capacitor values (C1 and C3) would need to be somewhat higher than before, e.g. 9 or  $10 \mu\text{F}$ .

Gain from either simple amplifier stage can be up to 100 or more, depending on the characteristics of the transistor used.



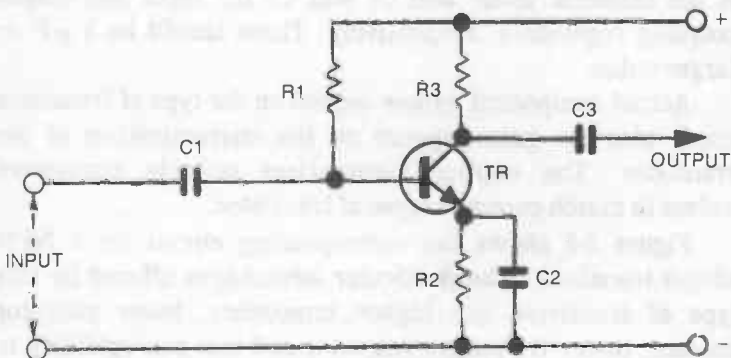
Component values:

R1—22 K ohm  
 R2—10 K ohm  
 R3—4.7 K ohm  
 R4—4.7 K ohm

C1—1  $\mu$ F or greater  
 C2—8 or 10  $\mu$ F  
 C3—1  $\mu$ F or greater  
 Q—HEP G0005, 2N1305, etc.

Fig. 6-1. PNP transistor amplifier.

If high gain is not the primary aim, the bypass capacitor C2 can, with advantage, be omitted on the NPN circuit of Fig. 6-2. This will introduce negative feedback, increasing the *quality* of the amplifier at the expense of roughly halving the gain.



Component values:

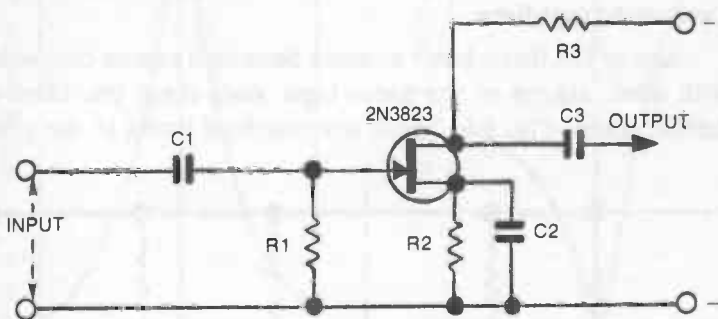
R1—4 M ohm  
 R2—470 ohm  
 R3—30 K ohm  
 C1—8 or 10  $\mu$ F

C2—50  $\mu$ F  
 C3—8 or 10  $\mu$ F  
 TR—2N212, or BC107

Fig. 6-2. NPN transistor amplifier.

This little trick increases input impedance, reduces distortion and improves the linearity of the amplifier.

To complete the picture of basic circuits, Fig. 6-3 shows an FET amplifier. The chief characteristic of this type of amplifier is a very high input impedance, but relatively low gain. Practically any type of FET will work as an amplifier in this configuration, the component values shown matching a 2N3823 or near equivalent. For matching purposes the input impedance is equal to the value of R1, and the output impedance approximately the same as R2. R2 can be adjusted down (or even omitted entirely) to produce what is, in effect, an impedance converter (high input impedance stage with low output impedance).



Component values:

R1—5 M ohm	C1—1 $\mu$ F
R2—10 K ohm	C2—50 $\mu$ F
R3—1 K ohm	C3—1 $\mu$ F

Fig. 6-3. FET amplifier.

### Adding a Volume Control

The most direct type of volume control which can be used with the basic circuits of Fig. 6-1 or Fig. 6-2 is a potentiometer inserted in the input side—Fig. 6-4. This then directly controls the strength of the input signal, and thus the output (which equals input signal strength multiplied by gain). A suitable potentiometer value would be 5K.

In the case of the FET amplifier the potentiometer can replace R1. Here the value required would be of the order of 10 megohms.

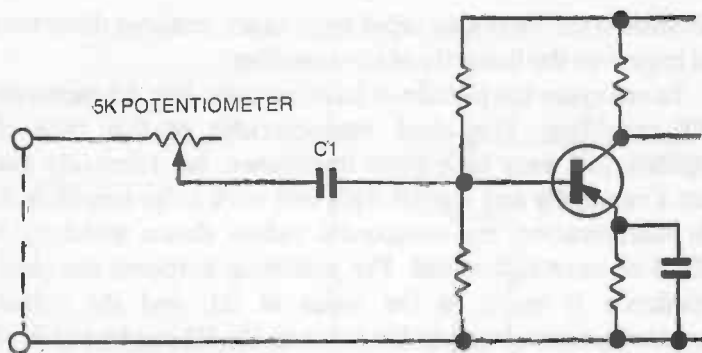


Fig. 6-4. Using a potentiometer as a volume control on the input side to an amplifier.

### Cascaded Amplifiers

Any of the three basic circuits described can be cascaded with other stages of the same type, each stage providing a further gain—Fig. 6-5. There are practical limits to the gain

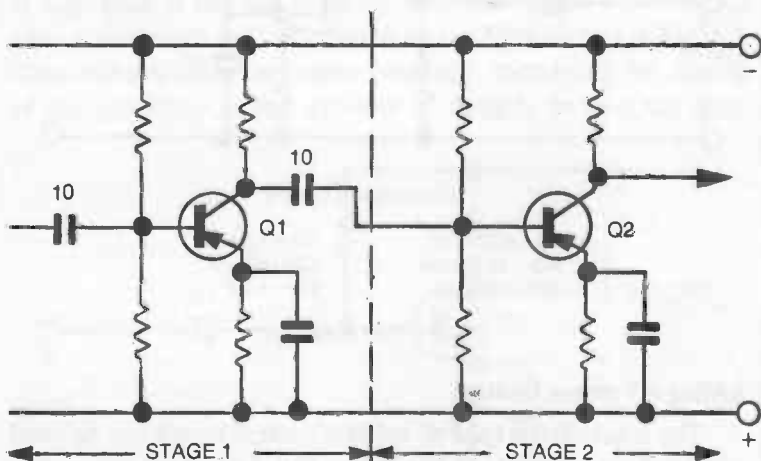


Fig. 6-5. Two identical amplifiers coupled together or cascaded. Output from the first stage is input to the second stage.

which can be achieved in this manner as, with increasing gain, there will come a point where the output signal is clipped and distortion appears. Also each succeeding stage will suffer a voltage drop and thus an effective loss of voltage gain. The FET amplifier is the exception in this respect.

## Tuned Amplifiers

Tuned amplifiers can be one of two types: *Bandpass*—meaning that they 'peak' at a particular frequency and so pass a particular frequency band, and *Bandstop*—meaning that they are tuned to reject a particular frequency if present and so eliminate it from the output signal.

These particular circuits may also be described as *filters*, i.e. bandpass filters or bandstop filters (see Fig. 6-6).

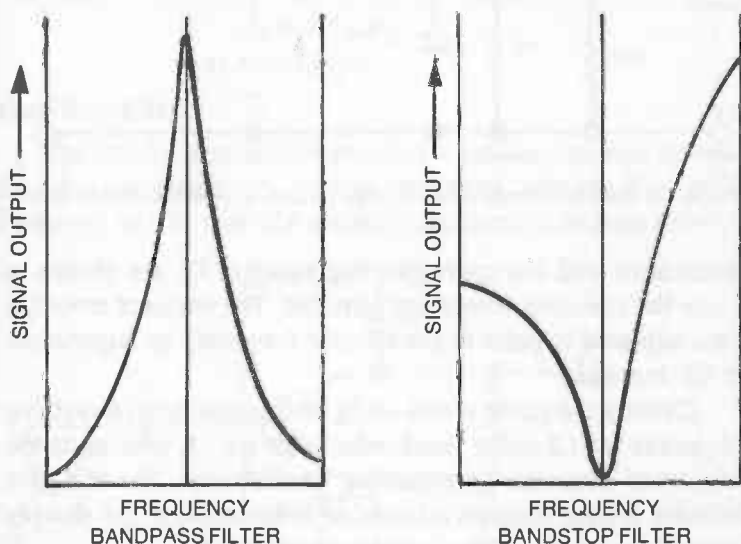


Fig. 6-6. Characteristics of the two basic filter circuits.

The tuned amplifier circuit of Fig. 6-7 is a bandpass type. The resonant circuit comprising L1 and C2 is tuned to the bandpass required. This circuit, together with C3 forms a negative feedback path from collector to base of the transistor, except at resonant frequency. In other words, at all other frequencies the feedback present reduces the gain of the transistor to virtually negligible proportions. The resonant frequency content of the input signal, however, provides no feedback, and so this signal is passed by the amplifier with full gain.

The circuit is adjusted by varying the inductance. L1 is a choke wound on a former with an iron dust core. Actual



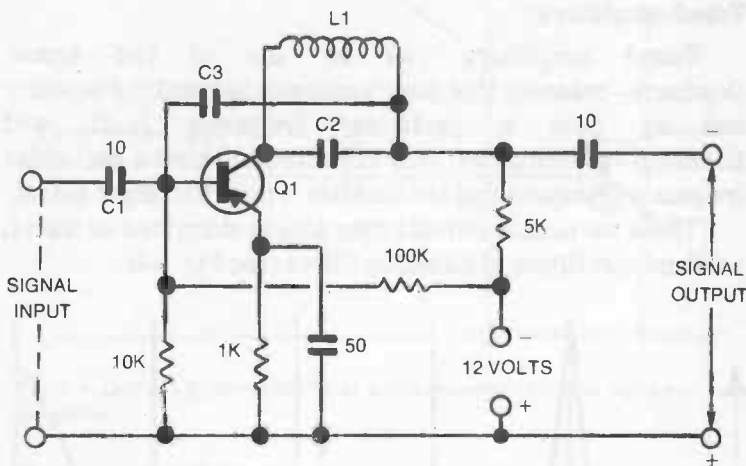


Fig. 6-7. Tuned bandpass type amplifier circuit. Q1 is HPE G0005 or equiv.

inductance and the corresponding value of C2 are chosen to cover the resonant frequency required. The resonant circuit is then adjusted to peak at the specific frequency by adjustment of the dust core.

Exactly the same effect could be obtained from a variable capacitor for C2 and a fixed inductance for L1, peaking to the frequency required by adjusting C1. However, this will give broader tuning than an adjustable inductance, so for sharply peaked tuning the original circuit is preferred.

Suitable values for L1 and C2 can be calculated from the standard 'tuned circuit' formula:

$$\text{Resonant frequency (kHz)} = \frac{1}{2\pi \sqrt{LC}}$$

where L = inductance in henries and C = capacitance in farads.

Since it is the values of L and C that have to be determined, it is easier to start by reworking the formula:

$$\sqrt{LC} = \frac{1}{2\pi \times f}$$

$$\text{i.e. } LC = \frac{1}{40 f^2} \quad (\text{approx})$$

where f = resonant frequency in kHz

Suitable values for L and C can then be obtained by guesstimating one value and then calculating the corresponding value for the other. This can be done several times, if necessary, to end up with realistic matching values.

Example: resonant or pass frequency required is 1000 Hz. A 5 henry (adjustable) choke is "guesstimated."

Substituting in the formula:

$$5 \times C = \frac{1}{40 \times (1)^2} \quad \text{or } C = \frac{1}{200}$$

$$= 0.005 \mu\text{F}$$

$$= 500 \text{ pF}$$

### Band Stop Filter

The bandstop amplifier employs a similar resonant circuit in what appears an almost identical circuit—Fig. 6-8. However, in this case the negative feedback is present only at

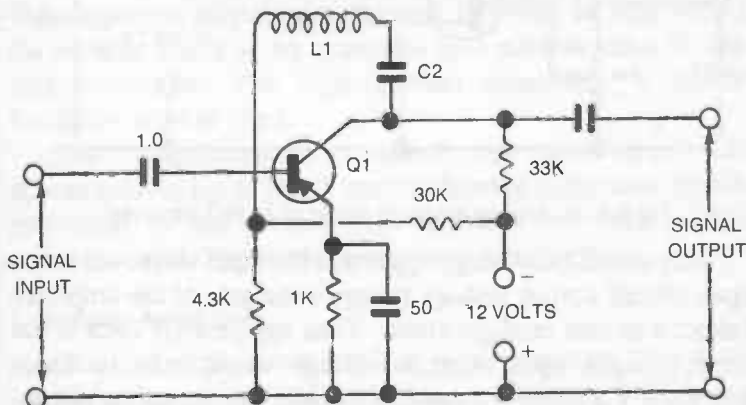


Fig. 6-8. Tuned bandstop amplifier circuit. The transistor is same type as Fig. 6-7. Other component values shown on diagram.

the resonant or 'stop' frequency. All other frequencies in the input signal are passed with normal amplifier gain. In practice the filter performance will be of the 'matched' type, the characteristic of which is an LC tuned bandstop amplifier (as shown in Fig. 6-6).

### RF and IF Amplifiers

RF amplifiers are again similar in basic layout, the transistor used being an RF type rather than an AF type. RF

and IF (intermediate frequency) amplifiers are primarily concerned with radio circuits, which are outside the scope of this particular book.\*

### DC Amplifiers

Amplifiers can also be used to boost, or provide gain, from purely direct current inputs as well as AF or RF signals. They can be designed to boost voltage (DC voltage amplifiers) or boost current (DC current amplifiers).

A very simple DC voltage amplifier is shown in Fig. 6-9 based on an FET. Using a 2N3823 FET (or equivalent) and a battery voltage of 12 for powering the circuit, there will be a standing voltage of about 0.6 developed across the output terminals.

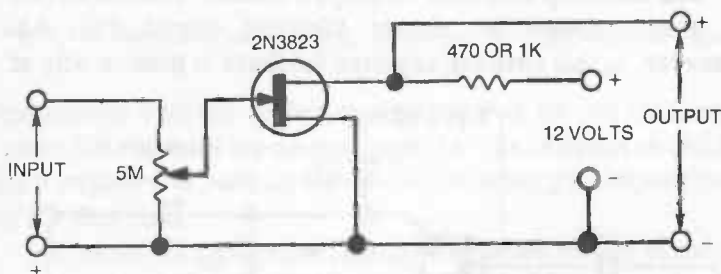


Fig. 6-9. DC voltage amplifier based on an FET transistor.

Any small DC voltage applied to the input will result in the open circuit output voltage rising to the gain of the amplifier (about 5 in this configuration). Thus applying 1.5 volts to the input, output open circuit voltage would rise to about  $5 \times 1.5 = 7.5$  volts. A 3 volt input would give an output voltage of about 15 volts—the limit to the input voltage being the maximum drain-to-source voltage the transistor can take. In this respect the value of R2 is fairly important. A value of 470 ohms would be satisfactory for input voltages up to 1.5, and 1K for voltages up to 4.5.

It is also possible with this circuit to adjust the actual output open circuit voltage for a maximum drain to any designed level for any given input voltage. Simply replace the 470 or 1K resistor with a 1K ohm potentiometer and adjust to set the output voltage.

\*Refer to TAB book 637 *Fun With Electronics* for radio circuit fundamentals and construction.

A conventional transistor is basically a *current amplifier* and again can be worked in a simple circuit of the type shown in Fig. 6-10 as a DC current amplifier. Battery power has to be applied to the circuit, as well as a DC input voltage. A silicon transistor works best as this has an inherently low static

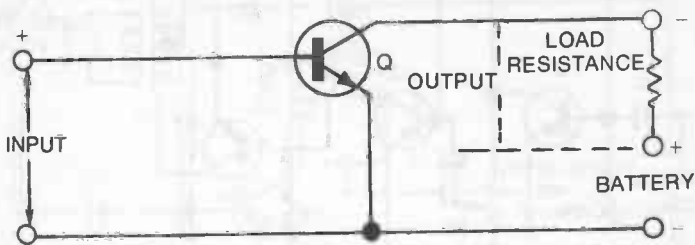


Fig. 6-10. DC current amplifier based on an NPN transistor.

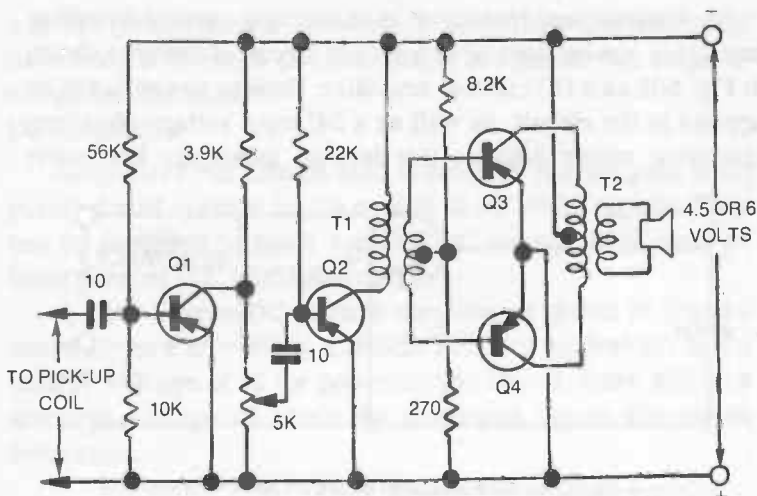
collector current and is not greatly affected by temperature. The maximum output current must, however, be kept within the working limits of the transistor by a suitable value for the load resistance. For high current amplifiers, a power transistor must be used.

The amplification produced by this circuit is approximately equal to the current flowing in the base circuit multiplied by the current gain characteristic value of the transistor used. The power gain is very much higher.

### Telephone Amplifier

This is a straightforward four stage amplifier (Fig. 6-11) circuit with push-pull output feeding a miniature 4- to 8-ohm speaker and capable of producing excellent volume, worked off a 4.5- or 6-volt battery. A volume control is included in the circuit. For convenience this can be of combined switch and potentiometer type, so that this component can act both as an on-off switch for the battery and volume control for the circuit once switched on.

To connect to the telephone a magnetic (inductive) pick-up is used, attached to the outside of the telephone case. It is illegal to connect directly into a telephone circuit in Britain. The best position for the pick-up coil must be found by trial-and-error. Usually it will be on the right-hand side of a



Q1 to 4—Motorola HEP G0005

T1—interstage transistor driver transformer

T2—Push-pull transistor output transformer

Speaker—ohm miniature (e.g. 3 inch dia.)

Fig. 6-11. Telephone amplifier circuit

modern hand set unit (not the part you hold), approximately level with the top of the dial and mid-way down the side.

Proprietary pick-up coils are encapsulated and fitted with a rubber suction cup for holding them in position. This is usually found to drop off frequently, so once the best position has been found, secure with a dab of contact adhesive, pressing firmly in place.

### Receiver Preamp

A radio frequency amplifier can be used as a preamplifier to boost the signal strength received by an ordinary radio receiver. This can be specially useful in areas of low signal strength where a pocket transistor radio is often inadequate to cope because it is lacking in sensitivity, and also for improving the *selectivity* of any set (i.e. making it capable of separating broadcast stations).

The RF preamp is a standard basic circuit (Fig. 6-12) with the addition of a tuned circuit L1 and C2 in the collector circuit. Components used here are exactly the same as in any radio

receiver, i.e. a standard aerial tuning coil on a ferrite rod or "loopstick" and a 365 pF variable capacitor. Power for the preamp circuit can be tapped directly from the receiver circuit to avoid using a separate battery.

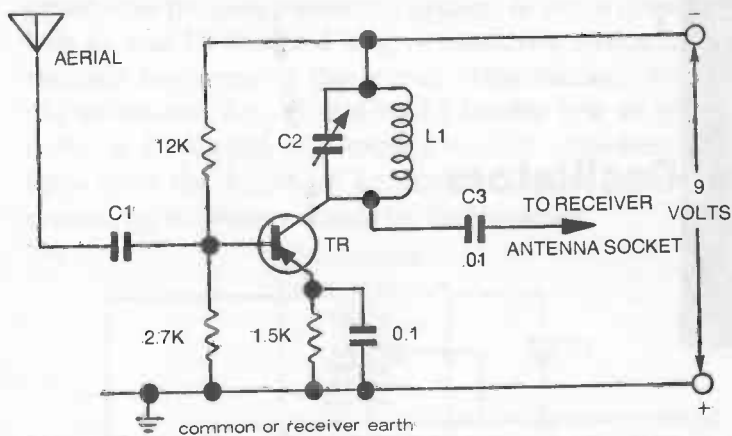


Fig. 6-12. Receiver preamplifier based on a standard tuned circuit (antenna coil L1 and 365 pF variable capacitor C2). Suitable transistor types are 2N1303, HEP G0003.

Output of the preamp is capacity-coupled direct to the receiver aerial socket, if one is fitted. If not, take this connection via C3 to the end of this circuit which is connected to the common ground of the receiver circuit. It is necessary to identify this common ground connection anyway as the ground connection of the preamp also has to be connected to receiver ground. Do *not* assume that this will be the battery + terminal in the receiver circuit. It could be the other way around.

The preamp may work satisfactorily without an external antenna connection. In this case C1 and the aerial shown on the circuit diagram can be omitted. Much better results, and more stations will be brought in at good listening strength, if an external aerial is connected to the preamp. Experiment with different values of C1 for best results, e.g. from, say, 100 pF up to 0.01  $\mu$ F, or use a 500 pF trimmer capacitor. You will find that experimenting with different capacitor values here (or using a trimmer) will *either* improve selectivity (or separation of the stations) *or* volume of signal. You cannot have it both ways!

# 7

## Oscillators

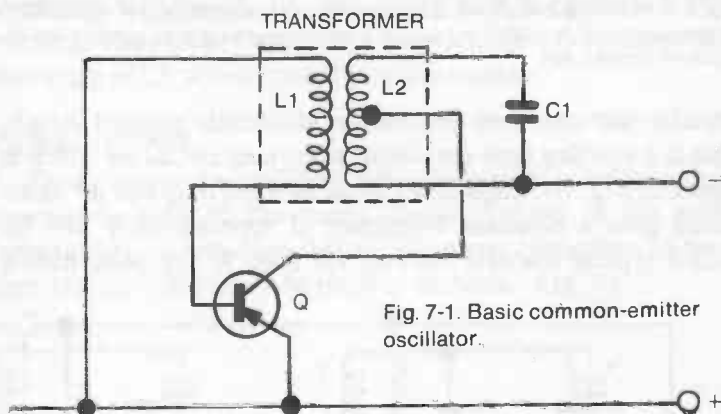
An oscillator is usually part of a circuit, although it can be used as a frequency generator for individual application. The working of an oscillator circuit is basically that of an amplifier when part of the output energy is returned to the input to produce a cyclic, or oscillating, change in the amplifier conduction. These changes can occur at radio frequencies (RF oscillator) or at lower audio frequencies (AF oscillator). In the latter case the oscillator generates a tone which can be heard, in a suitable output circuit.

The basic elements of an oscillator circuit are: an amplifier, a feedback arrangement to provide oscillation, and a frequency-selective system to stabilize the oscillation at a particular frequency.

A source of power is also necessary to replace losses in the circuit.

One of the three basic configurations can be used in a transistor oscillator circuit—common-emitter, common-base or common-collector. The common-emitter oscillator is usually preferred as the impedance match in the circuit is not at all critical and there is thus a wide range of tolerance as regards component values and individual transistor characteristics before the oscillator will not work.

A basic circuit of this type is shown in Fig. 7-1. L1 and L2 are transformer coils, the output through L2 inducing a corresponding current in L1 which is fed back to the base of the transistor. L1 is sometimes called a 'tickler' coil. L2 and C1 provide the frequency-selective system, or tuned circuit, with both L1 and L2 designed to give maximum feedback at the resonant frequency of this circuit. This resonant frequency can be tunable, e.g. by making L2 tunable (via an iron dust core); or C1 tunable (e.g. using a variable capacitor). At the same time the values of L1 and the tapped portion of L2 provide the impedance match for the transistor.



A working circuit of this type is shown in Fig. 7-2 based on a transistor as the amplifier. Component values given are for a range of oscillation frequencies from about 3-10 kHz (tunable by the 365—500 pF variable capacitor), i.e. this is an AF oscillator. Different component values would be needed for an RF oscillator. As shown, the circuit would be useful as a signal generator for aligning a superhet receiver. Optimum performance as a signal generator would be achieved by replacing the variable capacitor C1 with a fixed capacitor of 0.5  $\mu$ F, when the (fixed) frequency of oscillation should be approximately 10 kHz.

### Hartley Oscillator

It is possible to use one winding of a transformer for both the tuned circuit and feedback. The other coil of the



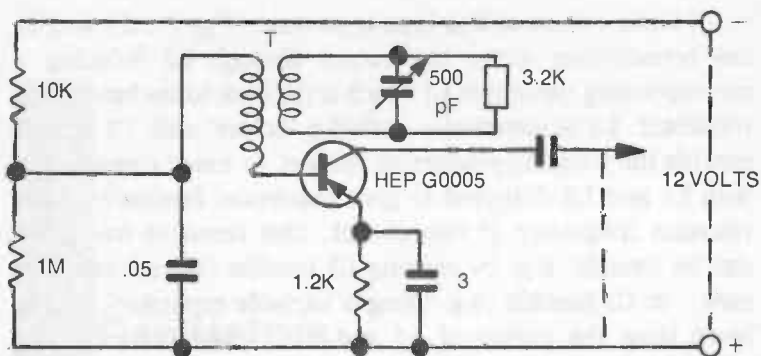
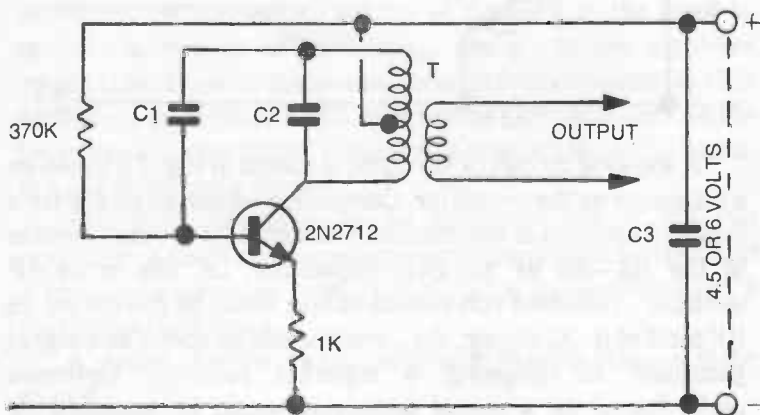


Fig. 7-2. Working circuit for a common-emitter oscillator: TR is a G0005; or equivalent. T is a 40:1 miniature transformer with a secondary inductance of about 5 mH.

transformer can then provide an identically coupled output. This is a Hartley type oscillator, a working circuit for which is shown in Fig. 7-7. Capacitor C3 can be fixed (e.g.  $0.02 \mu\text{F}$  value would give a resonant frequency of approximately 2000 Hz with a typical transformer) or variable. In the latter case a



Component values:

- C1— $0.1 \mu\text{F}$
- C2— $0.02 \mu\text{F}$
- C3— $0.02 \mu\text{F}$  or 50—100 pF
- T—500:30 ohm transistor output transformer with center tapped primary.

Fig. 7-3. Hartley oscillator based on a 2N2712 transistor, or equivalent.

variable capacitor of 50-200 pF would give a wide variation in signal tone generated in the audio range. Connection of low impedance phones to the second coil (output) of the transformer would enable the signal to be heard without further amplification being necessary. In other words, this circuit is a complete 'tone' generator.

There is nothing critical about this circuit and it should work with a variety of similar (near-equivalent) transistor types; or with other AF transistors with modified values for R1 and R2. The only thing likely to go wrong (apart from a component being faulty) is that the connections of L1 may be the wrong way round, i.e. the wrong half is connected for feedback. Thus if the circuit does not work, simply reverse the connection of L1, which should cure the trouble.

### Colpitts Oscillator

The Colpitts type oscillator is basically similar but taps the capacitance side of the tuned circuit instead of the coil (inductance). In practice this requires two capacitors in the tuned circuit, which may be fixed or variable—Fig. 7-4.

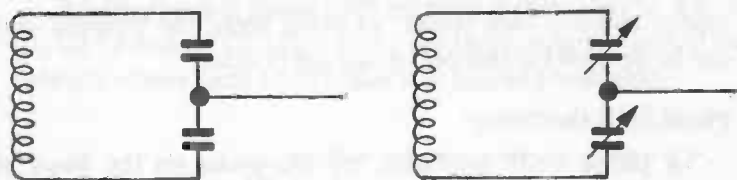


Fig. 7-4. Colpitts type oscillator taps capacitance of tuned circuit. Either fixed (left) or variable capacitors (right) can be used.

For a simple AF oscillator, this circuit may be simplified by using the phones themselves as the source of inductance in the tuned circuit, eliminating the need for a transformer or even a separate coil. The working circuit then simplifies to that shown in Fig. 7-5.

The equivalent inductance of the phones used, and the values of C1 and C2, determine the oscillation frequency. For phones of approximately 2000 ohms resistance, values of C1 = 250 pF and C2 = 125  $\mu$ F should result in a tone frequency of approximately 1000 Hz. Decreasing the values of C1 and C2

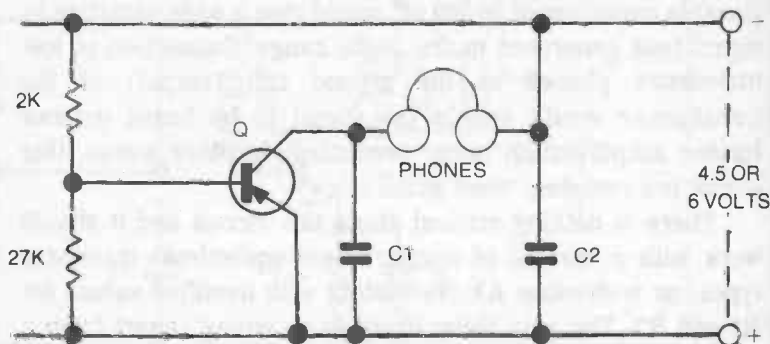


Fig. 7-5. Working circuit for a Colpitts oscillator. Typical component values are  $C_1=720$  pF and  $C_2=125$   $\mu$ F for phones of 2,000 ohms resistance. Q is a HEP G0005.

will raise the frequency; and raising the values of  $C_1$  and  $C_2$  will lower the tone frequency. A 1:10 ratio should be present between  $C_1$  and  $C_2$  for satisfactory working of the circuit, so this naturally precludes the use of variable capacitors for  $C_1$  and  $C_2$ , which might appear at first sight a logical solution for tone adjustment.

Circuits of the Colpitts type are used in the morse code sender circuits (see later), as being about the simplest that can be devised for this particular application.

### Phase Shift Oscillator

A phase shift oscillator circuit works on the basis of providing a 180 degree phase shift between output and input to initiate oscillation. This phase shift can be accomplished with a combination of resistance and capacitance providing an RC (resistance-capacitance) network.

A working circuit of this type is shown in Fig. 7-6. The RC network components are  $R_1$ ,  $C_1$ ,  $R_2$ ,  $C_2$ ,  $R_3$ ,  $C_3$ , each providing a separate "leg" contributing an equal amount to the phase shift.  $R_3$  is made variable to provide adjustment to get the circuit working (i.e. to adjust for any differences in the individual characteristics of the transistor specified). Theoretically  $R_1$ ,  $R_2$  and  $R_3$  should have identical values; and also  $C_1$ ,  $C_2$  and  $C_3$ . The tone frequency generated is then equal to:

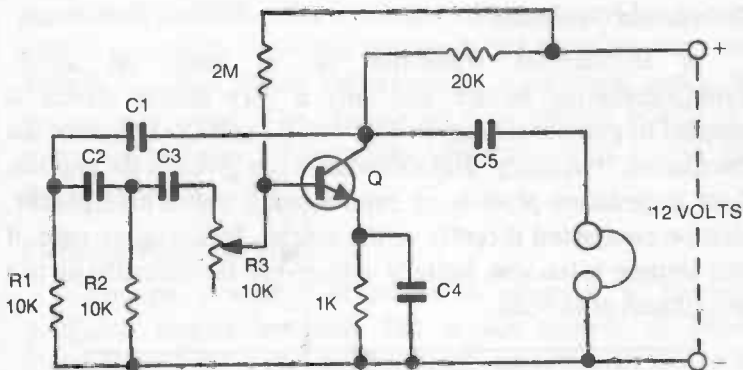


Fig. 7-6. Working circuit of a phase-shift oscillator. Q is an NPN type 2N2646, or CV9695.

$$\frac{1,000,000}{20 \times R \times C}$$

where R is in ohms and C is in microfarads.

For a tone frequency of 2000 Hz, suitable values for R1, R2 and R3 would be 10K; with corresponding values of  $0.0025 \mu\text{F}$  for C1, C2 and C3.

Another type of phase shift network is shown in Fig. 7-7, R1, C1, R2, C2 and R3, C3 again being the three separate legs of the network where each contributes a 60 degree phase shift.

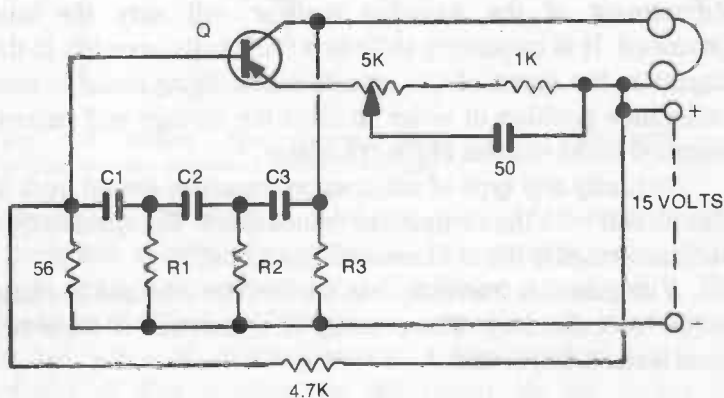


Fig. 7-7. Phase-shift oscillator circuit based on an NKT224, 2N633, 2N60 or AC128 transistor.

## Relaxation Oscillator

A *unijunction* transistor is, in itself, an amplifying/oscillating device and only a very simple circuit is needed to get it working. In Fig. 7-8, R1 and C1 determine the oscillation frequency. Suitable values are given in the caption. Low impedance phones, or even a small 8-ohm loudspeaker, can be connected directly to the output. In the latter case, if the volume is too low, battery voltage can be increased up to a maximum of 18 volts.

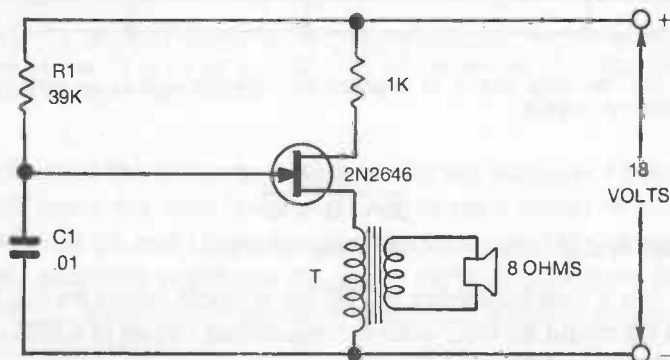


Fig. 7-8. Relaxation oscillator circuit based on a 2N2646 unijunction transistor. T1 is a general-purpose transistor output transformer.

A useful modification to this circuit is to replace R1 with a 10 or 25K potentiometer and a fixed resistor of 22K in series. Adjustment of the variable resistor will vary the tone produced. It is necessary to have a fixed resistance left in the circuit in the event of the potentiometer being tuned to zero resistance position in order to limit the voltage and current supplied to the emitter of the transistor.

Virtually any type of unijunction transistor should work in this circuit with the component values given. The specific type recommended is the old-time standby 2N2646.

A unijunction transistor has one *emitter* lead and two *base* leads (no collector). The polarity of connection of these two base leads is important.

### Comparing 'Notes'

It is interesting to compare the sound quality of the tones produced by different types of AF oscillator circuits, A

phase-shift oscillator, for example, will produce a fairly pure tone. A relaxation oscillator will produce a more rasping tone. This is because of the difference in waveforms generated during oscillation; The phase-shift type usually produces a sine wave while the other rasping tone comes from a "peaked" waveform.

### Light-Operated Oscillator

Although a source of power is essential to keep an oscillator circuit working, the actual amount of power required can be quite small—small enough, that is, to be provided by a light-sensitive device such as the solar cell. Such a circuit requires no battery and can be used as an alarm device, automatically switching on and giving a tone signal when the light-sensitive device is illuminated.

A working circuit is shown in Fig. 7-9 based on any of the general purpose hobbyist devices widely available as the light-sensitive element; and a HEP G0005 transistor as the

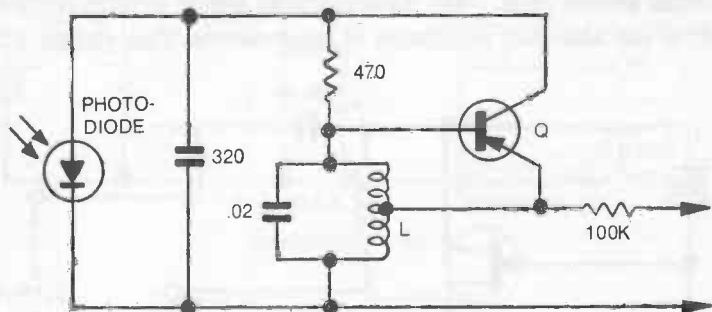


Fig. 7-9. Simple light-operated based on a photodiode. A phototransistor will also work in this circuit.

amplifier. The former take the place of a battery. The transistor is connected on to a Hartley oscillator circuit, the only critical component being the center tapped coil L. This consists of 600 turns of #40 gauge enamelled wire wound on a 1 1/2-in. piece of ordinary pencil. A loop is taken out at the center of this winding (at 300 turns) for the center tap connection.

When the photocell, or solar cell, is illuminated by stray light (e.g. sunlight), sufficient power about 1/2 volt should be

generated in the circuit for the tone to be heard in a high impedance earpiece connected directly to the output. To work as a light-operated alarm working a loudspeaker at least one stage of transistor amplification should be added (see chapter on Amplifiers), connected to a step-down transistor output transformer. The speaker is then connected to the output of this transformer.

### Crystal Oscillator

A crystal oscillates at a specific frequency (or harmonic frequency) determined by its manufacture. Thus a crystal can be used in an oscillator circuit to stabilize the oscillation to work only at the resonant frequency of the crystal, or some harmonic. This principle is used to stabilize transmitter frequencies for model radio control operation, for example, where law permits operation only within a specific (27 and 72 MHz) RF band.

Since an FET provides the simplest type of oscillator the circuit shown (Fig. 7-10) demonstrates 100 pF crystal control, using the absolute minimum of components. This circuit will

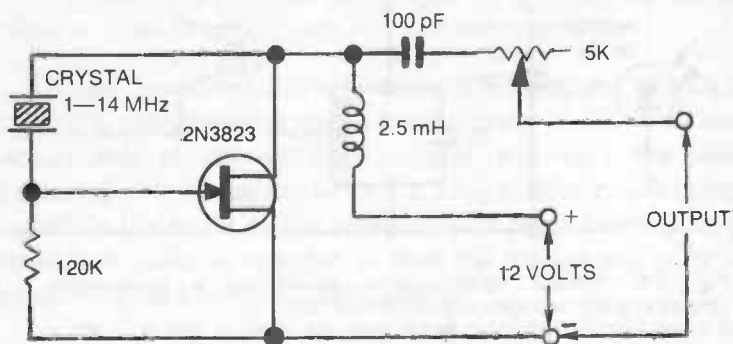


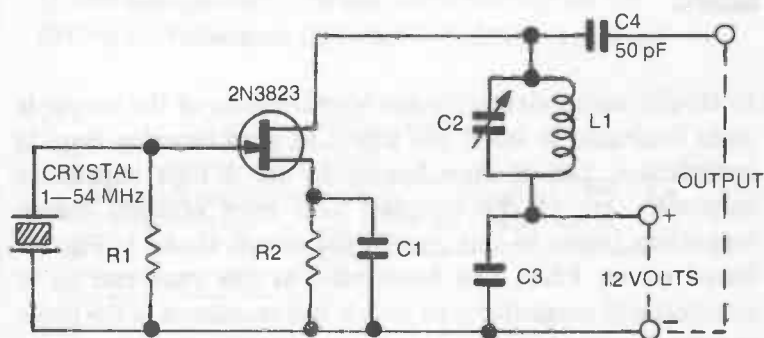
Fig. 7-10. Crystal controlled oscillator based on an FET transistor.

oscillate only at the fundamental frequency of the crystal, provided the circuit is not overloaded. This means ensuring that the impedance of the output lead is high enough to limit the current to a suitable level. If necessary, connect a 5K potentiometer in the output as a load control (as shown in the circuit diagram).

Output will be a single frequency oscillation, with the actual frequency dependent only on the resonant frequency of the crystal.

### Tuned Crystal Oscillator

This circuit (Fig. 7-11) again used an FET as an oscillator, but is a little more complex, with a number of additional components. Although this circuit oscillates at the crystal frequency, the output is variable for maximum RF signal via C2. C2 and L1 form a tuned circuit, the resonant frequency of which must be the same as that of the crystal, i.e. the values of C2 and L1 are chosen to provide this resonant frequency with the variable range offered by C2.



Component values:

R1—1 M      C1—0.01  $\mu$ F  
R2—1 K      C3—0.01  $\mu$ F

Fig. 7-11. Crystal oscillator circuit with tuned RF output.

This circuit is rather more susceptible to the effects of output load than the previous one, as not only can insufficient input load cause dangerous currents to be developed, but even with moderate or high loads giving satisfactory oscillation, the load can detune the resonant circuit L1 and C2, with consequent loss of RF output unless readjusted.



# 8

## Outputs

In simple audio circuits some amplification of the output is often desirable to boost the signal to good listening level in headphones, rather than having to use a high impedance earpiece. One of the simplest and most efficient output amplifiers to use in this case is the circuit shown in Fig. 8-1 based on an FET. The headphone in this case can be of conventional magnetic type with a coil resistance of the order of 2000 ohms.

The potentiometer R1 acts as a volume control in this output circuit. The tone quality of the phones can also be improved with a capacitor connected in parallel, as shown (C2). In theory, a variable capacitor could be used, but these are not practical at the capacitance values required. Instead capacitors of different values between, say 0.01 and 0.001  $\mu\text{F}$  should be tried, selecting the one which gives the best tone with the headphones used.

Another output problem which can arise is using low impedance phones or speaker, or a low-impedance earpiece fed by a transistor output stage. The latter requires a high impedance to match. The solution in this case is to employ a step-down transformer which acts not only as a coupling between output and phones, but provides a suitable step-down ratio for impedance matching (Fig. 8-2).

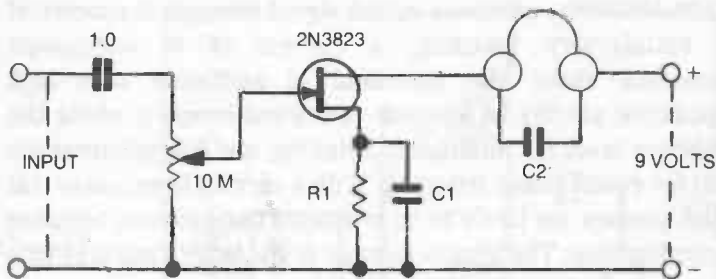


Fig. 8-1, Simple output circuit using FET transistor. Suitable component values are:  $R1 = 470$  ohms,  $C1 = 50 \mu F$ ,  $C2$  between  $0.01$  and  $0.001 \mu F$ .

Typical values for low-impedance earpieces are:

4 ohm DC resistance (15 ohm impedance at 100 Hz)

14 ohm DC resistance (60 ohm impedance at 100 Hz)

60 ohm DC resistance (250 ohm impedance at 1000 Hz)

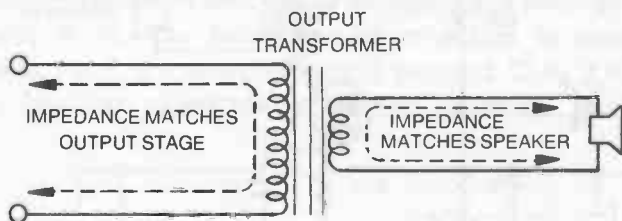


Fig. 8-2, Impedance matching via a step-down transformer (output transformer).

Matching transformer step-down ratios to give a nominal output impedance here of the order of 20,000 ohms (matching a typical transistor output stage) would be:

4 ohms—35:1 ratio

14 ohms—18:1 ratio

60 ohms— 9:1 ratio

Miniature speakers normally have a DC resistance of the order of ohms (nominal 8 ohms impedance), when approximate transformer ratios would be:

30:1 to give an output load impedance of 10,000 ohms

41:1 to give an output load impedance of 20,000 ohms

Incidentally, as far as output signal strength is concerned for satisfactory listening, a current of 10 *microamps* represents about the threshold of audibility with high impedance phones. A current of 0.1 *milliamps* is about the minimum level for intelligible listening, and 0.5 *milliamps* the level for comfortable listening. With a current in excess of this value, phones are likely to be swamped and listening becomes uncomfortable. The simple answer in the latter case is to fit a volume control to reduce the signal level if necessary.

Transformer output from a transistor output stage is referred to as Class A operation where the values of the bias and signal voltage applied to the transistor ensure that there is always collector current flowing—Fig. 8-3. This is the simplest type of circuit, but one which is inefficient. Efficiency does not

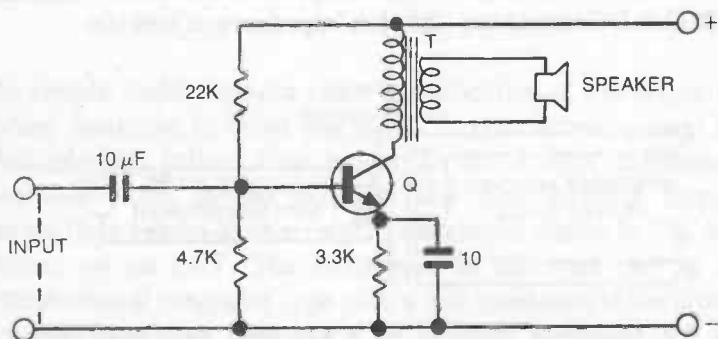


Fig. 8-3. Class A transistor output stage. Component values shown match HEP G0005 or equivalent transistor. T is a general purpose transistor output transformer.

matter so much, for this can be countered by increasing the power of the circuit, but distortion is readily introduced at high listening levels. The main advantage of Class A operation is that it is simple, and quite adequate power can be developed using only a few components.

Generally a more efficient power output can be obtained from a push-pull output stage, using two transistors in the type of circuit shown in Fig. 8-4. This is known as Class B operation. Best performance normally comes from using a complementary pair of transistors (one NPN and one PNP), suitably matched.

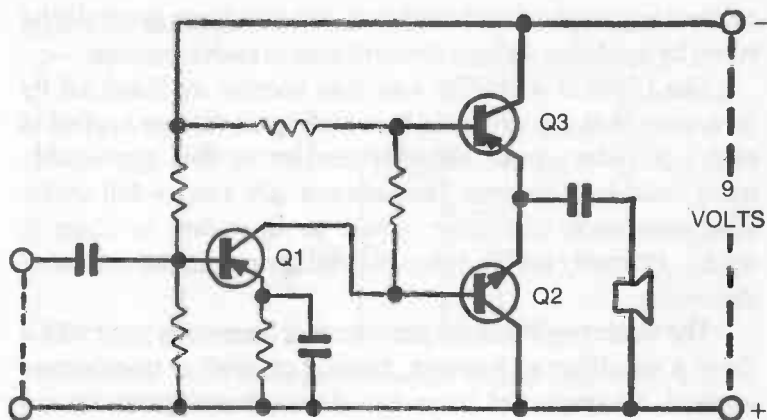


Fig. 8-4. Class B or push-pull output stage with complementary pair (NPN and PNP) output transistors Q2 and Q3.

The particular advantage of Class B operation is better quality reproduction with higher efficiency and lower average current drain. The latter can be important in transistor circuits, which are normally battery powered. Class B outputs can, however, generate crossover distortion which is

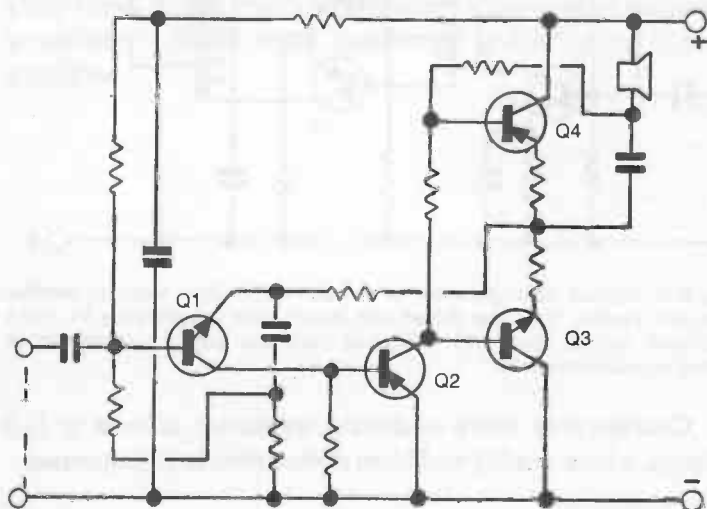


Fig. 8-5. Complementary pair push-pull output circuit Q1 works as a pre-amplifier. Q2 is the driver for the output push-pull stage Q3 and Q4. Negative feedback is taken from the output to the emitter of Q1.

particularly unpleasant to listen to, but which can generally be cured by applying a slight forward bias to each transistor.

The Class B amplifier can also operate as Class AB by arranging that the values of bias and signal voltage applied to each transistor cause collector current to flow appreciably more than half a cycle (but always less than a full cycle, otherwise each transistor would be operating in Class A mode). Properly set up, this can result in virtual elimination of distortion.

The basic push-pull output circuit is commonly used with a Class A amplifier as a driver, directly coupled, or transformer coupled. Examples of these two different configurations are shown in Figs. 8-6 and 8-7. In the latter case transformer coupling is also used between the Class B amplifier and the loudspeaker. This is virtually the standard type of output used in transistor radios.

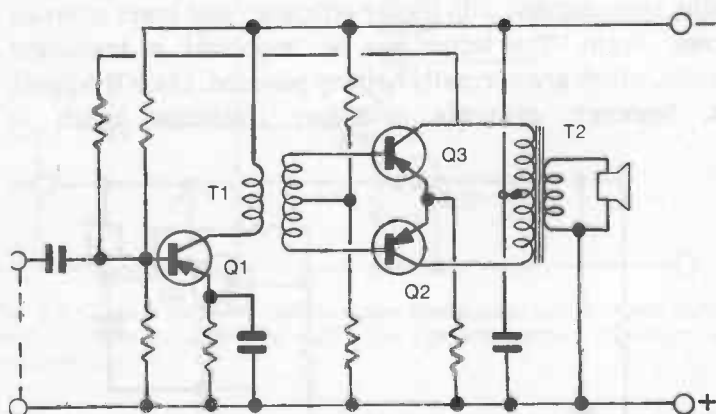


Fig. 8-6. Typical configuration of a push-pull output used in smaller domestic radios. Q1 is the driver with transformer coupling via T1 to the push-pull output stage. T2 is typical transistor output transformer to match impedance loads.

Considerably more elaborate treatment is used in hi-fi outputs, where quality and level of distortion is all-important.

### Class B Driver

This circuit (Fig. 8-7) is virtually a standard form of Class A amplifier adapted for driving a Class B output stage via a

COUPLING CAPACITOR

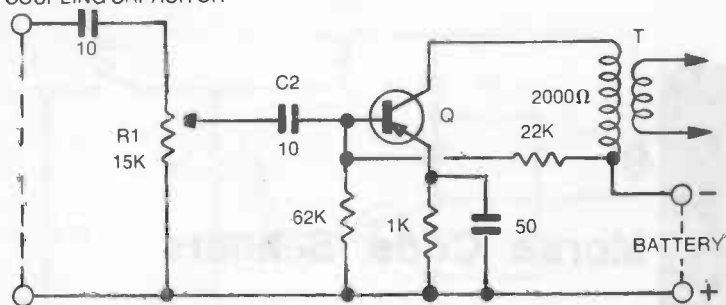


Fig. 8-7. Class B driver circuit. Component values shown match a 2N190 transistor, or equivalent.

matching transformer. Circuit components have been kept to a minimum for satisfactory performance. Potentiometer R1 acts both as a potential divider and gain control for the driver, C2 then being necessary to prevent grounding of the base of the transistor.

The output transformer needs to have a primary resistance to match the output impedance required for the transistor used e.g. 2000 ohm for a HEP G0005 transistor, or other types in this group. A 1500 ohm center-tapped secondary provides a suitable input impedance into a typical Class B amplifier.

## 9

# Morse Code Senders

Morse code signals are, traditionally, sent with a key and buzzer. The simple electromechanical buzzer has largely been replaced by a transistorized buzzer or simple audio frequency oscillator circuit.

Figure 9-1 shows such a circuit which is very easy to get working. Virtually any general purpose AF transistor will do, but the component values shown suit an HEP G0005 or equivalent.

A simple sending key is shown in Fig. 9-2. This comprises a strip of springy brass mounted on a wooden block with two woodscrews. The brass is bent upwards into a cranked shape and a large plastic button glued to the free end with epoxy adhesive to form a knob. Underneath the free end of the spring is a large brass drawing pin or a round-headed brass screw. Key connections are made to this screw and one end of the screws securing the other end of the brass strip. Connect on to one of the battery leads of the buzzer circuit.

To operate, the key should be placed on a table about 18 inches in from the edge. Sit opposite the key, with the right elbow resting near the edge of the table. The knob on the key is *lightly* grasped between finger and thumb and the key operated with a movement of the wrist—not a tapping action.

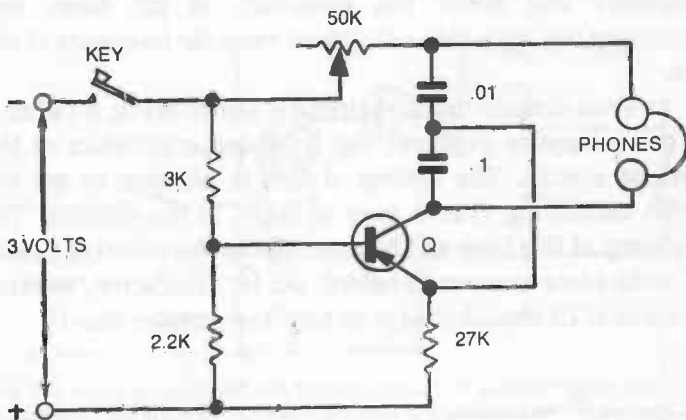


Fig. 9-1. Simple Morse code sender based on an OC71 transistor, or equivalent.

Adjust the spring of the brass strip by further bending, if necessary, to get an easy 'sending' action.

To check the working of the circuit, hold the key depressed when a steady tone should be heard in the phones. The volume of this signal can be adjusted by altering the setting of the 50K potentiometer. Altering this setting will also tend to change the note of the tone as well, i.e. act as a tone control as well as a volume control. You can also alter the tone of the signal by using different capacitor values. Increasing the value of these

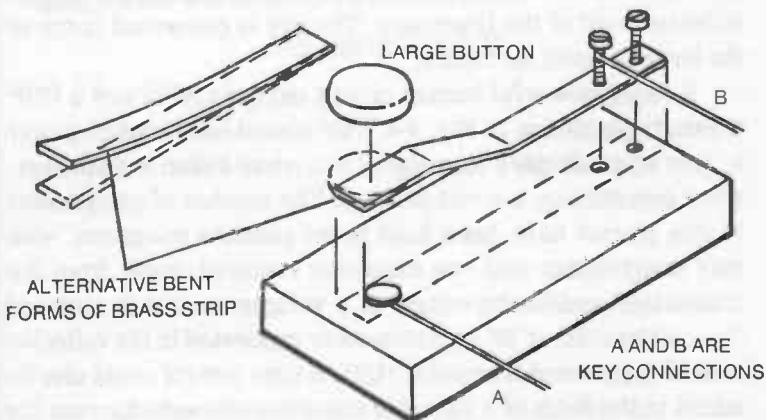


Fig. 9-2. Morse key made from spring brass strip mounted on a wood block.



capacitors will lower the frequency of the tone; and decreasing the capacitor values will raise the frequency of the tone.

An even simpler 'buzzer' circuit is shown in Fig. 9-3 when a 5K potentiometer replaces the fixed value resistors of the previous circuit. The setting of this is adjusted to get the circuit oscillating (i.e. a tone is heard in the phones). The frequency of this tone will be governed by the values of C1 and C2, in the same manner as before; but for satisfactory working the value of C2 should *always* be ten times greater than C1.

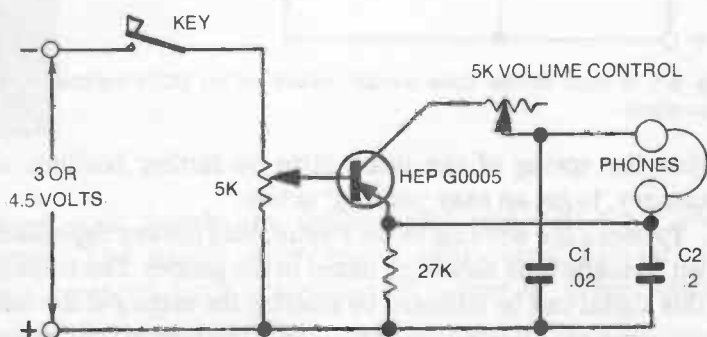


Fig. 9-3. Simplified Morse 'buzzer' circuit.

If a volume control is required for this circuit, this takes the form of a second 5K potentiometer connected in the collector lead of the transistor. The key is connected in one of the battery leads, as before.

A more powerful buzzer circuit using an NPN and a PNP transistor is shown in Fig. 9-4. This should have enough power to give a satisfactory tone signal in a small 8-ohm loudspeaker, when powered by a 9-volt battery. The number of components in this circuit have been kept to an absolute minimum, with only one resistor and one capacitor required, apart from the transistors and loudspeaker. If a volume control is required this can be a 2K or 5K potentiometer connected in the collector lead of the second transistor (Q2). A tone control could also be added in the form of a variable capacitor connected across the speaker, or try different values of fixed capacitors in this position to give the tone judged most suitable.

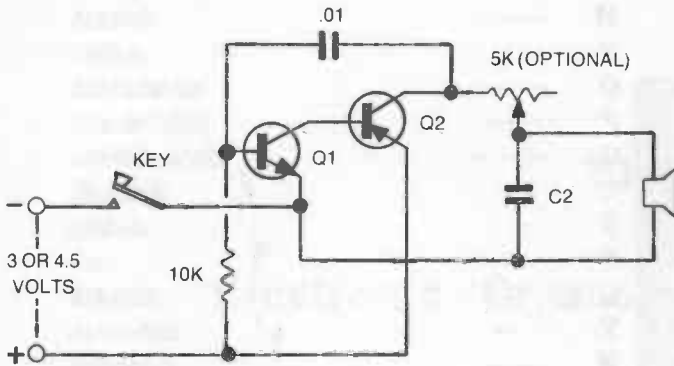


Fig. 9-4. More powerful Morse buzzer circuit. Q1 is an NPN type 2N2102 or equivalent. Q2 is a PNP power transistor type 2N2869 or equivalent. Find best value for C2 by experiment.

Transistor Q1 in this circuit is a NPN type 2N2102, or equivalent. Q2 is a power transistor—type 2N2869, HEP G6013, 40022, or equivalent. This has a metal case with only two leads emerging (marked e for emitter and b for base). The collector lead is connected internally to the case. The collector connection in this circuit is thus made directly to the bolt securing the case to the circuit panel. It is recommended that Q2 be mounted on a heat sink.

Any other type of AF oscillator can be used as a Morse code sender, merely by inserting the key in one of the battery supply leads—see chapter on Oscillators.

### THE MORSE CODE

A	· —	didah
B	· · ·	dahdididit
C	· — ·	dahdidahdit
D	· · ·	dahdidit
E	·	dit
F	· · · ·	dididahdit
G	· — ·	dahdahdit
H	· · · ·	didididit
I	· ·	didit
J	· — — —	didahdahdah
K	· —	dihdidah
L	· · · ·	didahdidit

M	--	dahdah
N	--	dahdit
O	----	dahdahdah
P	----	didahdahdit
Q	----	dahdahdidah
R	----	didahdit
S	----	dididit
T	-	dah
U	----	dididah
V	----	didididah
W	----	didahdah
X	----	dahdididah
Y	----	dahdidahdah
Z	----	dahdahdidit
1	-----	didahdahdahdah
2	-----	dididahdahdah
3	-----	didididahdah
4	-----	dididididah
5	-----	dididididit
6	-----	dahdidididit
7	-----	dahdahdididit
8	-----	dahdahdahdidit
9	-----	dahdahdahdahdit
0	-----	dahdahdahdahdah

Period	-----
Comma	-----
Question mark	-----
Error	-----
Double dash	-----
Wait	-----
End of message	-----
Invitation to transmit	-----
End of work	-----

## Electronic Organs

A tone generator produces a single note. Depending on the type of circuit involved, it is a simple matter to change the pitch of the note by altering certain component values. If these are arranged in the form of alternative circuits, which can be selected at will, we have the basis of a simple electronic organ capable of playing tunes.

To keep the number of components to a minimum, the starting point can be a Hartley oscillator using a single AF transistor of medium power and a transistor output transformer with a center-tapped primary. The basic oscillator circuit is shown on the right side of Fig 10-1. This is built on a Paxolin panel allowing enough space at one end to fit eight miniature potentiometers in line. These should be of the carbon preset type, available with either vertical or horizontal mounting, and can be obtained in a diameter size of 1 inch or less. Connections for these types of potentiometers are shown in Fig. 10-2.

In the circuit, two connections only are made to each potentiometer—a common connection to the wiper terminal; and one end of the resistance track of each potentiometer connecting to a separate brass screw mounted on the board. These brass screws are mounted in line and form the keys of the organ.

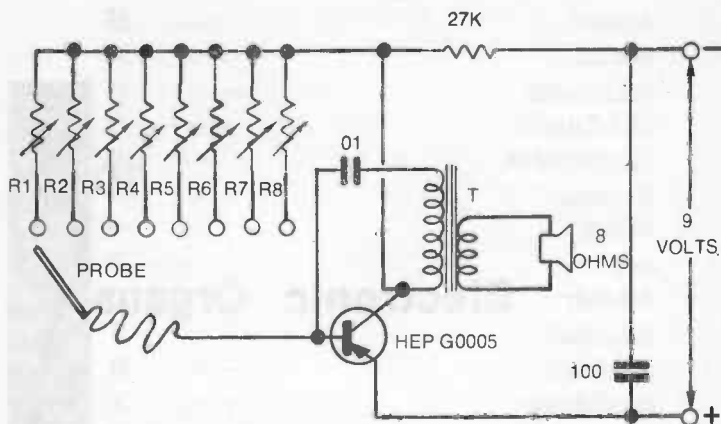


Fig. 10-1. Simple single-transistor electronic organ. The eight potentiometers are all 5K ohm. T is a transistor radio output transformer. All component values as shown on the diagram.

The common line connects back to the oscillator circuit. The other connection to the circuit is terminated in a probe, e.g. a short length of stiff plated wire (a spare plug from a meter lead is ideal).

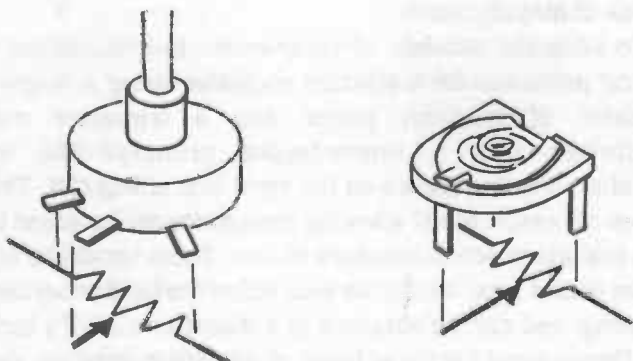


Fig. 10-2. Identifying connections on a standard potentiometer (left) or skeleton, or PC, type (right).

The organ is played by tapping the probe on one of the brass screws at a time. Each will produce a different note heard in the loudspeaker, but first it is necessary to tune the organ.

Starting by holding the probe on one of the middle screws (i.e. R4 or R5), adjust the potentiometer with a screwdriver until the note generated corresponds to middle C of a piano. This can easily be done by ear. Notes are then adjusted on either side, against a piano, until R1 to R8 covers a full octave. Again this is easy to do by ear—how accurately the organ is tuned depending very much on how musical your ear is!

Once all the potentiometers have been adjusted in this way, you can tap out simple tunes on your electronic organ, note by note. It is also possible to play two notes at once by touching two adjacent screws simultaneously with the probe, although this will “throw” the resultant note well out of the original octave selected and will probably not be all that musical.

If necessary you can also adjust the octave selected up or down by altering the value of the  $0.01 \mu\text{F}$  capacitor. Using a higher value will lower the octave range; using a lower value will raise the octave range. This opens up a further possibility of using two separate capacitors in place of the  $0.01$  capacitor, one giving a treble octave and the other a bass octave. A switch can then be used to switch from one to the other.

There is also the possibility of extending the number of notes to two octaves, i.e. by increasing the number of potentiometers used to fifteen. But this is the limit for this simple circuit.

Another similar electronic organ circuit is shown in Fig. 10-3 based on a Colpitts oscillator. This employs capacitors instead of potentiometers to govern the frequency of the individual tones. No setting-up is required in this case since the fixed value capacitors C1 to C8 are selected to give the required resonant frequencies in the circuit with the other component values given. The values to use are:

C1— $0.6 \mu\text{F}$   
C2— $0.33 \mu\text{F}$   
C3— $0.2 \mu\text{F}$   
C4— $0.15 \mu\text{F}$

C5— $0.1 \mu\text{F}$   
C6— $0.068 \mu\text{F}$   
C7— $0.05 \mu\text{F}$   
C8— $0.04 \mu\text{F}$

It may be difficult to obtain a complete set of these values and it may be necessary to use mixed capacitor types, e.g.

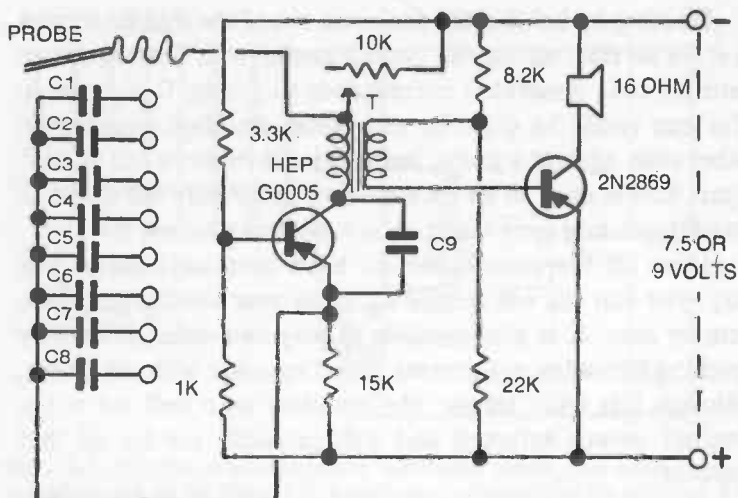


Fig. 10-3. Electronic organ based on a Colpitts oscillator circuit. See text for values of C1 to C8. C1 is 0.01  $\mu$ F. T is any typical miniature AF transformer.

electrolytic and polyester or polycarbonate, etc. If electrolytics or other polarized type(s) are used, it is important to observe the correct polarity of connection into the circuit.

One capacitor lead in each case should again terminate in a brass screw to enable the organ to be played with a probe. There is also the possibility of shifting the octave range by adjusting the value of C9 (a higher value will lower the octave, and vice versa, as before); and using two separate capacitors of different values in place of C9 to switch from one octave to another.

The power developed in this particular circuit is inadequate for loudspeaker operation, although low impedance phones connected directly to the secondary of the transformer would provide adequate listening levels. However, it is a very simple matter to add a single stage of amplification using a power transistor so that the organ can play through a 16 ohm miniature loudspeaker. This amplifier stage is shown on the circuit diagram.

To convert to a 'real' electronic organ instead of one where the notes are tapped out by a probe, it is necessary to build a

keyboard. This can be quite simple, using strips of springy brass mounted over a contact screw for each switching position, mounted in line as shown in Fig. 10-4. Each strip can then be capped with a fingering key cut from hardwood or

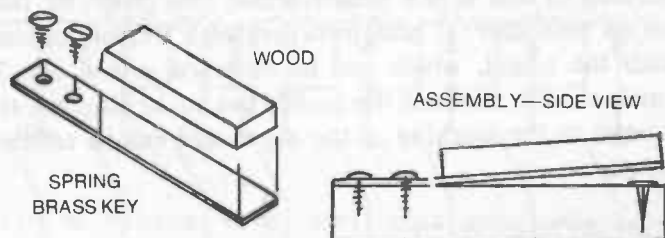


Fig. 10-4. Construction of the individual keys.

balsa strip, glued in place with epoxy adhesive. Connection to the circuit is straightforward. Each contact screw is connected to the individual resistors or capacitors, depending on which circuit is used (taking the place of the row of screws). All keys are then connected correctly and take the place of the probe, i.e. common connection is taken to the transistor base in the oscillator circuit.

The whole keyboard can be built on a suitably substantial base and the electronic circuit mounted underneath, as shown in Fig. 10-5.

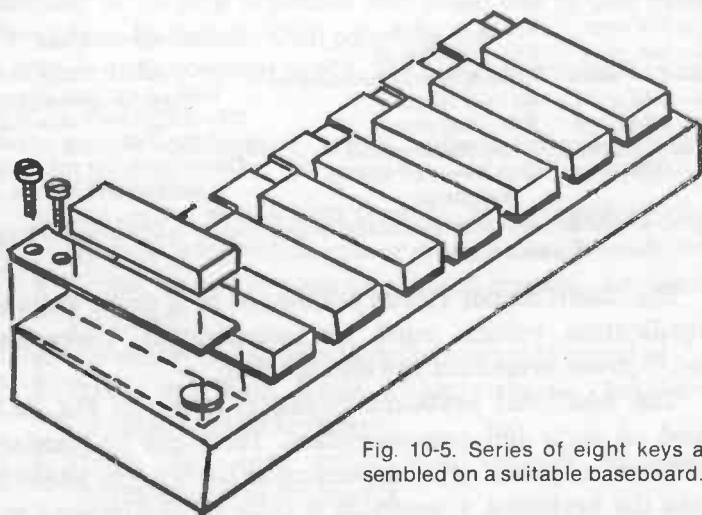
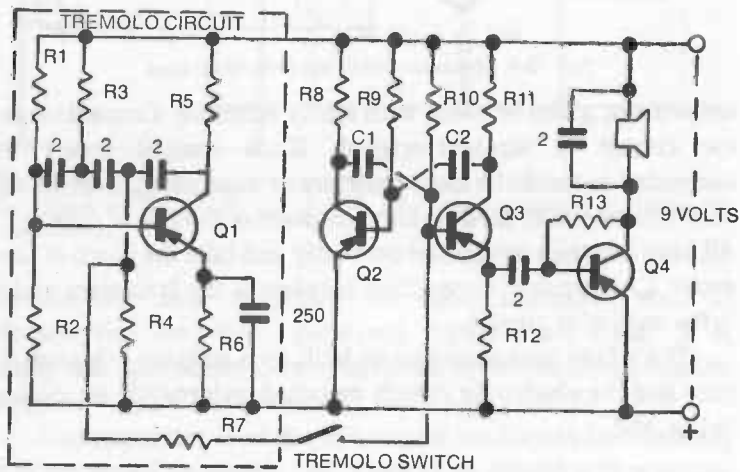


Fig. 10-5. Series of eight keys assembled on a suitable baseboard.



A more elaborate organ circuit is shown in Fig. 10-5 which is particularly suitable for keyboard working. The keyboard circuit is shown separately in Fig. 10-6.

This organ differs from the two simple circuits previously described in that it is a multivibrator tone generator rather than an oscillator. It also incorporates a tremolo circuit to enrich the sound, which can be switched in and out. This tremolo circuit, shown in the dashed box on the diagram, is not essential to the working of the organ and can be omitted if desired.



R1—82K ohm  
R2—10K ohm  
R3—4.7K ohm  
R4—4.7K ohm  
R5—4.7K ohm  
R6—1K ohm  
R7—100K ohm

R8—2.2K ohm  
R9—47K ohm or  
250 K ohm potentiometer  
R11—2.2K ohm  
R12—100 ohm  
R13—39K ohm  
Q to Q4—HEP G0005  
(Motorola)

Capacitor Values:

C1—0.1  $\mu$ F for treble circuit  
0.25  $\mu$ F for bass circuit  
C2—0.1  $\mu$ F for treble circuit  
0.25  $\mu$ F for bass circuit  
Other capacitor values as  
marked on diagram.

Fig. 10-6. More advanced electronic organ circuit. Additional tremolo circuit shown in dashed box.

The multivibrator circuit is followed by a single stage of amplification (which must be incorporated), generating enough power to operate an 8 ohm speaker.

The additional keyboard circuit is shown in Fig. 10-7, based on eight 10K potentiometers. These can be standard miniature, or preset type, depending on the size you intend to make the keyboard. Connection is quite straightforward and

each note in the octave is adjusted separately by the setting of its own potentiometer, starting with the end potentiometers associated with key 1.

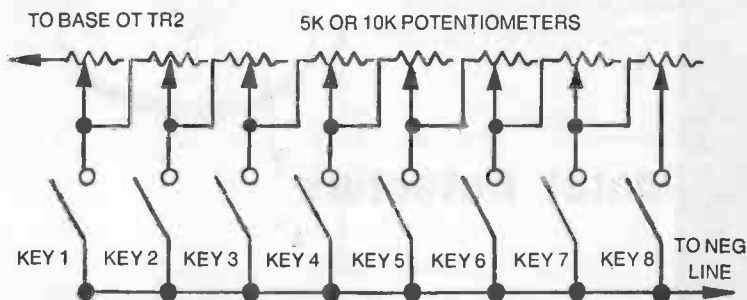


Fig. 10-7. Electronic organ keyboard circuit with potentiometer for individual tone adjustment.

For a complete electronic organ, two separate keyboards should be made—one for treble and one for base. This will then require two separate electronic circuits to be built complete with its own amplifier and tremolo (if the latter is to be incorporated). Component values for these two circuits are identical, except for the values of capacitors C5 and C6 as shown in the component list. With a double-banked organ, the treble circuit then connects to (and is initially tuned by) the treble keyboard and its potentiometers. The bass circuit is connected to its own keyboard and tuned one or two more octaves down by its individual potentiometers.

The particular circuit of Fig. 10-6 in fact can be built in six different versions:

1. Simple one-octave organ without tremolo, probe operated.
2. One-octave organ with tremolo, probe operated (the tremolo being switched in or out by switch S1).
3. Simple one-octave organ, without tremolo, keyboard operated.
4. One-octave organ with tremolo, keyboard operated.
5. Treble and bass organ without tremolo, keyboard operated via two keyboards.
6. Treble and bass organ with tremolo, keyboard operated via two keyboards.

# 11

## Metal Detectors

A metal detector is basically an audio oscillator which can be upset by the proximity of a metal object. This will cause a marked modification, or even disappearance, of the note heard, with maximum effect when the critical part of the oscillator is nearest to the metal.

This critical component is normally a large diameter coil, which is called the search coil. This is held in a substantially horizontal attitude and passed over the ground or surface beneath which the suspected metal is buried. What happens is that the inductance of the coil (against which the associated circuit is tuned to oscillate) is modified by the presence of adjacent metal, lowering the resonant frequency of the circuit and thus the frequency of oscillation.

As a rough rule the maximum depth to which a search coil will have its inductance sufficiently modified to detect a change in the circuit performance will be equal to the diameter of the coil itself—Fig. 11-1. Thus the larger the diameter of the search coil the better, when searching for buried metal. Unfortunately, however, the larger the physical diameter of the coil the more power is required in the circuit, and the more complicated the circuit needs to be.

A simple low power oscillator circuit can be built around a single inexpensive general-purpose transistor, such as an

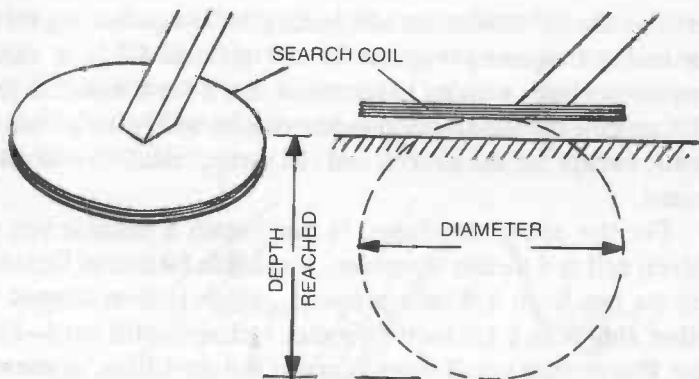


Fig. 11-1. Maximum depth to which a metal detector is sensitive is approximately the same as the search coil diameter.

HEP G0008, associated with a tuned circuit comprising the search coil and a variable capacitor. With suitable proportions for the coil this will have a frequency of oscillation of, perhaps, 100 to 500 kHz in a Hartley circuit, the actual oscillating frequency being determined by the setting of the variable capacitor. This is well above audio frequency range, but a simple oscillator circuit of this type will have a low frequency component which will be made audible by rectification. This function can be performed by a diode. This type of AF/RF oscillator is known as a beat-frequency oscillator.

A complete circuit of this type is shown in Fig. 11-2. L1 is the search coil which, in combination with variable capacitor C2, forms the resonant circuit. D is a germanium diode which

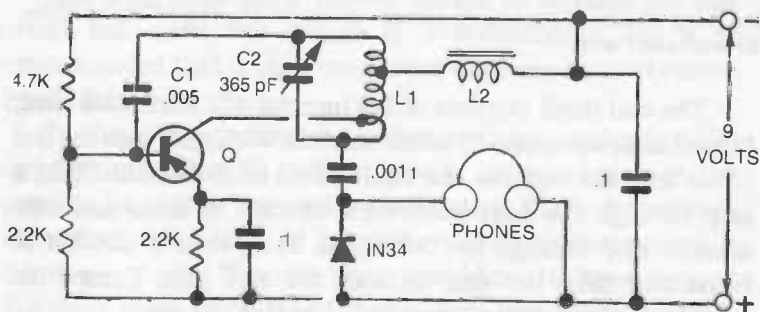


Fig. 11-2. Simple low-power (low diameter search coil) metal detector. L1 is the search coil, L2 a 2 or 3 millihenry RFC choke. Other component values as marked on diagram.

rectifies the RF oscillation and feeds a DC component signal of the audio frequency content to the phones. L2 is a radio frequency choke with an induction of about 2 or 3 millihenries. This and all the other components can be bought as standard items, except for the search coil (L1) which must be specially wound.

For the power developed in this circuit a suitable size of search coil is 6 inches diameter. A suitable former of this size can be cut from 1/4-inch plywood, which is then capped in either side with 6 1/2-inch diameter circles of stiff card—Fig. 11-3. Pierce four small holes in one of the card discs, as shown, through which the coil winding wire is taken for connections.

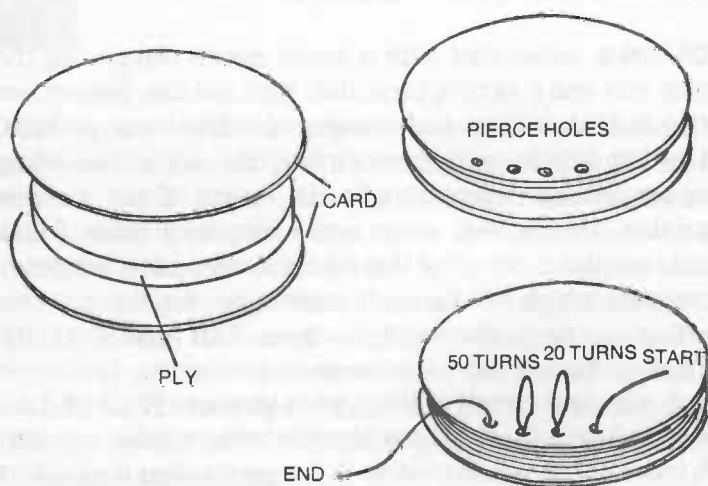


Fig. 11-3. Details of the search coil construction. Winding 100 turns of No. 28 enameled wire.

The coil itself consists of 100 turns of #28 enameled wire, tapped at 30 turns and 50 turns. In other word, just pass the end of the wire through the start hole, wind on 30 turns and take a loop through the next hole. Wind another 20 turns and take another loop through the third hole. Then wind on another 50 turns and take the end through the last hole. Secure the winding in place with a wrapping of insulating tape.

The actual circuit is assembled on a perf board. When completed, this board can be mounted on top of the search coil

former and the four search coil connections made to the circuit, as indicated. The 9-volt battery can be mounted on the other side of the search coil former to balance (e.g. in clips or a simple box). The addition of a handle then completes the assembly—Fig. 11-4.

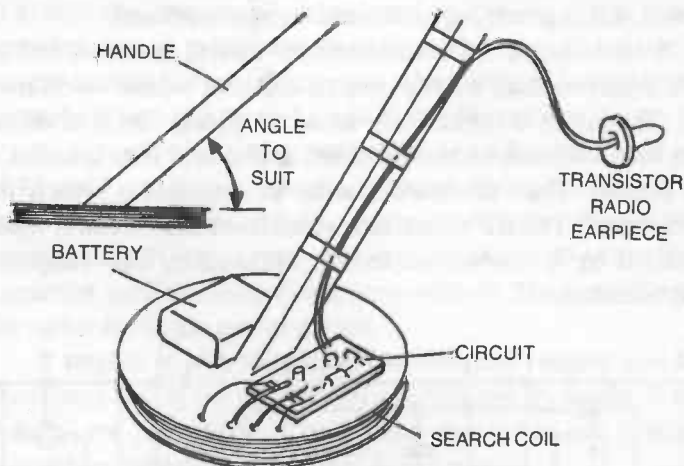


Fig. 11-4. The assembled metal detector. If no tone can be obtained, try a high impedance hearing-aid earpiece instead of a transistor radio earpiece.

An on-off switch can be mounted on the handle (in one of the battery leads). Phone connections are taken up the handle and taped in position to secure. Leave enough length of lead to connect to the phones, with adequate slack to maneuver the search coil at a ground level while wearing the phones.

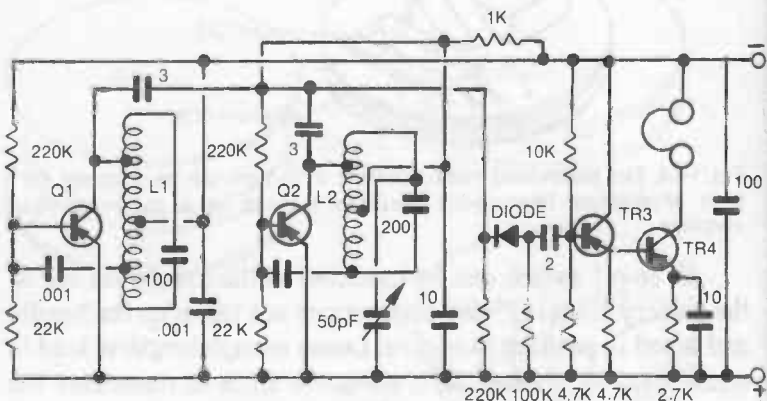
Any high impedance phones should be suitable for this circuit but since the device is a miniaturized one it is recommended that a high impedance earpiece be used rather than hi-fi type earphones.

To check the circuit for working, switch on and adjust the variable capacitor C2 until a steady note is heard in the earpiece (it may be necessary to add more, fixed, capacitance in parallel with C1). Now bring the search coil over a metal object, e.g. a coin. The note heard should drop in frequency, or disappear completely. If the change note is not very marked, try adjusting the variable capacitor to a different note and repeat the test. If the result is better, further adjust C2 in the

same direction until the note disappears when the search coil is over metal. If results are worse, adjust C2 in the opposite direction until optimum response is obtained.

You may also be able to improve the performance of your simple metal detector by increasing the number of turns on the search coil, e.g. adding additional turns at each end.

A more powerful metal detector circuit is shown in Fig. 11-5, incorporating both a search coil and a local oscillation coil. The latter is inductively tuned, implying that it is wound on a core and that core is adjusted until a beat note is heard in the phones. The variable capacitor in this case is merely for adjustment. The RF signal extracted from this circuit is again rectified by a diode, but this is followed by two stages of amplification,



Q1, Q2—HEP G0008  
 Q3, Q4—HEP G0005  
 L1 is the search coil  
 L2 is the local oscillation coil (see text)  
 Phones are high impedance type.

Fig. 11-5. Circuit for a more powerful metal detector using a search coil of 18 or 20 inch diameter. Component values as shown.

The search coil in this case can be made very much larger, e.g. 18 or 20 inches in diameter. Because of this increased diameter a much smaller number of turns is required. Recommended windings (again for wire) is 15 complete turns, tapped at 5 turns, 6 turns and 10 turns.

All the other components are standard, except for the local oscillation coil L2. This consists of 120 turns of #38 enamelled

wire wound on a 3/8-inch diameter former, tapped at 20 turns and 40 turns. It is important to get these tapping points connected the right way round in the circuit. Other component values are as specified in the parts list.

Final assembly of the metal detector can be similar to Fig. 11-4, with the search coil wound on a ply former; circuit panel mounted on top, with battery on the other side to balance. A stouter handle is required to carry the additional weight of the large diameter coil former and will need bracing to the ply.

To set up the detector, switch on and adjust the dust core of L2 until a satisfactory note is heard. Bring the search coil over some metal object, when the note should fade appreciably. Holding this position, adjust the 50 pF variable capacitor until the note disappears entirely. The circuit is then set up for optimum performance.

If unable to obtain satisfactory results, remove one turn from *each* end of the search coil winding and try again. If good results are still difficult to obtain, you could try changing transistors Q1 and Q2 for higher gain types.



## 12

# Multivibrators and Flip-Flops

A *multivibrator* is another form of oscillating circuit which automatically switches from one conducting state to another, and back again, and so on. This is also known as a flip-flop. Oscillation can occur at high frequency, and so such a circuit can be used as an audio tone generator. Equally, however, a multivibrator can be adjusted to oscillate at a very low frequency—one or two cycles per second or even slower. This can be used as a working circuit for clock or timing devices, like the *metronome*.

A basic flip-flop (multivibrator) circuit consists of two cross-linked transistors, working in an unstable state, as shown in Fig. 12-1. Slight unbalance in the component values, or anything else that contributes to random variations in current will cause one transistor to switch off, switching the other on. The on transistor will then switch off, switching the other on...and so on.

The frequency at which this will occur depends on the transistor characteristics and the associated component values. For example, in the circuit shown, using HEP G0005 transistors (or equivalents), the following component values will give an oscillation frequency of about 5 kHz:

R1—1K

R2—27K

R3—27K  
 R4—1K  
 C1 and C2—4700 pF

Using the same transistors the frequency of oscillation can be reduced to about 1 Hz or 2 Hz (once or twice per second) :

R1—10K  
 R2—10K  
 R3—1K  
 R4—1K  
 C1 and C2—100  $\mu$ F

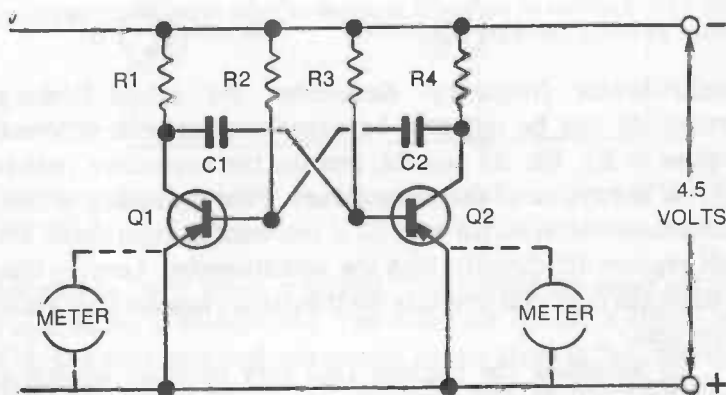


Fig. 12-1. Basic circuit for a multivibrator. Resistor values depend on transistors used: these and capacitors C1 and C2 govern frequency of oscillation (see text).

The higher frequency working could be listened to, as a tone, by replacing R4 with a high impedance earpiece. The low frequency working could not be heard in this manner but could be indicated by connecting two 0.5 volt voltmeters to the circuit, as shown dotted.

Exactly the same circuit can be used to make a flasher. In this case, using the transistors originally specified there will be insufficient power to operate a light bulb and so an additional amplifier (Q2) is needed. This can be an HEP G6003 or similar transistor, connected to one end of the circuit as shown in Fig. 12-2 with a 3.5-volt flashlight bulb in the emitter lead. This bulb will flash on and off at the same rate as the

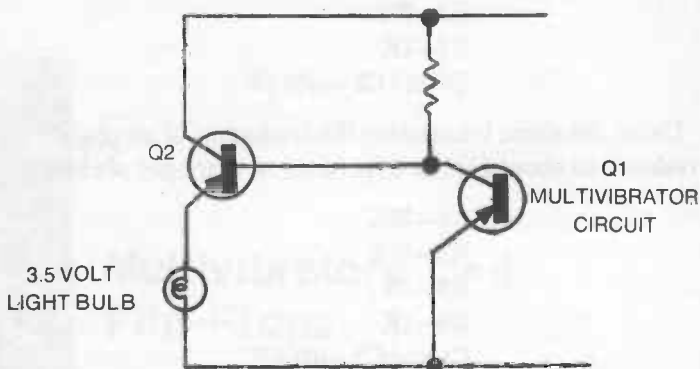


Fig. 12-2. Addition of transistor amplifier to basic multivibrator circuit to 'flash' a 3.5-volt flashlight bulb.

multivibrator frequency. Remember the actual flashing frequency can be adjusted by experimenting with different values of  $E_1$ ,  $R_2$ ,  $R_3$  and  $R_4$ , and the two capacitors (which should always be of the same value). First try adding a 100K potentiometer in series with  $R_3$  if you want to experiment. Do not replace  $R_3$  directly with the potentiometer. Leaving this resistance in circuit protects the transistors against accidental overload.

By adjusting the flashing rate very carefully against a stopwatch, you should be able to aim at a setting giving exactly one flash per second. Then you have a flashing clock, each tick or second being indicated by the bulb flashing once. This makes a useful form of timer for operations requiring seconds to be counted accurately. Enclose the bulb in a safelight color screen and you have a useful enlarger timer.

An identical flasher circuit (HEP G6003 transistor and bulb) can, of course, also be connected to the other end of the circuit. One bulb will then flash on as the other switches off.

Using higher power transistors the flasher can be made to work without the necessity of an additional amplifying transistor for each bulb. The bulb can also be used to replace one (or both) bias resistors. The flasher circuit then reduces to that shown in Fig. 12-3. A simple circuit of this type, built down to the smallest possible size, could work realistic winking lights on a model airplane.

## Metronome

The same basic multivibrator circuit of Fig. 12-1 using HEP G0005 transistors (or equivalent) can be connected to a 4-ohm loudspeaker to provide an audible output or beat note at the oscillating frequency ranging from about one every three

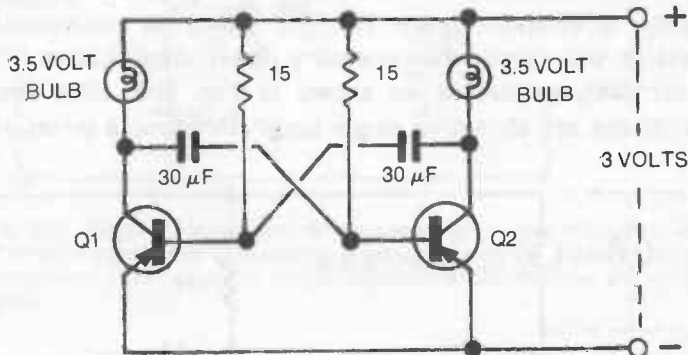


Fig. 12-3. Compact 'flasher' circuit based on two 2N1304 or HEP G0011 transistors.

seconds to three times a second. This covers the usual range required for a metronome. The complete circuit is shown in Fig. 12-4 with matched component values given in the caption. The 250K potentiometer is a frequency control. Adjusting this will vary the note of "beating" heard in the loudspeaker. The 10K resistor in series with the potentiometer is necessary to

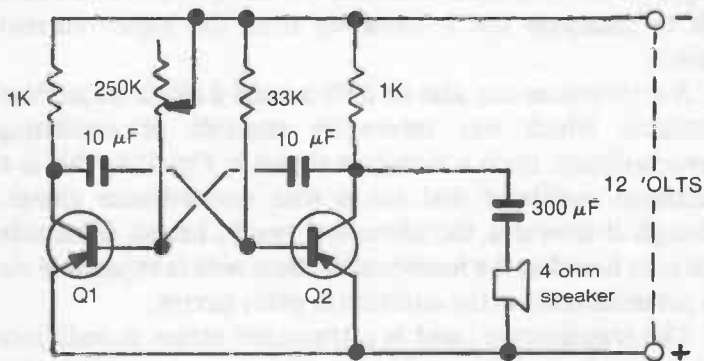


Fig. 12-4. Variable frequency metronome with loud speaker output. Power by a 12-volt battery.

limit the maximum current flowing in this in the event of the potentiometer being turned to zero resistance.

This same metronome circuit can be extended to operate a flashing lamp (or series of lamps) simultaneously with the audible note in the loudspeaker. For optimum results the two transistors used in the multivibrator circuit should be closely matched in characteristics. An HEP G6003 (or equivalent) transistor will supply the necessary power amplification for the lamp(s), connected as shown in Fig. 12-5. Here two alternatives are shown—a single lamp circuit, or a series of

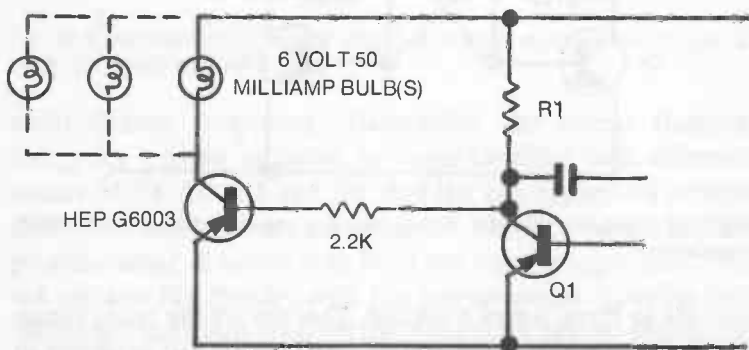


Fig. 12-5. Flashing light circuit added to one end of the basic metronome circuit. Q1 and R1 are components of the metronome circuit.

lamps connected in parallel. Up to four lamps can be operated simultaneously. The HEP G6003 will power a large number of lamps, if required, but in this case should be mounted on a heat sink to dissipate the self-heating from the higher current passed.

A metronome can also be built around a *single* unijunction transistor which has inherently unstable or oscillating characteristics. Such a circuit is shown in Fig. 12-6. This is a relaxation oscillator and not a true multivibrator circuit, although it provides the same end result, i.e. an adjustable beat note heard in the loudspeaker. Beat note is adjustable via the potentiometer in the emitter (or gate) circuit.

The transformer used is a transistor output transformer with primary center tap. The circuit may not work with the transistor connected across the full primary, in which case

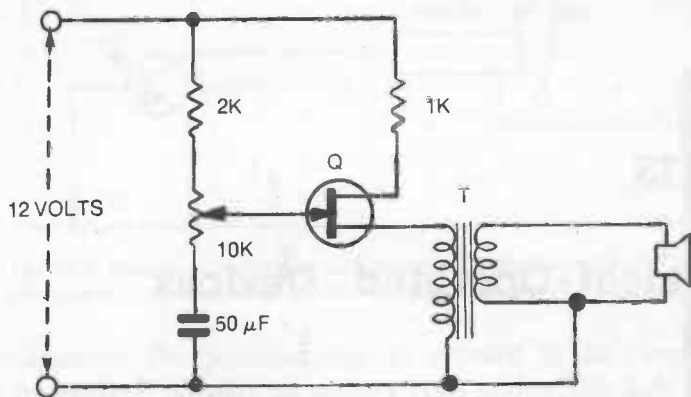


Fig. 12-6. Single transistor metronome based on a unijunction transistor, 2N2646 or equivalent. Component values are shown on the diagram. The transformer (T) is a typical output transformer for, or from, a transistor radio.

connect to the center tap. Virtually any unijunction type transistor should work in this circuit, using the component values given in the caption. If necessary a tone and/or volume control can be added in the output circuit from the transformer secondary to the loudspeaker. For volume control, connect a 1K or 5K potentiometer in one of the leads to the speaker. To combine with a tone control, connect a  $1 \mu\text{F}$  capacitor across the speaker terminals. Experiment with different capacitor values for best effect.

## Light-Operated Devices

Light sensitive devices fall into two main categories:

1. Those which are activated when illuminated by a light source such as daylight. These include *photoelectric cells* and solar batteries, either of which can be used as a source of power in electronic circuits.
2. Components which change their electrical resistance characteristics when light falls on them. These include *photodiodes* which have no-go, go characteristics (work like a switch); *light-activated silicon controlled rectifiers* (LASCRs), which have a similar switching action to photodiodes; and *phototransistors* which combine a switching action with amplification.

Fig. 13-1 shows a simple switching circuit based on a phototransistor. The transistor acts as a variable resistance device. Light falling on it decreases its resistance and this increases the current flowing through the emitter-collector circuit causing the relay to pull in. As the level of light falls off the resistance in this circuit decreases, until a point is reached when the relay drops out.

A suitable relay coil resistance to match phototransistor is 3000-5000 ohms. The relay should be of the sensitive type capable of being adjusted to pull-in at a current of about 2

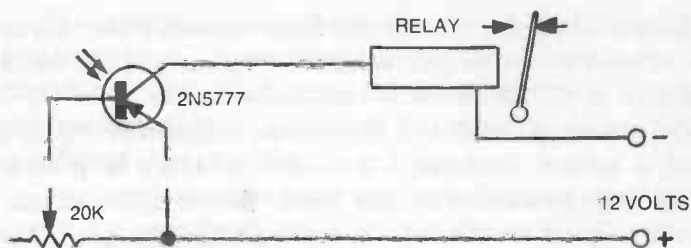


Fig. 13-1. Simple switching circuit based on a phototransistor. The relay contacts provide the switch action for an external circuit.

milliamps. The potentiometer is included in the circuit to provide final adjustment of the circuit to available light (and to different relay coil resistances).

The relay contacts are connected to an external alarm circuit. Connected as shown in Fig. 13-2A, the bulb lights, or the buzzer sounds, when the relay is pulled in. When the light level falls the bulb goes out (or the buzzer stops). Current to the other relay contact as in Fig. 13-2B, the bulb lights up, or the buzzer sounds, only when the light level falls below a predetermined level (as originally adjusted by the potentiometer).

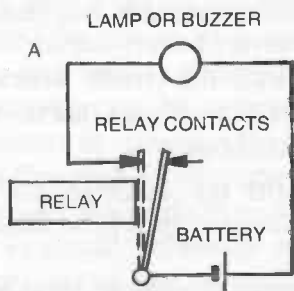


Fig. 13-2 A. Switches on lamp or buzzer when relay is pulled in.

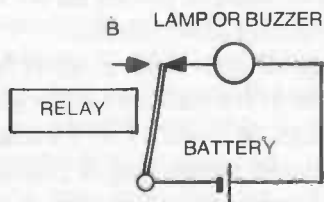


Fig. 13-2B. Operates lamp or buzzer when light level falls.



Instead of a bulb or buzzer the relay contacts could equally well be used to switch an electronic circuit on and off, e.g. a simple AF oscillator circuit.

An improved version of this circuit is shown in Fig. 13-3 where a second (ordinary) transistor is added to provide further amplification. This is a much more sensitive circuit, i.e. will respond or "switch" at much smaller changes in the level of illumination of the phototransistor. The circuit is set up for working as follows:

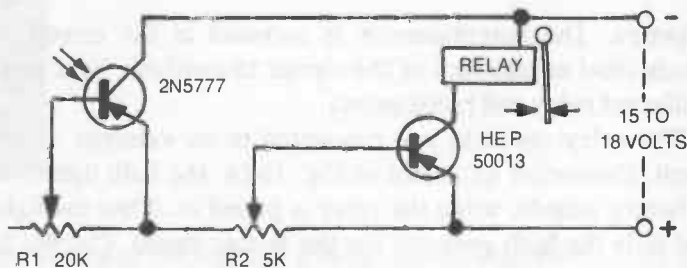


Fig. 13-3. Photoelectric switching circuit with improved sensitivity.

1. Adjust the relay to pull-in at a current of about 2 milliamps.
2. With the phototransistor completely shielded from light (e.g. covered over) adjust R2 so that the relay drops out with the circuit switched on. Check by switching off and on again that the relay does not pull in when switched on.
3. Adjust R1 with the phototransistor uncovered so that the relay pulls in at the level of illumination required.

For greater sensitivity readjust R2 to be nearer the relay pull-in point; and then readjust R1 as necessary. Again the relay contacts can be used to switch an AF oscillator circuit instead of a bulb or buzzer alarm circuit.

A disadvantage of both these circuits is that there is a steady current drain in the battery all the while the circuit is switched on. This can be reduced to a minimum by using a slightly different circuit employing a *photocell* instead of a phototransistor. An ordinary transistor is then used as an amplifier.

The complete circuit is shown in Fig. 13-4. Relay resistance can be anything up to 5K. Potentiometer R2 provides a means of adjusting the current flowing to match the coil resistance of the relay used. The relay should be adjusted to pull-in at about 2 milliamps or less.

The 500K potentiometer is a sensitivity control for the circuit, i.e. sets the circuit to work at the level of illumination

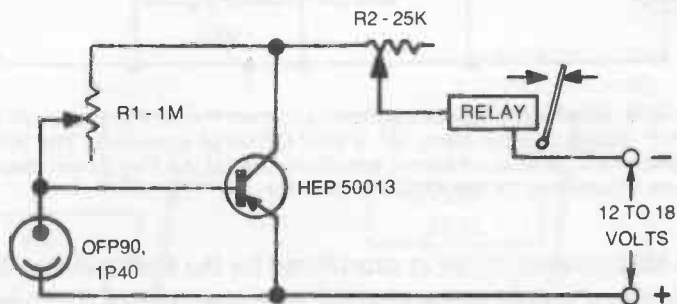


Fig. 13-4. Photoelectric switching circuit based on an old style photoelectric cell suitable for relays with coil resistances up to 5K ohms.

required. It can also be used to set the current drain to an absolute minimum level when the photocell is not illuminated, increasing the life of the battery when the circuit is to be left switched on for a long time (e.g. for use as an alarm). The more this potentiometer can be adjusted to leave as much resistance in circuit as possible the better. (Check for minimum current flow with a milliammeter inserted in one of the battery leads.) At the same time it must not leave too much resistance in circuit, otherwise when the photocell is illuminated the current rise may not be enough for the relay to pull in. The use of a sensitive relay which can be adjusted to a low pull-in current is therefore an advantage.

Again the sensitivity of such a circuit can be improved enormously by adding an additional stage of amplification, as shown in Fig. 13-5. Also in this case the current when the relay is not operated is virtually negligible, rising to 5 milliamps or more when the photocell is illuminated.

Two controls are available for setting up. The 500K potentiometer controls the overall sensitivity of the circuit. If

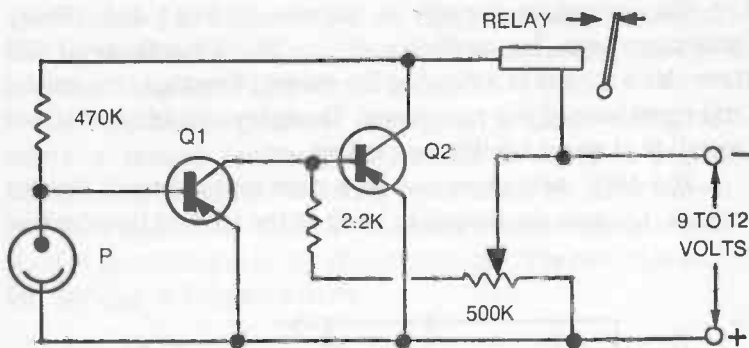


Fig. 13-5. Amplified photocell switching circuit. P is OFF90 photocell. Q1 is HEP G0005 or equivalent. Q2 is HEP G6006 or equivalent. The 500 K potentiometer acts as an overall sensitivity control. A 1 Meg potentiometer can be substituted for the 470K ohm resistor.

a 1 Meg potentiometer is substituted for the 470K resistor, this provides a means of varying the *switching time* of the circuit, or the time delay occurring between pull-in and drop-out of the relay.

Photoswitch circuits like these have a wide application as burglar alarms as well as counter circuits, etc., responding to interruption of a light beam directed at the light-sensitive element (photocell or phototransistor)—apart from their obvious use as warnings of when the level of daylight, or other illumination, rises above, or falls below, a certain level. In this latter form of application, such a circuit could be used to switch on artificial lighting when the daylight falls to a certain level. If a mains circuit is to be switched, however, this should be done through a second heavy-duty “slave” relay with mains-rated contacts capable of carrying the necessary load. The light switch relay then simply closes the circuit for the slave relay, as shown in Fig. 13-6.

Such a precaution is not necessary when the artificial lighting is a low voltage bulb. This can, in fact, be switched directly with an all-transistor circuit using a power transistor for the final stage of amplification, eliminating the need for a relay at all. Such a circuit is shown in Fig. 13-7.

This is basically the same type of photocell circuit followed by two stages of current amplification via Q1 and Q2.

Component values shown are for use with a 6-volt battery and 6 volt 3-watt bulb. To use the same circuit for a parking light, which automatically switches on when the daylight falls, connect to a 12-volt car battery and use 12 volt lamps. Component values needed are:

R1—10K  
 R2—1000K  
 R3—220K

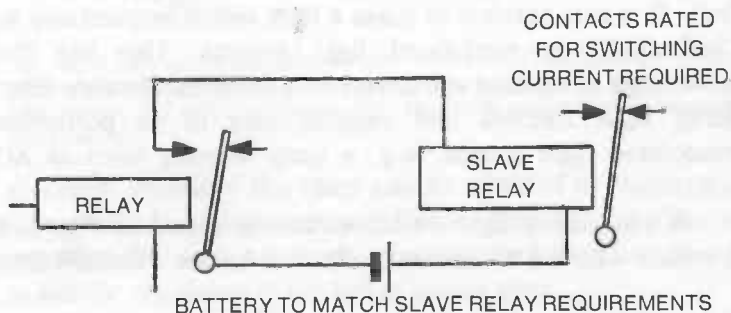


Fig. 13-6. Using the photoswitch relay to operate a slave relay enables heavier currents to be switched by the slave relay contacts.

In this case the bulb should be a 12 volt 2 watt or 12 volt 3 watt type.

Fitted to a car, the photocell should be in a place exposed to maximum illumination, e.g. one corner of a windshield or rear window (the whole circuit can be mounted in this position,

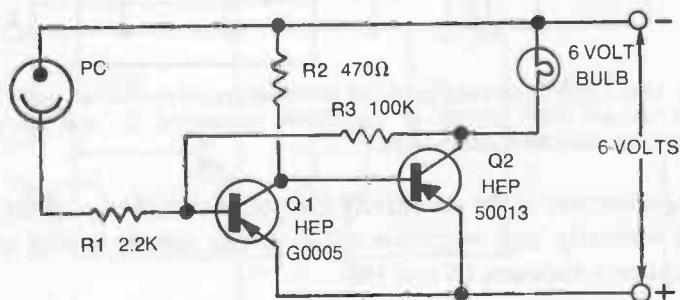


Fig. 13-7. Relayless photoswitch circuit operating a lamp as a signal device. Bulb lights when light level falls. Substitute a 5K potentiometer for the 2.2K resistor for a sensitivity control.

or just the photocell). The lamp is separate from the circuit, housed in a "parking light" fitting on the outside of the car. Battery connecting leads are taken to the car battery and a suitable car ground point, respectively. The battery lead should incorporate a 1-amp fuse.

### Modulated Light Switch

All the circuits so far described work on steady levels of illumination, e.g. daylight or light from a battery-powered bulb. It is also possible to make a light switch respond only to "pulsation" or modulated light sources. This has the advantage of making the device free from interference from stray light sources and respond only to its particular modulated light source (e.g. a lamp working from an AC source).

A modulated light switch circuit is shown in Fig. 13-8 together with the necessary component values. The 100K ohm

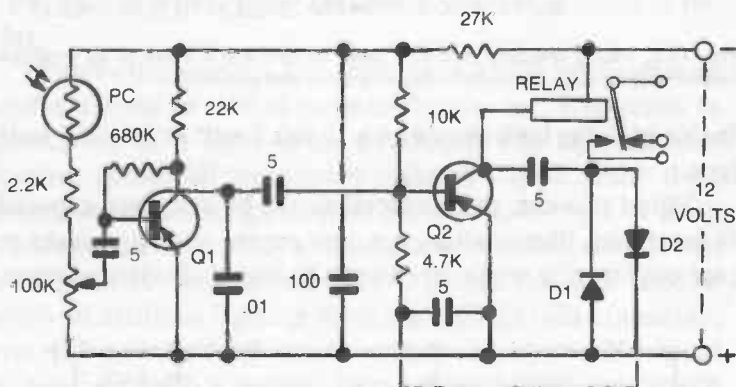


Fig. 13-8. Light switch alarm circuit which works off modulated light. Q1 and Q2 are HEP G0005 or equivalent transistors. D1 and D2 are germanium diodes such as 1N34.

potentiometer is the sensitivity control. It should be possible to use virtually any sensitive relay in this circuit having coil resistance between 1K and 10K.

### Alarm Circuit With "Reset"

Fig. 13-9 shows a very simple light switch circuit using a two pole relay with a coil resistance of 2K or 3K and a

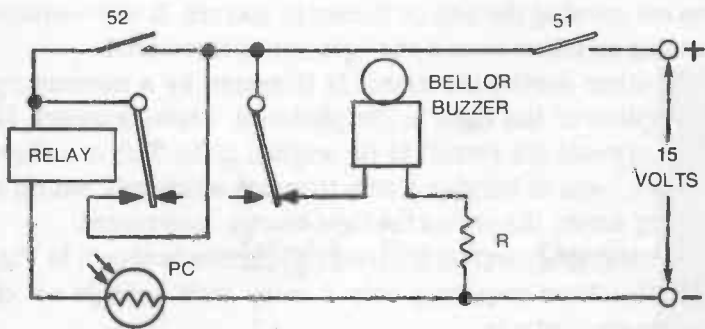


Fig. 13-9. Light switch circuit with reset. The value of resistor R is found by experiment to suit the resistance of the bell or buzzer coils. Switch S2 for reset action. PC is a cadmium sulfide photocell available from hobbyist part sources.

photocell. Provided the relay can be adjusted to pull in at a current of 3 to 4 milliamps, no difficulty should be experienced in getting this circuit to work, adjusting the value of resistor R to suit the resistance of the bell or buzzer used.

Switch S1 switches on the circuit, when the buzzer or bell will sound. With the photocell illuminated, momentary depression of the pushbutton switch S2 will cause the relay to pull in, switching off the bell or buzzer. The circuit will then remain in this state until the light beam to the photocell is interrupted. Immediately after this happens the relay will

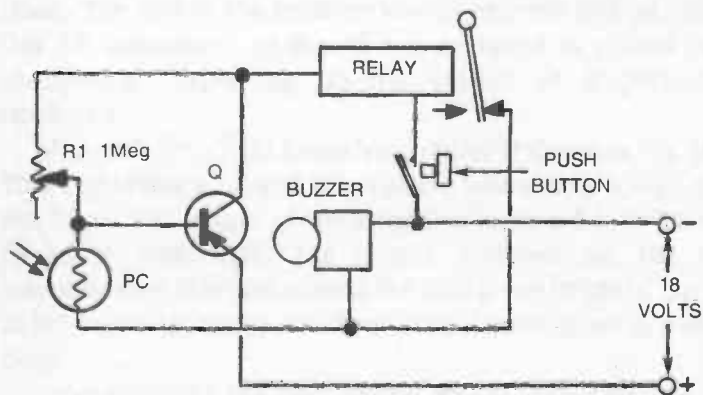


Fig. 13-10. Light switch circuit with self-holding facilities. Circuit is reset by pushbutton switch PBS. Transistor type used is HEP S0013 or equivalent.

drop out causing the bell or buzzer to operate. It will continue sounding an alarm even if the light source is restored.

In other words, the alarm is triggered by a momentary interruption of the light to the photocell. Pressing switch S2 will then reset the circuit to its original state. This is a more effective form of burglar alarm than one which only sounds a warning during the period the light beam is interrupted.

Another trigger alarm circuit with reset is shown in Fig. 13-10, this time requiring only a relay with a single set of changeover contacts.

Adjust the potentiometer R1 until the relay just drops out with the photocell illuminated. Any interruption of the light should then cause the relay to pull in and hold in (completing the alarm circuit through its contacts) even when illumination is restored. The pushbutton is a press-to-break type and is the reset switch. Operating it causes the relay to drop out and "reset" the alarm circuit.

## Light Beam Radio

Sound may be transmitted by light beams as well as radio waves. For such a method of working a transmitter is required which converts sound input through a microphone into a varying current which is then used to modulate the light output given by a bulb in the circuit. This sound-modulated light is then beamed to a receiver, the detector part of which is a photodiode or phototransistor. Output from this detector is in the form of a DC current modulated at the same frequency as the beam. The rest of the receiver circuit extracts and amplifies this AF component so that it can be heard in phones or a loudspeaker, depending on the amount of amplification employed.

A circuit for a light beam transmitter is shown in Fig. 14-1. This comprises a crystal microphone followed by a high-gain amplifier. The output of the amplifier feeds a 2.5- or 3.5-volt flashlight bulb. With the circuit switched on, the 10K potentiometer is adjusted until the bulb glows brightly, but not at full intensity, which could result in it burning out in a short time.

Speaking into the microphone should then modulate the light emitted by the bulb, i.e. cause the light to vary in intensity at the same frequency as the speech waves. It should



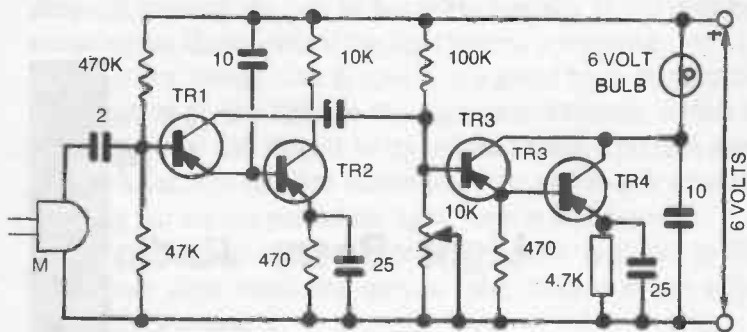


Fig. 14-1. Circuit for a light beam transmitter. Component values are as shown. TR1, TR2 and TR3 are OC72 transistors, or equivalent. M is a crystal microphone.

be possible to observe this effect if the transmitter is tried out in a darkened room. This will confirm that the transmitter is "working."

The receiver circuit can be kept very simple for a start. Using an International Rectifier S1M, or equivalent, photocell as a detector this can be coupled directly to a unijunction transistor via a 1:10 transformer, as shown in Fig. 14-2. The 1 megohm potentiometer provides the necessary bias and also

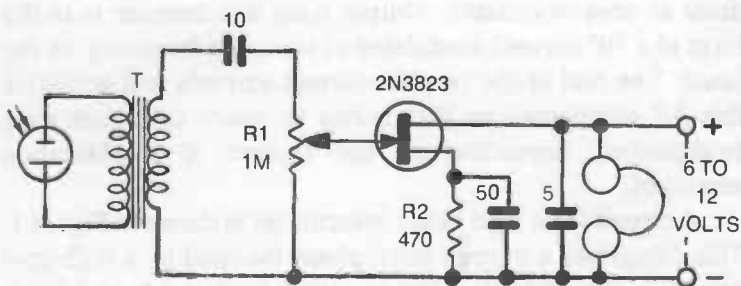


Fig. 14-2. Matching light beam receiver. T is a 1:10 transformer with primary resistance 200 ohms and secondary resistance 2000 ohms or a 10:1 transformer connected the opposite way round (Argonne AR-123).

acts as a volume control. R2 and C2 provide stabilization of the transistor, but can be omitted. The transformer is a typical transistor output transformer used the other way around, i.e. output side connected to the phototransistor and "input" side

to the transistor. High impedance headphones (rather than a single earpiece) should be used.

The weakest link in the system is the light beam path. The transmitter bulb should be mounted in a good reflector, adjusting the bulb position carefully to give a concentrated parallel beam. A flashlight reflector can be used but one taken from a car spotlight would probably be better.

The whole of the receiver should be enclosed in a light-tight box with an opening immediately opposite the photo-transistor. The photo transistor must be positioned so that the light-sensitive side is facing towards this opening. A small card or plastic tube should be fitted into the opening to assist in focusing the transmitter light beam on the receiver detector—see Fig. 14-3. Obviously, too, the transmitter must be positioned so as to direct its light beam directly on to the receiver tube.

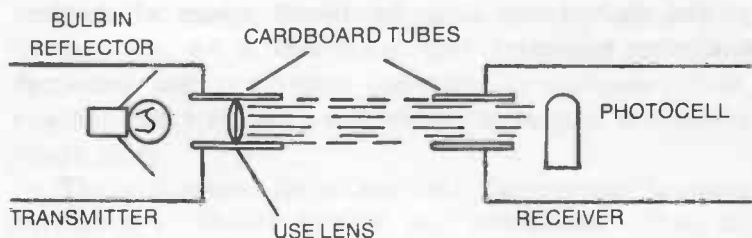


Fig. 14-3. Ideally a light-beam transmitter should direct a parallel beam of light directly into the receiver photocell. Phones are high impedance type.

The effective range over which satisfactory transmission can be achieved can prove relatively short. That is why headphones are preferred to an earpiece for listening. They blank off direct reception of sound. Nevertheless this form of speech transmission is sufficiently different and technically interesting to justify trying out, even if only on an experimental basis.

It is possible to improve the range by building a more sensitive receiver, i.e. incorporating a greater degree of light input signal amplification. It also helps particularly to amplify the higher frequencies in the modulated signal, since these are

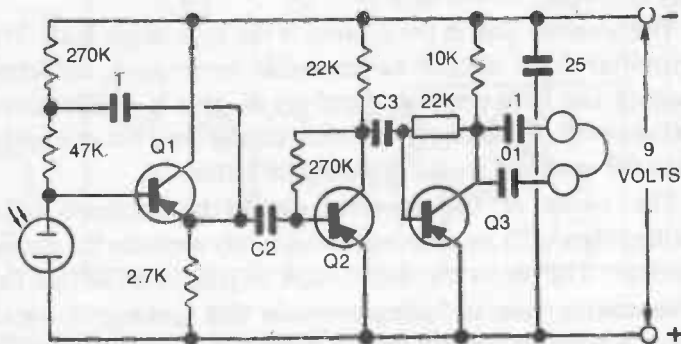


Fig. 14-4. A more sensitive—but more complicated—light beam receiver circuit Q1, Q2, Q3 and HEPG0005 transistors, or equivalent.

highly attenuated by a light-beam transmitter. A circuit of this type is shown in Fig. 14-4 where it is recommended that the optimum values of C2 and C3 be found by trial and error, using the *lowest* values which give satisfactory results.

## Temperature-Sensitive Devices

Thermistors are temperature-sensitive resistors, the actual resistance offered by the device in a circuit depending on its temperature. As a thermistor gets hotter its resistance decreases, and vice versa. Connected in a simple circuit, together with a meter, a thermistor can be used to measure temperature.

The basic circuit for an electronic thermometer is shown in Fig. 15-1. Battery voltage and millimeter range are selected to match the resistance characteristics of the thermistor available. Battery voltage must be such that, for a given minimum thermistor resistance (hot resistance), the current flowing through the circuit must not exceed the maximum rating for the meter, i.e. max. battery voltage = max. meter current  $\times$  min. thermistor resistance. Thus, for a 50 milliamp meter

$$\text{max. battery voltage} = \frac{\text{min. thermistor resistance}}{20}$$

For example, the measuring temperature range required is, say, up to 150°F and the quoted thermistor resistance at this temperature is 60 ohms:

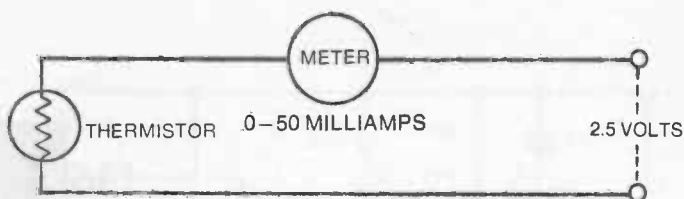


Fig. 15-1. Connecting a thermistor to work as an electronic thermometer.

$$\text{max. battery voltage} = \frac{60}{20} = 3 \text{ volts}$$

This means that if the milliammeter reads 50 the temperature indicated is 150°F. The milliamp scale can be calibrated directly in degrees temperature by comparison with a standard thermometer at different temperatures, or calculated from the full resistance/temperature characteristics of the thermistor, if known.

Such a simple circuit has distinct limitations in sensitivity and accuracy of reading. An electronic thermometer will perform better if the thermistor circuit is amplified and read by a more sensitive (i.e. lower working range) milliammeter, as shown in Fig. 15-2. The potentiometer included enables the circuit to be adjusted for maximum meter reading at minimum thermistor resistance, ensuring that the full range of the meter is used for readings. The milliammeter scale can

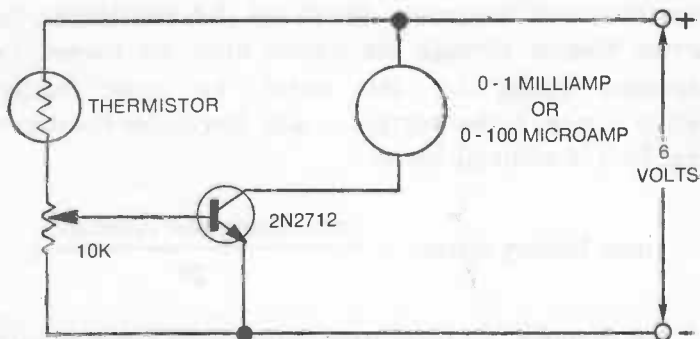


Fig. 15-2. Thermistor electronic thermometer circuit with amplification for greater sensitivity.

only be calculated in terms of equivalent temperatures by direct comparison with another thermometer at different temperatures. Note, however, that in both circuits described, zero temperature will always occur at some positive scale reading on the meter.

A particular attraction of the simple electronic thermometer is that the temperature sensing device (the thermistor) can be quite remote from the indicating device (the meter). Thus the thermistor can be outdoors for measuring outside temperatures, coupled by two thin insulated wires to the meter circuit indoors.

## 16

# Inductive Loop Radio Control

Inductive loop radio control needs a preliminary explanation for most modelers are unfamiliar with the system. It is essentially a short-range control system, the field covered by the control being limited by a large circle, square or rectangle of wire forming the "inductive loop." That more or less limits it to simple radio control applications of devices or models which only move slowly and can be controlled within a restricted space (e.g. a model car or land vehicle).

The control loop is provided by a transmitter and receiver in the usual way, the receiver being connected to a suitable actuator for controlling the model or device concerned. The only real advantage of an inductive loop system is that relatively simple circuits are required for the transmitter and receiver. There is also the fact that the system is virtually interference free within the loop although it could be affected by other electrical devices working within the loop. Similarly, the system will not interfere with other electrical appliances, etc. unless this is also located inside the loop, or close to the wire forming the loop.

### The Transmitter

Figure 16-1 shows a suitable circuit for the transmitter. This is an oscillator circuit with amplification and employs

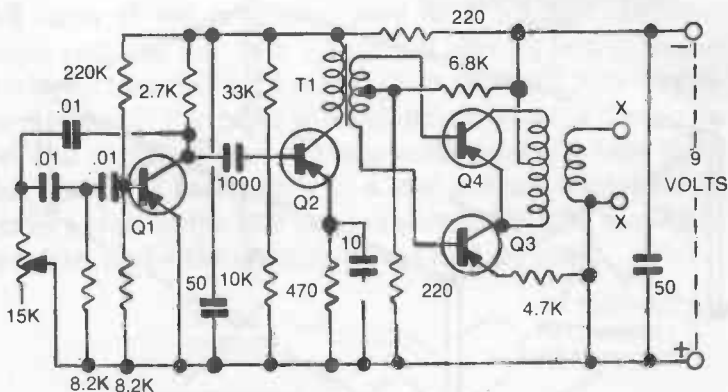


Fig. 16-1. Transmitter circuit for inductive loop radio control. T1 is a 5:1 transformer. T2 is a 10:1 transformer. Inductive loop (see Fig. 16-2) connects to output of T2 at X-X. Key signal by switch in battery lead. The transistors are HEP G0005, or equivalent.

four transistors. Amplifier stages and output are transformer coupled. A fairly large number of components are involved but this is necessary to derive enough output power. The circuit is, however, quite straightforward to construct and can be built into compact form on a perf board.

Power is supplied by a 9-volt battery. The switch in one battery lead should be a pushbutton type, or better still a microswitch. As well as acting as an on-off switch for the transmitter, this also forms the keying switch by means of which transmitter signals are sent.

### The Inductive Loop

This is two turns of any thin, insulated wire encircling the area over which control is required, e.g. taken around the walls of a room. Outdoors it could be strung between poles about 3 feet high—Fig. 16-2. Maximum size to suit the transmitter would be “legs” about 15 feet long (or a circle of about 15 feet diameter). Inside a room, simply use the full dimensions of the room.

### The Receiver

The receiver circuit is shown in Fig. 16-3. It uses rather more components than the transmitter, but again is quite



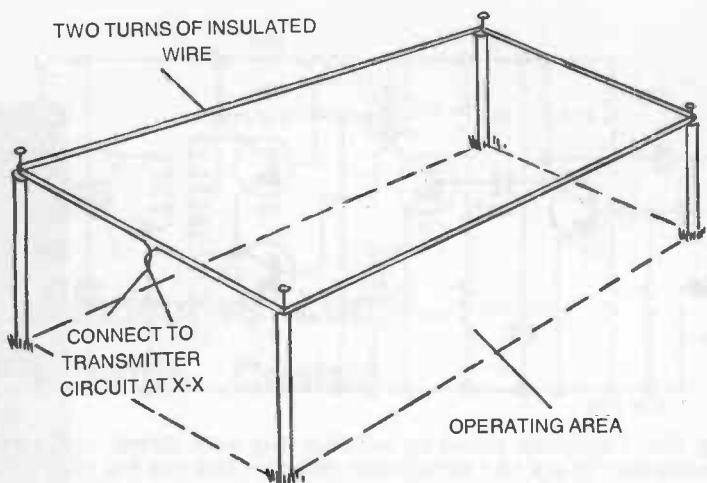


Fig. 16-2. The inductive loop is a winding of thin enamelled wire taken around posts. Area enclosed by loop receives the transmitter signal.

straightforward to construct and can be built in a compact size using subminiature resistors and capacitors. All are standard radio components except for the pick-up coil and relay.

The pick-up coil replaces the antenna and tuned circuit on a conventional radio receiver. It consists of a single winding of

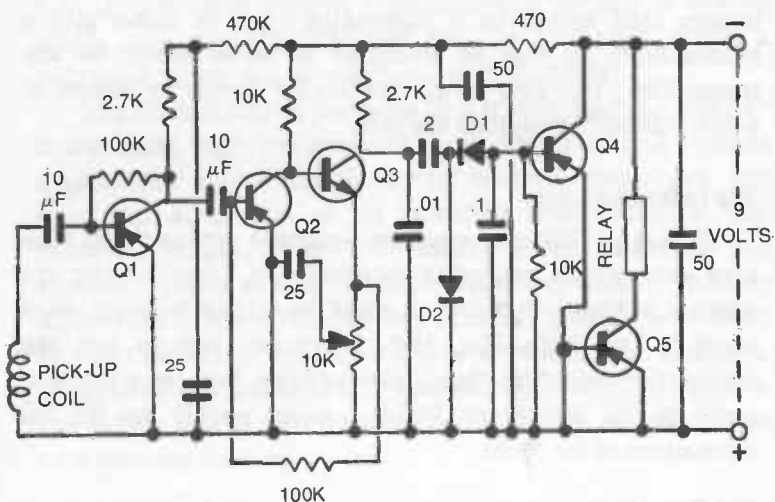


Fig. 16-3. 'Inductive loop' radio control receiver. Transistors are HEP G0005 type, or equivalent. D1 and D2 are germanium diodes. Relay coil resistance approximately 5000 ohms. For details of pick-up coil, see Fig. 16-4.

3000 turns of #40 enamelled wire on a 3/8 inch diameter ferrite rod—see Fig. 16-4. Fit the rod with 3/4 inch diameter cheeks cut from stiff card spaced 1 inch apart and wind the coil layer-on-layer. For rapid winding, bind one end of the ferrite rod with insulating tape and grip in the jaws of a hand drill. Mount the drill horizontally in a vice and use a mechanical winder to reel on the 3000 turns required. When the winding is complete, bind with insulating tape to hold in place.

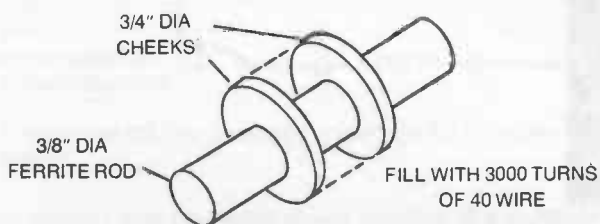


Fig. 16-4. Pick-up coil for 'inductive loop' receiver.

The relay should have a coil resistance of approximately 2000 ohms. Any sensitive or high-speed relay should do, but preferably use one specially made for radio control receivers. These may be hard to find since most modern radio control receivers are now relayless and there is less demand for relays, but a shop specializing in radio control equipment for models should be able to provide one.

Some adjustment of the relay may be necessary to get it to pull-in and drop-out under the influence of the transmitter being keyed on and off, respectively. As an initial check, connect a 500 milliamp meter in one of the receiver leads and observe the current change when the transmitter is keyed on and off. Adjust the potentiometer for maximum current change. If the relay does not respond to this current change, then adjust it until it does.

The relay works as an on-off switch to control the actuator. This can be a electromagnetic type (e.g. an escapement) or motorized type (e.g. an electric motor or single channel motorized actuator).

## 17

# More Instruments

Testing or measuring sometimes calls for measuring very low currents of the order of microamps. Microammeters are relatively expensive instruments and far less rugged than readily obtainable milliammeters. However, it is easy to convert a milliammeter into a microammeter by fitting a DC amplifier circuit to the meter. The only practical disadvantage of such circuits is that they have a high input resistance, resulting in an appreciable voltage drop. They cannot, therefore, be used for microamp measurements in circuits where voltage drop can appreciably affect the accuracy of reading required.

Figure 17-1 shows a microammeter circuit based around a 0-1 milliamp meter and a general purpose PNP transistor HEP G0005 or equivalent. Potentiometer R4 is the zero set adjustment, used to set the meter reading to zero with no DC input to the circuit. R3 is the calibration control used to adjust the meter to full scale when a known maximum value of microamp current is fed to the input, e.g. with 10 microamps fed in, R3 is adjusted to give full scale reading on the meter, which now corresponds to 10 microamps. The milliammeter used should have a *linear* scale since this curve has a linear response.

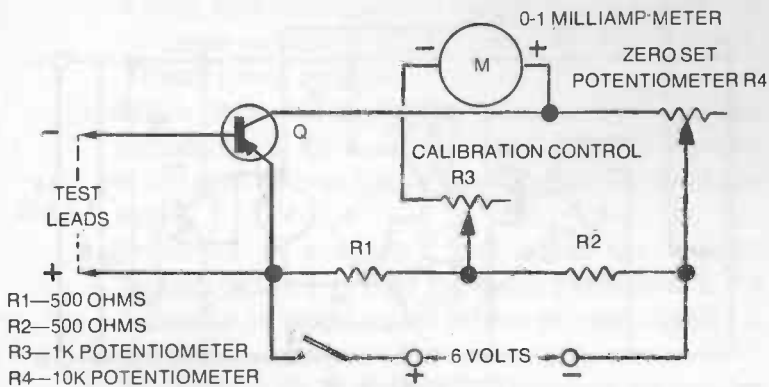


Fig. 17-1. Sensitive DC microammeter adjustable for full scale reading of 10 microamps.

The circuit can be made much simpler if a suitable NPN transistor is used ( 2N2712 or equivalent) since the collector current with zero signal is negligible and the meter will virtually read zero. Thus only one potentiometer is required, which is used for calibration. This simplified circuit is shown in Fig. 17-2.

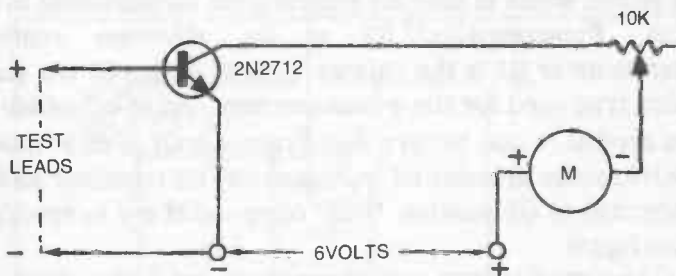


Fig. 17-2. Simple microammeter circuit using a NPN transistor type 2N2712, or equivalent. Meter again has a 0-1 milliamp movement.

### Transistor Tester

This is a more elaborate transistor tester (Fig. 17-3) enabling the two leakage currents  $I_{\infty}$  and  $I^1_{\infty}$ , and  $\alpha$  or common emitter amplification factor to be measured by switching the current to appropriate positions. It is designed specifically to use with low or moderate power PNP transistors only.



is zero, then the transistor is faulty (open circuit). If the meter reading is a maximum, then the transistor is faulty (short circuit).

5. Switch S1 to position 3. The meter reading will now indicate  $I_{co}$  of Q2 in microamps. Again if the meter reads zero or maximum, the transistor is faulty, as above.
6. Switch S1 to position 4 and adjust the balance (potentiometer R1) until the meter reads zero. If the transistor is faulty (short circuit or open circuit) it will not be possible to adjust the meter to zero.
7. Press switch S2. The meter will now read the emitter base amplification factor ( $\alpha$ ) of Q2, full scale reading representing 100. If the meter reading is past full scale, then the  $\alpha$  is greater than 100.

### Signal Generator

This signal generator circuit (Fig. 17-4) oscillates at 80-1000 Hz and is designed for AF signal injection for tracing

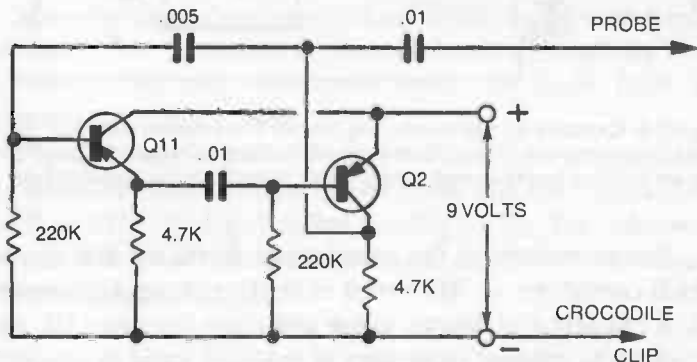


Fig. 17-4. Simple signal generator circuit with a frequency of about 1 kHz using HEPG0000, transistors for Q1 and Q2.

faults in the audio end of receivers. It can also be used for signal injection at the RF end since the oscillations generated also contain strong AF and IF harmonics.

The construction should be kept as compact as possible, with short connections, as this will improve the stability of the oscillator. The ground line is extended by a wire terminating in

an alligator clip to connect the receiver ground. The output line is terminated in a short wire probe for tapping on to various parts in the receiver circuit.

### Capacity Tester

A Hartley oscillator can be used as a capacity meter for measuring the values of unknown capacitors. The complete circuit is shown in Fig. 17-5. The transformer used is a typical miniature transistor output transformer with a tapped primary. Capacitor C1 can be of fixed value (e.g.  $0.1 \mu\text{F}$ ) since the frequency of the oscillator is not important as long as it is in the audio range. C2 is then made the same value.

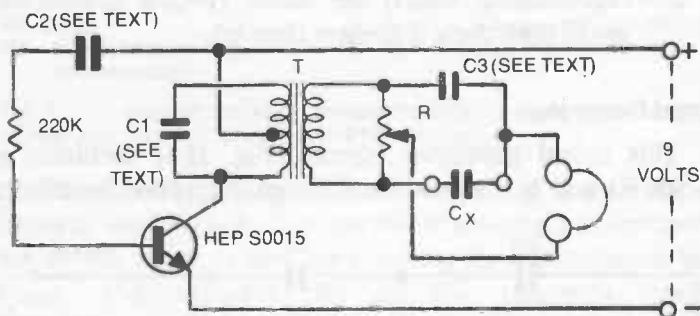


Fig. 17-5. Capacity bridge measuring circuit. T is a typical transistor radio output transformer. R is a 5K linear potentiometer. Cx is capacitor of unknown value to be measured. Phones should be of high impedance type.

The secondary of the transformer forms the test circuit which comprises an RC circuit consisting of a potentiometer R1, a capacitor of known value and close tolerance C3, and provision to connect capacitors of unknown value to complete a simple circuit. High impedance phones (or a high impedance earpiece) are connected across the center of the bridge.

To check the circuit, connect a capacitor of the *same* value as C3 in position Cx set the potentiometer to its mid position. No tone should be heard in the phones. Now adjust the potentiometer first one way and then the other. Movement away from mid-position should cause a tone to be heard, the strength of the tone rising with increasing adjustment from

mid-position, either way. Check that the tone disappears at mid-position of the potentiometer and mark this position.

The setting of the potentiometer can now be calibrated to read capacitor ratios directly. Start by connecting a  $1 \mu\text{F}$  capacitor in  $C_x$  position and find the adjustment point on the potentiometer where the bridge is balanced (i.e. the tone disappears). Mark this  $\times 10$ . Now replace  $C_x$  with a  $0.01 \mu\text{F}$  capacitor and find the balance point by turning the potentiometer the other way. Mark this  $\div 10$ .

Provided the potentiometer is a *linear* type, then the scale between  $\div 10$  and 0 and 0 and  $\times 10$  can each be divided into ten equal divisions, enabling capacitor readings to be read off directly between  $0.01 \mu\text{F}$  and  $1 \mu\text{F}$ .

*Note.* For accurate calibration close tolerance capacitors must be used. However, actual capacitance values are seldom critical, and so although realized capacity values of unknown capacitors may be as much as 100 percent out, this will have little significance in practice.

## Ohmmeter

Most electronics enthusiasts have a multimeter, which has facilities for resistance measurements. Lacking a multimeter, an ohmmeter can easily be made from a voltmeter, or milliammeter.

Fig. 17-6 shows the circuit required to turn a voltmeter into an ohmmeter. Measurement is first made with the terminals A and B shorted, giving a meter reading of  $V_1$ . The unknown resistance is then connected across A and B and the lower meter reading noted ( $V_2$ ).

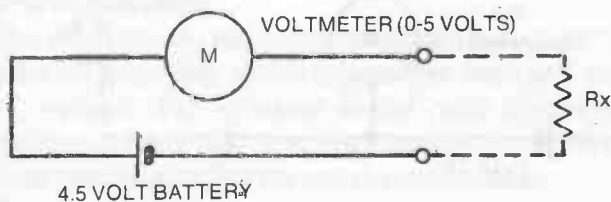


Fig. 17-6. Using a voltmeter as an ohmmeter. Scale can be calibrated to read ohms (see text). For a 0-10 volt meter, use a 9-volt battery.



The value of the unknown resistance can then be calculated as:

$$R_x = \frac{V_2 \times R_m}{V_1} - R_m$$

where  $R_m$  = resistance of meter (ohms)

By using a series of known resistors, it is possible to calibrate the meter scale to read ohms directly, i.e. starting from 0 (A and B shorted), and noting meter positions when, say 1K, 2K, 3K, etc., resistors are connected across AB.

Because of the high resistance of a voltmeter, this circuit will not measure low resistance accurately (e.g. resistances between 200-300 ohms).

Fig. 17-7 shows the circuit required to turn a milliammeter into an ohmmeter. The potentiometer R1 is adjusted to give full scale deflection on the meter with terminals A and B open. The unknown resistance is then connected across A and B and the meter reading noted. The value of this resistance can then be calculated as follows:

$$R_x = \frac{I \times R_m}{I_0 - I}$$

where  $I$  = current reading with  $R_x$  connected

$I_0$  = current with AB open (full scale)

$R_m$  = resistance of milliammeter.

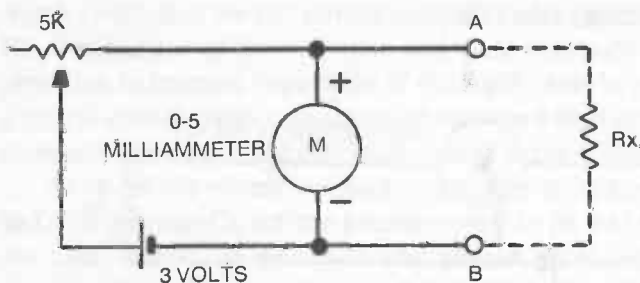


Fig. 17-7. Circuit for using a 0-5 milliammeter as an ohmmeter. Values of unknown resistance  $R_x$  are calculated (see text), or the meter scale recalibrated to indicate ohms direct.

Again using a series of known resistances in turn for  $R_F$  the meter can be calibrated to read ohms directly (with full scale deflection = 0 ohms). This circuit is suitable for measuring low resistance values.

### Field Strength Meter

This field strength meter (Fig. 17-8) is basically an elementary receiver which will detect any transmission present to which the tuned circuit C and L is tuned, indicating the strength of the signal on the milliammeter. In the presence of relatively strong signals, no external aerial should be necessary. However, for weaker signal detection, an external

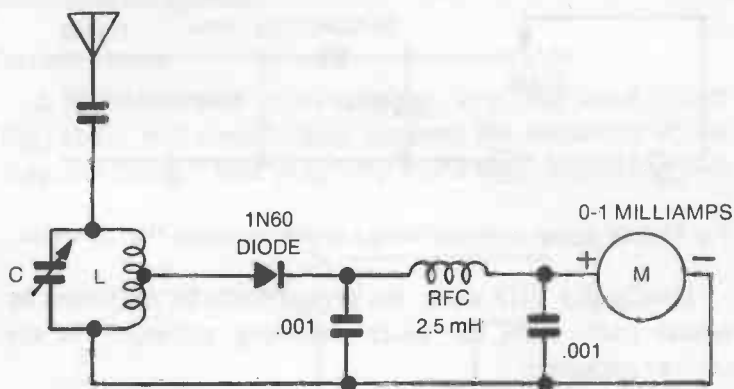


Fig. 17-8. Simple field strength meter using proprietary aerial coil L and matching tuning capacitor C.

aerial will be necessary. For a portable field strength meter, housed in a small box, this aerial can be of the telescopic type, preferably a submultiple of the resonant length of the transmitter frequency.

The only variable circuit components are L and C1 which are selected according to the transmitter band or frequency range required. For checking model radio control or CB transmitters, where the frequency covered is 27 MHz, the following specification for the coil (L) can be used:

Ten turns of 28 gauge enamelled wire wound on a miniature (1/4 inch) diameter coil former. Matching value of

C1 is 20 pF. Final adjustment should be made against a transmitter known to be radiating, adjusting C1 until maximum signal strength is indicated on the meter. The field strength meter will then be broadly tuned to the 27 MHz band.

### RF Signal Generator

This very simple circuit (Fig. 17-9), using a silicon diode, is a useful RF signal generator for adjusting the front end of a superhet receiver circuit, particularly for FM work. R1 is a potentiometer enabling the DC current flowing through the diode to be adjusted, thus varying the amount of RF noise fed to the receiver via the probe.

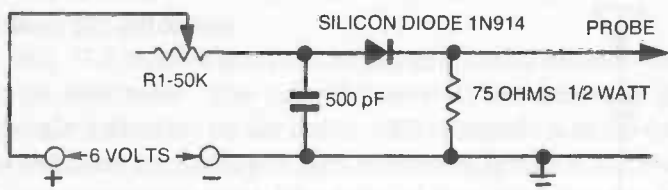


Fig. 17-9. RF signal generator using a silicon diode type 1N21, or similar.

Ideally, for VHF work, the probe should be connected by coaxial cable with the outer sheathing connected to the receiver ground.

Note that only a silicon diode can be used in this circuit.

### Inexpensive Baby Alarm

This very simple circuit (Fig. 17-10) is capable of giving excellent loudspeaker volume from a single transistor amplifier and sound input via a carbon microphone (not a crystal type). The microphone should be placed as near as possible to the noise source. It is then connected by two wires to the alarm circuit which can be built on a small panel. Speaker, panel and the battery can be fitted into a suitable enclosure or cabinet, together with a two-pole on-off switch.

Exactly the same circuit design can be used to make a loudspeaker or electronic megaphone. In this case a large cone should be fitted to the speaker to give directional characteristics to the sound output.

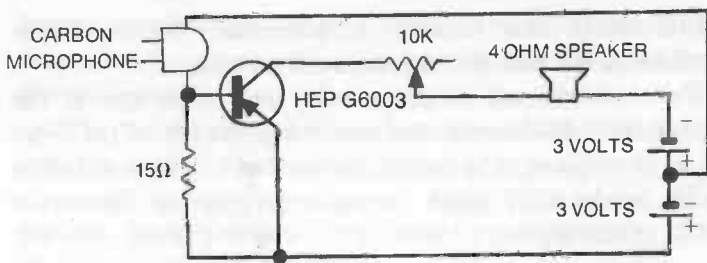


Fig. 17-10. A very simple baby alarm circuit. The potentiometer acts as a volume control.

Another possible application of this circuit is for an indoor public address system!

### Current Savers

A transistor used as an amplifier in a relay input circuit (Fig. 17-11) will considerably improve the sensitivity of the relay, i.e. make it pull in at very much lower signal currents

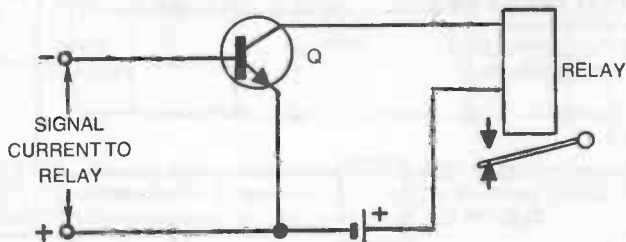


Fig. 17-11. Simple amplifying circuit which enables a relay to be operated by very much lower signal currents than usual.

than in a straightforward circuit. Additional DC input is, of course, required to power the amplifier circuit. Current drain in this circuit can, however, be kept quite low.

The basic circuit shown is for a general purpose PNP transistor. The relay coil resistance represents the collector load, and the transistor type should be chosen accordingly. The current required to operate the relay is predetermined by the relay design and relay adjustment. The signal current required to operate the relay, however, is lower by

approximately the current amplification factor of the transistor in the common emitter configuration.

For conventional sensitive relay coil resistance of the order of 1000–2000 ohms, and operating currents of the order of 1 to 2 milliamps, general purpose switching transistors should work with input signal currents of the order of 10-20 microamps.

### Rain Alarm

This simple circuit (Fig. 17-12) detects moisture collecting on the sensor plate, triggering the transistor into condition and pulling in the relay. This closes the circuit to operate the alarm bell.

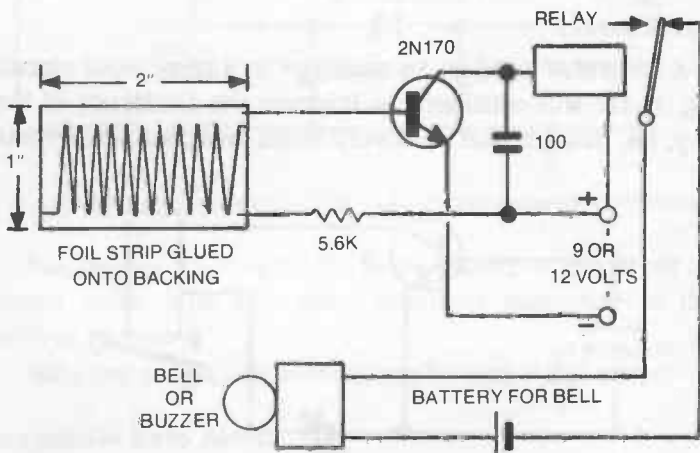


Fig. 17-12. Complete rain alarm with sensor plate and relay switching circuit operating a bell or buzzer. For the transistor type shown relay coil resistance should be 1000 ohms.

The sensor plate is made by sticking a piece of aluminum or copper foil on to a piece of perf board. Zigzag cuts are then made through the foil, using a stout modeling knife so that the two halves of the foil are physically separated by a narrow gap. The closer the gap, the more sensitive the plate will be to moisture collecting on it. Alternatively, the sensor plate can be etched from printed sheet stock.

The sensor is mounted outdoors, inclined at an angle of about 45 degrees. It is connected to the alarm circuit via two

thin insulated wires. No adjustment is required other than to check that the alarm operates when the two halves of the foil are shorted out.

The transistor and alarm circuits can be powered by a single 9- or 12-volt battery. If the bell or buzzer proves to draw too much current, causing the relay to drop out, then a separate battery circuit can be used for the bell (taken through the relay contacts). Alternatively, a latching-type relay circuit can be used.

### Stabilized DC Supply

This circuit (Fig. 17-13) provides a very stable DC output from a mains transformer output. Two outputs are provided:

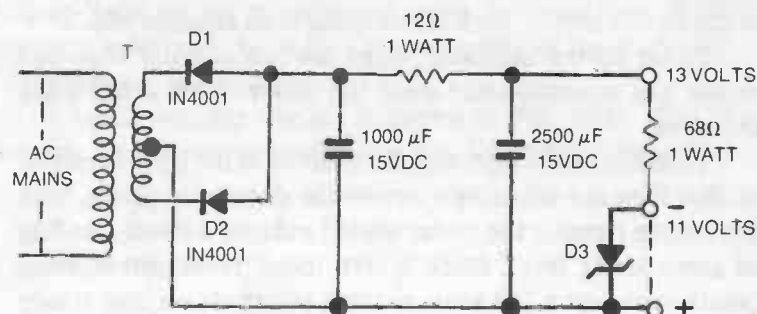


Fig. 17-13. This circuit provides two stabilized DC outputs from AC supply. T is a transformer with step-down ratio to give 12.6 volt output. Both resistors must have a rating of 1 watt or higher.

one of nominal 13 volts with a maximum current drain of 150 milliamps, and one giving a *stabilized* 11 volt 50 milliamp output. Stability of the latter is maintained within plus or minus 5 percent by the zener diode.

Note that this is a positive ground supply. Physical ground connection should be made between the positive line and the ground in the mains plug.

### Distributor Dwell Indicator

This simple indicator (Fig. 17-14) can be used to measure the dwell or closure time of the points in a car distributor. The actual circuit comprises one diode, a resistor, a potentiometer,

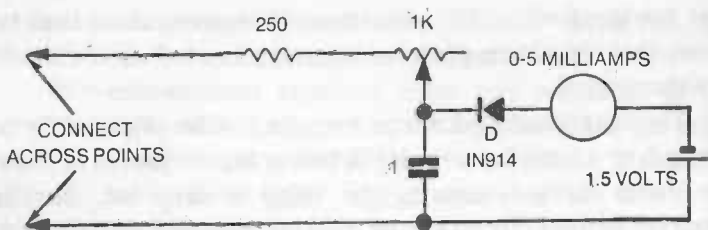


Fig. 17-14. Dwell indicator circuit using a diode for current 'blocking', so that the meter simply reads 'on' or 'off', corresponding to closure or opening of points, respectively.

and one capacitor mounted on a suitable panel together with a milliammeter and 1.5-volt battery. Panel shape and size should be proportioned so that the complete instrument can easily be held in the hand. Leads are taken from the two points of the circuit shown, each terminating in an alligator clip.

To set up the indicator, short the two alligator clips and adjust the potentiometer until the meter reads a full scale deflection.

To use the indicator, clip the leads on to the ignition circuit so that they are effectively across the distributor points. With the engine running the meter should indicate a steady reading at some lower level. Since a zero meter reading represents points open and a full scale reading points closed, this steady position is a direct measure of the proportion of open to closed times, e.g. a steady reading of 1 (when the full scale reading is 5) would indicate 1/5th closed time or a dwell of  $360/5 = 72$  degrees. The meter can, in fact, be calibrated in degrees dwell time for direct reading.

It can be noted that the circuit is not fed by the distributor, i.e. the meter is only influenced by its own battery. The diode blocks any voltage from the distributor circuit reaching the meter. The capacitor shorts to each peak voltage that occurs whenever the points open, and thus protects the diode and meter from such voltage peaks.

### Inverters

Inverters are circuits which can step up (or step down) DC voltages, in the same way that a transformer can step up (or down) AC voltages. A transformer is still used in an inverter,

but the primary circuit must also incorporate some means of transforming the DC input into AC for the transformer coupling to work. In the secondary circuit, rectification must be introduced to turn the AC induced in the secondary coil into DC again at the output. This DC to DC step-up is considerably more complicated than AC step-up (or step-down). If an inverter is to step-up a DC voltage to an AC voltage then, of course, rectification is not needed in the secondary circuit and the output can be tapped directly from the secondary. However, there may be a need for smoothing the output via capacitors.

The usual demand is to step-up a DC input voltage, rather than step it down. The principle of working the inverter is the same in both cases. It is simply a matter of using step-down or step-up ratio on the transformer, with the resistance of the primary matching the output requirements of the transistor AC generator, or oscillator.

A basic inverter circuit is shown in Fig. 17-15. This is suitable for low voltage operation, e.g. DC input voltage of up

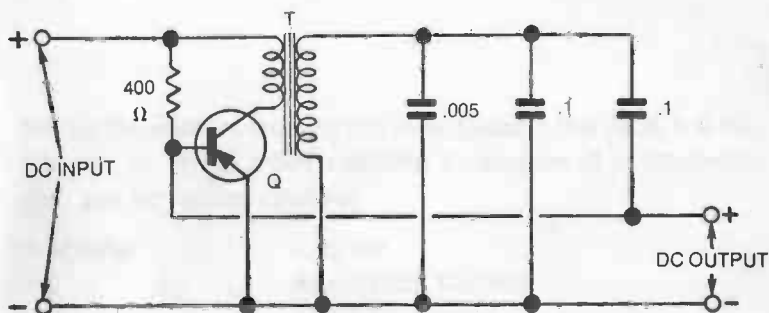


Fig. 17-15. Basic inverter circuit for low voltage operation. Transformer ratio chosen for step-up required (see text).

to 3 using an HEP G0005 or equivalent transistor. Voltage step-up ratio is approximately one-half of the transformer ratio, e.g. a 1:20 transformer ratio should give a DC output voltage of 15 volts from a 1.5 volt input. Efficiency, defined as *power out* (volts  $\times$  current drain) divided by *power in* should be of the order of 75 percent.



An experimenter's circuit for higher working power is shown in Fig. 17-16, using a power transistor in the oscillator

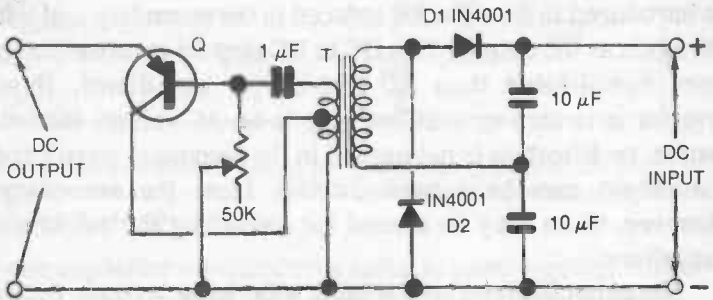


Fig. 17-16. Inverter circuit for higher power working. Q is an NPN type power transistor. Diodes D1 and D2 are silicon type. Transformer ratio selected according to the voltage step-up required.

circuit. The oscillator is a Hartley type using a miniature transformer with a center tapped primary. The potentiometer forms a potential divider in the primary circuit which permits the output voltage to be adjusted over a fairly wide range.

## Common Abbreviations

Not all these abbreviations are to be found in this book, but this list can be useful when studying catalogues of components, etc., and for further reading.

A or amp	Ampere
AC	Alternating Current
AF	Audio Frequency
AFC	Automatic Frequency Control
AGC	Automatic Gain Control
AM	Amplitude Modulation
AVC	Automatic Volume Control
BA	British Association Screw Thread
BC	Bayonet Cap
BFO	Beat Frequency Oscillator
C	Capacitor
CW	Carrier Wave

D	Diode
DC	Direct Current
DCC	Double Cotton Covered
DPDT	Double Pole Double Throw
DPST	Double Pole Single Throw
DSC	Double Silk Covered
EMF	Electromotive Force (Voltage)
F	Farad
FET	Field Effect Transistor
FM	Frequency Modulation
FSD	Full Scale Deflection
H	Henry
Hertz or Hz	Cycles per Second
HZ	High Impedance
HF	High Frequency
HT	High Tension
I	Current
IC	Integrated Circuit
IF	Intermediate Frequency
IFT	Intermediate Frequency Transformer
k or kilo	1000
kHz	Kilohertz
kV	Kilovolts (100 volts)
L	Inductance
LF	Low Frequency
LZ	Low Impedance
M	Mega ( $\times$ 1 million)
m	Milli ( $\div$ 1000)
$\mu$	Micro ( $\div$ 1,000,000)
$\mu$ A	Microamp
mA	Milliamp
$\mu$ F	Microfarad
$\mu$ H	Microhenry
mH	Millihenry
MCW	Modulated Carrier Wave
MHz	Megacycles (millions of cycles) per Second
mV	Millivolt
N	Nano ( $\div$ 1,000,000,000)

$\Omega$	Ohms
P	Primary
PU	Pick Up
pF	Picofarad
Q	Q Factor (of coil)
R	Resistor
RC	Resistance- Capacitance
RF	Radio Frequency
RFC	Radio Frequency Choke
RMS	Root Mean Square
SBC	Small Bayonet Cap
SCC	Single Cotton Covered
SCR	Silicon Controlled Rectifier
SPDT	Single Pole Double Throw
SPST	Single Pole Single Throw
SSC	Single Silk Covered
S.W.G. or s.w.g.	Standard Wire Gauge
T	Transformer
TO	Transistor Outline
TR	Transistor
TRF	Tuned Radio Frequency
UHF	Ultra High Frequency (above 200 kHz)
V	Volt
VFO	Variable Frequency Oscillator
VHF	Very High Frequency (up to 200 kHz)
W	Watt
WT	Wireless Telegraphy, or Morse
X	Reactance
Z	Impedance
ZD	Zener Diode

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