CALECTRO

25¢

FET
CIRCUIT BOOK

A BRIEF EXPLANATION OF THE WORKINGS OF THE FIELD EFFECT TRANSISTOR AND A VARIETY OF INTERESTING CIRCUITS TO CONSTRUCT.

FR-172

FORWARD

The Calectro FET Book is intended to provide the Hobbyist and Experimenter with a basic understanding of how a FET works and a number of interesting circuits. Circuits of general interest have been selected wherever it could be determined that a "FET" is superior to the now familiar (Bi-Polar) Transistor.

All circuits have been built and thoroughly tested, but we cannot assume responsibility for their function or consequences of application. If normal care in construction is followed, you should find many hours of enjoyment in building your own circuits and employing them in your own creative applications.

Note to the beginning hobbyist; you can build the circuits in this booklet. If you have never "built" a circuit before, it may be easier to begin with a project that is presented in greater detail. The Calectro Handbook contains many very detailed projects, an electronic symbols chart and other information helpful in learning to read schematics easily. Take your time, and enjoy yourself.

INTRODUCTION TO THE FIELD-EFFECT TRANSISTOR

In recent years the superiority of the Field-Effect Transistor (FET) has been more fully appreciated in many applications that may promote, within the next decade, the gradual demise of the popular bipolar transistor in all but a few applications.

Historically, the physics of the FET was understood in rather elementary form as early as the 1930's; however, because of the spectacular work of Brattain, Bardeen and Shockley at the Bell Telephone Laboratories in New Jersey in 1947 where the bipolar transistor was invented and developed, all attention was diverted from the fledgling FET and focused on this promising new discovery. As a consequence the potentials of the FET laid dormant until around 1966.

Fundamental to the FET is that all current flow is carried only by the free majority carriers in the semiconductor channel. This differs from the bipolar transistor, whose name suggests that both positive and negative free carriers take part in its operation. In the FET the total number of carriers available to carry current is controlled by the application of an electric field to the channel surface.

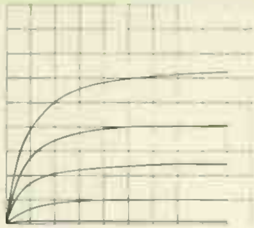
The major contributions afforded by a majority carrier semiconductor (FET) are:

1. High "input" or control impedance;
2. Excellent high frequency characteristics;
3. Lower noise figure is theoretically possible;
4. Square-law transfer characteristics;
5. Low harmonic distortion;
6. Symmetrical operation (source & drain may be reversed);
7. No carrier storage in switching applications;
8. No offset voltage;
9. No thermal run-away or secondary breakdown problems;
10. Tolerant to high nuclear radiation dosages;
11. Easily integrated into LSI.

The remarkable field-effect transistor is more like a vacuum tube in its characteristics than any other semiconductor. Consequently, the FET is not like the conventional transistor familiar to many hobbyists and experimenters. The experimenter familiar with vacuum tubes will quickly adapt himself to using FETs.

However, although the FET is a three-terminal device (as is the triode vacuum tube), the electrical characteristics are more like the pentode than a triode as shown in Figure 1.

Fig. 1



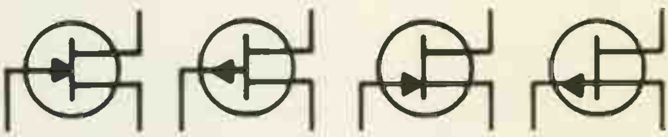
500 uA. per VERT.

1 V. per HOR.

500 mV. per STEP

The symbology used to identify the junction-FET takes four conventional forms.

Junction FET (JFET)



symmetrical geometry		asymetrical geometry	
N-Channel	P-Channel	N-Channel	P-Channel

Although most experimenters will have little need to know whether a JFET is symmetrical or not it is helpful to understand the technical terminology. In most cases, and quite probably in every situation faced by the experimenter, the internal fabrication of the FET will allow the interchange of source and drain. Of course the gate must always be biased with reference to that terminal used as source. The terminology "source" "drain" and "gate" will be defined shortly.

For the most part FETs are constructed using what is commonly called an Interdigitated Structure; that is, the source and drain are much like a pair of combs intermeshed with the gate separating the fingers in a serpentine fashion as depicted in Figure 2.

Now the symmetrical geometry only means that there are as many source fingers as there are drain fingers. The asymetrical geometry indicates that there is at least one less drain finger than source fingers, which may be done to reduce the output capacitance for high-frequency FETs.

A simplified cross-section of a FET allows for a rudimentary explanation of its operation, shown in Figure 3.

Fig. 2

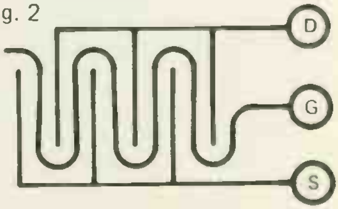
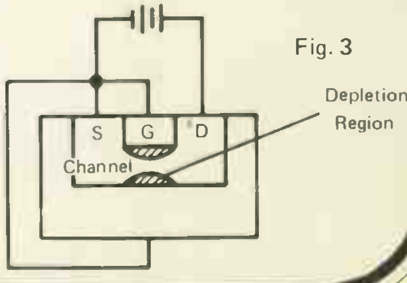


Fig. 3



FIELD-EFFECT TRANSISTOR CONT.

If the gate is connected to the source and the full applied voltage, V_{DS} appears between the drain and source, then current will flow. Now the amount of current that will flow depends upon the saturation of the channel—that path between drain and source. It is analogous to a garden hose where the faucet provides the pressure (source of voltage) and the size of the garden hose determines the maximum flow of water (saturation current). The FET gate is, in this analogy, equivalent to a constriction placed around the garden hose midway between the source of water (faucet) and the hose nozzel. As the hose in constricted the water flow diminishes appropriately. Likewise the FET: the gate bias causes a depletion to exist in the channel forcing a reduction in the current flow between source to drain. This constriction can actually cut off the current flow completely.

Now to put some technical terms into the picture: the channel is divided—one end labeled Source, the other Drain. The constriction is the Gate. Here we can further explain another analogy. The gate is equivalent to the vacuum tube control grid, the source is equivalent to the cathode and the drain equivalent to the plate. As the grid cuts off plate current by negative bias (with respect to the cathode) so also the gate cuts off drain current by negative bias with respect to the source. This definition and comparison with a vacuum tube is for N-channel FETs; the P-channel FET is quite another story, working essentially the same way if all polarities are reversed. Sort of the opposite of a vacuum tube!

Now the maximum current that can possibly flow without permanent damage to the FET is called the Saturation Current, I_{DSS}. The gate voltage required to fully stop this current flow is the Pinch-Off Voltage, V_P. When drain current is allowed to flow the current is Drain Current, I_D.

Field-effect transistors are classified much like vacuum tubes except they are not so forgiving to overvoltages and excessive current flow where the dissipation might be exceeded. Amplifier type FETs have a suggested drain voltage specification, generally somewhere between 10 to 20 volts, a bias level for cutoff, V_P, and a range of maximum drain current available at zero bias, I_{DSS}.

Additionally, the forward transconductance is specified and, unlike the vacuum tube data sheet, a figure for output conductance is provided rather than plate resistance. Of course, output conductance is simply $1/R_P$.

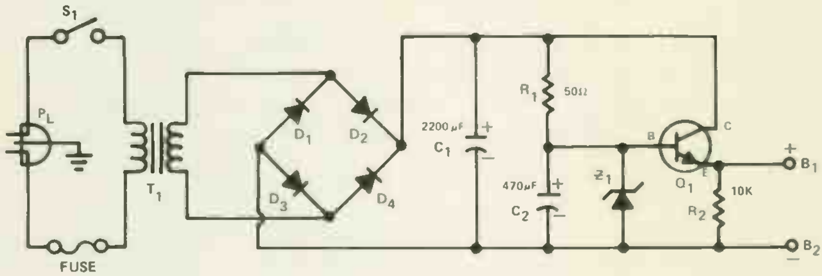
The other familiar parameters, such as capacitance, should be well known to most experimenters and hobbyists.

Certainly unlike high frequency vacuum tube data sheets, all semiconductors whether bipolar or FET, generally provide complete high-frequency parameters either in the form of Admittance parameters or as S-parameters. As a consequence it is possible for the serious designer to obtain near-exact designs of optimum performance with a minimum of trial and error experimentation.

REGULATED POWER SUPPLY
(BATTERY ELIMINATOR)

Batteries can be an expensive proposition if a circuit is to be used regularly. It is often more practical to simply plug-in to the (usually) convenient 110-120 volt wall outlet.

Here is an easy to build power supply that can be built for 6, 9 or 12 volt usage up to 1 ampere (plenty for the projects in this book). Calectro part no. K4-560 is a package of three zener diodes, one for each voltage. Select the voltage you want and use the equivalent zener diode to regulate the voltage. You can build this circuit as an integral part of a project; or separately for general use. Speaking of general usage, why not all three "zeners" and a rotary switch (such as No. E2-165) to select any one of the three voltages?



BILL OF MATERIALS

SYMBOL	QTY.	DESCRIPTION	CALECTRO PART NO.
R1	2	100 OHM Paralleled Resistors	B1-465
R2	1	10K OHM Resistor—½ Watt	B1-396
C1	1	2200MF 25V Capacitor	A1-134
C2	1	470MF 25 V Capacitor	A1-132
D1,D2,D3,D4	4	Diode	K4-555 or K4-557
PL	1	A.C. Line Cord	L3-717
T1	1	Transformer 110 VAC to 12.6VAC	D1-747
S1	1	SPDT Switch	E2-116
B1,B2	2	Binding Posts	F2-926 or F2-930
Q1	1	NPN Power Transistor*	K4-525
Z1	1	Zener Diode**	K4-560
Fuse	1	Fuse 3AG 1 AMP	D2-127
	1	Fuse Holder	E2-497 or E2-495

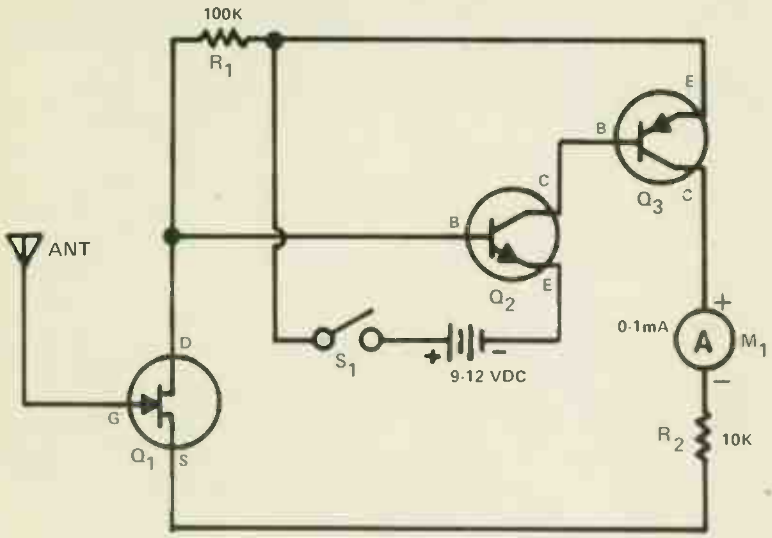
* Heat Sink necessary, metal case or K4-680. Also recommended is the K4-650 Heat sink insulator kit.

** See Text

ELECTROMETER

This circuit is an accidental discovery and we wish we had more time to play with it. Run a comb through dry hair and it will detect the static electricity at several feet. Blow cigarette smoke in the direction of the antenna and it will deflect the needle. It is extremely sensitive to static fields. The antenna can be an 18 to 24 inch length of wire.

What else can it do? We don't really know, but it can be a lot of fun and would be an excellent Science Fair Project (with a bit of imagination). How will it behave with an out door antenna, during thunder storms, before earthquakes, etc? We don't know yet. But it does do some pretty strange things, some of which we can account for, some not.



BILL OF MATERIALS

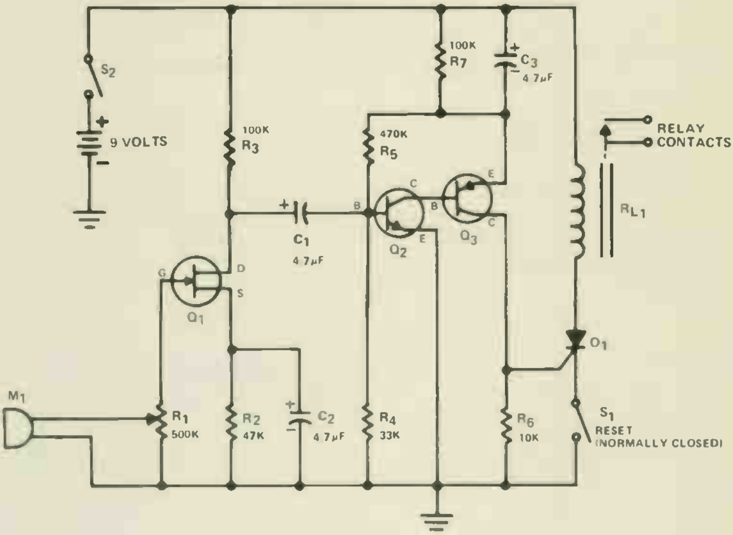
SYMBOL	QTY.	DESCRIPTION	CALECTRO PART NO.
R1	1	100K OHM-½ Watt	B1-408
R2	1	10K OHM-½ Watt	B1-396
Q1	1	FET	K4-632
Q2	1	Transistor NPN	K4-506
Q3	1	Transistor PNP	K4-505
S1	1	Switch SPST	E2-104
M1	1	1ma Meter	D1-912

FET SOUND SWITCH

Perhaps one of the most useful and novel circuits, The Sound Switch, can be put to numberous uses. Sensitivity can be set to turn on a lamp with a snap of the fingers, at 15 feet away. Walk into your house at night and whistle and turn on the lights. Set the sensitivity down and when you arrive at your garage door, a "beep" of the horn can turn on outside safety lights.

This author has found the Sound Switch most useful in the bedroom at night. It is easy to set so that normal conversation does not "trigger" the circuit, but a whistle or clap of the hands will do so. It isn't limited to just lights, of course. Glue the mike to a door and no burglar in the world can pick the lock without setting off the circuit.

The switch stays "on" until you reset switch.



BILL OF MATERIALS

SYMBOL	QTY.	DESCRIPTION	CALECTRO PART NO.
R1	1	500K OHM Pot. (Also S2)	B1-661
R2	1	47K OHM Resistor—½ Watt	B1-404
R3 ,R7	1	100K OHM Resistor—½ Watt	B1-408
R4	1	33K OHM Resistor—½ Watt	B1-402
R5	1	470K OHM Resistor—½ Watt	B1-416
R6	1	10K OHM Resistor—½ Watt	B1-396
C1,C2,C3	3	4.7 MF Capacitor	A1-102
Q1	1	FET	K4-632
Q2	1	Transistor NPN	K4-506
Q3	1	Transistor PNP	K4-505
D1	1	Silicon Control Rectifier	K4-584
M1	1	Mike	Q4-189
RL1	1	Relay	D1-966
S1	1	Push Button Switch*	E2-141
S2	1	(Switch of R1)	B1-661

*Wire normally closed—open to reset.

FET TIMER (0-24 HOURS)

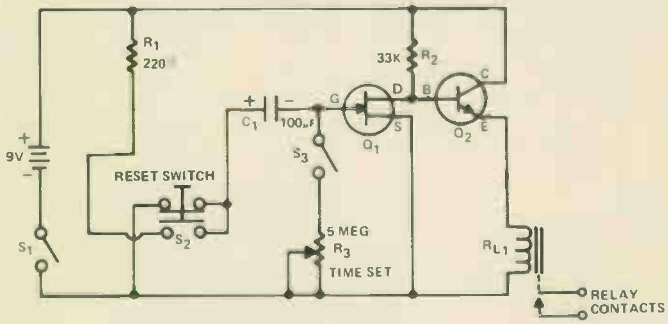
A favorite application is to leave the garage light on for a few minutes until you have safely entered the house. Or you can turn a light on at a pre-determined time to discourage burglary or help you find your way in during night time hours. This circuit can switch up to 350 watts on or off.

As drawn, the circuit has a minimum time of zero to a maximum of 19 minutes. If SW3 is left open, the time elapse is 24 hours 20 minutes (but don't count on it, it depends upon the leakage of C1 and one I tried "Held" for five days). SW3 can be omitted entirely (just wire as though the switch was closed) if a maximum time setting of 19 minutes is adequate. For a darkroom timer, change R3 to 500K (No. B1-687) and maximum time will drop to 2½ minutes and the settings will be finer.

For other uses, below is a scale to give you a general idea of how to modify the circuit for your own application. All you need to do is substitute a ½ watt resistor in place of SW3

Value of Resistor Substituted for SW3	R3 Set for Minimum Time Elapse	R3 Set for Maximum Time Elapse
1 Meg.	5 Min.	24 Min.
2.2 Meg.	10 Min.	30 Min.
3.3 Meg.	15 Min.	33 Min.
4.7 Meg.	24 Min.	41 Min.
10 Meg.	45 Min.	55 Min.
60 Meg.	4 hrs. 30 min.	5 hrs.
80 Meg.	5 hrs. 53 min.	6½ hrs.
etc.	etc.	etc. to 24 hrs. plus

Normal variations in parts used will change the above times slightly. Calibration is easy, stop a clock and let the timer turn it back on; if the clock is two hours "slow" you can count upon that particular setting for two hours.



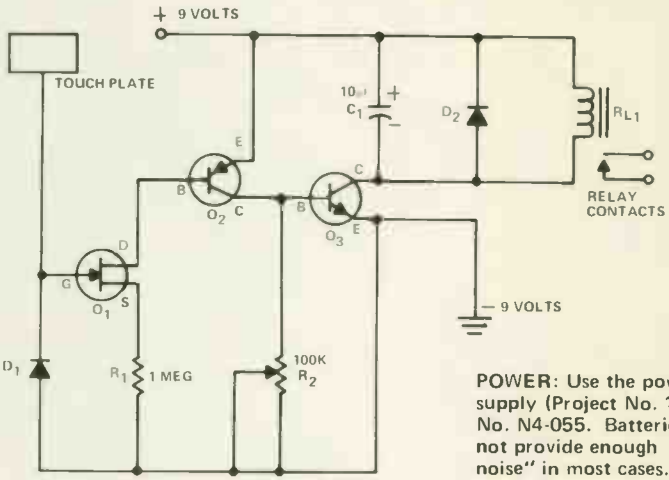
BILL OF MATERIALS

SYMBOL	QTY.	DESCRIPTION	CALECTRO PART NO.
R1	1	220 OHM Resistor	B1-376
R2	1	33K OHM Resistor	B1-402
R3	1	5 Meg. Potentiometer	B1-693
C1	1	100MF Capacitor	A1-130
Q1	1	FET	K4-632
Q2	1	Transistor NPN	K4-506
RL1	1	6 Volt Relay	D1-966

TOUCH SWITCH

Given some thought, a touch switch can be used in dozens of ways. It works by using your body as an "antenna" to pick up the stray electrical noise present practically everywhere. The "Touch Plate" can be concealed by using a screw head as a touch plate and a door lock (the common electrical type) can be released by only those who know where to touch. As the sensitivity can be varied, you can set the switch to work only if your finger is moistened first.

As the switch is sensitive to stray electrical noise, the lead wire should be kept fairly short. We built our circuit in a metal box (a must) and used the tip jack for a touch plate. Using shielded cable (Hi-Fi or co-ax), you can extend the touch plate out to distances. The center conductor connects to the gate and the shield to ground. Fair warning, extending the touch plate can get pretty tricky and can be an infuriating experience. We recommend the touch plate be kept as close to the gate of the FET as possible.



POWER: Use the power supply (Project No. 1) or No. N4-055. Batteries do not provide enough "stray noise" in most cases.

BILL OF MATERIALS

SYMBOL	QTY.	DESCRIPTION	CALECTRO PART NO.
R1	1	1 MEG Resistor	B1-420
R2	1	100K OHM (Pot)	B1-665
D1,D2	2	Diode	K4-550
C1	1	10MF 50V Capacitor	A1-151
Q1	1	FET	K4-632
Q3	1	Transistor NPN	K4-506
Q2	1	Transistor PNP	K4-500 or K4-505
RL1	1	Relay	D1-966

The touch plate consists of an isolated piece of metal--touching it triggers the circuit. It is suggested to use an F2-879 test tip jack.

HALF WATT CODE TRANSMITTER FOR 40 & 80 METERS

Work DX with a half watt? It's not only possible but many serious "Hams" spend a good deal of their time running fractions of a watt. 40 meters will "skip" amazing distances almost anytime and 80 meters carries well at night.

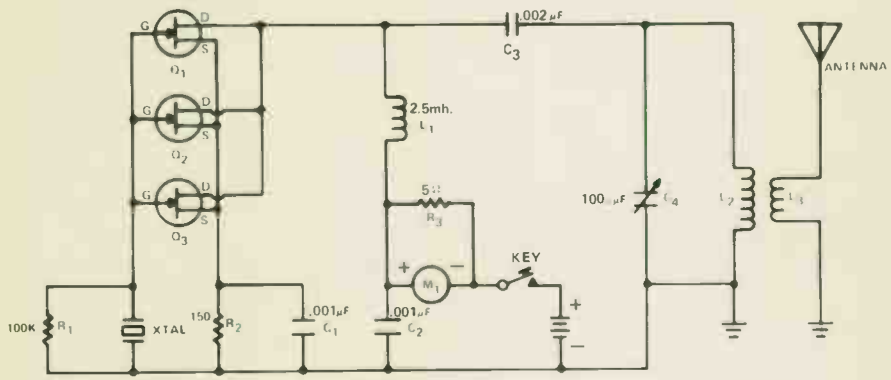
Tune C4 for minimum (dip) reading with no antenna connected. Connect your antenna and tune "up scale" as long as you can hear a clean signal in your receiver.

Making the coils: L2 is 21 ga. magnet wire (No. L3-610) wound "shoulder to shoulder" on a 3/4" dia. wood dowel rod; wind to full length of 1-3/8" long. L3 is 1/2" long 21 ga. magnet wire wound over one end of L2. It is easiest to glue the coil to the dowel rod with GC No. 37-2 COIL DOPE "painted over" the wire after each coil is wound.

Power: Anything from "AA" batteries to a power supply. At 12 VDC, output is .307 watt and at 22 VDC, almost 0.6 watt. Maximum safe voltage is about 30 volts, but no increase in output was noticed above 22 volts. This author had many enjoyable hours using a battery-pack of "AA" cells at only 12 volts.

Other frequencies can be obtained by calculating the coils; 100Mhz is as high as the circuit will perform.

Antenna? A random long-wire seems to be quite adequate, but a well tuned antenna system can add hundreds of miles.



BILL OF MATERIALS

SYMBOL	QTY.	DESCRIPTION	CALECTRO PART NO.
R1	1	100K OHM Resistor	B1-408
R2	1	150 OHM Resistor	B1-374
R3	1	5 OHM Resistor*	B1-360
C1, C2	2	.001MFD Capacitor	A1-026
C3	1	.002MFD Capacitor	A1-027
C4	1	100PFD Variable Capacitor	A1-226
Q1,Q2,Q3	3	FET	K4-634
M1	1	0-1MA. Panel Meter	D1-938 or D1-912
L1	1	Millen No. 34100-34104 Series	
L2,L3	1	Hand wound coil (See Text)	
Xtal		Fundamental Crystal	
Key		Code Key	J4-820

*Two 10 OHM in parallel.

EIGHT RANGE D.C. VOLTMETER

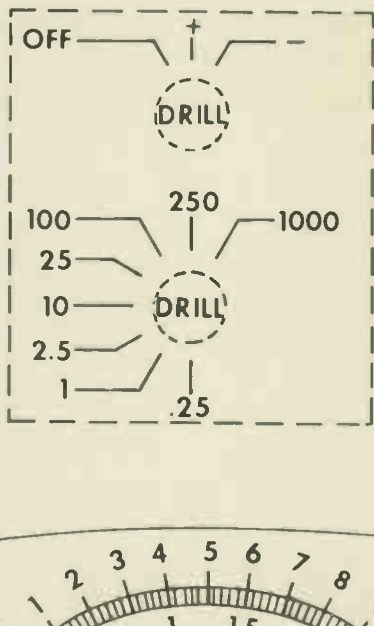
The solid state successor to the highly accurate V.T.V.M. Although the resistors are 10%, there is an "averaging effect" and accuracy proves out to be better than 3%.

You will need a voltage standard for Calibration and Mallory Nos. PX1 or TX13 or any other Mallory cell with an "R" suffix in the part no. provides exactly 1.35V.

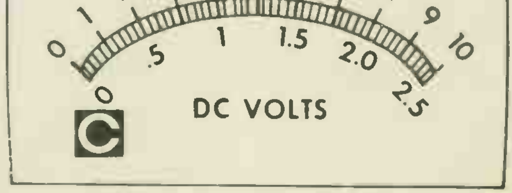
The negative tip jack must be grounded to the chassis and the positive probe should be shielded audio or co-ax cable. Connect the "shield" to ground. Zero set with the probes shorted. Glue the meter face over the "stock" meter face being careful not to disturb the meter movement.

Properly wired, you can save several times the cost of commercially available units and have a very reliable piece of test equipment. (A more detailed explanation is in the CALECTRO HANDBOOK No. FR-73-C (50 cents) on page 67.

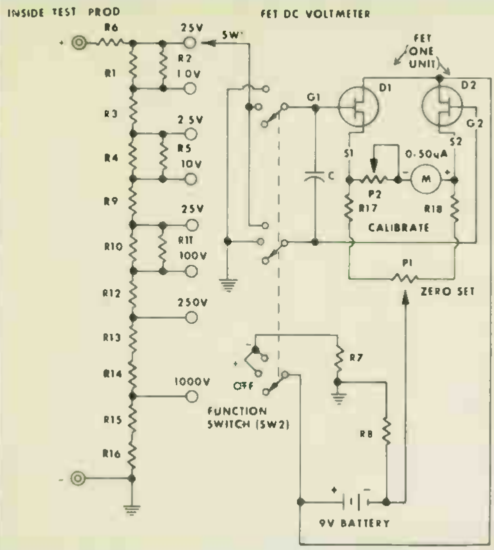
DIAL PLATE



METER FACE



EIGHT RANGE D.C. VOLTMETER CONT.

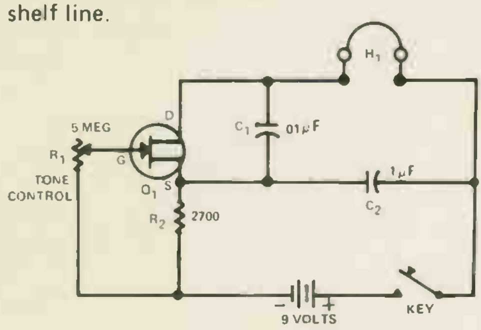


BILL OF MATERIALS

Symbol	Quantity	Description	Calectro Cat. No.
R1,2	2	Resistor, 15 meg ohm	GC 26-148 or equal
R3,4,5	3	Resistor, 1.5 meg ohm	GC 26-124
R6	1	Resistor, 1 meg ohm	B1-420
R7,8	2	Resistor, 47 K ohm	B1-404
R9, 10, 11	3	Resistor, 150 K ohm	B1-410
R12	1	Resistor, 15 K ohm	B1-398
R13	1	Resistor, 4.7 K ohm	B1-392
R14	1	Resistor, 2.7 K ohm	B1-389
R15	1	Resistor, 1.5 K ohm	B1-386
R16, 17, 18	3	Resistor, 1 K ohm	B1-384
P1,2	2	Potentiometer 2000 ohm	B1-643
F.E.T	1	Dual F.E.T	K4-635
C	1	Capacitor, 0.02	A1-030
M	1	Meter 0-50 microamp	D1-910
SW1	1	Rotary Switch, 1P-11 Pos. N.S.	E2-161
SW2	1	Rotary Switch, 3P 3 Pos. N.S.	E2-165
	2	Knobs	E2-705
	1	Cabinet	J4-746
	1 pkg	Test Tip Jacks	F2-873
	1	Battery Connector	F3-052
	1	Battery Holder	F3-062
	1	Mini-Mount	J4-782
	1	Perf Board	J4-612
	1 pkg	Terminals	J4-636
	Misc	9-volt transistor battery (pref. mercury type), solder, hardware, hookup wire, material for test leads, test prods, etc.	

CODE PRACTICE OSCILLATOR

A one transistor code practice oscillator is usually not all it should be. This particular circuit gives a pure tone and is free from "chirping" and distortion. A standard 9 volt transistor battery will last for just about as long as it's shelf line.



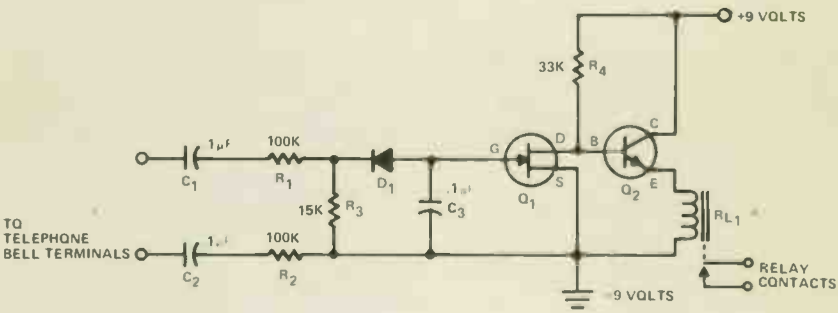
BILL OF MATERIALS

SYMBOL	QTY.	DESCRIPTION	CALECTRO PART NO.
R1	1	5 MEG Pot	B1-693
R2	1	2.7K OHM Resistor	B1-389
C1	1	.01MF Capacitor	A1-029
C2	1	.1MF Capacitor	A1-032
Q1	1	FET	K4-632
H1	1	2000 OHM Headset	J4-825
Key	1	Standard Key	J4-820

TELEPHONE REMOTE RINGER

This circuit allows you to use the ringing voltage of your telephone to switch practically anything. You can ring a remote bell in the garage or out in the "back forty". Or you can ring a bell for that extra phone you installed upstairs without affecting the telephone companies equipment in any way. Connected to a latching relay, you can dial your own number to turn on a light before starting for home at night.

Keep the leads to the telephone fairly short. If you make them too long, random electrical noise could set off the unit. The best bet is to keep the circuit close to the telephone with only a few inches of lead wire. The relay wire, of course, can be run for great distances. The leads marked "to telephone" (schematic) connect to the bell terminals of your telephone.



BILL OF MATERIALS

SYMBOL	QTY.	DESCRIPTION	CALECTRO PART NO.
R1,R2	2	100K OHM Resistor	B1-408
R3	1	15K OHM Resistor	B1-398
R4	1	33K OHM Resistor	B1-402
C1,C2,C3	3	.1MF Capacitor	A1-082
Q1	1	FET	K4-632
Q2	1	Transistor NPN	K4-506
D1	1	Signal Diode	K4-550
RL1	1	6V Relay	D1-966

CALECTRO

handbook

A VALUABLE GUIDE FOR THE ELECTRONIC HOBBYIST AND EXPERIMENTER! HUNDREDS OF BASIC ELECTRONIC PARTS AND ACCESSORIES LISTED AND DESCRIBED.

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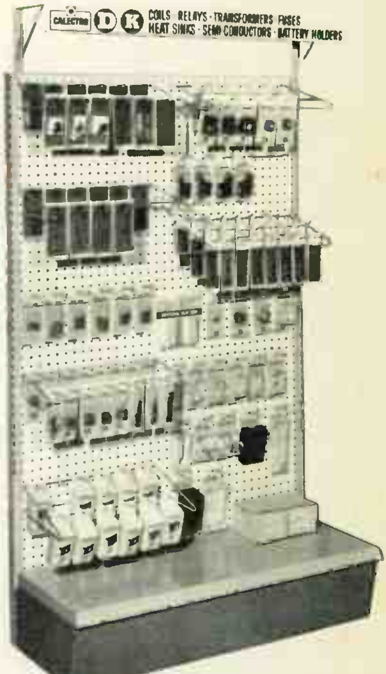

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