Gaines, B. R. (1964). Photoconductors: The Cadmium Sulphide photo-conductive cell in practice Part 1. Practical Wireless 40, 753-755, 774, 844, 847-848, 890.

PHOTOCONDUCTORS

BY B. R. GAINES

The Cadmium Sulphide Photo-conductive Cell in Practice — PART I

UNTIL the advent of the photo-transistor, the only light-sensitive devices generally available were the barrier-cell used in photographic exposure meters, the photo-emmisive cell used in sound-film projectors and the selenium photo-conductive cell (often made up from a burnt-out rectifier!).

None of these has the sufficient sensitivity or ease of use for practical general-purpose work, and it was only when photo-transistors became readily available about six years ago that real interest in light operated devices was stimulated.

Even photo-transistors have disadvantages in some applications however, especially where robustness, high-sensitivity, wide-range of illuminations, power-handling, voltage-handling or exact measurement of light intensity have to be catered for. There has, however, become available a device which fulfils all these requirements: this is the Cadmium Sulphide Photo-conductive Cell, which operates on the same principle as the old Selenium Cell but is in all respects a great advance on these.

The characteristics of one very good example of this type of cell, the Ericcson K42, are shown in Fig. 1. The K42 may be regarded as a resistor whose resistance is determined by the amount of light falling upon its sensitive surface.

It is the enormous range of this resistance from 10Ω in bright sunlight to more than 10MΩ in darkness, from virtually short circuit to virtually open circuit, which makes this cell so useful.

Its colour response also does not have the great peak in the infra-red of photo-transistors and extends over the entire visual range, making the K42 suitable for light measurement.

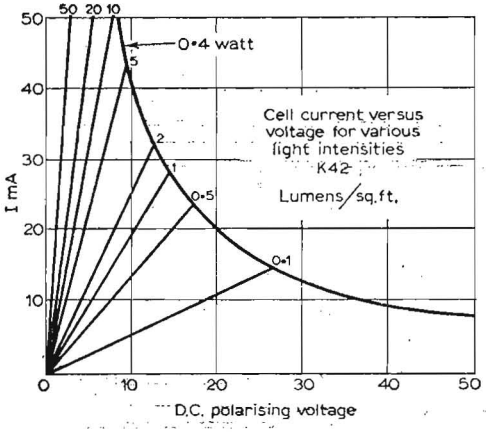
The sensitive part of the K42 consists of a layer of cadmium sulphide with traces of copper and chlorine added. This unit is potted in epoxy resin inside a metal can behind a glass window sealed with silicone rubber.

Fig. 1 (below): Data on the Ericcson K42 photo-conductive cell.

A: Maximum Ratings

Maximum Polarising Voltage	50V
Maximum Photocurrent	50mA
Maximum Power Dissipation	0·4W
Ambient Temperature Range	—25°C-60°C

B: Sensitivity



C: "Rule of Thumb" Sensitivity Guide

Cell Resistance in:

Bright Sunlight	10Ω
Daylight	60Ω
Late dusk	1kΩ
Darkness	10MΩ

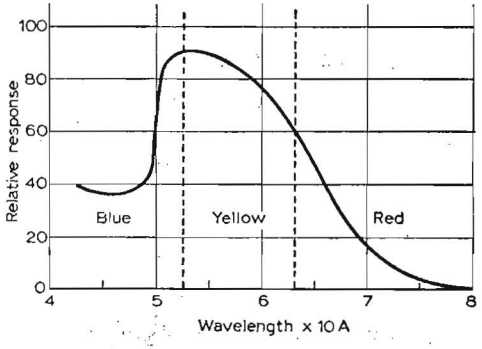


Fig. 2: This graph indicates the K42's relative response to different colours.

The system is extremely robust and moisture resistant, and the writer has certainly found no way of damaging the K42 except by using it with voltages and currents well outside the manufacturer's ratings. The constructional part of this article centres about the K42 and describes its use in light-operated switches and automatic volume controls.

Direct Operation of Relays

Because of its high sensitivity and ability to handle large currents the K42 is able to control relays directly without prior amplification; in this application it may be regarded as a variable resistance of 100Ω or less in light, 1kΩ in the dim light of late dusk, 10MΩ in darkness.

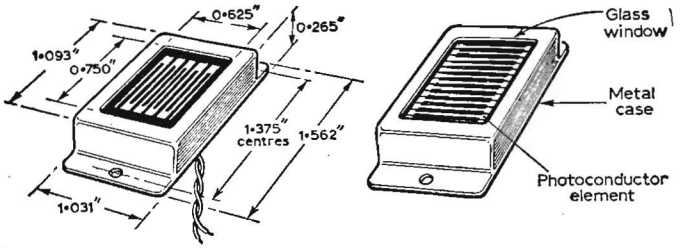


Fig. 3 (above): Dimensions and general appearance of the K42.

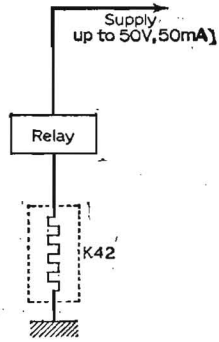


Fig. 4 (right): The K42 in series control of a relay.

Fig. 5 (below): Here R1 is added in parallel with the relay to provide additional backlash. Its operation with R1 disconnected is described in the text.

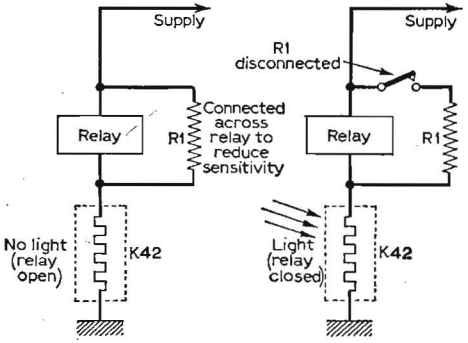


Fig. 4 shows the simplest circuit for direct relay operation in which the K42 is placed in series with the relay coil and its power supply. When the photo-conductor is in darkness little current flows because its resistance is high, and the relay is open. When light falls on the cell its resistance decreases and sufficient current flows to close the relay.

Note that there is no need for a protective diode across the relay coil, since the K42 in series with the relay coil does *not* generate large back e.m.f.'s as do some transistor circuits.

In the operation of the circuit of Fig 4, there is "electrical backlash" in that, whilst the relay may close on a certain current (about 6mA for a 1kΩ P.O. relay with one contact), it will not open again until the current falls rather below this (about 4mA for the relay considered).

This effect is of considerable importance in practical applications which require the relay to operate on currents due to slowly changing illumination.

If there is little backlash the relay tends to "chatter" when the light-level brings the current near its open/close point; backlash by making a very definite difference between open and close currents obviates this defect.

The only restriction on the relay used in Fig. 4 is that it should not require more than 50mA or 50V to operate. The writer has found that Post Office relays with coil resistances of about 1kΩ work satisfactorily on a supply of 12V and has designed parking light switches about these.

Almost any relay may be used however, and the simplest procedure with one of unknown properties is to find out what voltage will just cause it to operate and then to use a supply voltage about one and a half to two times this, subject to the restriction above.

Parking Light Switch

The simple circuit of Fig. 4 has insufficient backlash to guarantee chatter-free operation when the K42 is used to open and close a relay in the slowly changing light of dawn and dusk.

Additional backlash can be created by connecting a shunt resistor, R1 (Fig. 5), in parallel with the relay coil when the relay is open. This takes some of the current supplied to the relay and thus reduces its sensitivity when open.

If R1 is disconnected once the relay has closed the sensitivity goes back to normal, and hence the difference between "open" and "close" currents has been made greater, i.e. the backlash has increased. In practice the relay is made to switch the shunt resistor in and out by means of its own contacts.

Fig. 6 shows a practical circuit for this type of parking light switch and the method of connecting it into the car wiring. The centre section is the

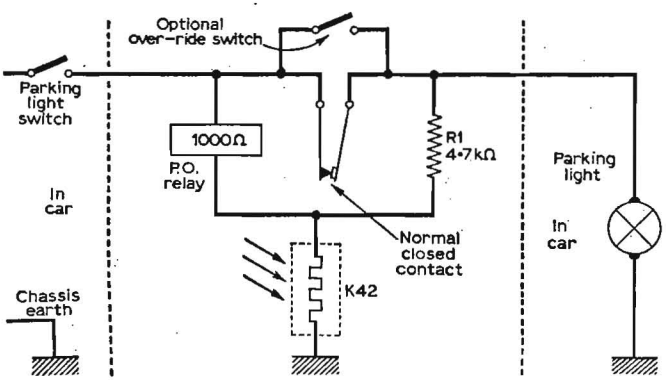


Fig. 6: A car parking light system using the K42.

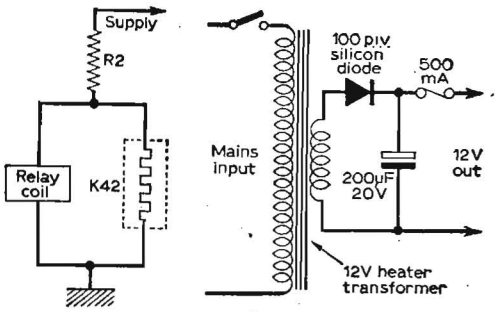


Fig. 7 (left): Parallel control of a relay.

Fig. 9 (right): A power supply for 12V relays.

switch itself which is essentially that of Fig. 4 with the addition of automatic backlash described above.

The K42 is in series with the relay coil, opening the relay during the night, and therefore the switch contact on the relay must be of the "normal-closed" type. This same contact is used to switch the shunt resistor R1 in parallel with the relay coil when the relay is closed, thus increasing the backlash as described above.

If a relay of different resistance to that shown is used, R1 should be changed to be about five times the relay resistance. The "over-ride" switch bypasses the relay contacts and converts the parking light to normal manual operation.

The actual details of construction and connection of the parking light switch will vary with the requirements of the individual car. The K42 must, of course, be placed so as to see the full effect of the ambient light, and the most convenient place to put it is just behind the front window facing outwards; it need not face straight up into the sky.

The relay unit can usually be found a place behind the dash or in the map or glove compartment; for reliability a sealed relay is preferable, and some protection of the contacts should in any case be provided.

The wire to the parking light may be broken into and the automatic switch fitted (Fig. 6) at any point after it has left the main lighting switch. The chassis-earth connection should be securely attached to the metal-work.

A 2A fuse in the 12V line is some worth-while protection against blowing the main car fuses when installing the unit!

Parking Light Switch II

In many towns parking lights are only required after 11 p.m. or when the street-lighting goes off, and the automatic switch has only to switch them off at dawn, there being no advantage in one which would switch them on long before they were required.

This "single-shot" working has the advantage that relay chatter can be completely eliminated by a switch which switches *off* the lights automatically, but requires manual re-setting to switch them on. Then the relay opens at dawn and once open stays open.

The previous circuit could be changed to this mode of operation, but there is an alternative way of controlling a relay directly with a K42 which is sometimes advantageous and the writer will describe this rather than cover the same ground again.

In this mode of operation the K42 is connected in parallel with the relay coil and therefore shares with it the current supplied by R2 (Fig. 7). In darkness the K42 has a high resistance and all the current flows through the relay.

In light the K42 is low resistance and takes most of the current so that the relay opens. R2 should be greater than a third of the relay resistance and must limit the current through the K42 to less than 40mA.

This switch is converted to single-shot working described above, by arranging for the relay to cut off its own power supply when it opens, so that it cannot close again.

Fig. 8 shows a practical circuit for this type of parking light switch and the method of connecting

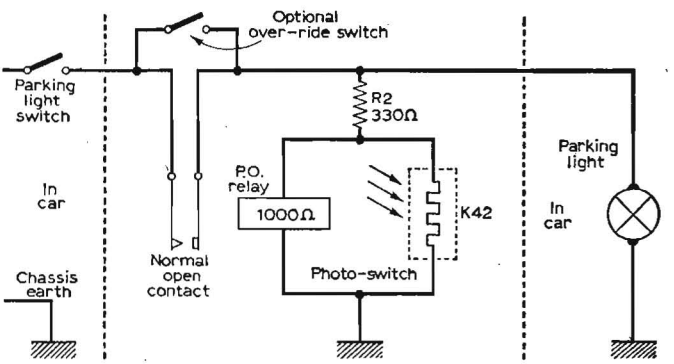


Fig. 8: A 'single-shot' parking light system (II).

it into the car wiring. Only one switch contact on the relay is used as before, but since the relay is now *closed* in darkness this must be of the "normal-open" type.

This contact not only controls the supply to the parking light but also that to the relay itself, and hence once the relay opens it cuts off its own supply and cannot close again.

When the lights are to be switched on at night the supply to the relay must be momentarily switched on, whence the relay will lock-in until it opens automatically at dawn.

The simplest way to do this is to push in the relay armature, which makes the relay contact and acts as the required starting switch; if some means of locking the armature in is also provided this

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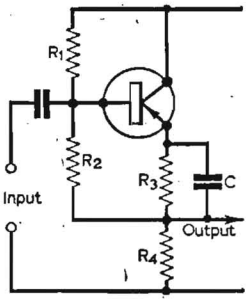


Fig. 23: Common-emitter circuit diagram.

The gain of this circuit is slightly less than unity but the output voltage remains more or less constant for whatever load is applied to it providing the current being drawn is allowing the transistor to work within its power limitations.

We have then a method of providing a method of amplifier stage impedance matching.

It is often desirable to have a reasonable power output from an amplifier. Unfortunately the characteristics and limitations of the more inexpensive transistors do not allow a large power dissipation. Power transistors are expensive and require a high static current.

An amplifier known as a "push-pull" amplifier is very often used to overcome such difficulties. The circuit diagram is in Fig. 24.

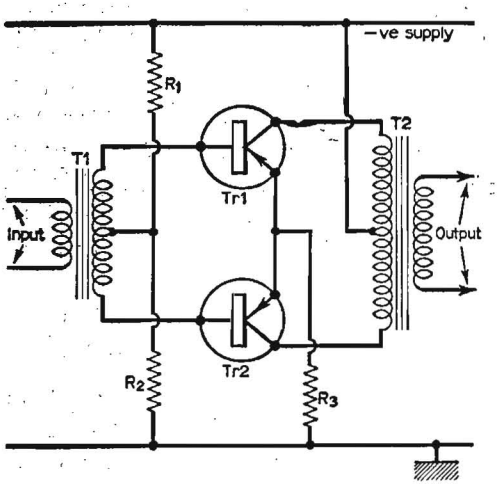


Fig. 24: The push-pull transistor amplifier.

To direct current the windings of the transformers are virtually short circuits. R_1, R_2 and R_3 act as biassing resistors for both Tr1 and Tr2.

Across the secondary windings of T1 the positive and negative half cycles of the signal would alternatively act in opposite directions. Tr1 will amplify one half of the cycle, Tr2 will amplify the second. T2 operates in the opposite manner to T1 and an amplified output is obtained.

Part 4 follows next month

PHOTOCONDUCTORS

—continued from page 755

will serve as an over-ride switch, cutting out the photo-cell control and converting from automatic to manual operation.

Alternatively both starting and over-riding may be done electrically by fitting an over-ride switch as shown in the diagram. Switching this on momentarily locks in the relay at night, and leaving it on cuts out the automatic control; in some cars the parking-light switch position already provided may be used in this way.

The same considerations about construction and mounting applied to the previous switch also apply to this.

Light Operated Switches in General

The circuits so far described have obvious applications not only to parking light switches but also to automatic shop display-lighting switches, simple burglar alarm systems, automatic counters etc. The following notes will help the reader to modify the previous circuitry to his specific requirements.

In counters and alarms speed of operation is essential since the light beam may be broken for only a fraction of a second. The K42 cells do not change their resistance instantaneously when the illumination changes but have a time constant of about one tenth of a second. Thus the relay used must be sensitive and of the high-speed type.

In burglar alarm systems the alarm once set off by the breaking of a light-beam must continue to sound even when the beam is made again. Thus the single-shot working in which the relay cuts off its own power supply is essential; this also ensures that the alarm sounds if the power supply to the relay fails.

When controlling shop-lighting or any other high-power system it is essential to have heavy duty contacts on the relay. The light-contacts commonly found on P.O. relays rapidly deteriorate when used to switch high voltage and power.

There are cadmium sulphide photo-conductive cells which will operate a.c. relays direct from the mains, but these are larger and more expensive and the K42 will *not* do so. Some d.c. power supply must always be provided, either batteries or rectified a.c. The latter need not be well-smoothed, and a simple power supply to drive 12V relays is shown in Fig. 9.

The reader will notice that so far no provision has been made in the circuitry for adjustment of the sensitivity of the K42 control circuits. This is because optical adjustment by means of masks over the K42 is far easier, less wasteful of power and more reliable than electrical control.

The sensitivity of the K42 is proportional to the sensitive area exposed to light, and by placing masks over the glass window the sensitivity may easily be controlled.

Any opaque material may be used for masking and the writer has found black p.v.c. tape most useful. To make the K42 sensitive to light from one direction only it may be placed at the end of an opaque tube facing in that direction.

Part 2 next month

PHOTOCONDUCTORS

BY B. R. GAINES

Audio Volume Control with the K42

PART 2

ALTHOUGH a photoconductor is essentially a non-linear device in that its resistance even at constant illumination decreases slightly with increasing applied voltage, at low voltages the departures from non-linearity are so slight that the cell can be used to control small-signal audio-frequencies without introducing distortion.

The basic circuit of a light-operated volume control is shown in Fig. 10. The photoconductor forms the lower leg of a potential divider across the signal voltage. When illuminated it has a resistance of about 100Ω and there is an attenuation of 1,000 times of 60db—when in darkness it has a resistance greater than 10mΩ and the attenuation is negligible. If this arrangement is to be used as a volume control it is required that the photoconductor should change logarithmically when a control is advanced linearly (as in the usual 'log pot'), because the ear responds to stimuli in this way.

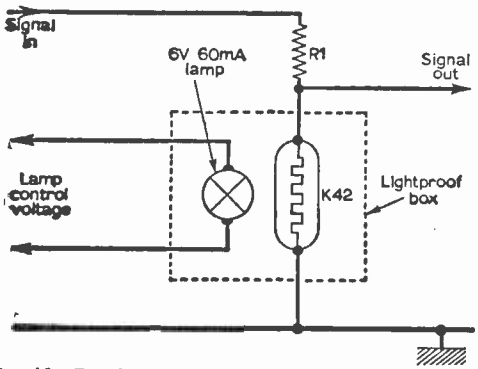


Fig. 10: The basic circuit of a light-operated volume control.

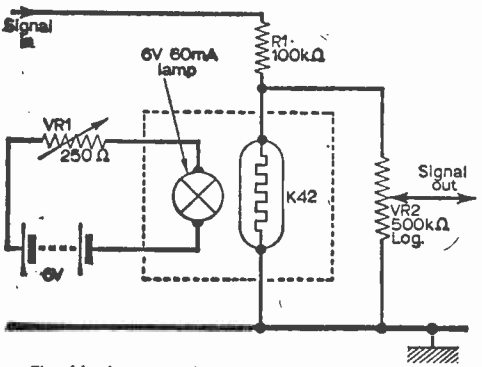


Fig. 11: A practical remote volume control circuit.

A plot of the resistance of a K42 illuminated by a 6·3V 60mA lamp bulb close to its glass window in a light-proof box is shown in Fig. 12, the resistance-scale being of the logarithmic or decibel form. The voltage across the lamp was varied by a resistor VR1 in series with the 6V supply. Curve J shows the variation of photoconductor resistance with lamp voltage, and curve K shows the variation with the lamp series resistance. To get a "log pot" law a control would have to give a straight line on this diagram, and it will be seen that the lamp-voltage curve departs greatly from linearity. The lamp series-resistance curve K however, is much straighter because of the "constant current" characteristic of incandescent lamps, hence a linear series resistor provides the required control.

Remote Volume Control

A practical circuit for a remote volume control is shown in Fig. 11. VR2 is the normal volume control in the amplifier and is set so that with the lamp off the signal is at the maximum required level. VR1 is the remote control: decreasing the resistance of this allows more current to flow

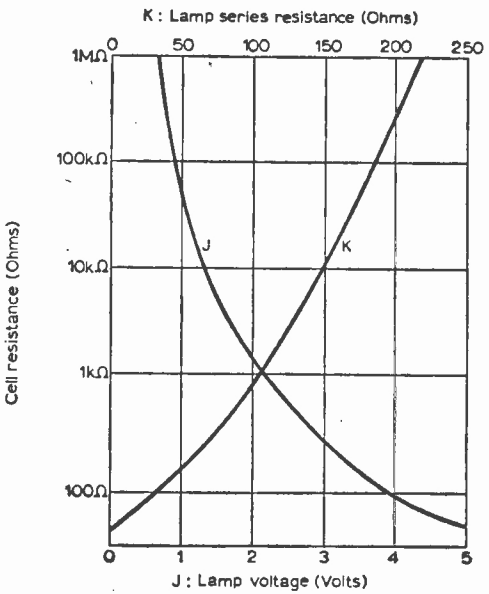


Fig. 12: Resistance graph of the K42 illuminated by an incandescent lamp.

through the lamp making it brighter, thus decreasing the resistance of the photoconductor and hence the signal voltage to the amplifier. If VR2 is not to be used it should be replaced by a 500kΩ fixed resistor to limit the output resistance of the divider when feeding directly into a valve grid. This circuit has the advantage that switching off the lamp leaves the amplifier in its normal operating state, so that power is taken from the battery only when the volume is turned down by remote control.

Even though the cells have a fairly slow response time they are still sufficiently sensitive to 50c/s to pick up the slight ripple on mains-driven bulbs and a d.c. supply to the bulb must be used. The photoconductor must also be protected from ambient lighting so that it responds only to the light of the lamp. They may be mounted close together in a light-proof box or the lamp may be taped to the glass window of the K42 with black p.v.c. tape and the whole unit cocooned in this tape. If ambient light leaks into the photocell its resistance will fall and full volume will not be obtained.

Obviously this circuit has a disadvantage over the usual volume control in that it requires a lamp dissipating some 200mW to control audio-voltages of negligible power. This is inefficient but has the great advantage for purposes of remote control that the controlling leads carry no signal voltage and may be as long as required since hum pick-up and brief switching transients on these leads do not get into the audio side. Also the slow response of light bulb and cell provides freedom from potentiometer noise.

Volume Compressor

It is often required to produce a constant output signal from a source which is fluctuating greatly in intensity, e.g. to reduce output variations in a public address system due to differences in the placing or vocal intensity of speakers. There are valve volume compression circuits which achieve this, but they are generally very complicated and difficult to set up. By driving the volume control lamp from the output of the power amplifier it is controlling (Fig. 13) a volume compressor *par excellence* can be constructed such that a thousand to one change of input voltage causes only a three to one change in output voltage, at any power from 60mW upwards.

The reason for this great compression of dynamic range may be seen by reference to curve J of Fig. 12 which shows the variation of photoconductor resistance with lamp voltage. Suppose R1 is 1MΩ and the input signal to the amplifier via the volume control is such that there is 2V output across the lamp, then the photoconductor resistance is 1kΩ and the volume control is attenuating by 1,000.

Now suppose the input signal falls so that the output across the lamp is 1V, then the photoconductor resistance is 100kΩ and the volume control is attenuating by only 10. Thus an input voltage swing of 200 has produced an output voltage swing of only 2!

The circuit of Fig 13 stabilises the output at about 1V which represents 60mW into a 15Ω load or 300mW into a 3Ω load. To make the circuit capable of stabilising any level of output above this figure a variable resistor (VR1) is placed in series with the lamp bulb (Fig. 14). The greater this resistor the greater the output from the amplifier necessary to maintain 1V across the bulb. Thus this control acts as the volume control determining the stabilized output; the normal volume control on the amplifier performs a different function which will be explained in the next paragraph.

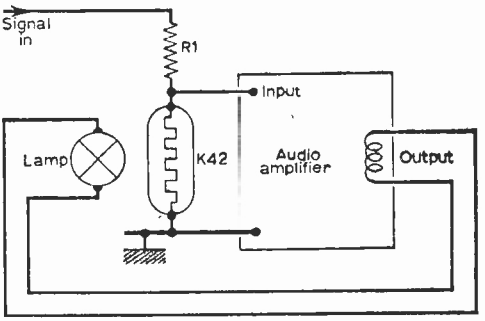


Fig. 13: A volume compressor circuit.

The table below gives the approximate values of VR1 for various maximum output powers into 3Ω and 15Ω loads.

Power	Load 3Ω	Load 15Ω
60mW	—	0
300mW	0	60Ω
1W	40Ω	150Ω
3W	100Ω	300Ω
10W	250Ω	600Ω

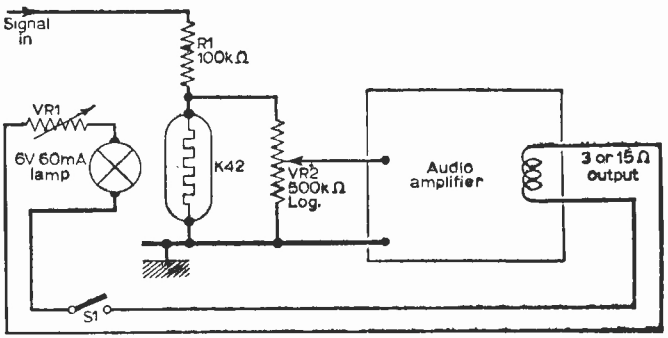


Fig. 14: A volume compressor for variable output levels.

In setting up the final circuit (Fig. 14) the constructor must decide what is the lowest signal which must give full output from the amplifier. The latter must then itself have the sensitivity to give the required output on this signal before all the control circuits are added, since these circuits only attenuate large signals and do not amplify smaller ones. The control VR2 is used to adjust the amplifier sensitivity so that it just gives the required output power on this minimum signal; it controls the range of compression not the output volume.

To set up the circuit the lamp is switched off, the minimum signal fed in and VR2 adjusted to give the required output into the loudspeaker. Then the lamp is switched on, a signal near maximum fed in and VR1 adjusted to give about the same output. Any signal below the minimum will not be compressed and will be amplified normally at maximum sensitivity. Any signal above minimum will come out at the pre-set volume. Since the gain of the system is greatest on low inputs the signal to noise ratio will be increased on these by the volume compression achieved. This trading of noise for compression limits the range of compression which is realisable in practice.

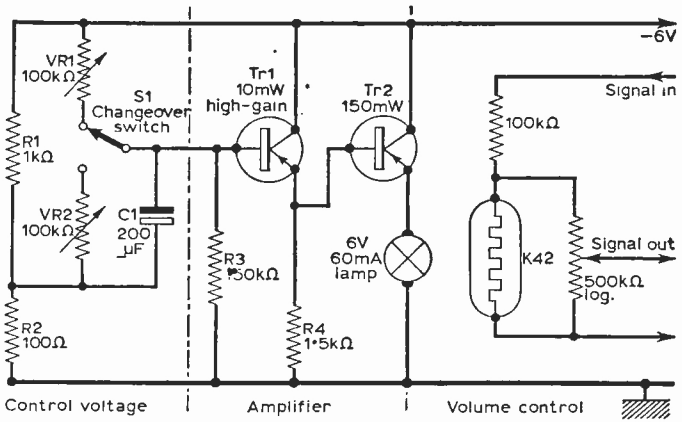


Fig. 15: A circuit for automatic attack/decay control.

Automatic Attack/Decay Control

Automatic volume controls which when switched on "swell up" the sound at a pre-determined rate, and when switched off allow the sound to decay at some pre-determined rate, are used in electronic musical instruments to control the "attack/decay" envelope of the notes: variations of this on a sound of given pitch make all the difference between gentle bowing of a violin and the percussive "ting" of a bell. Also in sound studios similar automatic controls are used to fade sound effects in and out gradually rather than suddenly switching them on.

This type of control is of great help to the amateur tape-recordist trying to mix several inputs with only one pair of hands—instead of having to turn a volume control by hand when he wants to bring in a sound effect, he can just flip a switch and the automatic control will do the rest. As with the volume compressor there are valve circuits to perform this task, but they are complex and generally introduce distortion—here again the K42 circuit scores in simplicity and versatility.

The volume control of Fig. 10 is used again but with the lamp driven by an automatically controlled voltage from a d.c. power amplifier. The output from this amplifier is an almost exponentially rising or decaying voltage which compensates for the non-linearity in the lamp/photoconductor system and produces a constant rate of change of sound in decibels per second — this giving the required audio effect. The rates of rise and fall of this voltage may be pre-set and determine the time taken for the sound to attack and decay.

The circuit of the automatic attack/decay control may be considered in three stages (Fig. 15):

(1) The lamp-driven volume control which is the same as that of Fig. 10 and needs no further explanation.

(2) The two transistor d.c. power amplifier which consists of two emitter followers in cascade. This configuration gives no voltage gain, but matches the very low resistance of the lamp to the high output impedance of the control circuitry.

(3) The control voltage circuit which provides a varying voltage whose rates of rise and fall can be pre-set as required.

The d.c. amplifier circuit is very simple and should present no difficulty in construction provided the correct types of transistors are used. Tr2 provides the power for the lamp and must be capable of dissipating 150mW, any audio transistor with this power rating and medium to high gain is suitable, e.g. NKT223, NKT224, OC81, etc. Tr2 should be in good condition and high-gain, NKT223, NKT224, OC71, etc. — a poor transistor will work but the longest attack/decay times will be unobtainable. When the input to the amplifier is disconnected the output voltage should be less than 0·3V and the lamp should not glow. When the input is connected to the 6V negative rail the lamp should glow brightly.

The control voltage is provided by alternately charging a large capacitor C1 through resistors VR1 and VR2 by means of the changeover switch S1. The resistors are made variable so that the time taken for the sound to swell up or die away may be pre-set. From Fig. 12, curve J, it may be seen that the photoconductor attains its maximum resistance with a lamp voltage of 0·7V and is not affected by voltages below this. Therefore the control voltage must vary above 0·6V and to ensure this C1 is returned not to earth but to a potential divider consisting of R1 and R2 whose junction is about 0·6V negative to earth.

Consider the switch S1 switched to VR2 and C1 completely discharged: the input voltage is then

—continued on page 890

is a combination of factors in L1 and L2. Frequency of oscillation depends on this combined value, known as mutual inductance, and the value of capacitor C1.

On application of the voltage source a voltage is seen across C1 and L2 in parallel. C1 will charge and begin to discharge through L2. This will change the voltage difference across C1, thus changing the potential at the base. A change 180° out of phase with this will be seen in coil L1 due to amplifier action and hence fed back into the coil L2 with a further 180° phase displacement. Energy would normally be lost in the coil L2 but due to the feedback via Tr1 and L1, oscillation is able to continue at a fairly constant amplitude.

There are two main methods of obtaining an output from this type of oscillator; normal amplifier output may be taken from the collector (point A in Fig. 30) but very small values of current only may be drawn, otherwise oscillation will cease due to lack of feedback. A more common method is to use a third winding on the transformer (B in Fig. 30) from which slightly larger values of current may be drawn but whose presence changes the mutual inductance value of the transformer and hence the frequency output.

There are other types of LC oscillators using feedback in a similar manner to the one in Fig. 30 but there is not space to deal with them here.

RC oscillators are also of several types and again only one shall be dealt with here—the "phase-shift" oscillator.

The phase-shift oscillator is allowed to oscillate at one frequency only, which is determined by the values of capacitance and resistance used in the "phase-shift network".

Similar to the LC oscillator, a grounded emitter amplifier is used to amplify the oscillations but an RC network is used to provide feedback in place of the inductive method.

The circuit shown in Fig. 31 provides a current

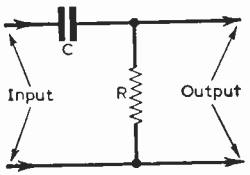


Fig. 31 (right): A CR circuit giving 60° phase shift.

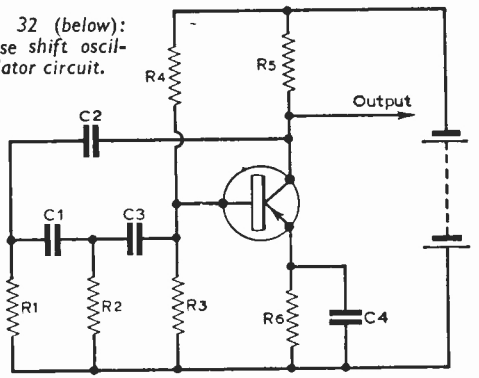


Fig. 32 (below): Phase shift oscillator circuit.

phase shift of 60° between input and output, therefore three of them connected in series would give a 180° phase shift.

Fig. 32 shows the diagram of a phase-shift oscillator.

R_3, R_4, R_6 and C4 provide the base-emitter biasing. R_3 is also a part of the phase-shift network. Obviously there are several losses in the CR network and to overcome these the amplifier stage should have a gain of at least 29 times.

The output is taken from the collector of the transistor.

Part 5 follows next month

PHOTOCONDUCTORS

—continued from page 848

0·6V and the lamp is off so that the volume control is up at maximum output. Now S1 is switched to VR1 the "decay" control: C1 slowly charges up through VR1, the voltage across the lamp rises and the resistance of the photoconductor falls so that the volume control output decreases, reaching its minimum when C1 is fully charged; the volume control is now off.

Now S1 is switched back to VR2: C1 slowly discharges through VR2, the lamp voltage falls etc.—the whole cycle being repeated in reverse until the initial state with C1 completely discharged and the volume control at maximum is reached.

With the values of C1, VR1 and VR2 given, the attack and decay times can be varied from several seconds down to practically instantaneous. If longer times are required C1 may be increased to 1,000μF or more.

In this article the writer has described only a few of the possible applications of photoconductive cells. They are a comparatively recent device and many manufacturers in Great Britain and the U.S.A. are working on improved forms and new applications. Their use to replace relays in switching circuits has perhaps the greatest potential at present: a neon lamp or electroluminescent panel can control several photoductors, switching them from virtually open-circuit to virtually short-circuit by means of its light output. The most important improvement to be made in these devices is a great decrease in their response time, at present over one tenth of a second. Cadmium Selenide cells can bring this down to one hundredth of a second and other compounds may bring it much lower. Other photosensitive devices of entirely different principles are also becoming available and the ultimate value of the photoconductor cannot yet be judged, but it is safe to say that it will be with us for many years, assuming greater importance as improved forms become available.

Acknowledgement is made to Ericcson Telephones Ltd. for permission to use their published data on the K42.

The K42 is available from Service Trading Co. at 8s. 6d. It is *not* available direct from the manufacturers in quantities less than 500. ■

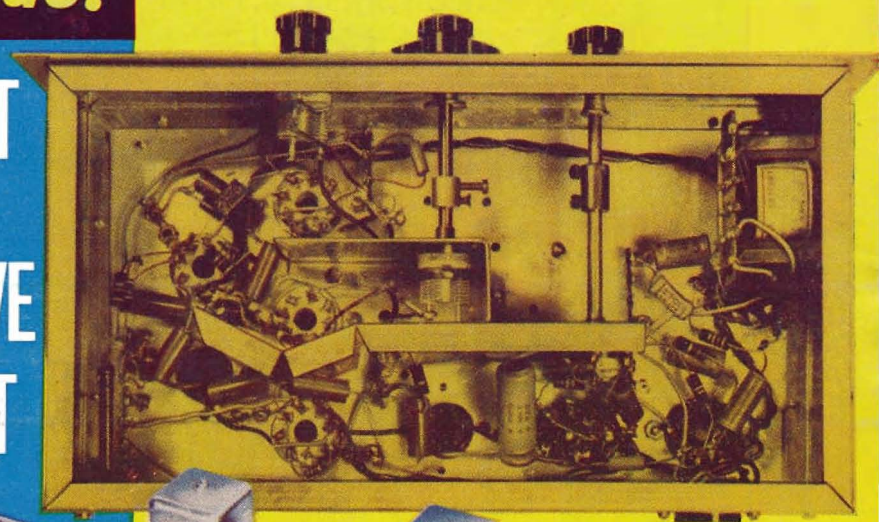
PRACTICAL WIRELESS

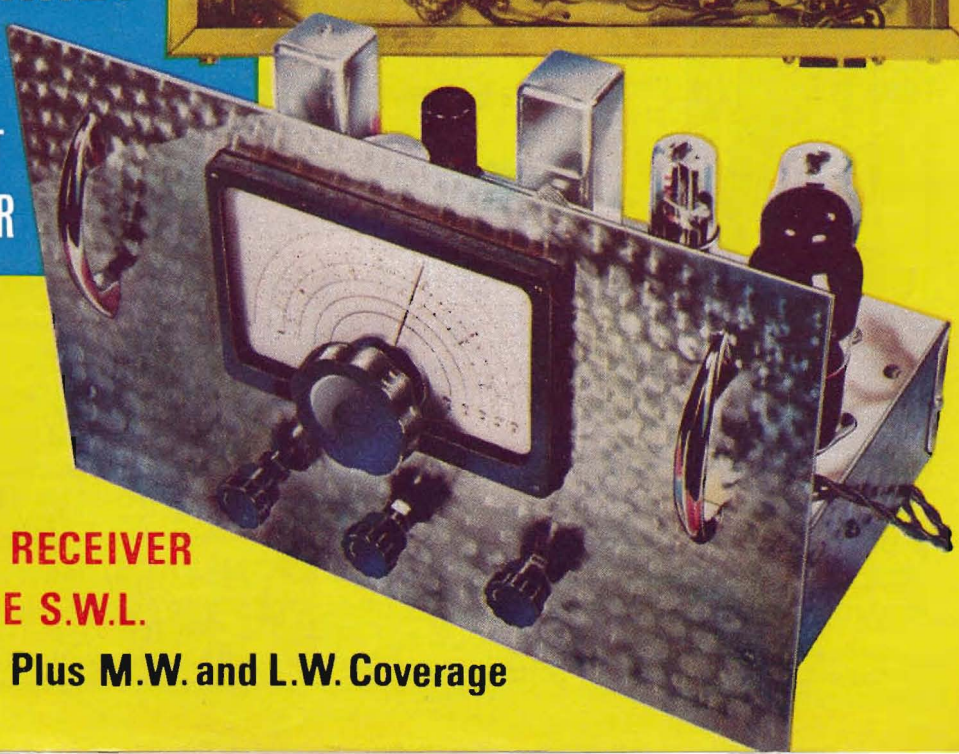
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