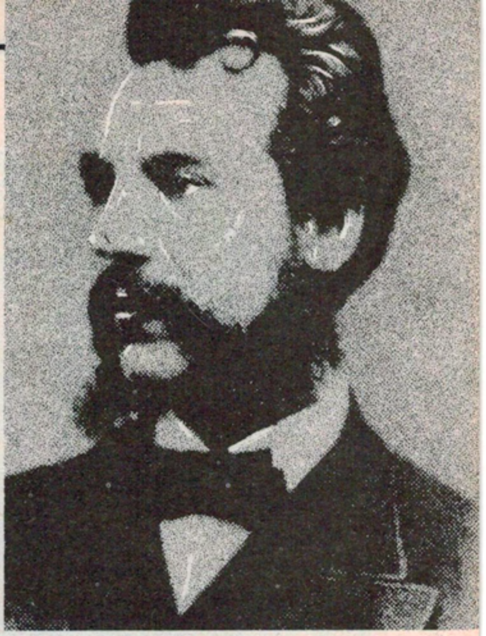
Build a 'photophone' light beam transceiver



Bell, inventor of the photophone, pictured in 1876, the year he patented the telephone.

Unlike the telephone, the photophone is probably Alexander Graham Bell's most obscure invention. Instead of wires, you can talk on a beam of light. This modern — solid state! — version is simple to build and remarkably effective.

Phil Wait
William Fisher

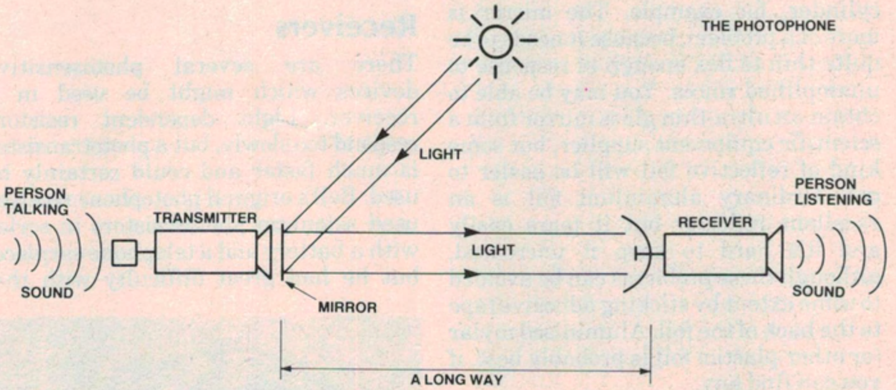
A PHOTOPHONE is a device for sending voice signals along a light beam. The word 'photophone' dates from 1880, when Alexander Graham Bell coined it to describe his own light-beam communication system. At his death in 1922, Bell was still convinced that the photophone was his most important invention, more important even than the telephone, which by that time had spread into a worldwide network.

However, the world in general disagreed with Bell and went ahead with communication systems using wires or radio waves as carriers, in preference to light waves. (The development of fibre optics may reverse this trend, but that's another story.) The photophone was forgotten by everyone except a few historians of science.

In the interests of nostalgia and entertainment we have revived this ancient invention, using some modern electronics instead of the cumbersome and unreliable modulation and detection equipment that Bell was forced to use. (He was working in the pre-electronic age, nearly thirty years before triode valves were invented and seventy years before transistors.)

The principle

The basic principle of the photophone is that a normally flat mirror is made to flex slightly by sound waves impinging on it. A light beam is reflected off the mirror and aimed at a photosensitive receiver. As the mirror is flexed by the sound waves it becomes alternately convex and concave, which means that the beam reflected onto the receiver becomes alternately wider and narrower, in time with the sound wave. The total number of photons in the light beam is not altered by these changes in its width, but the fraction of that energy which falls on the receiving surface does vary (providing the beam is always wider than the receiver). So the intensity of the light received varies with the width of the light beam, which in turn varies with the curvature of the mirror, which is caused by the pattern of sound waves hitting it.

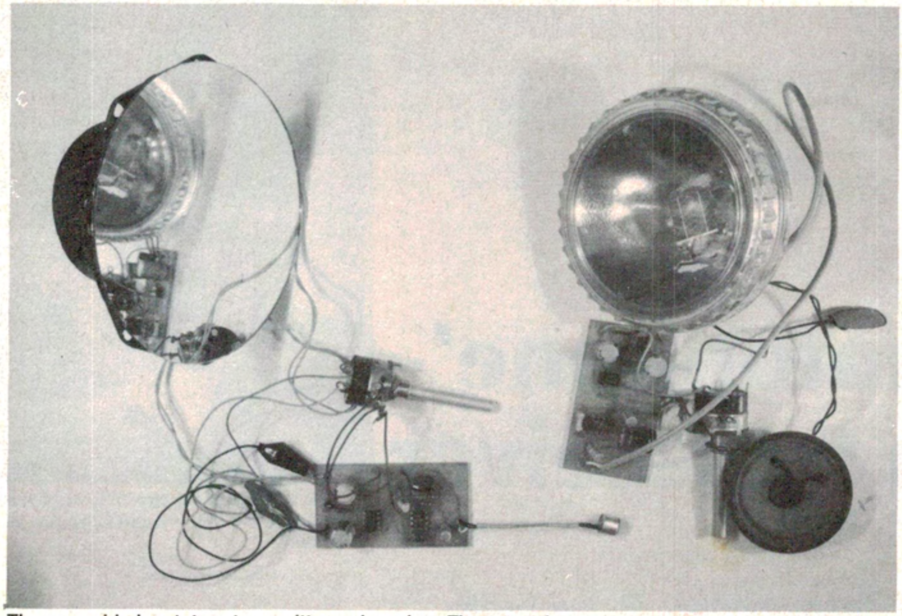


Illustrating the basic principle of the photophone.

The variations in light intensity at the receiver can be converted into an electrical signal which drives a loudspeaker via an amplifier to reproduce the sounds originally produced at the transmitting end. The whole arrangement is a kind of amplitude modulation of the light beam, with the mirror acting as the modulator and the photosensitive surface acting as the demodulator.

Transmitters

The first problem is to make the mirror flex in time with the sound wave. Bell's original mechanism for doing this was very simple. He used a thin mirror ▶



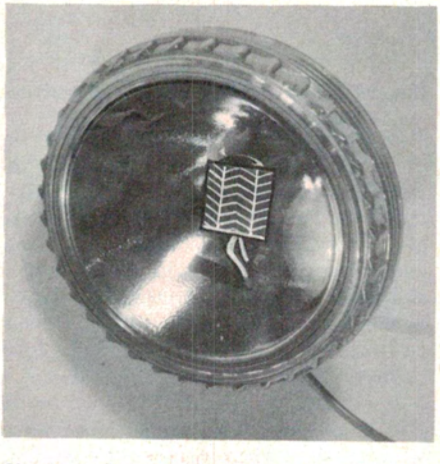
The assembled prototype transmitter and receiver. The transmitter was powered by a 6 V lantern battery, the receiver by a 9 V transistor radio battery. We used a solar cell mounted in a lantern reflector, as described below.

firmly glued over the end of a flexible tube. When he spoke into the other end, sound waves travelled down the tube to make the mirror vibrate. This method is quite effective and you can use any kind of tube — a rigid cardboard or metal cylinder, for example. The mirror is more of a problem, because it needs to be quite thin to flex enough in response to unamplified voices. You may be able to obtain an ultra-thin glass mirror from a scientific equipment supplier, but some kind of reflective foil will be easier to get. Ordinary aluminium foil is an excellent reflector but it tears easily and it's hard to keep it uncreased, although these problems can be avoided to some extent by sticking adhesive tape to the back of the foil. Aluminised mylar (or other plastic) foil is probably best, if you can find any.

For our own transmitter we opted to use a circular glass mirror of normal thickness, such as you might buy in any chain store as a shaving mirror (the flat variety — not concave). We mounted this on the frame of a 150 mm diameter circular loudspeaker and made an amplifier to drive the speaker with sufficient power to flex the mirror. If you want to use this method, buy the speaker first, then look around for a shaving mirror the same diameter or slightly larger. Remove the metal or plastic rim and you will usually find two mirrors, one flat and one concave. Discard the concave mirror and glue the flat one to the metal rim (NOT the cone) of the speaker, using epoxy resin. Don't use a silicone compound like Silastic, because the joint must be rigid. The wider the speaker and mirror you use, the better the range and the lower the distortion, because a wider mirror can flex more. The amplifier and microphone are described under 'Electronics'.

Receivers

There are several photosensitive devices which might be used in a receiver. Light dependent resistors respond too slowly, but a phototransistor is much faster and could certainly be used. Bell's original photophone receiver used selenium photoresistors in series with a battery and a telephone earpiece, but he had great difficulty with this system. (Bell deserves credit for any success with this astonishingly crude arrangement. As Dr. Johnson remarked about a dog walking on its hind legs — it was not done well, but it is astonishing that it was done at all!)



Close up of our receiver input device. This consists of a small solar cell piece mounted in a reflector taken from a 'Dolphin' lantern. To mount the cell, we cut a slot in one side of the reflector, put Silastic on the rear of the solar cell (leads already attached) and inserted it in place. It proved very effective.

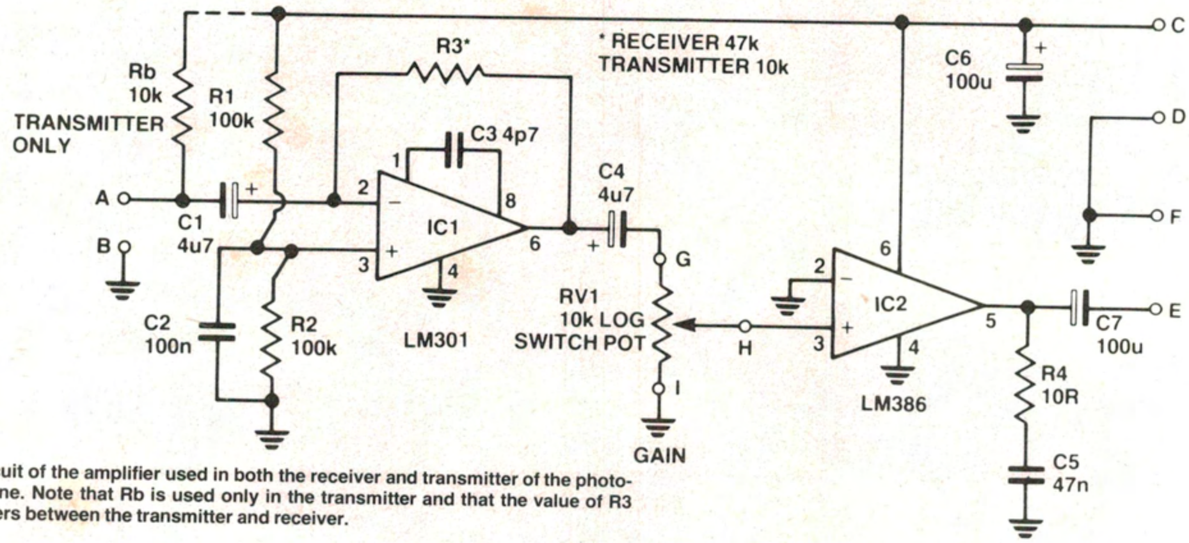
For our receiver we opted to use a 'solar cell', which is a kind of silicon photodiode. The large area and easy availability of solar cells make them the best choice overall. The effective area of the cell was made even larger by mounting it near the focus of a parabolic reflector taken from a hand lantern and an even larger effective area could be obtained by using a car headlamp reflector. Bell's original photophone used a reflector nearly a metre in diameter to gather the light, but anyone thinking of using very large reflectors should remember that the reflector must not be wider than the beam it is collecting, otherwise the modulation cannot be detected.

Light sources

In principle any light source will work. At night, with no other lights nearby, a pocket flashlight has been reported to work by some experimenters, but we haven't tried this ourselves. In daylight you need an intense and collimated (i.e: parallel) beam to get any reasonable range. A gas laser (such as a helium-neon type) is an ideal source, which in principle could give you a range of several kilometres in open country or over water, but some precautions are necessary. A low power laser is safest, preferably one having an output of one milliwatt. If possible, a 'beam expanding telescope' should be fitted to it. This increases the diameter of the beam making it easier to aim and reducing possible harmful effects to the eyes of any person who may accidentally look into the beam. The person setting up the receiver should not look toward the laser. Note that the beam at the receiver must be larger than the receiving device. This is where a beam expanding telescope helps.

This project makes a good 'science demonstration' project if your school science department has a suitable laser.

However, a much more readily-available light source is the Sun whose light output is quite intense and has reasonably parallel rays. Using reflected sunlight, we found that we could communicate intelligibly by photophone over distances of a few hundred metres. With more efficient transducers (ours were deliberately simple) this distance could probably be extended. ▶



Circuit of the amplifier used in both the receiver and transmitter of the photophone. Note that Rb is used only in the transmitter and that the value of R3 differs between the transmitter and receiver.

Electronics

To amplify speech to drive the loudspeaker of the transmitter, we designed a simple amplifier around two ICs — an LM301 voltage amplifier and an LM386 power amplifier. There was no point in making a low noise, low distortion amplifier because the transmitting and receiving transducers are relatively noisy and non-linear. However, performance is quite acceptable. Speech signals from an electret microphone insert are amplified by the LM301, then attenuated by a gain-control potentiometer before being fed to the LM386, whose output drives the loudspeaker. The large speaker needs a lot of current to drive it, so a six volt lantern battery is the best kind of power supply.

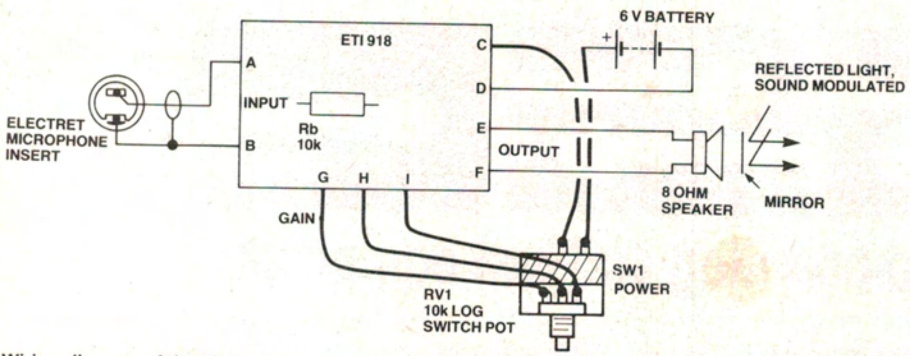
The receiver uses a very similar amplifier to boost the tiny signal derived from the solar cell, the dc component of this signal being blocked by a capacitor. The receiver amplifier is so similar to the transmitter amplifier that it uses the same pc board design. The only differences are that the feedback resistor (R3) around the LM301 op-amp has a larger value in the receiver to give

HOW IT WORKS — ETI-918

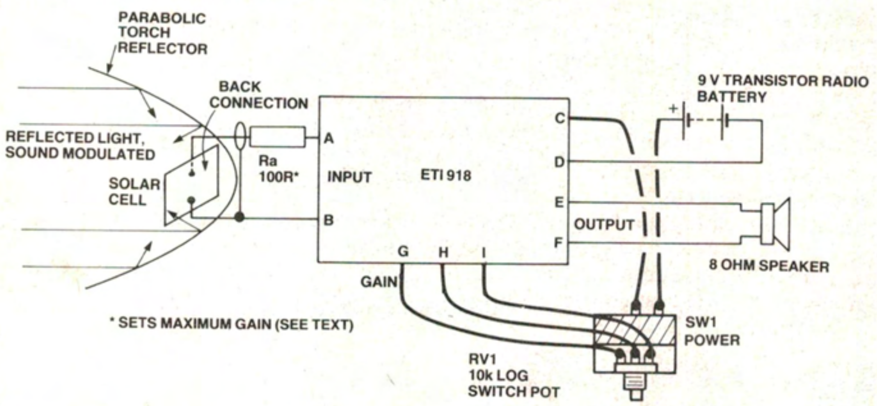
Sound received by an electret condenser microphone is amplified by the transmitter amplifier and used to drive a loudspeaker. A plane (i.e: flat) mirror attached to the housing of this loudspeaker is flexed by the sound wave emitted by the speaker, so that it becomes alternately convex and concave as the sound pressure increases and decreases. A beam of sunlight reflected by the mirror onto a solar cell at the receiving end becomes broader or narrower as the mirror flexes, in phase with the sound pressure variations. Providing the beam always completely covers the collecting surface, a broader beam means that fewer photons are collected by the solar cell and a narrower beam means that more photons are collected.

The variation in the number of photons collected causes a proportional variation in the current generated by the solar cell. These current variations cause variations in the voltage across resistor Ra, and these voltage variations are amplified by the receiver amplifier, which drives a small loudspeaker to reproduce the sounds spoken into the transmitter microphone.

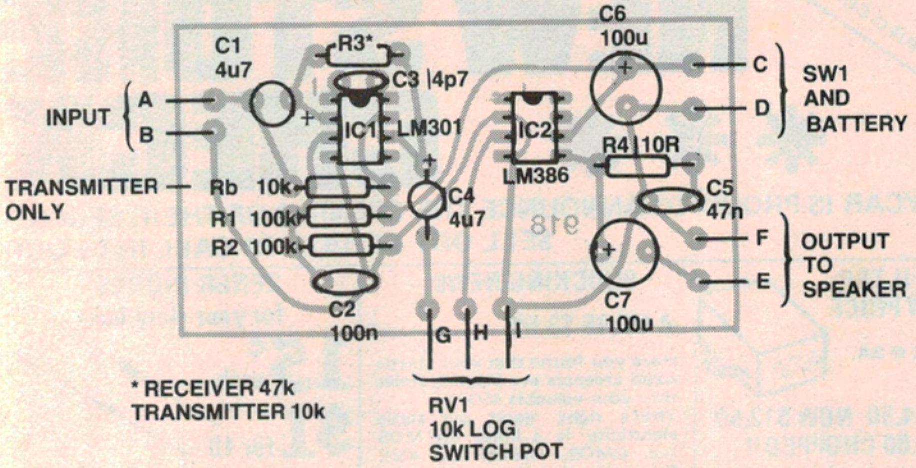
The transmitter and receiver amplifiers are essentially similar, each using an LM301 op-amp (IC1) for voltage multiplication and an LM386 power amplifier (IC2) with a switch potentiometer (RV1) between these two ICs for manual gain control. Resistor Rb (in the transmitter amplifier only) provides bias for the electret microphone. Capacitor C1 blocks dc signals. The gain of IC1 is set by the ratio of the resistance of R3 to the impedance of C1 at audio frequencies. The potential divider formed by R1 and R2 biases the non-inverting input of IC1 up to half the supply voltage, so that IC1 can be used with a single ended supply. C4 blocks any dc offset of IC1's output, R4 and C5 prevent instability around the output stage and C8 prevents any dc offset from being applied to the speaker. C4 and the internal resistance of the battery form a low-pass filter that removes battery noise from the supply line.



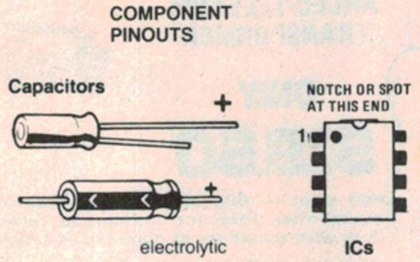
Wiring diagram of the photophone transmitter. Note the wiring to the rear of the electret microphone insert. You'll find one connection attaches to the mic case. This is the 'common' and goes to B on the pc board. Some inserts have leads already attached. Usually the common lead will be black. Use a shielded lead between the mic and the input to the amp.



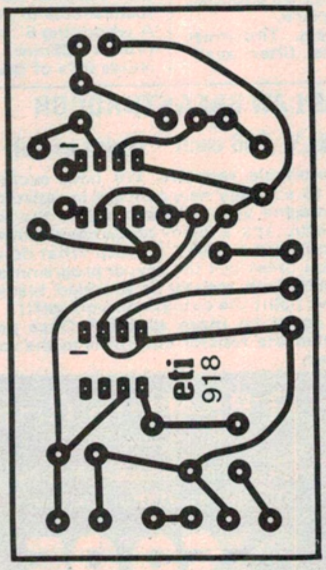
Photophone receiver wiring diagram. Use a shielded lead between the solar cell and the amplifier input. Don't forget to connect a 100 ohm resistor in series with the lead to terminal A on the amp.



Component overlay for the amplifier. Note that Rb is not needed in the receiver amplifier and that the value of R3 differs between the transmitter and receiver.



See 'Shoparound' page in this issue for where to buy components



Printed circuit board artwork, full size.

higher gain, and the transmitter has an extra resistor (Rb) to bias the microphone. Only a small speaker is necessary for the receiver, so that a nine volt transistor radio battery can be used as power source.

Construction

We haven't designed any kind of box for this project. Obviously permanent housings for the transmitter and receiver will make the photophone much easier to use, but you can't make them until you've done some experimenting and finally decided what shape and size of reflectors you are going to use. In any case, this is a magazine about electronics, not carpentry or metalwork!

The two amplifiers should present no difficulties in assembly, providing you remember the usual precautions — check the orientation of capacitors, diodes and transistors, use a smallish bit when soldering the IC pins and let the ICs cool down for a few seconds between soldering each pin.

The electret microphone insert is polarised, so it can only go one way round. Make sure you solder the negative lead (usually black) to point B on the pc board and the positive lead (usually red) to point A. Glue the flat mirror to the metal rim of the transmitter loudspeaker (not to the cone), using epoxy resin (not any other adhesive).

Some solar cell pieces come with leads attached, some do not. If you have to attach your own leads, do it very carefully, using a low wattage iron and thin flexible wire. Most cells have electrodes on the front and back surfaces: solder to the back electrode first, by forming a small pool of solder near the edge of the cell and holding the end of the wire in the pool until it cools. The front electrode is usually in the form of a thin strip and needs more care. Apply enough solder to form a bump or ridge, reheat the solder and position the second wire. The leads must be protected from strain and can be glued to the reflector if one is used. Connection to the amplifier should be made through shielded cable. Don't forget to insert the 100 ohm resistor (Ra) in series with the lead that connects to point A on the pc board (see the overlay diagram). The solar cell can be held in position with plasticene while you are experimenting, or with silicone compound (such as Silastic) for a more permanent bond.

Operation

Leave the receiver with a friend and walk in the direction of your shadow, then point the transmitter so that the sun's reflection is directed at the receiver. It helps to put the receiver in the shade, so that you can see the spot of light from the transmitter mirror more easily.

You'll find that only a very small movement of the transmitter is enough to move the spot off the receiver, so it's easier if, once you've got the direction approximately right, you keep the transmitter steady on the ground or on a table and move the receiver to make the fine adjustments. Alternatively, you could keep the receiver fixed and mount the transmitter on a tripod.

A word of warning — don't point the light beam at your assistant's eyes (or anyone else's) if you're using the sun as the light source. To be safe, wear sunglasses (half-silvered types cut out most light) and never look directly at the mirror. ●

PARTS LIST — ETI-918

The following is a list of parts needed to build an electronically amplified transmitter and receiver to our specifications. The numbers in brackets represent the total number of components required of that value or type. If you are not using an amplifier in your transmitter, you will only need one of each component listed (i.e: one of R1, one of R2, etc.)

Resistors	all ½ W, 5%
R1, R2	100k (4)
R3	(2) see text
R4	10R (2)
Ra	100R (1)
Rb	10k (2)
Potentiometers	
RV1	10k log. switch pot
Capacitors	
C1, C4	4u7/16 V RB electro. (4)
C2	100n greencap (2)
C3	4p7 ceramic (2)
C5	47n greencap (2)
C7, C8	100u/16 V RB electro. (4)
Semiconductors	
IC1	301 op-amp (2)
IC2	386 power amp (2)

Miscellaneous
One or two ETI-918 pc boards, one electret microphone insert, small solar cell piece, parabolic torch reflector, small 8 ohm speaker, 150 mm 8 ohm speaker, 150 mm or larger diameter round mirror to match diameter of speaker, 6 V lantern battery, 9 V transistor radio battery, short length of shielded cable, insulated hookup wire.

Price estimate

$35 — $40	**$22 — $25**
(complete)	(electronics only)