*A police observer using a hand-portable passive sight infra-red viewer*

think of it as radio waves which pass through physical obstructions, whereas visible light requires line of site communication.

This property is extremely useful, as we shall see later, in that an infra-red beam can be directed to a given point without being seen. High power lamps can be used here with a black opaque screen to cut off visible light rays. Clear glass will pass all visible light but will only pass near infra-red rays up to about 2·5 microns.

If transmission in the intermediate and far infra-red regions is required certain semiconductor materials can be used. Up to recent times germanium and silicon have been used, but now gallium arsenide is proving very valuable.

It is possible to detect infra-red by absorption and conversion of heat. However, this can be a cumbersome process, as was shown by early experiments where a blackened thermometer was used.

# INFRA-RED COMMUNICATIONS

**By M. A. COLWELL**

INFRA-RED radiation occurs in similar form as visible radiation, but occurs in that part of the electromagnetic frequency spectrum below visible light (see Fig. 1). Therefore it has the properties of wavelength and frequency just as visible light has, but because its wavelength is longer, it is not visible to the naked eye.

However, light from tungsten filament lamps contains a very high proportion of infra-red (about 90 per cent) and is useful for experimental and industrial work whereby, with the use of filters, the visible light can be made invisible (Fig. 2).

When the wavelength of any kind of electromagnetic radiation becomes very short, i.e. for frequencies above about 3,000 megahertz, it is more convenient to refer to wavelength in microns, micrometers or Ångstroms. The infra-red region lies in the 0·75 to $10^3$ microns range, one micron being equal to one $10^{-6}$ metre, although the division between infra-red and microwave frequencies is not clearly defined.

This region is further sub-divided into "near" (0·75 to 1·5 microns), "intermediate" (1·5 to 10 microns) and "far" (beyond 10 microns) regions, while above 300 microns it is often referred to as the "submillimetre" region.

## PROPERTIES OF INFRA-RED

Electromagnetic radiation in the infra-red region is sometimes able to penetrate objects which would otherwise stop visible light. Here it is important to

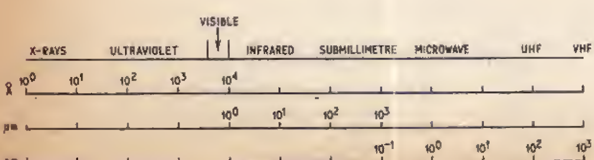


*Fig. 1. Electromagnetic spectrum*

More lately, thermocouple detectors or photoconductive cells were made to respond over a wide frequency range, then perhaps filtered as required. This method is disadvantageous because the response to temperature changes in the transmitting object were too slow.

Current developments illustrated in this article show examples of detection of pure infra-red radiation from natural sources ("passive") and reflected radiation dependent on an infra-red beam being bounced off an object ("active").

## CARRIER WAVE

There is now a new line of thinking based on the active system whereby the transmitted infra-red can be used as the carrier wave for pulse code frequency

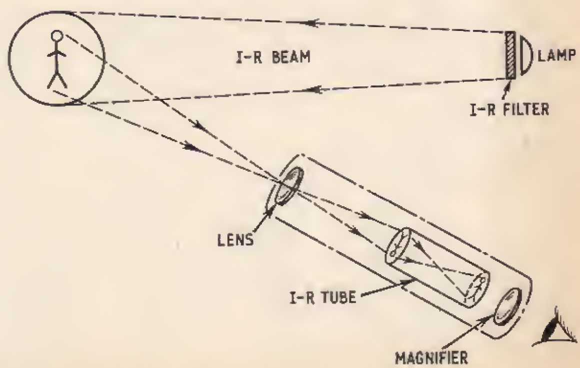


*Fig. 2. An active infra-red system consisting of an infra-red source, which is a normal lamp with a filter to remove the visible part of the spectrum, and an optical viewing system incorporating an image converter tube*

modulated audio signals. Propagation is by waveguide or line of sight, the waveguide being in the form of 2 micron diameter glass fibre.

This technique (known as "fibre optics") is becoming a commercially viable proposition, although certain difficulties still remain to be ironed out. Much work has been carried at the Ministry of Technology Signals Research and Development Establishment near Christchurch in close collaboration with industry to develop a system of communication in which telephone land lines transmitting at pure audio can be replaced by glass fibre.

## GLASS FIBRE OPTICS

The engineering aspect of producing suitable glass fibre is critical, chiefly in the elimination of impurities, particularly traces of iron, which gives ordinary glass the typical green appearance on its cut surface. Glass required for fibre optic communication must be "white" to avoid filtering and unnecessary attenuation, and must be of the correct dimensions.

In this, the single-mode or waveguide fibre, there are only a few possible modes of transmission and maximum bandwidth is obtained, typically 10,000MHz over 1km. This type of fibre is most suitable where very wide band, single channel systems are required, such as data or telephone trunk links.

If several fibres are contained in one "cable" no insulation is necessary between each provided the physical conditions of each fibre have been satisfied. This is because the refractive index of the glass ensures that the infra-red or light beam is kept within the bounds of each fibre. Consequently, common experiences such as stray capacitance and l.f. radiation and cross-talk are virtually non-existent in fibre optic communication. On the other hand, attenuation is at present still a problem which can be overcome by using line repeaters.

To minimise attenuation the beam must not be allowed to touch the walls. Early experiments involved the insertion of expensive servo-operated lenses at intervals along the length of fibre. More recently, it has been found that if the core is sheathed with a suitable glass cladding of lower refractive index the light will be adequately contained within the core.

Strange as it may seem, the glass fibre although only about as thick as human hair, has a high tensile strength

*An infra-red optical two-way telephone using YIG (yttrium iron garnet) modulator. Frequencies up to 100kHz and a range up to 2km is obtainable* (M.E.L. LTD.)

*The scene through a passive sight looking at an intruder under overcast, starlight conditions*

and is inherently flexible. If suitably protected from crushing and given a protective plastics coating, it can be inserted into cable ducts with the ease of conventional copper wire. So here we now have a 200-core cable with an overall diameter about the same as the conventional plastics covered *single*-core bell wire. Consequently more channels can be fed through underground ducts than with the present copper cable.

## LASER TRANSMISSION

Having looked at the link between two stations, what about the stations themselves; how does one get the signal into the fibre at one end and out at the other? The answer quite briefly is the laser and a silicon photodiode. The laser must emit a beam which can be injected into such a small diameter, must have high speed and efficiency and operate in the near infra-red region. Gallium arsenide electroluminescent sources are used in the laser which transmits at room temperature, a pulse code modulated signal. The laser beam is injected accurately near the source into the fibre end, which is sheathed in polished Perspex for laboratory convenience, and to reduce scattering on entry. The received signal is picked up by a silicon photodiode, decoded and amplified in the usual way.

By using glass fibre the laser beam is not dependent on straight line-of-sight transmission paths; indeed, there is no reason why the fibre should not be layed haphazardly or even in coil form, provided that bends and kinks are not unnecessarily severe.

## TUNING THE LIGHT BEAM

Optical communications systems rely on the usual signal generation as applied to any other form of radio communication. Harmonic generation, frequency mixing and frequency tuning take place at optical frequencies. Tuning is an interesting subject on its own and when applied to laser technology the results can be in the form of pure colour generation.

Experiments at S.R.D.E. have demonstrated the ability to "fire" a pre-tuned colour beam for a fraction of a second on a white screen. Development here is still at the purely experimental stage, but apart from being used in signal transmission, there is the possibility of applying the technique to coloured light displays.

A narrow band source of radiation can be tuned over most of the visible and near infra-red regions of the spectrum. The tunable source results from the selective addition of a laser frequency to a frequency from a continuum of frequencies generated by the laser in a liquid placed immediately in front of a non-linear electro-optical crystal.

## NEODYMIUM-GLASS LASER

A high power Q-switched neodymium/glass laser (Fig. 3) is used to generate an intense continuum of frequencies in a 20cm cell of carbon disulphide. As soon as the laser beam enters the liquid, it causes a non-linear increase in the refractive index of the liquid. The laser beam is forced into propagating in a region of relatively high refractive index, and is reflected in on itself at the interface between these two regions.

After a further non-linear increase in the refractive index, the laser is self-trapped and rapidly collapses into a filament, the smallest so far identified having diameters of about 2 to 5 microns. The power density in the filament is very high—about $10^9$ watts per square centimetre—leading to efficient stimulated scattering.

On leaving the carbon disulphide cell the intense continuum and unchanged laser radiation are directed

*A modified pair of binoculars used as an optical transceiver. The range is about half a mile, but the required power is minimal in comparison to conventional systems*

into a lithium niobate crystal where frequency addition takes place. Tuning of the sum frequency is achieved by altering the temperature of the lithium niobate. A tunable difference frequency has also been generated so that tunable narrow band frequencies can be generated in practically the whole 0·3 to 13·0 micron spectral range.

## ACTIVE LINE-OF-SIGHT

Other methods of active infra-red communication are generally based on line-of-sight transmission paths, although the modulation process is here applied to the transmitting crystal attached to a modified pair of binoculars. This method is limited in range to about half a mile, but the required power is minimal in comparison to conventional systems.

This makes the system particularly useful in environments where reflections from nearby structures would interfere with conventional systems. Examples would be in the building industry, ship's intercom and ship-to-ship radio telephone.

The added attraction is that the two stations, once lined up could be used for viewing as well as speech, forming a visual radio-optical telephone. The speech modulated signal is transmitted by a gallium arsenide lamp through the right-hand lens of the binoculars to the left-hand lens of the receiving binoculars. Inside this the optical picture is passed through to the eye piece in the normal way, while the speech signal is picked up by a silicon photodiode after being deflected by a specially coated prism.

## INTERFERENCE FREE

The link uses a pulse frequency modulation system at 20kHz, eliminating the critical factors of heat haze causing signal fluctuations, hand shake or changes in daylight level. A voice operated switch is incorporated to change from receive to transmit; the system is interference free and is completely secure from eavesdroppers.

The gallium arsenide *pn* junction in the lamp is forward biased to emit infra-red light at 0·9 micron wavelength. The range of the instrument is dependent on visibility and increases to about half a mile at a visibility of about 10,000 metres, although it is expected that improvements will be made in due course.

The foregoing principles have now been released for commercial exploitation, having been developed originally for military purpose, and are born out of the concept of using separate infra-red light beams to flood a particular scene or object for viewing with infra-red sensitive viewers.

The current state of the art in infra-red detection is expected to be put to use in industrial or civil espionage control and crime detection.

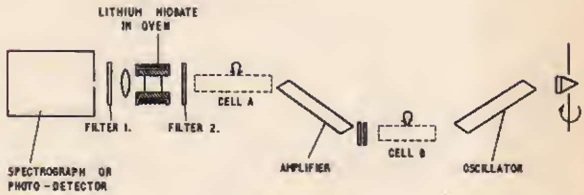


*Fig. 3. Block diagram of the neodymium glass tunable laser*

A typical example has been cited whereby the Thames river police are finding it increasingly difficult to make an arrest of dockside warehouse prowlers without arousing the attention of the prowler. The "telescopic" infra-red viewer can be used in pitch dark to watch the activities of an intruder. Of course, a lighted match or torch will apparently flood the infra-red scene immediately giving the security patrol an even better picture.

## PASSIVE LINE-OF-SIGHT

The passive system relies on the detection of objects by their emission of temperature variance with atmospheric temperature. The photograph of the potential intruder shows up clearly with the building. It is now possible to make devices which can discriminate a 1 degree difference between an object and its background. As a result such a device will detect the presence of an animal, a vehicle or human being.

A more advanced method is the thermal imager, incorporating several detectors and a scanning system. The signal is applied to a cathode ray tube to give a visual picture from heat contrasts rather than colour and brightness contrasts.

## IMAGE INTENSIFIER

Although not strictly relevant to infra-red, it is worth looking at recent development of image intensifiers because their applications are similar to those of passive infra-red detectors.

The image intensifier is a passive night vision device which can amplify light directly by 50,000 times. It is a small cylindrical encapsulation with three light intensifying modules each supplied by an e.h.t. of 15kV (Fig. 4).

Each module is a vacuum envelope with fibre optic input and output windows. A photocathode on the inner surface of the input window emits electrons according to the intensity of incidental light. These electrons are electrostatically focused and accelerated on to a phosphor screen on the output window to give a visible image.

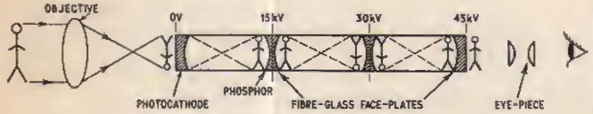


*Fig. 4. A three-stage cascade intensifier tube.*

A single module is not sensitive enough for poor light conditions; this is why three are usually banked together in a single envelope.

This intensifier needs no special lighting conditions, so true reproduction of natural light can be achieved, even in starlight conditions. The performance is dependent on atmospheric visibility, ambient brightness and contrast.

Applications lay in intensifying x-ray images, night navigation, and microscopy.

## FUTURE POSSIBILITIES

Infra-red detection has numerous applications in industry and public life. The Ministry of Technology has released details of the work described in this article and it is expected that the following lines will be followed up on the basis of infra-red experiments already, and still being, carried out.

Tremendous possibilities in the study of wild life and nature conservation seem apparent when one is told that Vampire bats have been successfully bred in this country for the first time under close observation by infra-red.

Automatic fire alarm systems become a much more simple and reliable proposition and can double up as intruder alarms at the same time.

Infra-red radio and television links can be coupled with trunk telephone lines in the laser powered fibre optic system.

Closed circuit broadcasting in a room equipped with a centrally placed gallium arsenide transmitter and infra-red detection equipment overcomes problems of multi-image reflection and absorption experienced from conventional radio devices; no wires are needed.

Telephone tapping is avoided by using the infra-red modulated binocular and fibre optic systems.

Development work is still going on at S.R.D.E. and co-operation from manufacturers including Barr and Stroud, English Electric, E.M.I., Elliott Bros., Hilger and Watts, Marconi Instruments, Mullard, Plessey and 20th Century Electronics, has brought to light some advances that could well place infra-red techniques in its rightly deserved place in civil communications.

Acknowledgement is made to the Ministry of Technology, S.R.D.E. Christchurch, for illustrations used in this article. ★