system about the optical axis, as was done in fig. 11, so the resulting camera layout will be rather less compact.

**Summary** In colour television, the light coming from the scene to be transmitted has to be split into a blue, a green and a red component. In most colour-television cameras, including those the Philips Company has been manufacturing in recent years, colour separation is achieved with a system of dichroic mirrors consisting of interference layers deposited on flat glass plates. This form of colour-separation system has a number of inherent drawbacks: the mirrors take up a relatively large amount of space, the objective fitted to the camera has to have a fairly large back focus, the support plates cause aberrations, the mirrors are exposed to damage, and large angles of incidence have to be reckoned with. The last-named drawback, which is associated with spurious colour gradation across the image, with unsatisfactory colour separation, and with unfaithful colour rendering when the incident light is polarized, is explained at length in this article.

All these difficulties are eliminated or greatly reduced by a newly developed system in which the colour-selective interference layers are enclosed in a cemented assembly of prisms. Several versions are described. Here the effective angles of incidence have been reduced from 42° and 35° to 31° and 31° respectively (or to 20° and 41° in another version of the new system). A graph is given illustrating the resulting improvement in colour-separating efficiency.

# FINGERPRINTING VIA TOTAL INTERNAL REFLECTION

by N. J. HARRICK *). 535.394:343.977.33

"The Rays of Light in going out of Glass into a Vacuum, are bent towards the Glass; and if they fall too obliquely on the Vacuum, they are bent backwards into the Glass, and totally reflected; .... if the farther Surface of the Glass be moisten'd with Water or clear Oil, or liquid and clear Honey, the Rays which would otherwise be reflected will go into the Water, Oil or Honey; and therefore are not reflected before they arrive at the farther Surface of the Glass, and begin to go out of it. If they go out of it into the Water, Oil, or Honey, they go on .... "

"... more evident by laying together two Prisms of Glass, or two Object-glasses of very long Telescopes, the one plane, the other a little convex, and so compressing them that they do not fully touch, nor are too far asunder. For the Light which falls upon the farther Surface of the first Glass where the Interval between the Glasses is not above the ten hundred thousandth Part of an Inch, will go through that Surface, and through the Air or Vacuum between the Glasses, and enter into the second Glass, .... "

Newton, Opticks, 2nd (English) ed. 1717, book III, part 1, query 29.

If one looks directly at a finger, the relief of the skin cannot be seen very clearly because there is little contrast between the hills and valleys. There is, therefore, little point in taking a direct photograph of this relief and in fact fingerprinting as applied e.g. in crime detection is still being done by the age-old ink process [1]).

Recently a photographic method has been developed which is capable of producing fingerprints of superior quality and promises to do away with the untidy ink process. The apparatus used is shown in *fig. 1*. It was based on the phenomenon of frustrated total reflection which was already known by Newton and so aptly described in the lines we have reproduced above. In modern terms, we can describe the phenomenon as follows.

If light travelling in a glass prism strikes a glass-air boundary at an angle $\Theta$ such that it is totally reflected, no light will propagate in the adjacent air but there is nevertheless a penetration of the electromagnetic field into it [2]). This is indicated by *fig. 2*; if $\lambda_g$ denotes the wavelength in the denser medium (glass), the depth of penetration is about 0.1 $\lambda_g$ near grazing incidence but reaches indefinitely large values near the critical angle $\Theta_c$ for total reflection. Owing to this penetration of the field, energy can be extracted from it when suitable matter is brought sufficiently near to the glass surface.

This can be demonstrated by a number of well-known experiments. If water, for example, is placed on a totally reflecting surface of a glass prism, it remains dark, but if a few drops of fluorescein are added to the water, a thin sheet of the liquid adjacent to the prism surface is seen to light up. If a second glass prism is placed at a distance $d$ of a

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[1]) For an interesting account of the history and techniques of fingerprinting, the reader is referred to: H. Cummins and C. Midlo, Fingerprints, palms and soles, Dover (reprint), New York 1961.

[2]) Incidentally, this entails a certain displacement of the totally reflected beam along the reflecting surface. Curiously enough, Newton's ideas also included such a displacement since he suggested that the path of the ray was a parabola with the vertex in the rarer medium (Principia Phil. Nat., book I, prop. 96). Experimental evidence of the displacement was obtained only as recently as fifteen years ago: see F. Goos and H. Hänchen, Ann. Physik 1, 333, 1947.

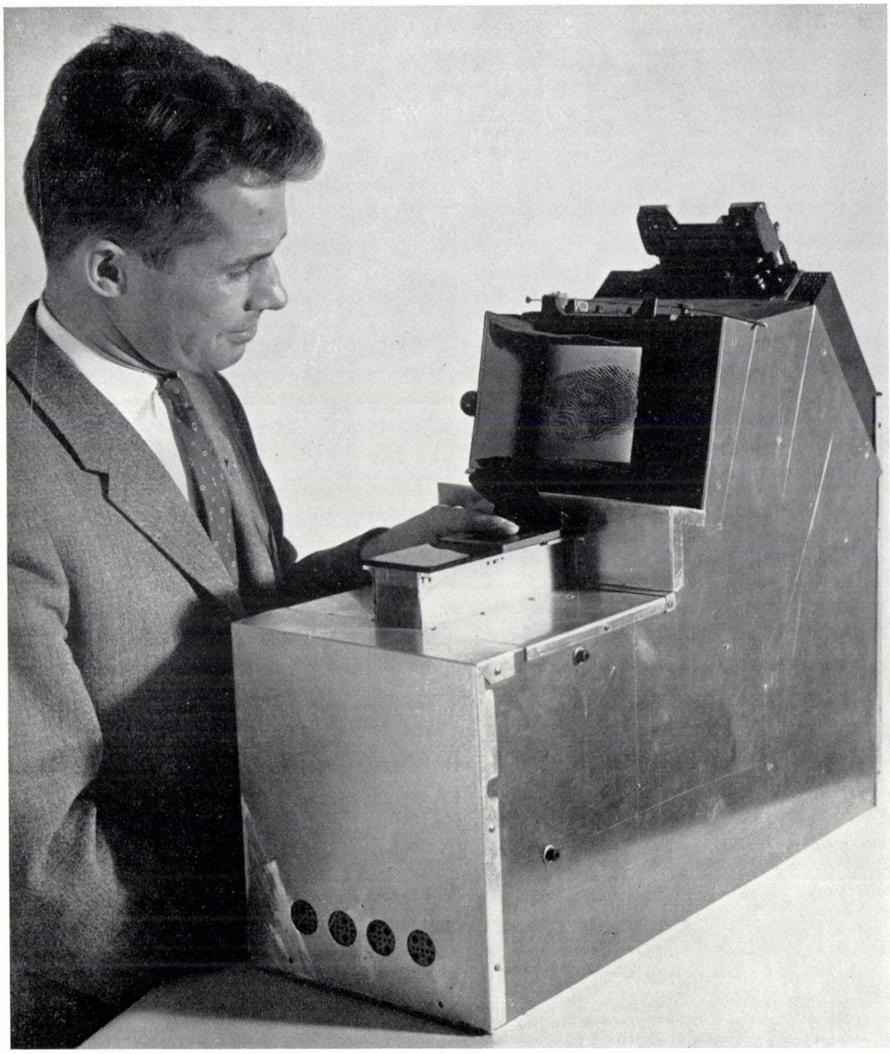

Fig. 1. Fingerprint recording apparatus. The finger is pressed on a face of a glass prism. On the ground-glass viewing screen an image of the surface relief of the finger at magnification 4× is produced. No ink is used. At the back of the apparatus a plate camera is mounted by which either negatives or instant prints using Polaroid film can be made. (Another apparatus has been built using a 35 mm camera.)

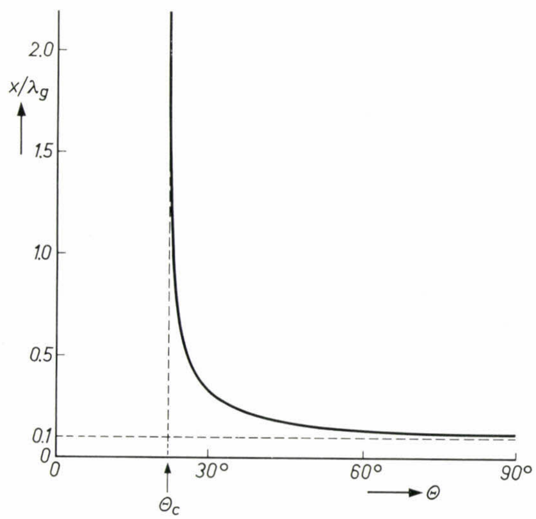


Fig. 2. At total reflection, there is a certain penetration of the electric field into the rarer medium, the field amplitude falling off with distance from the interface in an exponential manner. The penetration depth $x$, defined as the half-value distance, depends on the angle of incidence $\Theta$ as shown in the graph. $\Theta_c$ is the critical angle for total reflection, $\lambda_g$ is the wavelength of the light in the denser medium.

fraction of a wavelength from the first prism, energy of the penetrating field is used for propagation in the second prism, so that a transmitted beam is obtained. The reflectivity of the prism surface can thus be continuously adjusted between 100% and zero by adjusting the distance $d$, as shown in *fig. 3*. The latter experiment has given rise to applications such as a *light modulator*, obtained by modulating the distance $d$ and used for telephony on a light beam during the Second World War [3]), and a *cold mirror*, based on the fact that the penetration of the field increases with increasing wavelength $\lambda_g$, so that by suitable adjustment of $d$ the heat waves are transmitted and only the light is totally reflected.

Our application for fingerprinting is of the same nature: when a finger is lightly pressed on the totally reflecting glass surface the total reflection is frustrated at the ridges of the skin which make contact with the prism (and the now transmitted light

[3]) Electronics **17**, No. 1, 156, 1944.

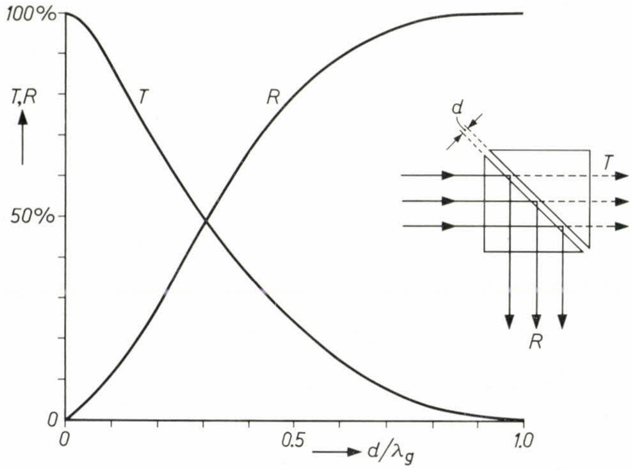


Fig. 3. By placing a second glass prism close to the totally reflecting surface of the first prism (distance $d$, see insert), energy is extracted from the penetrating field. The fraction of reflected ($R$) and transmitted light ($T$) will vary continuously according to this graph with variation of the distance $d$.

is absorbed in the skin), but not at the valleys or in the pores, where the reflection is still total.

A few points of the apparatus illustrated in fig. 1 should perhaps be explained. A mirror is provided in the optical system, as shown in *fig. 4*. This has been done in order to eliminate any confusion for those who are used to looking at ink prints, which are *reversed* images. The image screen (or the photographic plate which can be put in its place) is tilted with respect to the optical axis in order to compensate for the distortion arising from viewing the object (finger in contact with prism surface) obliquely: oblique incidence, of course, is essential for obtaining the effect. The magnification on the image screen is about 4×, which is adequate for a detailed examination of fingerprints, since the pores and other details can be seen quite clearly.

In *fig. 5* a fingerprint obtained in this way [4]) is compared to one taken by the ink technique. The latter was obtained from the same finger by a police officer, at our request (and was considered a good print). Note the high contrast, improved definition and absence of smudging in fig. 5*a*. The dots clearly visible in fig. 5*a* but not in *b* are pores in the ridges of the skin. *Fig. 6* is a photo of another fingerprint in which these pores show up even more clearly. A larger portion of the finger can be shown in a print by gently pressing the sides of the finger down towards the surface. It is also possible to increase the visible portion by suitably curving the contact surface of the prism, in which case, however, the required optics will become more complicated because the surface of the prism acts as a curved mirror.

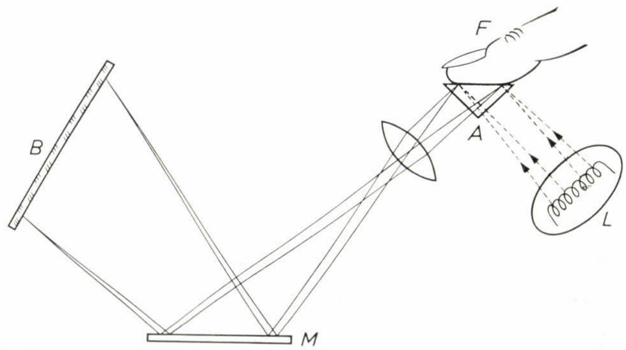


Fig. 4. Schematic diagram of fingerprint recording apparatus. *F* finger. *A* prism. *L* light source. *B* viewing screen. The mirror *M* serves a dual purpose: it reverses the image, so that the fingerprints on viewing will be similar to those obtained by the ink technique; and it simplifies the photographing procedure, since arrangements are made so that *M* can be tilted to deflect the image from *B* to the focal plane of the camera (not drawn).

[4]) The print of fig. 5*a* appeared as the cover picture on an issue of the J. appl. Phys. where this technique was first described: N. J. Harrick, J. appl. Phys. **33**, 2774, 1962 (No. 9).

*a* *b*

Fig. 5. *a*) Fingerprint recorded with the total-internal-reflection apparatus. *b*) Print of the same finger as in (*a*) obtained by the traditional ink method.

*Fig. 7* is a print of a portion of an infant's foot, reproduced on the same scale as the fingerprint of fig. 6. Footprints of infants are often used in hospitals for identification. The details on an infant's foot or palm are so fine that they generally do not show up when an ink impression is made; the latter will reveal only the outline of the foot and creases in the skin.

In addition to the greater clarity and rendering of detail that can be achieved and the cleaner procedure (since no ink is required), it will in some cases be an important advantage over the previous technique that the image can be viewed before printing and the print can be made instantly. Yet with all of these advantages, the apparatus is quite simple.

Fig. 6. Another fingerprint, in which the pores in the ridges of the skin are very distinct.

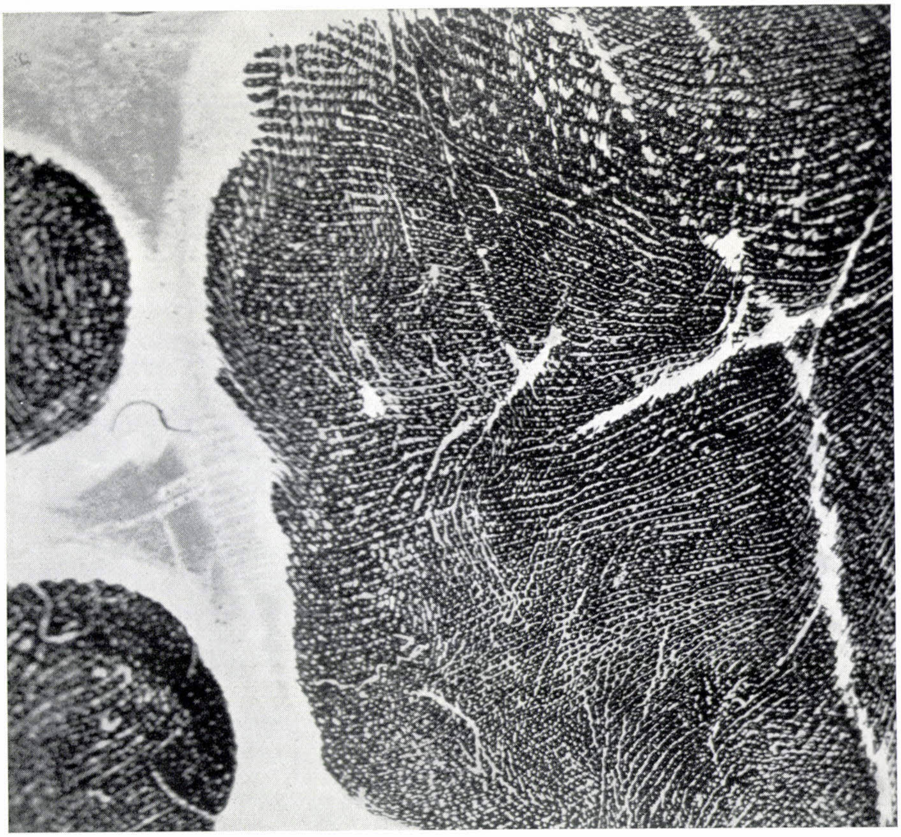

Fig. 7. Print of a portion of an infant's foot recorded with the total-reflection apparatus and reproduced on the same scale as the fingerprint in fig. 6.

Using essentially the same arrangement, frustrated total reflection can be put to other important uses, such as microscopic examination of samples in medicine and biology (where in some cases it can replace the technique of dark-field illumination for contrast enhancement) and the study of adhesives. More sophisticated methods still based on the same principle have been used for the study of the infrared spectra of monolayer films and also of the spectra of surface states in solid-state physics (in connection with research on transistors) [5]).

[5]) N. J. Harrick, Phys. Rev. Letters **4**, 224, 1960 and Phys. Rev. **125**, 1165, 1962. These and other applications have been reviewed in: N. J. Harrick, Annals New York Acad. Sci., Conf. on Clean surfaces (suppl. Surface phenomena in semiconductors), vol. **101**, 928-959, 1963.

**Summary.** The total internal reflection of light e.g. in a glass prism can be frustrated to an adjustable degree by placing another object close to the reflecting surface. Advantage has been taken of this phenomenon (described already by Newton) for several applications, such as light modulation, cold mirrors, infrared and surface-state spectroscopy, etc. A novel application is the production of high-contrast fingerprints (images of surface reliefs) which is described in this article.