Technical Notes

The following five Technical Notes have been contributed by authors at the Bell Telephone Laboratories, Inc., Holmdel, NJ 07733. Other contributions of a comparable nature will be welcomed for Journal *publication.*—Ed.

Photographic and Photoelectric Detection of Optical Pulse Codes

By J. S. COURTNEY-PRATT and L. E. HARGROVE

In 1965, we studied the light output of an intracavity-modulated gas maser using photographic and photoelectric techniques. The description of the work has been published in *Jour. SMPTE, 74:* 1085–1095, Dec. 1965. We found that we could easily photograph the individual pulses of light even when there was optical attenuation (from the output end of the maser to the photographic emulsion) of about a factor of 1500. With this attenuation, the photographic dots were still quite detectable, i.e., the signal/noise ratio was still reasonably large.

At another time during the experiments, we allowed the light from the maser to fall on one of the new fast photocells that had been developed at Bell Telephone Laboratories. The output from the photocell was displayed using a sampling oscilloscope. The pulses are well above noise. The peak pulse height was perhaps 10 or 15 times the rms value of the noise. This meant that we were much more easily able to detect the pulses photographically than photoelectrically.

In our work, photographing the glints from the mirrors on Telstar (see the paper by Courtney-Pratt, Hett and McLaughlin, *Jour. SMPTE, 72:* 462–484, June 1963), we found that it was considerably easier to detect the pulses photoelectrically than it was to detect them photographically. The glints from the mirrors on Telstar have a duration of about a millisecond, whereas the pulse duration from the intracavity-modulated maser is about a million times shorter.

Why is it that in one set of experiments (Telstar glints) it was easier to distinguish a light pulse using a photocell while in the other set of experiments (the maser experiments) it seemed easier to detect the pulses using photographic recording? It seems that the reasons might very well be quite general and be dependent on the time scale. To detect very brief pulses at high pulse rates, the bandwidth of the photocell must be large. Some forms of noise in the amplifier associated with the photocell would increase either as the square root of the bandwidth or perhaps even directly as the bandwidth depending on the origin of the noise.

Suppose, on the other hand, we know just where on the photographic emulsion a patch of light may fall or may not fall. We can consider the photographic density with or without the light, and we should consider what change in density the light produces relative to the statistical fluctuations in density that occur in correspondingly sized patches of the emulsion where it is otherwise unexposed. If there is no reciprocity failure in the emulsion, the signal should be just as detectable whether it is recorded at high speed or not, as the noise associated with the fluctuations in photographic density is unaffected.

Consider a communication channel in which one modulates the intensity of the maser beam. For simplicity, consider on-off modulation or pulse code modulation with a pulse duration t (or a little less) and a pulse repetition frequency $1/t$. If $1/t$ is small (say less than a million cycles per second) it would probably be much easier to detect the pulse code using a photomultiplier as the detector. Suppose, however, we wish to increase $1/t$ to 10^9 or even higher. It then seems that it is difficult to obtain a photocell in which the noise is low enough that we could use small signals. Photographic detection would appear relatively better. We could take out the advantage in several ways: perhaps we could use a smaller transmitter; perhaps transmit over greater distances, or under more adverse conditions; or perhaps could distinguish more levels of signal than the simple on and off. There would be the delay in processing the film, but rapid processors can operate in a matter of a second or two. Readout could be at full speed because local readout source intensity could be as high as one wished. Alternatively, if one wished to have considerably easier readout systems, one could readout at some lower frequency. Alternatively, with pulse sequence multiplexing, one could use different photocells (one for each multiplex channel), and divert the readout signal after its passage through the recorded sequence on the film to the appropriate photocells.

Multiple Images

By J. S. COURTNEY-PRATT

Some time ago, I was asked to consider ways of producing multiple images of the kinds required in microcircuits and semiconductor work. One could make use of the multiple reflections between two (partially transmitting) reflectors spaced a short distance apart to produce a string of images. The quality of these images would be dependent only on the quality of the reflecting surfaces and so could be high. The intensity drops off from one to the next by a small factor, but the drop could be as small as a few per cent and perhaps even less, and in any case could be compensated if one wished by use of a tapered or stepped wedge at a later point in the system. One could use each of these reflected images as a source for a second set strung out in a different direction, probably at right angles to the first set, or perhaps at 60°. One would then achieve a two-dimensional array of images. The intensity in the absence of a correcting mask would vary a little from one image to the next. On the other hand, the image quality could be high and the optical components required would not be critically difficult to manufacture.

Increase of Flux Per Unit Area by Refraction From a Plane Surface

By J. S. COURTNEY-PRATT

Some time ago, I was making calculations on the amount of light that is reflected and refracted at a surface near the critical angle for total internal reflection. To check a point, I began to read Section 28 of the book *Fundamentals of Optics*, 2nd. Ed., by F. A. Jenkins and H. E. White (McGraw Hill Book Co., 1950). I noticed particularly the following paragraph on page 564: "It is the total energy of the reflected and refracted rays that is complementary. Now the energy of the beam of light with constant amplitude depends on the index of refraction of a medium as well as on the square of the amplitude. It also depends on the area of the beam, and, as was shown in Section 2.1, the cross-sectional area of the refracted beam increases with the angle of incidence by the amount $\cos \Phi'/\cos \Phi$."

Jenkins and White have commented that the beam gets larger when it is refracted obliquely into a more dense medium.

I had been considering a beam of light that was incident on the bounding surface from the more dense side. I had been drawing curves of the amount of energy that would be refracted out of the dense medium as a function of the angle of incidence. I checked again the angles of incidence and refraction for that angle that would give an energy in the reflected beam of 75% and therefore an energy in the refracted beam of 25% of the incident energy. I realized that the width