MATH'S NOTES

BY IRWIN MATH, WA2NDM

WHAT'S NEW AND HOW TO USE IT

A Primer on Optical Communications—Part I

First I would like to wish all readers of this column the best for 1997. May this be the year all of your hopes, dreams, and aspirations come true!

I will begin the new year with a series of columns that will introduce most of you to the world of light wave communications. As I stated in December, and previously, there are many new worlds awaiting the experimenter. Hopefully this series will inspire some of you to take a look at one of them. Now to business.

We all are familiar with "The World Above 50 MHz" from articles in this magazine and the other amateur radio publications. We all have come across microwave-related articles on occasion, and some of us have even built, or considered building, 10 GHz (and higher) transmission links using Gunn diodes and the like. In the next several columns, however, we will explore a totally new area—the world above 150,000 GHz, or the world of light wave transmission. We will learn about the various similarities to and differences from lower frequency RF and how to employ this technology in our experimentation. We will learn about optical transmission methods from the transmitter to the receiver, look at "optical antenna equivalents," and finish our discussion by touching on the new technology of fiber optics. Since *CQ* is, after all, an amateur radio journal, and since I fully believe in homebrewing as I have mentioned ad-infinitum, actual circuitry will be given, wherever possible,

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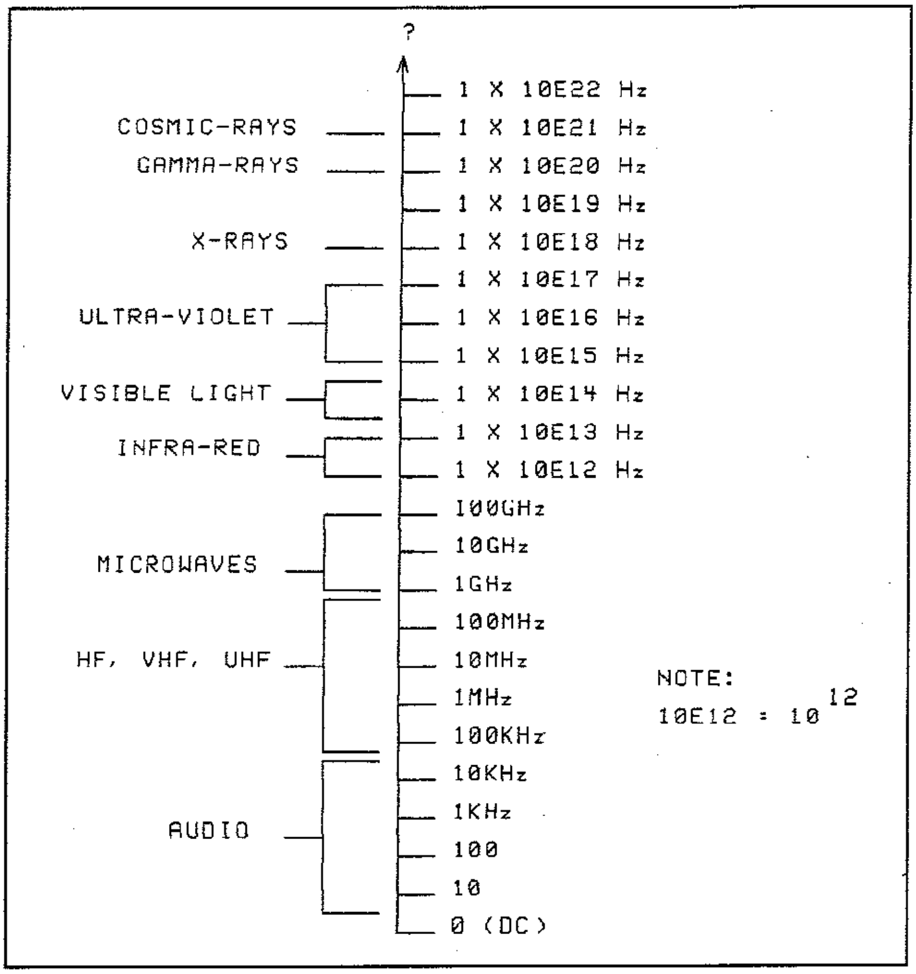

Fig. 1– A rough approximation of the electromagnetic spectrum.

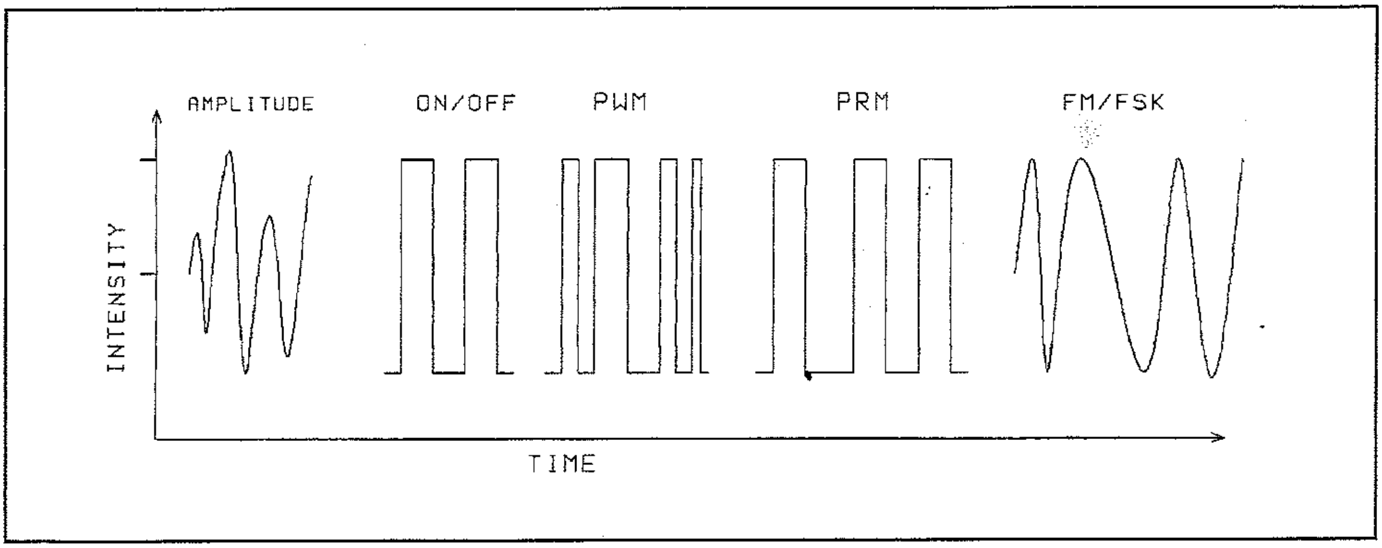

Fig. 2– Some of the ways that an LED can be modulated.

to enable the experimenter to gain real hands-on experience.

When one thinks back to the time in 1912 when amateurs were restricted to the "useless frequencies" below 200 meters (1.5 MHz and above) and the discoveries and contributions they made without extensive laboratories and sophisticated equipment, one can only wonder if these feats can be repeated in the apparently "restricted transmission range" of light wave signals. I believe they can, so perhaps we can "show them all" once again! I certainly hope so.

Fig. 1 is a simple chart showing the relationship of the various electromagnetic frequencies currently known and used by man. As one can see, the light wave frequencies (from 1x10E12 Hz to 1x10E14 Hz) are farther away from the bands we are used to than audio is from 2 meters! Light is, nevertheless, electromagnetic radiation (the same as RF), and as we will see, exhibits similar behavior.

Generating these super-high frequencies is simple. A light bulb, LED, or Laser Diode does it all the time. Amplifying, modulating, and mixing them for transmission purposes is something else, however, but not beyond the capabilities of the average amateur radio operator. Simple point-to-point communications systems can easily be built, so all is certainly not lost. Doing research and developing the art is what "separates the men from the boys," as the expression goes.

In any optical transmission system, as in its RF counterpart, there must be a transmitter and a receiver. In the case of an optical transmitter the source of the carrier is usually an LED or a solid-state Laser Diode. For our initial discussions we will employ LEDs, as they are much lower in cost, safer, and easier to use. We will touch on lasers later.

Fig. 2 shows some of the ways that we can modulate an LED. We can use amplitude modulation (or "intensity modulation," as the field calls it) by varying the brightness of the LED around some quiescent point in the same manner that an AM transmitter varies the amplitude of its carrier. We can use CW by turning the light source on and off, the equivalent of turning an RF carrier on and off. We can even use wide-band or narrow-band "FM" by varying the frequency of a sine or square wave "carrier" that in turn is used to turn the LED on and off. (When a square wave is used in this manner, the modulation scheme is know as "pulse FM.") Keep in mind, however, that in this case the FMing is done on the electrical signal that drives the light source, not on the actual light source itself. To actually vary the frequency of a light source would result in "color modulation," a technique that is experimental at present (but certainly not impossible).

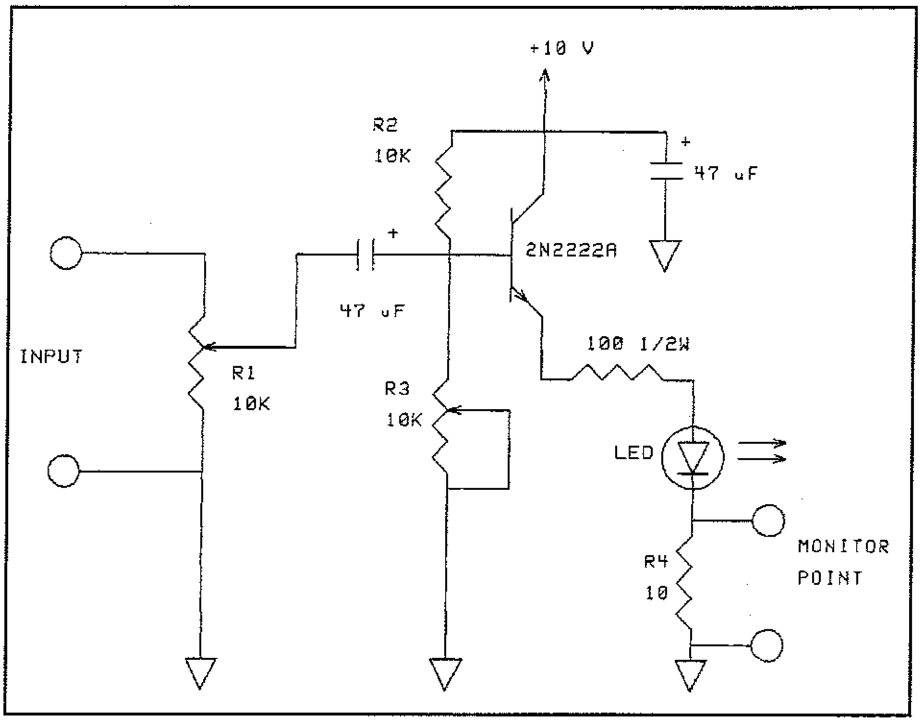

Fig. 3– Simple intensity modulated optical transmitter.

The nature of the signal to be transmitted, for the most part, is what usually determines the modulation method to be used in an optical communications system. This is primarily because only on-off and variable intensity are the easy ways to modulate an LED. Audio- and video-type signals, for example, usually use AM. Morse Code, RTTY, and other digital-type signals use on-off modulation. You could also use on-off modulation for audio or video by one of two methods. The first would be to use the signal to FM modulate the output of a digital oscillator and then use this output to turn the transmitting LED on and off. The other way would be to convert the audio or video into a true digital format with A/D devices, and later reconvert the received digital pulse train back to analog with D/A devices. Both methods are currently used, but require more complex circuitry (beyond the scope of this series) especially with wide-band signals such as video.

Fig. 3 is a schematic diagram of a simple AM light wave transmitter. You will note that it consists of little more than an emitter follower, a few resistors, and an LED. To "get our feet wet," any visible red indicator LED, such as the RadioShack 276-087, may be used. Once the unit is operating, this LED can be changed to a higher power device if desired. You can build the circuit on a piece of perfboard or even in one of the popular experimenter's plug-in breadboards.

After building the circuit, turn R1 to the 0 ohms position (maximum attenuation) and R3 to the 0 ohms position also (no LED bias). Now apply power to the circuit. Connect an oscilloscope (set to 0.1 volts/division, DC coupled) across the 10 ohm monitoring resistor. Each tenth of a volt developed across this resistor corresponds to 10 milliamperes of current flowing through it and the LED in series with it. Slowly adjust R3 for a reading of 0.2 volts DC. This corresponds to 20 ma of current flowing through the LED, which should be on at this point. The 20 ma level is the zero signal quiescent or half-power point, and R3 can be thought of as the power-output or carrier-level control. Since this circuit is capable of providing quiescent current levels of almost 50 ma, be careful. If you try to drive more current through the LED than it can handle, you may damage it.

Now apply a 1 kHz sine wave to the input while observing the monitoring point on the oscilloscope. Set the generator to 1 volt rms (2.8 volts peak-to-peak). Slowly increase R1 (which now becomes the percent of modulation control) until the lower half cycle of the sine wave is almost at 0.05 volt (5 ma) and the upper half cycle of the sine wave just reaches 0.4 volt (40 ma). This is twice the normal level of a 20 ma LED, but since the lower half cycle of the sine wave is at 5 ma, the average LED current is approximately 20 ma and the LED is not overdriven. Later you can experiment with higher drive currents.

Once this is achieved, the transmitter is fully operational and fully modulated. If you try to increase the level of the modulating signal further, you will clip at the lower end when the LED cuts off and possibly damage the LED at the higher end due to excessive current. If you wish to test your transmitter, a simple solar cell connected to a pair of high-impedance earphones will serve as a very simple test receiver. In optical communications circles this type of receiver is the equivalent of the early crystal set. At the moment, however, it will illustrate that the circuit is actually transmitting the sine wave. You may have to orient the solar cell directly over the LED to get a usable signa,l but you should hear the 1 kHz tone.

Now that we have some idea of how to build an optical transmitter, next month we will look at ways of elaborating on it to transmit audio in the form of speech.

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MATH'S NOTES

BY IRWIN MATH, WA2NDM

WHAT'S NEW AND HOW TO USE IT

A Primer on Optical Communications—Part IV

Last month we completed construction of an optical receiver. Now it is time to investigate "optical antenna" techniques so that our equipment can be converted into a true communications device.

The purpose of an optical antenna, obviously, is the same as that of its RF counterpart—namely, to "launch" the signal from the transmitter into the air and to then receive it at the receiver. Due to the ultra-short wavelength of light, however, it is very easy to produce narrow output beams. As a result, whip and ground-plane omni-directional radiators or long-wire/dipole-type configurations normally are not used. In fact, they often are more complex to implement at these wavelengths. Highly directional, beam-producing optical antennas are the norm. Just look at a flashlight! The term "optical antenna" therefore primarily refers to a group of techniques employed to direct (and collect) the light in a relatively tight beam.

Fig. 1 is a diagram of the approximate radiation pattern produced by the LED (by itself) used in last month's transmitter. You will notice that the light from such an emitter diverges at a fairly high angle (which can be anywhere from about 25 to 50 or more degrees). After only a few feet or so the field intensity of the milliwatt radiating LED drops off very quickly. This is the main reason why TV remote controls have an operating range of only 20 to 30 feet. Obviously, some method is needed to steer the majority of the output in the direction we wish if a practical communications link is to be implemented.

The most common scheme for directing light from an LED is by the use of a simple double-convex (or magnifying) lens placed in front of the LED. The correct position of this lens is based on the focal length of the lens, as we will see shortly. The focal length of any lens can be found by producing an image of a distant point, such as a light bulb, on a white paper or cardboard screen with the lens as shown in fig. 2. The distance from the lens to the image is the focal length. The point at which the image falls is called the "focal point." Note that at the focal point there is an image (inverted) of the source of the light. When one uses a magnifying lens as a "burning lens," the hot spot (which is the focal point) is a tiny image of the sun. If you try this, be careful. The

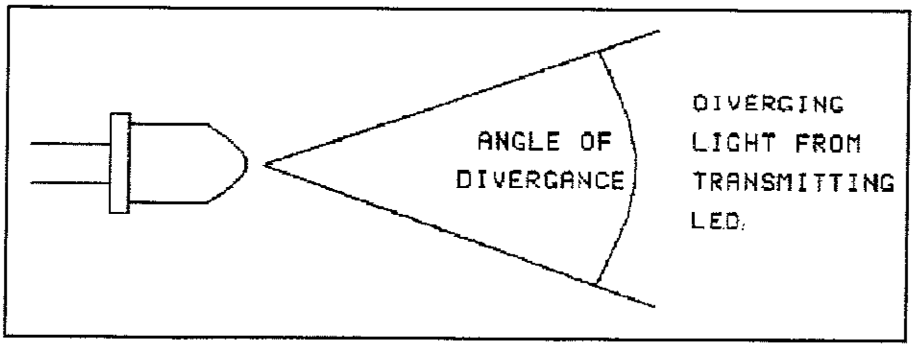

Fig. 1– Typical divergence of light from an LED.

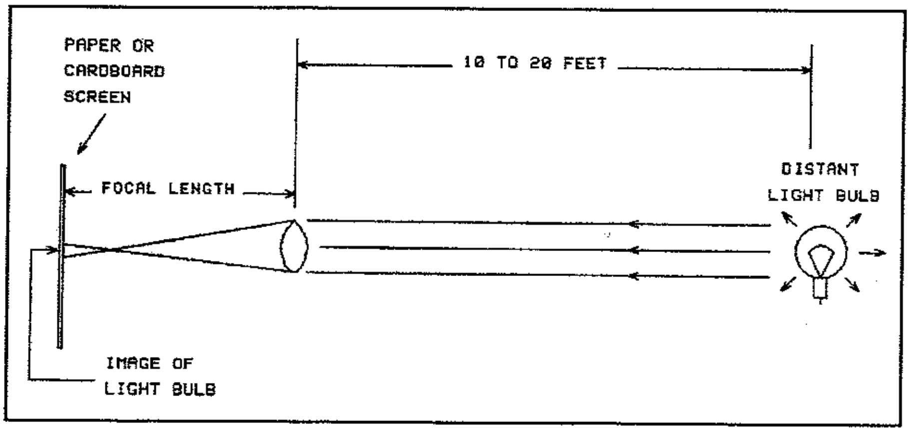

Fig. 2– Method for finding the focal length of a lens.

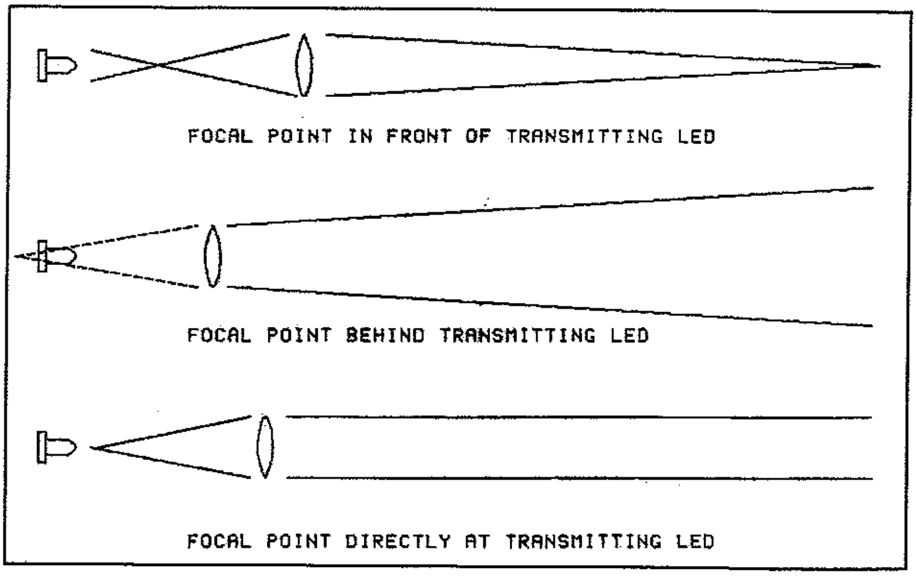

Fig. 3– Various possible lens/LED locations.

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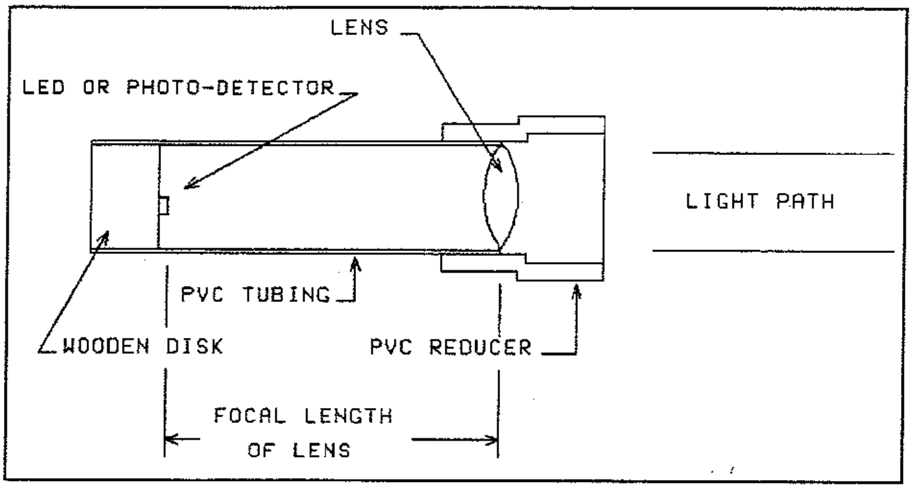
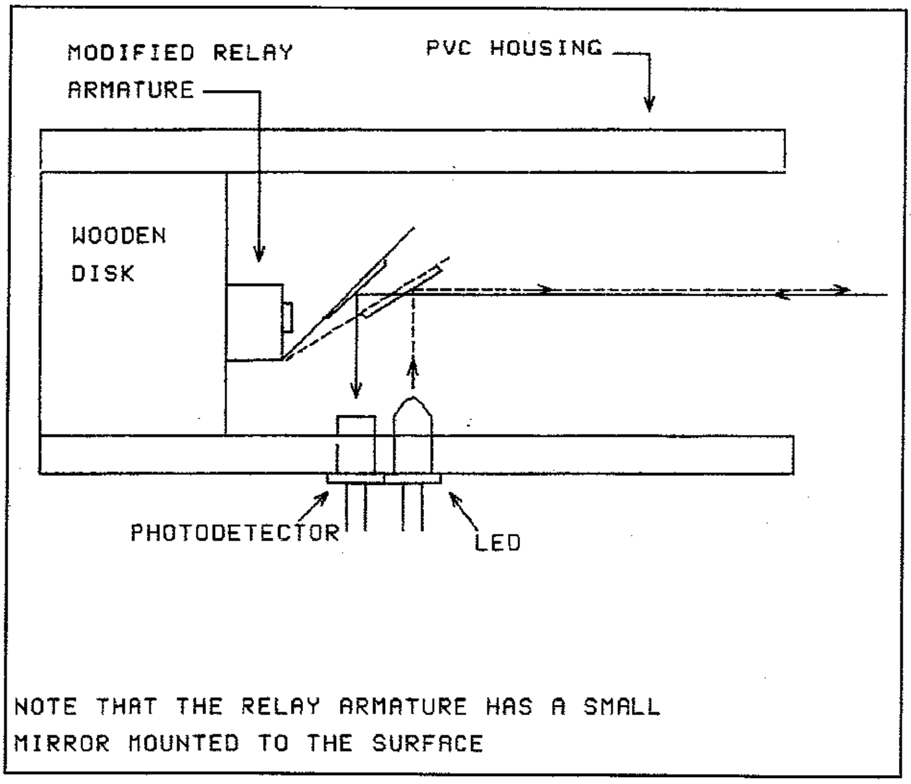


Fig. 4– Simple transmit or receive lens assembly.

sun's image can be hot enough to start paper burning!

Once the focal length is known, there are three possible positions such a lens can have in relation to the LED. These are shown in fig. 3. If the lens is placed so that its focal point falls in front of the LED, the light will converge into a point (image) at some distance in front of the lens. If the lens is placed so that its focal point falls behind the lens, then the light will diverge (spread) and the result will be even worse than with the LED alone. However, if the lens is placed so that its focal point lies directly at the light-emitting surface of the LED, a collimated (parallel) beam of light will result. Although this beam will not be perfectly parallel (a discussion of why is beyond the scope of this investigation), it certainly will suffice for our preliminary experiments. In addition, if the transmitting lens has a long focal length, the degree of collimation will be small. Furthermore, the larger the diameter of the lens, the more light it will collect from the LED. A further discussion of collimation and the detailed use of lenses can be found in any good physics textbook.

At the receiving end of an optical communications link the idea is to collect as



NOTE THAT THE RELAY ARMATURE HAS A SMALL MIRROR MOUNTED TO THE SURFACE

Fig. 5– Method for switching from transmit to receive.

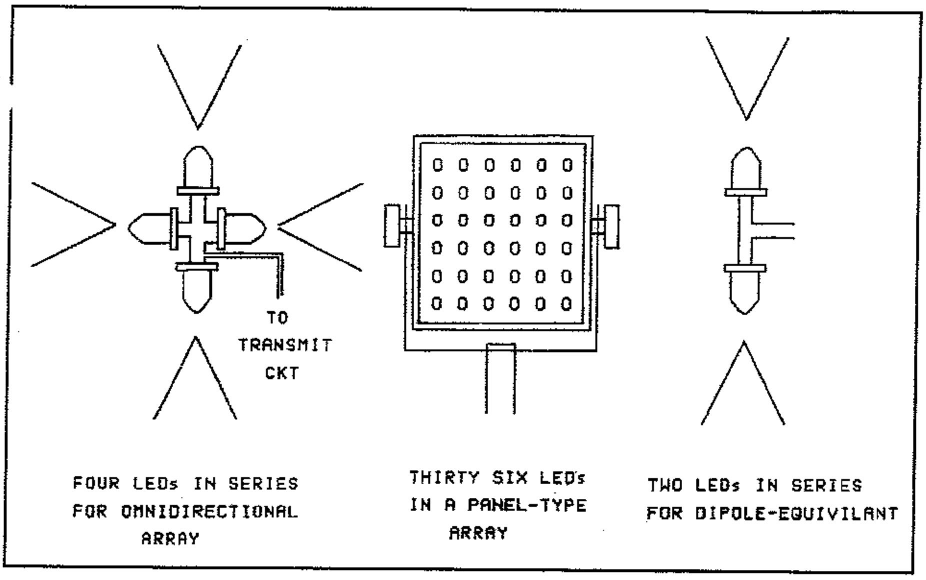


Fig. 6— Various possible optical antennas.

much of the transmitted light as possible and focus it onto the photo-detector. As in the case of the transmitter, this also requires that the photo-detector be located at the focal point of the lens used and that the lens be as large as possible to collect the maximum amount of light. Since both of these requirements for lenses are essentially the same, it is not unreasonable to use the same lens for both transmitting and receiving. After all, in RF we usually use the same antenna for both.

Fig. 4 describes the simplest way to implement a lens-based system. With this scheme you will need two assemblies: one for transmitting and one for receiving. Both are mounted in PVC pipe with the optical emitter and detectors mounted to wooden or plastic disks that can slide in the tubing for fine adjustments. A PVC reducer is used as a sun shade on one end for a finished "professional" look. A PVC end cap can also be used to protect the hoto-elements after adjustment.

To align the transmitting lens assembly, slide the wooden block to the approximate focal point of the lens being used. Turn on the transmitter (lighting the LED) and arrange one of the receivers at least 10 feet away on the optical axis of the system. First adjust everything so that you have some measurable output from the first stage of the receiver. An oscilloscope connected to the output of the stage should be used to make this measurement. Now carefully slide the wooden disk back and forth until maximum voltage is measured. When this is accomplished by means of set-screws in the PVC tube, or with a small dab of glue, secure the wooden disk into place.

If you have the patience and skill, you might wish to attempt the scheme shown in fig. 5. Here only one lens assembly is used and a mirror, mounted to the moving armature of a solenoid or relay, directs the optical path to a photo-detector or LED as required. When building this sort of assembly, alignment is critical to get everything optimized. However, the convenience of a single antenna is worth it. If you do attempt such an "antenna," use a long-focal-length lens and one with a diameter as large as you can reasonably afford for best results. I have seen some 4 inch diameter plastic lenses sold as inexpensive "reading glasses" that would be ideal. You might also wish to request the Edmund Scientific Company catalog (call 609-573-6250), which is chock full of lenses, mirrors, and the like. Similar schemes can be implemented with mirrors, telescopes, or whatever else your imagination can come up with.

For those who wish to experiment with omni-directional optical antennas or dipole-equivalents, you can connect several LEDs in series, or even implement arrays of LEDs. Fig. 6 shows various suggestions. In a future column, if interest is there, we will be pleased to continue this series, offering circuitry for using laser diodes as emitters and even describing modulation techniques other than simple AM. If you come up with equipment that is easily reproducible, I will be glad to comment and pass it on to other readers. Write to me with your suggestions.

With regard to the field of fiber-optic communication, much of the information contained in the prior three columns is almost directly applicable. In fact, for the most part, only the light-emitting and detecting schemes really change very much. Next month, in the concluding portion of this series, we will take a closer look at this technology.

This concludes the initial description of the field of free-space optical communications as slanted toward the amateur radio experimenter. I sincerely hope it has sparked the imagination of at least a few of my readers. Although communicating with light employs frequencies that are magnitudes beyond the RF spectrum that we are used to, the possibilities are enormous. This is a new technology just waiting for innovation. Get out the old soldering iron (and lens cleaners) and show the world that the amateur community and "Yankee Ingenuity" are not dead yet!

73, Irwin, WA2NDM