LECTURE 21

FIBER OPTICS

One of the reasons for taking up the topic of fiber optics is that its significant history occurred within my scientific lifetime, and I can therefore give you a report of how the topic looked to me at the time it was occurring. Thus it provides an illustration of the style I adopted when facing a newly developing field of great potential importance. The field of fiber optics is also, of course, important in its own right. Finally, it is a topic you will have to deal with as it further evolves during your lifetime.

When I first heard of a seminar on the topic of fiber optics at Bell Telephone Laboratories I considered whether I should attend or not - after all one must try to do one's own work and not spend all one's time in lectures. First, I reflected that optical frequencies were very much higher that the electrical ones in use at that time, and hence the fiber optics would have much greater bandwidth - and bandwidth is the effective rate, (bits per second), of transmission, and is the name of the game for the telephone company, my employers at that time. Second, I recalled that Alexander Graham Bell had once sent a telephone conversation over a light beam - but then he was a bit of a gadgeteer all his life. So it could be done, and had been done long ago. Third, I also knew about the internal reflections as you go from a higher index medium to a lower index medium - you see it in still water when viewed from below where there are angles which totally reflect the light back down into the water, Figure 21-1. Hence I understood, in a fair way, what an optical fiber would be - they were a novel idea then. I certainly had had enough experience in college labs with drawing glass into fibers to understand how easy it would be due to the effects of surface tension to make round fibers of a fairy uniform diameter, and to some extent the corresponding role of surface tension for liquid glass. Hence I took the time to go and learn about this promising new development.

During the early part of the talk the speaker remarked, "God loved sand, He made so much of it." I heard, inside myself, that we were already having to exploit lower grade copper mines, and could only expect to have an increasing cost for good copper as the years went by, but the material for glass is widely available and is not likely to ever be in short supply.

Either at that lecture, or soon afterwards I heard the observation, "The telephone wire ducts in Manhattan (NYC) are running out of space and if the city continues to grow, as it has of late, then we will have to lay a lot more ducts and this means digging up streets and sidewalks, but if we use glass fibers with their smaller diameters then we can pull out the copper wires and put the glass fibers in their place." This told me that for that reason alone the Labs would have to do everything they could to develop glass fibers rapidly, that it was going to be an ongoing source of computation problems, and hence I had better keep myself abreast of developments.

Long before this, once I had decided to stay at the Labs and realized my poverty in the knowledge of practical electronics, I bought a couple of Heathkits and assembled them just for the experience, though the resulting objects were also useful. I knew, therefore, the amount of soldering of wires that went on, and immediately identified a difficult point to watch for - how did they propose to splice these fine, hair sized, glass fibers and still have good transmission? You could not expect to simply fuse them together and expect to get any decent transmission.

Why such small diameters as they were proposing? It is obvious once you look at a picture of how a glass fiber works, Figure 21-2. The thinner the diameter, the more the fiber can bend without letting the light get out. That is one good reason for the smaller and smaller proposed diameters, and it is not the cost of the material nor the extra weight of larger diameter fibers. Also, for many forms of transmission, a smaller diameter fiber will clearly have less distortion in the signal when going a given distance.

There was another major dividend that I soon realized. The fibers are so efficient, meaning that they lose so few photons, that "tapping" a line will be a difficult feat. Not that it is impossible, only that it will be difficult. About the same time I came to realize (due to some computations I was doing with a group in chemistry) that fiber optics were resistant to electromagnetic disturbances - especially atomic bomb explosions in the upper atmosphere or on a battle field, or even lightening strikes. Yes, fibers were bound to get large amounts of support for further research from the Military, as well as from the Labs directly.

A trouble that soon arose, and I had anticipated it, was that the outer sheathing put on the fine Hair-sized fibers might alter the local index of refraction ratios and let some of the light escape. Of course putting a mirrored surface on the fiber would solve it. They soon had the idea of putting a lower index glass sleeve around the higher index core, at human sizes where it is easily done, and then drawing out the resulting shape into the very thin fibers they needed.

Much later I heard of not one layer, but a smoothly graded change in index of refraction, and recognized that this was the same thing as the strong focusing that had been developed some years before for cyclotrons. The grading could be done either by chemical or radiation treatments. Rather than have sharp reflections, you can use the gradual bending of the rays back to the center as they get away from the middle of the fiber, Figure 21-3.

I did not try to follow all the arguments for the multi-mode vs. the single-mode methods of signaling - and while I did a number of simulations via computers for the two sides of the debate, I sort of backed the single mode on the same grounds that we had backed the binary against any higher base number systems in computers. It is a technical detail anyway, including the details of detectors and emitters, and not a fundamental feature of the optical signaling.

Along the way I was constantly watching to see how they were going to splice the fibers. With the passage of time there were a number of quite clever ways proposed and tested, and the very number of alternates made me decide that probably that feature which first attracted my attention would be handled fairly easily - at least the problem would not prove to be fatal in the field where it has to be done by technicians and not in the labs where things can be done by experts under controlled conditions. I well knew the difference by watching various projects (mostly in other companies) come to grief on the miserable fact that what can be done reliably in the lab by experts is not always the same as what can be done in the field by technicians who are in a hurry and are often operating under adverse conditions, to say the least.

As I recall they first field tested fiber optics by connecting a pair of central offices in Atlanta, Georgia. It was a success (the trial required some years to complete). Furthermore, outsiders from the glass business began to make glasses that were remarkably clear at the frequencies we wanted to use - meaning the frequencies at which we had reliable lasers. They said that if the ocean waters were as clear as were some of the glasses then you could see to the bottom of the Pacific Ocean!

I soon noticed that in the fiber cables we were: (1) detecting the optical signals, (2) converting to electronic form, (3) amplifying it, and (4) converting back to optical form. It is hard to imagine a worse system design. So it was immediately evident to me that the Labs, and many others, would have to work intensively on optical amplification. Watching things from afar, it soon became evident that there were several candidates for optical amplifiers, and therefore probably one or more would materialize as standard field equipment. One of the virtues of solitons is that they can be amplified without changing their shape (which does not degrade as it goes along the fiber) while pulses are regenerated, (which effectively reshapes them and appears to be slightly more complex an operation than simple amaplification).

All the practical parts seemed to be coming together remarkably well, and as you know we now use of fiber optics widely. I have told you as best I can, how I approached a new technology, what I looked for, what I watched for, what I ignored, what I kept abreast of, and what I pondered. I had no desire to become an expert in the field; I had my hands full with computers and their rapid development, both hardware and software, as well as the expanding range of applications. Every new field that arises in your future will present you with similar questions, which you will effectively answer by your later actions.

The present applications of fiber optics are very wide spread. I had long realized that as time went on the satellite business was in for trouble. Stationary satellites for communication must be parked above the equator; there is no other place for them. A number of the countries along the equator have, from the earliest days, claimed that we were invading their airspace and should be paying for the use of it. So far they have not been able to enforce their claims, as the advanced countries have simply continued to use the space without paying for it. I leave to you the justice of the situation: (1) the blatant ignoring of their claims, (2) whether or not they have a legitimate point, and (3) if because they are unable to use it now everyone else must wait until they can - if ever! It is not a trivial question of international relations, and there is some merit on all sides.

The satellites are now parked at about every 4° or so, and while we could park them closer, say 2°, we will have to use much more accurate (larger diameter?) dishes on earth to beam signals up to them without one signal slopping into the adjacent satellites. To a fair extent we can widen the bandwidth of the signaling and thus for a time extend the amount of traffic they can carry, but there are limits due to the atmosphere the signals must traverse. On the other hand, fiber optics can be laid down on earth with any density you wish; cables of fibers can be easily made and the total possible bandwidth boggles the mind. The use of satellites means <u>broadcasting</u> the signal - cables give a degree of <u>privacy</u> and the ability to make the user pay rather than get a free ride. Both satellites and cables have their advantages and disadvantages. At present satellites are frequently being used for what are essentially private communications and not broadcast situations. Time will probably readjust the matter so that each is used in their best way.

Where are we now? We have already seen transoceanic cables with fibers instead of coaxial wave guides at a great deal less cost and a great deal more bandwidth. We are at the moment (1993) haggling over whether to use the most recently developed <u>soliton</u> signaling system or the classical pulse system of communicating across the Pacific ocean to Japan. It is, I think, a matter of engineering development - in the long run I believe that solitons will be the dominant method, and not pulses. I advise you to watch to see if there is a significant change in the technology - certainly if for the transmission of information via solitons win out over the current pulse signaling method then this should produce basically new methods of signal analysis in the future, and you had best keep abreast of it if it happens, or else you, like so many other people, will be left behind.

I read that in the Navy, as well as in the obvious Air Force and commercial aviation applications, the decreased weight means great savings that can be used for other things. On a tour of the carrier Enterprise some 14 years ago, being even then well aware of the trend to optical fibers, I looked especially at the duct wiring and decided that fibers will replace all those wires in so far as they are information handling wires. For the distribution of power it is another matter entirely. But then, will centralized power distribution remain the main method, or will, due to battle conditions, a decentralized power system aboard a ship become the preferred method? It would better blend in with the obviously redundant fiber optic systems that will undoubtedly be installed as a matter of safety practice. And battle ships are not that different from World Trade type skyscraper office buildings!

We now have fiber optic cables that are sufficiently armored that trucks can run over them safely, fibers so light that missiles are fired with an unreeling fiber attached throughout the flight - and that means two way communication, both to direct the missile to the target and to get back what the missile can see as it flies.

Being in computers, I naturally asked myself how this could and would impact the design of computers. You probably know that we now (1993) often interconnect the larger units of a computer with fiber optics. It seems only a matter of time before major parts of internal wiring will go optical. Cannot one make, in time, "mother boards" by which the integrated circuit chips are interconnected, using fiber optics? It does not seem to be unreasonable in this day of the material sciences. How soon will fiber optic techniques get down to the chips? After all, the band width of optics means, inferentially, higher pulse rates! Can we not in time make optical chips, and have a general light source falling on a photocell on the chip (like some hand held calculators) to power the chip and avoid all the wiring of power distribution to the chips? Figure 12-5.

Can we replace chip wiring with light beams? Light beams can pass through one another without interference, (provided the intensity is not too high), which is more than you can do with wires. Figure 12-6.

This brings up switching. Can crossbar switches be made to be optical and not electronic? Won't the Bell Telephone Laboratories and others have to work on it intensively? If they succeed then it will not it be true that switching, which has traditionally been one of the most expensive parts of a computer, will become perhaps one of the cheapest? At first memory was the expensive part of computers, but with magnetic cores, and now with electronic storage at fantastically cheap prices, the design and use of computers has significantly changed. If a major drop in switching costs came about, how would you design a computer? Would the von Neumann basic design survive at all? What would be the appropriate computer designs with this new cost structure? You can try, as I indicated above, to keep reasonably abreast by actively anticipating the way things and ideas might go, and then seeing what actually happens. Your anticipation means that you are far, far better prepared to absorb the new things when they arise than if you sit passively by and merely follow progress. "Luck favors the prepared mind."

That is the reason for this talk - to show you how someone tried to anticipate and be prepared for rapid changes in technologies that would impact their research and work. You can't lead everywhere in this highly technological society, but you need not be left behind by every new development - as many people are in practice.

I have said again and again in this course, my duty as a professor is to increase the probability that you will be a significant contributor to our society, and I can think of no better way than establishing in you that habit of anticipating things and leading rather than passively following. It seems to me that I must, to accomplish my duty to you and to the institution, move as many of you as I can from a passive to a more active, anticipating role.

In today's Lecture you see that I claim to have made no significant contribution, but at least I was prepared to help others who were more deeply involved by supplying the right kinds of computing rather than slightly misconceived computations that are so often done. I believe I often supplied that kind of service at Bell Telephone Laboratories during 30 the years I spent there before my retirement. In the fiber optics area I have told you some of the details of what I did and how I did them.

Let me now turn to predictions of the immediate future. It is fairly clear that in time "drop lines" from the street to the house (they may actually be buried but are probably still called "drop lines"!) will be fiber optics. Once a fiber optic wire is installed then potentially you have available almost all the information you could possibly want, including TV and radio, and possibly newspaper articles selected according to your interest profile (you pay the printing bill that occurs in your own house). There would be no need for separate information channels most of the time. At your end of the fiber there are one or more digital filters. Which channel you want, the phone, radio or TV can be selected by you much as you do now, and the channel is determined by the numbers put into the digital filter - thus the same filter can be multipurpose if you wish. You will need one filter for each channel you wish to use at the same time, (though it is possible that a single time sharing filter would be available), and each filter would be of the same standard design. Alternately, the filters may come with the particular equipment you buy.

But will this happen? It is necessary to examine political, economic, and social conditions before saying that what is technologically possible will in fact happen. Is it likely that the government will want to have so much information distribution in the hands of a single company? Would the present cable companies be willing to share with the telephone company and possibly lose some profit thereby, and certainly come under more government regulation? Indeed, do we as a society want it to happen?

One of the recurring themes in these Lectures is that frequently what is technologically feasible, and is even economically better, is restrained by legal, social, and economic conditions. Just because it can be done economically does not mean that it should be done. If you do not get a firm grasp on these aspects then as a practicing seer of what is going to happen in your area of specialization you will make a lot of false predictions that you will have to explain as best you can when they turn out to be wrong.

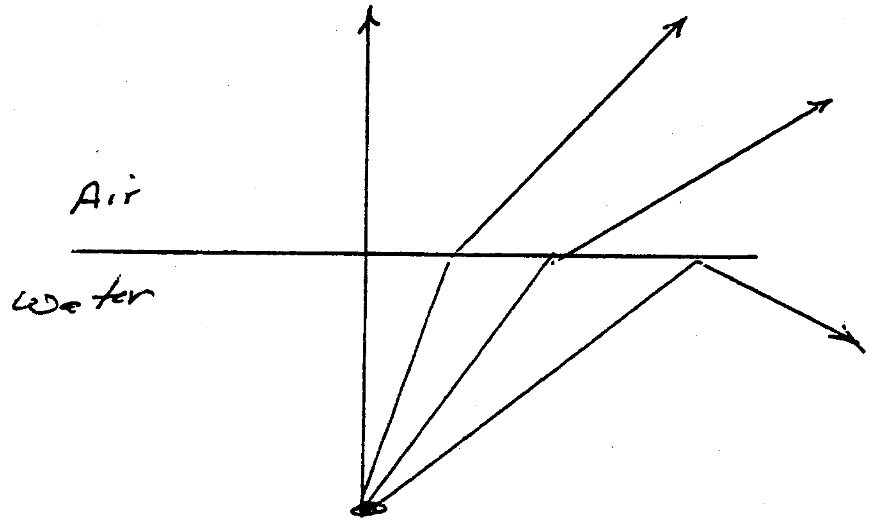


Figure 21-1

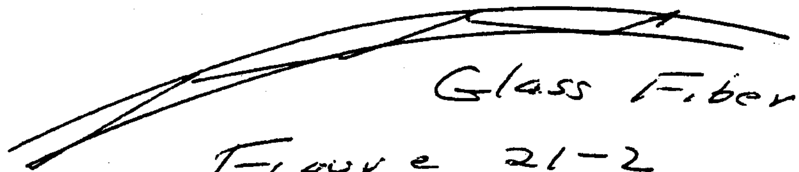


Figure 21-2

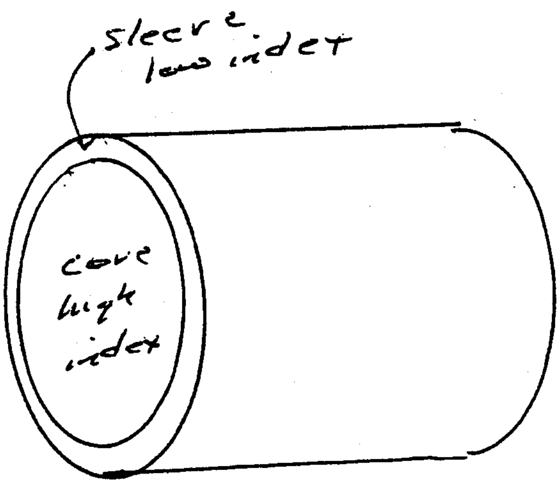
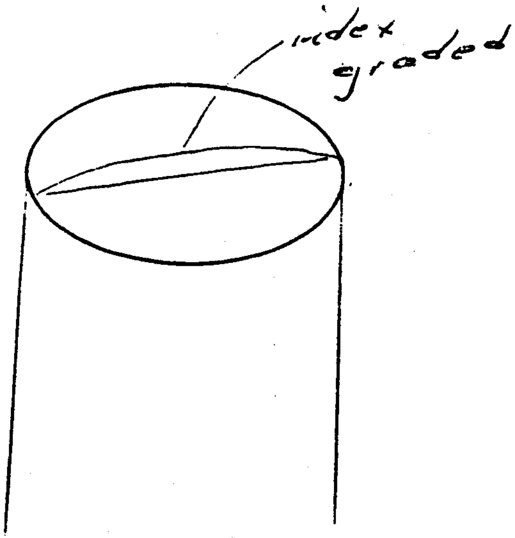


Figure 21-3-a



21-3-b

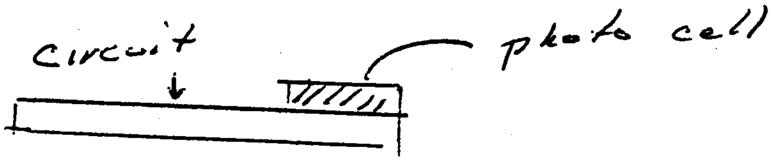


Figure 21-5

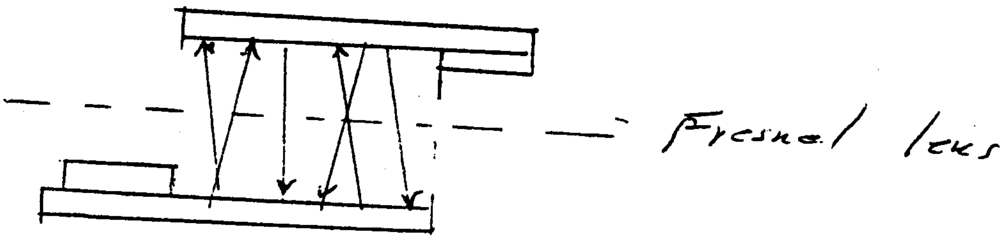


Figure 21-6