AMETEK
POWER INSTRUMENTS

FIBER OPTIC COMMUNICATIONS FOR UTILITY SYSTEMS

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By

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Pulsar

The Bright Star in Utility Communications

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Fiber Optic Communications for Electric Utilities

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INTRODUCTION

In terms of modern science, fiber optics is one of the newer technologies to appear on the scene. It is probably the first technology that has been used for communications that has such obvious advantages to the electric utility industry and in particular the relaying field. The first relay system, the LCB current differential relay, that used fiber optics for its channel was introduced in 1982, and since that initial introduction, many other relay products that make use of fiber optic communications have been introduced. The use of light waves for communications is not new.

> "Alexander Graham Bell succeeded in transmitting voice over a beam of light from the roof of the Franklin School House in Washington, D. C. to a detector in Mr. Bell's laboratory at 1325 L Street. This was a distance of 213 meters, and the new device was called the "photophone." On August 30, 1880, a New York Times editorial stated: "The ordinary man ... may find a little difficulty in comprehending how sunbeams are to be used. Does Prof. Bell intend to connect Boston and Cambridge ... with a line of sunbeams hung on telegraph poles, and, if so, what diameter are the sunbeams to be, and how is he to obtain them of the required size? What will become of the sunbeams after the sun goes down? Will they retain their power to communicate sound, or will it be necessary to insulate them, and protect them against the weather by a thick coating of gutta-percha? The public has a great deal of confidence in Scientific Persons, but until it actually sees a man going through the streets with a coil of No. 12 sunbeams on his shoulder, and suspending it from pole to pole, there will be a general feeling that there is something about Prof. Bell's photophone which places a tremendous strain on human credulity."

Once again the wisdom of the press has been proven wrong. It wasn't until 1960, that the concept of using a glass fiber for communications was proposed by researchers at Standard Telecommunication Laboratories Ltd. The concept has grown very rapidly since then, making the fiber optics industry one of the fastest growing around the world.

In the case of fiber optics the channel path can be well isolated from the noise. The ambient light surrounding a fiber optic cable can be considered noise to the optical channel. However, the fiber can have an opaque covering which prevents or "shields" the fiber from all outside interference. Thus, no noise is added to the signal during propagation between transmitter and receiver.

WHY FIBER OPTICS IN UTILITY COMMUNICATIONS (IN PARTICULAR PROTECTIVE RELAYING)

Relaying, SCADA and voice channels have been plagued by noise when using leased lines, microwave and power line carrier. Leased lines are also influenced by extraneous voltage interferences. The noise and extraneous voltages affect the various channel applications in different ways. Thus having varying effects on system operations. Fiber optics offers a good solution to both noise and extraneous voltage problems. The main advantages to power system communications are discussed in this paper.

Lack of Noise and Interference

The lack of noise interference is what makes fiber optics so attractive to all types of users of communications channels. In a channel that uses lower frequency electromagnetic wave propagation, noise from outside the channel is added to the desired signal during the process of getting the signal from the transmitter to the receiver. This noise, if large with respect to the signal, will have a corrupting influence on the signal making the channel worthless.

In fact, the designer of the fiber optic system has the control of the noise under his influence. The most significant noise is added to the fiber optic channel by the light detector and first stages of amplification at the optical receiver. In this area of the circuit, the designer must be careful in his design. He can control noise by the choice of components, the circuit design, and the circuit shielding.

Extraneous Voltage Interference

Longitudinal Induced Voltages

Longitudinal induced voltages come about because of the parallel association of communications cables with power circuits. During normal conditions of load current flow, there is little voltage induced in the communication cable. This is because load is a balanced set of currents, and the electromagnetic field some distance away from the power line is near zero. The same reasoning holds true for a three-phase fault or a phase-to-phase fault. In the case of a phase-to-phase fault, the fault current contains positive and negative sequence components both of which are a balanced set of currents and thus no resultant field is present in the vicinity of the communications cable. However, for any fault involving ground, the situation is different. The ground fault has not only positive and negative sequence components but also a zero sequence component. It is the zero sequence component that causes the induction. This is because it is not a balanced set of currents and an electromagnetic field is present at the communications cable. It is this zero sequence field that is responsible for the longitudinal induced voltage. Figure 1 shows a representation of the induced voltage. The induced voltage is equal, with respect to ground, for each wire of the pair. This, of course, assumes that the pair of wires is twisted as shown. As long as there is not an insulation failure, the induced voltage does not present a threat to the relay system. On the other hand, if one wire was to fail and flash over to ground, then the full force of the induced potential will be seen by the channel terminal device.

Fiber optic channels are not affected by longitudinal induced voltage since the cables are made of glass.

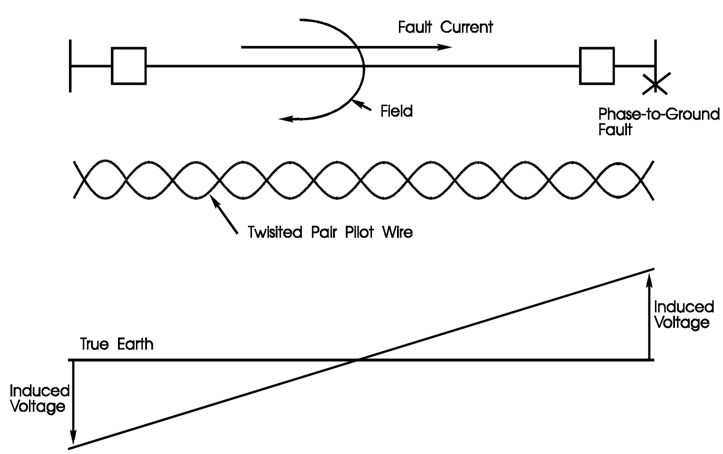

Figure 1. Example of Longitudinal Induced Voltage

Station Ground Mat Potential Difference (GPR)

The Ground potential rise problem also occurs only during a ground fault on the power system. The voltage profile of the GPR is shown in Figure 2. It is caused by the fact that some (not all) of the fault current returns through the resistance between the true earth and the station ground mat. The resultant voltage not only causes a potential difference between the ground mat and true earth, but it also affects the surrounding earth outside the station. This effect will decrease as distance from the substation increases as shown in Figure 2. As with longitudinal induced voltage, the GPR creates little problems for the relay system until an insulation failure occurs, and then the effect can be a misoperation of the relay system and/or a hardware failure. Fiber optic channels are not affected by GPR since the cables are made of glass.

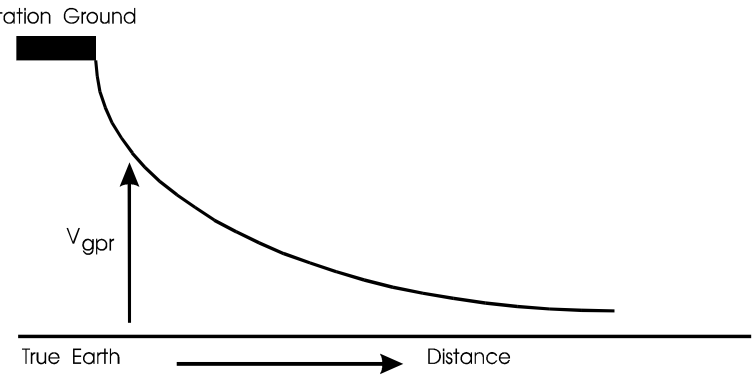

Figure 2. Example of Station Ground Potential Rise

For a much more complete discussion of both longitudinal induced voltage and ground potential rise, refer to references 3 and 4 listed in the back of this paper.

Bandwidth

The bandwidth of fiber optic cables is very large. Our technology has only just begun to tap the potential bandwidth of fiber optic cables. An even brighter note is that the bandwidth is available without government licensing. The potential is now there for utility right-of-ways to transport not only large blocks of power to customers, but to transport large amounts of information as well. The excess bandwidth can be used to offset the cost of installing the fiber as well as generating revenue for the utility.

PROPERTIES OF FIBER OPTIC CABLE

The fiber optic cable is the component that guides light information from the transmitter to the remote receiver. It must do so without allowing any light to leave the fiber and with losses such that the detector can still act on the received signal. Fibers may be broken down into three general categories. They are stepped-index multi-mode, graded-index multi-mode, and stepped-index single-mode fibers. The stepped-index multi-mode fiber will be used to explain how a fiber performs its function.

The first optical property to discuss is index of refraction. Index of refraction is a property of material substances that relates to the ratio of the velocity of light in free space (c) to the velocity of propagation in the material (v). The index of refraction (n) is then given by the Equation 1.

$$n = \frac{c}{v} \qquad (1)$$

As an example, common glass used in optical instruments will have an index of refraction of 1.46 to 1.96. Few materials will have an index of refraction larger than this. One such material, however, is a diamond. It has an index of refraction of 2.42. It should be noted that the index of refraction will change with changing light wavelength, and the index of refraction plays a very important role in a fiber optic cable.

The law of refraction is known as Snell's law. Figure 3 shows what happens to a beam of light as it transverses from a material of one index of refraction to a material of another index of refraction. A beam of light that is incident on the surface at a 90° angle is passed from one material to the other in a straight line. On the other hand, a beam of light that is incident at some angle u will have its direction modified slightly (refracted), and the angle with respect to the surface on the second material is n'. Thus the light beam is bent as it passes through the surface. Snell's law describes this behavior in Equation 2.

$$n \sin \phi = n' \sin \phi' \qquad (2)$$

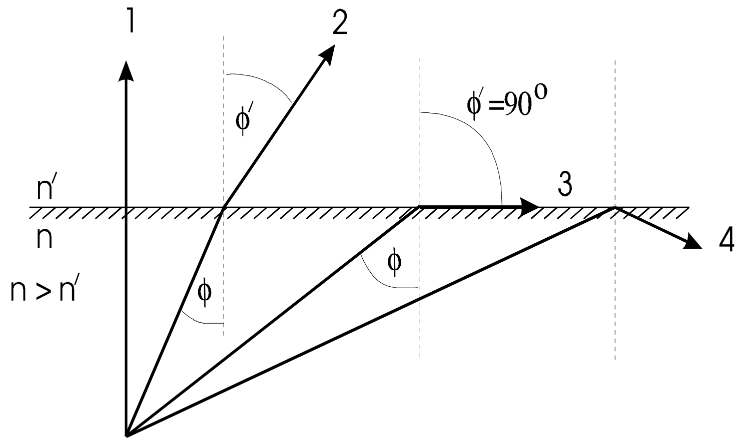

Figure 3. The Law of Refraction (Snell's Law)

When the angle of incidence reaches a point such that the refracted light beam is tangent to the surface as beam 3 does in Figure 3, then the angle of incidence is referred to as the critical angle and has been designated f_c. If the angle of incidence becomes larger than f_c, then total reflection from the surface occurs and no light is passed through the surface. This phenomenon is shown in beam 4 of Figure 3.

Figure 4 then shows these principles coming into play in a fiber optic cable. In order for the fiber to work, the index of refraction of the core must be greater than that of the cladding and the index of refraction of the cladding must be greater than that of air. Light rays enter the core of the optical fiber at some angle with respect to the optical axis. Once in the core, the light ray will eventually come to the surface between the core and the cladding. When the angle with respect to the perpendicular from the surface, is greater than the critical angle (q_c), then all light is reflected back into the core of the fiber. Thus light will propagate to the other end of the fiber. The critical angle is given by Equation 3.

$$\sin \phi_c = \frac{n_2}{n_1} \qquad (3)$$

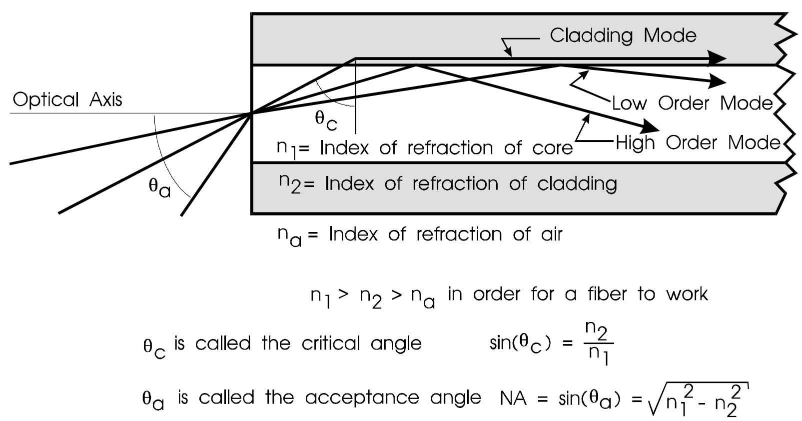

Figure 4. Snell's Law as Applied to Fiber Optic Cable

In Equation 3, n_1 is the index of refraction of the core and n_2 is the index of refraction for the cladding. This formula is derived from Snell's law above where f' is 90° and thus the sine of 90° is 1. If the angle at the core/cladding surface is less than the critical angle, then the ray of light enters the cladding and is called a cladding mode. As shown in Figure 4, for a given f_c at the surface of the cladding and the core, the ray of light will have a corresponding angle f_c at the surface between the air and the core material. The value of f_c that causes the critical angle to occur inside the fiber is called the acceptance angle of the fiber.

That is, f_c defines the largest cone of light that can enter the fiber and have that light propagate in the fiber. Any light that reaches the core surface at an angle greater than the acceptance angle will go into the cladding or even leave the fiber. The numerical aperture (NA) of the fiber is defined as the sine of the acceptance angle. It is given by Equation 4.

$$NA = \sin\theta_a = \sqrt{(n_1^2 - n_2^2)} \qquad (4)$$

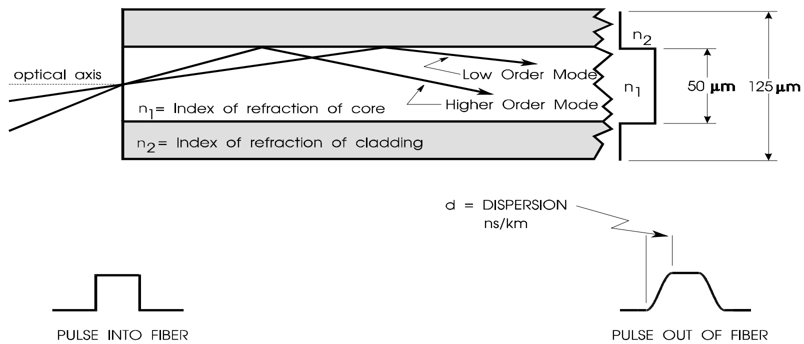

Figure 5. Example of a Stepped-Index Multi-Mode Fiber

Thus all the light one can place in the cone defined by the numerical aperture will go into the fiber to transmit information.

Note that in Figure 4 the light rays entering the cable at different angles will travel different distances to reach the receiving end of the fiber. Since all the light rays are the same wavelength, their velocity of propagation will be the same. However, because of the different distances the rays travel, they will arrive at the receiving terminal at different times. If a pulse of light is input to the fiber, then the edges of the pulse will be spread out at the receiving terminal. This is a characteristic known as dispersion (d) and is measured in terms of nanoseconds per kilometer. The total dispersion is then dependent on the length of the fiber. Since the dispersion will limit how fast one can apply pulses to the transmit end without the pulses interfering with each other at the receiver, the signaling frequency that can be applied to the fiber is limited. Hence, dispersion is related to fiber bandwidth. It is the fiber bandwidth that is most often specified in fiber data sheets, and is quoted as MHz-km. The system bandwidth then is also dependent on the length of fiber being used in an application.

Stepped-Index Multi-Mode Fiber

An example of a stepped-index multi-mode fiber is shown in Figure 5. The stepped-index fiber is the same as discussed in the previous section. That is, the fiber is constructed of two layers of glass. Each layer has a different index of refraction. The inner part is the core and the part surrounding the core is the cladding. In a stepped-indexed fiber, the index of refraction changes abruptly at the surface between the core and the cladding. The core is usually 50, 62.5 or 85 micrometers in diameter, and the core plus cladding diameter is 125 micrometers. Many larger fibers also exist in this category of fiber. The term multi-mode in the fiber name refers to the fact that the core diameter is rather large in comparison with the wavelength of the light used (820 to 860 nanometers) and many modes can exist in the fiber. It is because of these different modes that the dispersion can be large, thus placing a severe limit on fiber bandwidth.

Graded-Index Multi-Mode Fiber

The stepped-index multi-mode fiber soon gave way to a new type of fiber known as graded-index multimode fiber. An example of this type of fiber is shown in Figure 6. The graded-index fiber is different in that the index of refraction changes gradually as the core of the fiber is traversed. The index of refraction is highest at the center of the core and slowly decreases as the cladding is approached. This change of the index of refraction is given by Equation 5.

$$n_r = n_c\,(1 - ar^2) \qquad (5)$$

In Equation 5 n_c is the index of refraction at the center of the fiber, r is the distance from the center of the core, and a is a constant. The NA of the fiber will be related to the constant a.

Figure 6 shows how the different modes propagate in a graded-index fiber. Rather than being reflected abruptly from the cladding they are gradually bent as they progress down the fiber, and the result is that the path lengths are more equal. This then causes less dispersion to take place and the fiber bandwidth is significantly increased. The core diameter will be 50, 62.5 or 85 micrometers in diameter, and the cladding plus core will be 125 micrometers in diameter.

Stepped-Index Single-Mode Fiber

The latest type of fiber to be developed is the stepped-index single-mode fiber. The theory is that if the core of the fiber is reduced to a small diameter with respect to the wavelength of the light being transmitted, then only one mode of propagation can occur and dispersion is greatly limited. The number of modes of propagation (N) is given by Equation 6.

$$N \approx a \left[\frac{\pi NAd}{\lambda}\right]^2 \qquad (6)$$

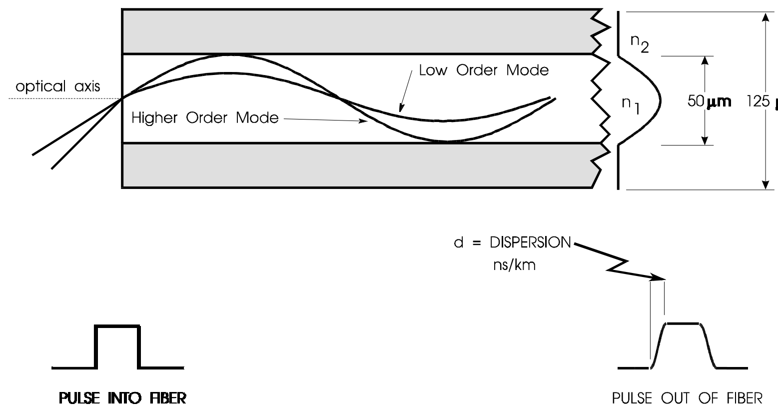

Figure 6. Example of Graded-Index Multi-Mode Fiber

In Equation 6 NA is numerical aperture, d is the diameter of core, l is the wavelength of light, a=0.5 for stepped-index fiber, and a=0.25 for graded-index fiber. With the advent of longer wavelength sources and new manufacturing techniques the single-mode fiber has become common place. An example of single-mode fiber is shown in Figure 7. The core diameter will be 9 micrometers and the wavelength of the light used will be 1300 or 1550 nanometers. The dispersion is very small, and the bandwidth very large in comparison to the stepped-index multi-mode fiber. Another advantage of using the longer wavelength of light is that the fiber losses are much lower than for the 820-860 nanometer range.

Table I summarizes the different characteristics of the various fibers. One should remember that numbers of the nature given in Table I are subject to change due to the rapid development that takes place in the fiber optic field. These numbers are offered as a general guide for the reader.

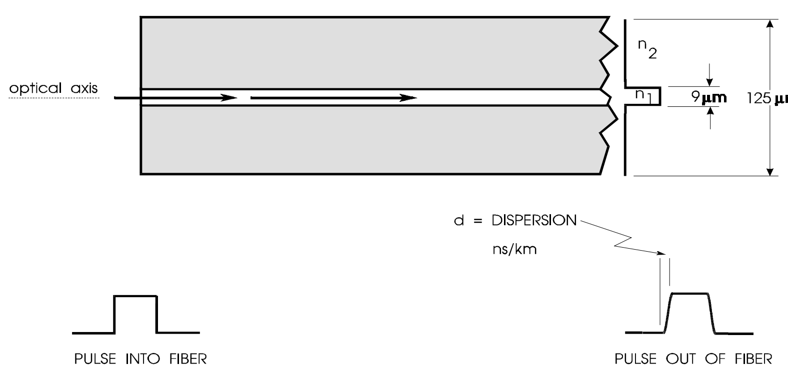

Figure 7. Example of Stepped-Index Single-Mode Fiber

Table I. - Summary of Fiber Characteristics

FIBER TYPE	CORE DIAM. mm	9	OVERALL DIAM. mm	NUMERICAL APERTURE	BANDWIDTH GHz - km
MM, SI	50 - 500		125 - 800	0.2 - 0.3	0.03 - 0.05
MM, GI	50, 62.5 or 85		125	0.2 - 0.3	0.2 - 1
SM, SI			125	0.1* / 0.3**	20* / 20**

MM,SI= Multi-mode stepped-index 850 nm wavelength light except as noted
MM,GI= Multi-mode Graded-index *1300 nm wavelength light
SM,SI= Single-Mode stepped-index **1550 nm wavelength light

MULTIPLEXERS FOR FIBER COMMUNICATIONS

The communications equipment applied to fiber optic channels is usually digital. The digital communications equipment in the US follow the ATT digital multiplex standards. This allows for several levels of communications. The lowest level is DS1 which operates at 1.544 Mbps, and the highest level is DS4 that operates at 274.176 Mbps. An outline of the North American modulation plan is shown in Figure 8. The DS1 level consists of 24 voice channels and the DS4 level is 4032 voice channels. Each voice channel is at the DS0 level and operates at 64 kbps. The boxes shown in Figure 8 are the multiplexers. The name attached to a multiplexer refers to the level of their input and the level output. Thus an M13 multiplexer is one that takes in 25 DS1 channels and outputs a DS3 level. Not all countries around the world operate at the same levels as North America. In Europe the levels are per CCITT, with the first level starting at 2.048 Mbps and carrying 30 voice channels. Japan is also slightly different from the North American standard. The various levels for all three major standards are in Table II. The present ATT and CCITT standards are for wire and microwave networks that were available at the time and then adapted to fiber optics. Both the US and Europe are cooperating on a new standard that will be fiber optic related. This new standard is the Synchronous Optical Network or SONET. SONET has levels much higher than those in the electrical standards due to the available fiber bandwidth. The SONET standard also has the advantage that the complete network is synchronized at all levels. Network management will also be better in that channel bandwidth has been set aside for that purpose. Although equipment is on the market at this time, one must realize that the standard is not complete. It should be noted that any T1 (DS1 level) equipment that is built today will be compatible with the future SONET standard.

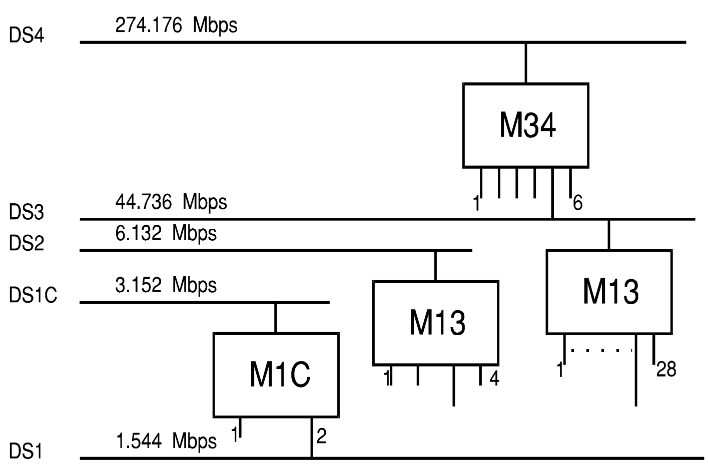

Figure 8. PCM Hierarchy & Multiplex Plan in North America

Table II. - PCM Hierarchy

System Type (Level)	1	2	3	4	5
North America					
Number of Channels	24	96	672	4032	
Line Rate (Mbps)	1.544	6.312	44.736	274.176	
Japan					
Number of Channels	24	96	480	1440	5760
Line Rate (Mbps)	1.544	6.312	32.064	97.728	400.352
Europe					
Number of Channels	30	120	480	1920	7680
Line Rate (Mbps)	2.048	8.448	34.368	139.264	560.0

Utilities in the US and around the world are making use of digital channels over fiber optics for their communication needs. Most utilities in this country have made use of both T3 (DS3 level) equipment and T1 equipment. Since T3 carries 672 voice channels it matches well with analog microwave in terms of channel capacity, and digital microwave equipment operates at the DS3 level. Thus many utilities that have large communications requirements have used T3 equipment. However, it cannot be cost justified to run T3 to all substations in a large utility, and a small utility may not require the bandwidth of T3. Therefore, T1 equipment has been also extensively utilized for communications. Because the DS0 level is a voice channel input it is the best place for the relay system to interface with the channel. The relay channel equipment will take the contacts from the relay system and multiplex them on to a 64 kbps channel. The relaying channel equipment will be able to demodulate the 64 kbps information and provide the contacts out to the relay system. The dependability and security of relaying information are very high due because of both digital channels and of fiber optics. Also since the effective channel bandwidth is larger digital fiber optic channels will be much faster than the existing audio tones over analog voice channels. The times for digital relay channels will range from 1 to 6 ms depending on security coding of the information.

T1 MULTIPLEXER CONCEPTS

Pulse Code Modulation

All digital multiplexers use pulse code modulation (PCM) to take an analog signal and place it on a digital channel. Pulse code modulation includes three processing steps. They are sampling, quantization and coding.

First the analog wave must be sampled at a periodic rate. An analog signal must be sampled at a rate that is at least twice the highest frequency in the signal. In the case of voice, the signal is filtered so that the highest frequency possible is something less than 4 kHz. Therefore, the signal must be sampled at 8000 times per second. The concept of sampling is shown in Figure 9. The resulting signal no longer is purely analog but just samples whose amplitudes reflect the amplitude of the analog signal. The resulting signal appears as shown in Figure 10.

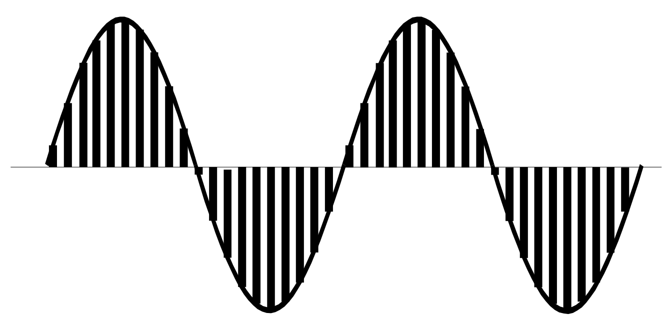

Figure 9. PCM: Sampling an analog signal

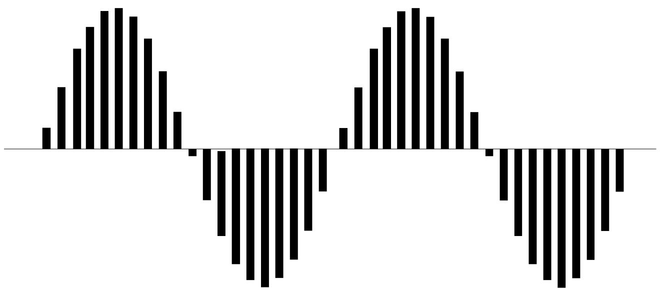

Figure 10. PCM: Sampling an analog signal

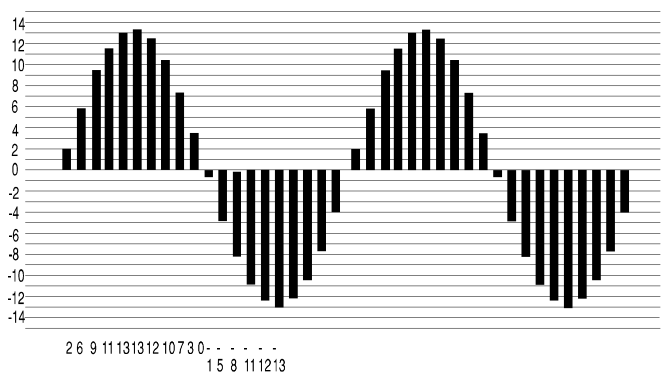

Figure 11. PCM: Quantization

The sampled amplitudes are at levels that match the original signal exactly. In the case of a digital system only discrete levels can be sent. Therefore, the signal must be Quantized. This is the process of rounding off the magnitude of each sample to the closest discrete digital level that can be transmitted. This process is shown in Figure 11. In Figure 11 the number of levels that have been selected for the full range of amplitudes is ± 15 plus the zero level. Therefore, in this example the sine wave can be quantized into 32 levels. These levels can then be represented by integers shown below each sample. In an actual T1 system the number of total levels is 256. This makes for a much finer quantization than the example in Figure 11.

Since the new quantized samples are not exactly at the levels of the original signal then the reconstructed signal at the receiver is noisy. The resulting noise is called quantizing noise and is generally small. The magnitude of the quantizing noise will get higher as the signal level gets lower. In order to prevent the quantizing noise from getting too large at lower amplitudes the digital levels are not equal distance apart. They are closer together at the lower levels than they are at the higher levels. This has the result of lowering overall noise level for most general signals.

Now that each sample has been quantized to an integer value it can be represented by a binary code. The code for the example of Figure 11 could be a 5 bit code of 1s and 0s. It takes only five bits to represent 32 levels. The process of converting the quantized samples to a binary code is called encoding and is the third step in the PCM process. Figure 12 shows the encoding process for the example in Figure 11. The first sample is level 2 and the first five bits in Figure 12 represent a 2 in binary. The first bit in the stream of five bits is the most significant bit. These five bits must occur in time before the next sample comes

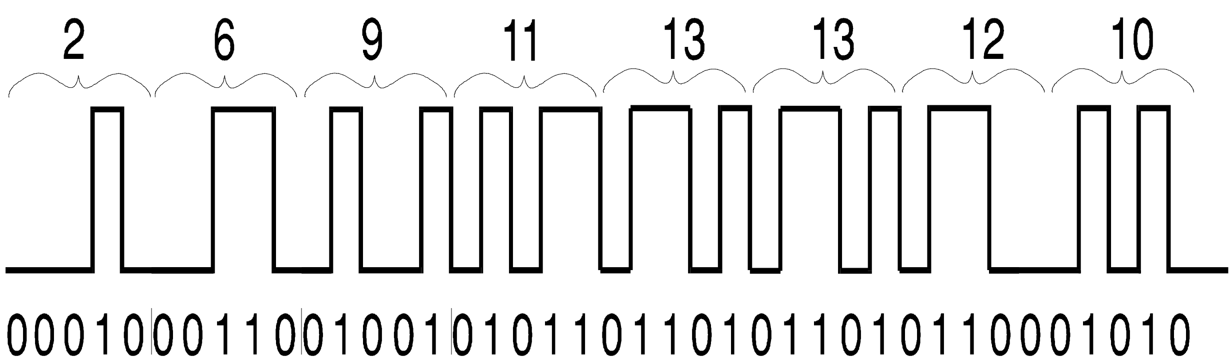

Figure 12. PCM -- Encoding Process

along. When the next sample comes, which is a level 5, then 5 more bits are added to the stream. These 5 bits represent a 5 in binary. In this manner the serial bit stream is produced which will be transmitted to the other end of the line. In the case of a T1 system the number of bits required to represent the 256 levels is 8. If the signal is sampled at a rate of 8000 times a second, then the samples are 125 ms apart. Since an 8 bit code must fit into the 125 ms time between samples, the data rate for the encoded voice channel is 8 bits/125 ms or 64,000 bits per second. Thus the base data rate for a single digital voice channel is 64 kbps and is known as the DS0 level.

This completes the pulse-code-modulation process. The next step is to place 24 voice channels into a serial data stream that is the DS1 data level.

Encoding Voice Channels to a T1 Frame

The 8 bits from each of 24 voice channels are interleaved together to form a continuous serial bit stream. The process of adding these channels together is shown in Figure 13. The eight bits of a sample of channel 1 is taken and then eight bits from channel two are attached and eight from channel three, etc. After a sample has been taken from each channel, a synchronizing bit is added at the end of the stream. This constitutes a single T1 frame. The frame consists of 8 bits for each of 24 channels plus one synchronizing bit. Thus the total frame length is 193 bits. The system is required to place an 8-bit sample from each channel before the next sample comes along for channel one. Thus, 193 bits are placed on the bit stream every 125 ms, and the data rate required to accomplish this process is 193 bits/125 ms or 1.544 Mbps.

The synchronizing bit that is placed on each frame is used by the receiver to determine the beginning of each frame. The pattern of the synchronizing bit is different depending on the type of frame being transmitted. Two types of frames can be used. One is called D4 and the other is ESF (Extended Super Frame). Most all modern equipment will use ESF since it provides for better system control features. Since only one synchronizing bit occurs out of 193, a T1 system can take anywhere from 10 to 30 ms to synchronize after a sever noise hit on the line. The synchronizing time depends on the data being sent and the type of framing being used (D4 or ESF). The final bit stream out of the T1 will be a binary signal and will look like the top wave form of Figure 14. There are two problems associated with sending this code over a pair of wires and through repeaters. One, the wave form contains a dc quantity, and two it does not send the clock information. The clock information needs to be sent in order to synchronize the receiver to the transmitter. In order to eliminate the dc and at the same time send the clock, a technique known as alternate mark inversion is used. This means that every other logic 1 is sent with an opposite polarity. The resulting wave form is shown in the second signal in Figure 14. Of course, this type of encoding is only used when one is

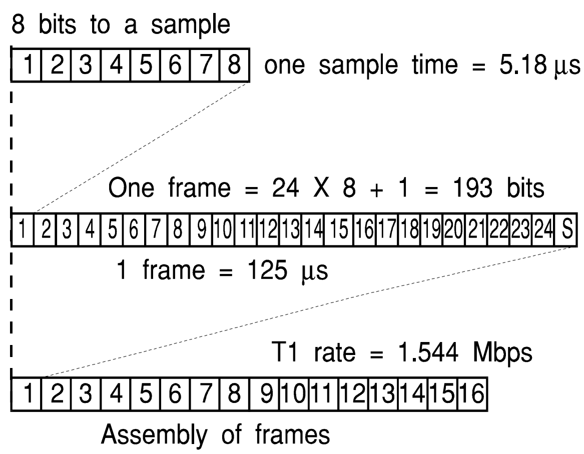

Figure 13. Assembly of a T1 Frame

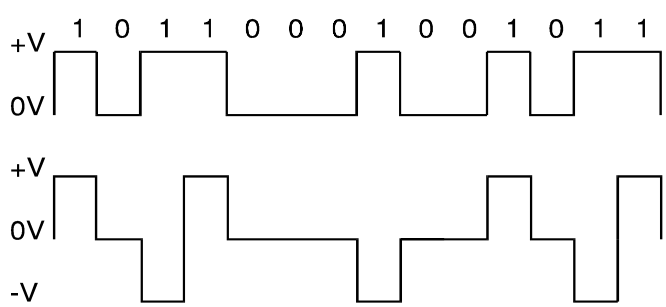

Fig. 14. Alternate Mark Inversion: Encoded T1

using an electrical T1 output. When using the T1 on a fiber optic channel, the output is often Manchester encoded. This is shown in Figure 15. In the case of Manchester encoding there is a dc present, but the fiber channel does not care. The clock information is also sent with this encoding. One thing to note about the Manchester encoded signal is that it will require twice the bandwidth to transmit as opposed to the original signal.

RELAYING CONSIDERATIONS WHEN USING DIGITAL CHANNEL EQUIPMENT

In general, when transferring a relay system from a power line carrier or audio tone channel to a digital system, no problems occur. The digital channel will be faster and if used over fiber optic cable will be more reliable. A relay system may be applied to a digital channel in one of two ways. The first and least desirable method is to use a standard audio tone and connect it to a 4-wire channel module. This method is no different from a relay system design point of view as leasing a line from the telephone company or using your own microwave system. The second method is to eliminate the audio tone or power line carrier channel equipment and use one of the specialized relay interfaces supplied by most manufactures of digital fiber optic equipment. This method of applying a relay system to a channel should be much more reliable and faster than the first. In the second method, there is less hardware to fail. The system will be more secure since the specialized channel card can monitor its own data coming in as well as monitoring the T1 transceiver. Thus it can block for incorrect data much faster than any external type of device. However, there are two types of relay systems that require special consideration.

Directional Comparison Blocking

This system is sensitive to time delay of the channel in that it must have a coordination timer set longer than the channel time in order not to trip for external faults. On newer microprocessor based relays and solid state relays this timer is adjustable over a wide range. So it must be remembered to check this timer setting vs. the delay of the new digital channel time including output relays. The best way to approach this is to check the channel delay of the digital channel and the channel delay of the system from which the relay is being removed. If the digital channel is slower then the coordination timer needs to be increased by at least that much. If the digital channel is faster than the old channel then the channel delay can be decreased by that much.

In the case of the older electro-mechanical systems then the problem is not as easy to solve. In these systems it is best to be sure that the new digital channel is faster. If this is not the case, then the relay will have to be modified in order to accommodate the extra channel delay. It is for this reason, suggested that the specialized relay module used for directional comparison blocking have a transistor output stage.

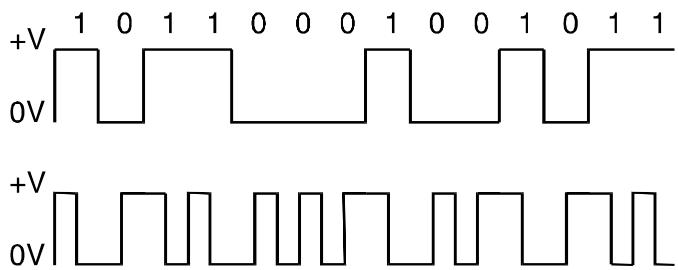

Figure 15. Manchester Encoded T1 Output

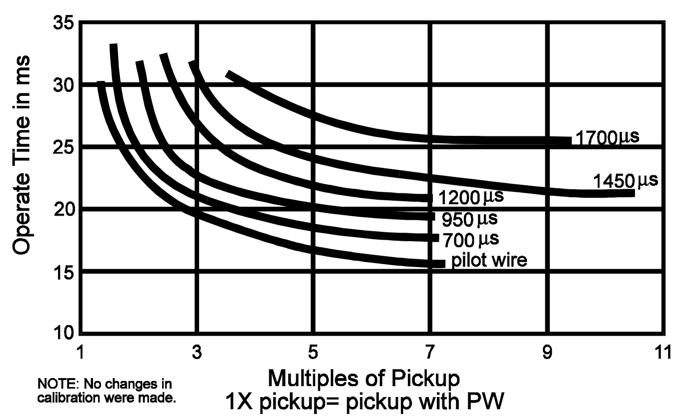

Figure 16. HCB/HCB-1 Operate Time vs. Current for Various Channel Delays

Pilot Wire Current Differential Relays

These relays and the need to eliminate the metallic circuit have been the driving force behind much of the development of fiber optic digital channels. However, these relays were not designed to handle any channel delay, and this must be taken into consideration. Contrary to popular opinion there is no one number that can be stated for the acceptable time delay for a pilot wire relay. The time delay that can be tolerated depends on many factors. These are relay setting, fault current levels and required tripping speed.

For internal faults, the larger the fault current is as compared to the setting of the relay then the relay can tolerate more delay in the channel. However, as delay goes up then trip time also increases and it is not a one for one relationship. Thus one must consider how much slower the relay can trip and still meet critical switching time requirements. This is difficult for most people since they have always considered these relay systems to be high speed and did not consider trip time. The curves in Figures 16 and 17 show the effects of channel delay on the HCB and HCB-1 relay. Figure 16 shows the change in operating time with respect to the trip time when using a 2000 W, 1.5 µf pilot wire. One can observe from these curves that the pickup time of the relay is changing. Thus Figure 17 shows the change in absolute pick up level vs. channel delay. From this curve it can be seen that the HCB and HCB-1 relays can accept an absolute maximum delay of 2.75 ms. However, one would not want to apply it in a system with this much delay because it may never trip. These curves are offered so that the user may judge for him or herself what the maximum channel delay that can be tolerated in their application is. These curves only apply to HCB and HCB-1 relays, but the same general effect will occur with any pilot wire relay.

For external faults, the smaller the fault current with respect to the setting the more time delay the relay can accept. Note that this is just the opposite of the internal fault case. Tests on HCB and HCB-1 relays indicate that as the designers would have it the relay is very secure for external faults and can tolerate a large channel delay in most applications. In most cases the HCB and HCB-1 can accept as much as 6 ms of channel delay without misoperating. Therefore, only the internal fault cases need to be considered in most applications.

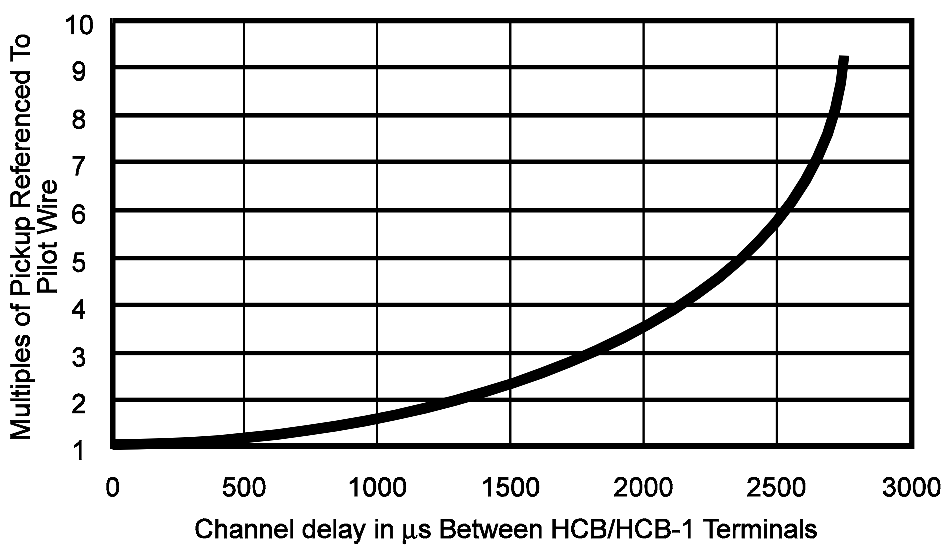

Figure 17. HCB/HCB-1 Pickup vs. Channel Delay

FOCUS -- A NEW GENERATION

FOCUS provides a flexible package for multiplexing virtually any type of signal or data directly onto fiber optic cable. Electrical interfaces are also available to multiplex the T1 signal to higher digital levels using M12 and M13 multiplexers. Refer to Figure 18. The FOCUS system also provides for drop and insert as well as spur channel capability. This allows FOCUS to operate as a complex T1 network. In a network, fiber optic and electrical links may be mixed. Thus, it can be mixed with digital microwave, higher levels of optics and leased T1 channels. The drop and insert feature improves channel conservation and is especially suited for three-terminal line applications. FOCUS provides a standard T1 output in either the D4 or ESF format. This assures compatibility with all standard communication networks and DS0/DS1 test equipment that adhere to the ATT standards.

The FOCUS hardware is designed to operate within the harsh environment of the substation. All external relaying interfaces and general connections to FOCUS exceed applicable ANSI, IEEE and IEC standards for fast transient, surge withstand, EMI and RFI. All voice interfaces will meet existing telephone standards. Interface modules for a variety of communication needs may plug into any of 12 position-independent slots to the chassis. Refer to Figure 19. One 19" wide, 3 R.U. high chassis provides enough space for most substation channel requirements. For communication intensive substations requiring a large number of channels, other than voice or data, one additional 3 R.U. expansion chassis can be added.

FOCUS provides superior reliability with the optional dual power supply design. In-service repair or replacement of individual channel cards can be made without powering down the chassis. The microprocessor-based Maintenance Module designates all channel time slots and provides self diagnostics for quick easy fault isolation. Using Microsoft Windows™ based software, FOCUS is completely configurable from a local or remote location. Therefore there are no dip switches or jumpers to decrease reliability or flexibility. The maintenance module also provides a point-to-point service voice channel, separate from the channel cards, to assist in system setup. Major and minor alarms are available locally in the form of indication LEDS and relay contacts. The alarms may also be accessed locally via computer through the RS-232 port or remotely via the WRELCOM LAN. An example of a simple FOCUS network is shown in Figure 20.

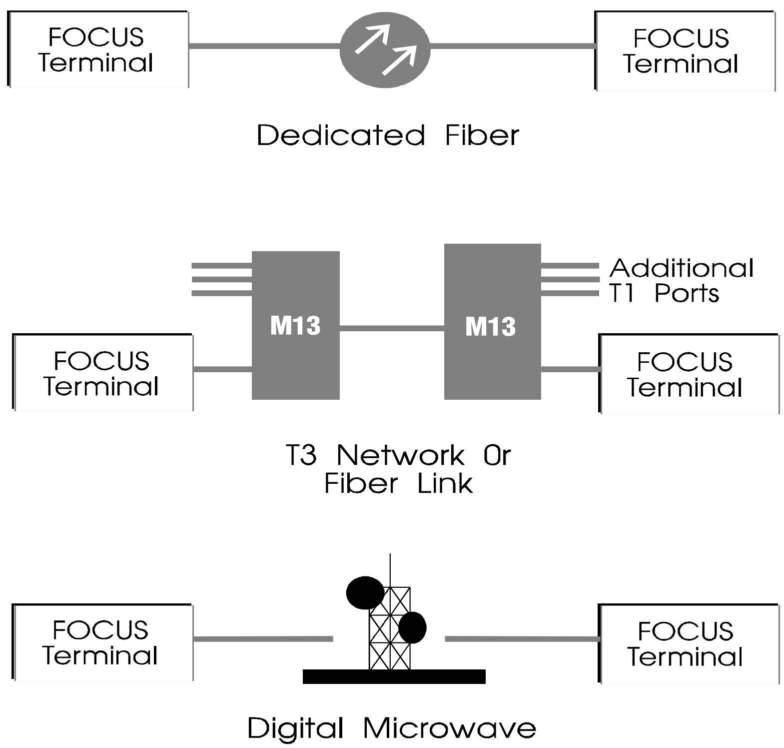

Figure 18. Types of FOCUS Communications Links

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Specialized Communications Modules

Relay Module

The Relay Module provides four relay functions over a single DS0 time slot. Each function can be seperately programmed for function (transfer trip or unblock) and dependability and security. In addition to the four trip functions there is also a guard function that is transmitted when no trip is required on any of the four functions. The response to a channel trouble condition depends on the programming of the function. If the function is programmed for transfer trip then the trip output is blocked during a channel trouble condition. If the function is programmed for unblock then a trip output occurs for 150 ms following a channel trouble condition. After a period of 150 ms, the trip output is reset and the function is blocked from tripping. Each function can also be independently programmed for guard return. If a function is programmed for always guard return following a channel trouble then it will always require a guard to occur before the trip can be accepted. On the other hand, a function may be programmed to ignore guard return if a valid trip was being received before the channel trouble occurred. In this case, if a function was receiving guard prior to the channel trouble then a guard return is required. If the function was receiving trip when the channel trouble occurred then the function will return to trip without the need for guard. This feature would be used when the function is applied to a line relay system where 52b keying is being used.

Pilot Wire Relay Interface Module

The Pilot Wire Relay Module allows a pilot wire relay such as the HCB, HCB-1 or SPD to be connected to the input/output. This module will then transfer the current differential relay quantity to the remote line terminal in a transparent fashion. That is, the relays do not know that they are not connected to a pair of wires. The Pilot Wire Module will also simulate the optimum pilot wire resistance for the HCB and HCB-1 relays. This will provide for the most sensitive tripping during single end feed conditions. The module provides for channel monitoring functions and a single direct transfer trip function. Therefore, there is no need to leave any dc monitoring relays in service. Also the isolating transformer and all the old channel protection equipment may be removed from service. However, if desired, the pilot wire current monitoring switch and meter may remain in service if desired. This module will provide a channel delay time that is fast enough so as not to cause any problems in the pilot wire protection scheme. It requires a single DS0 time slot.

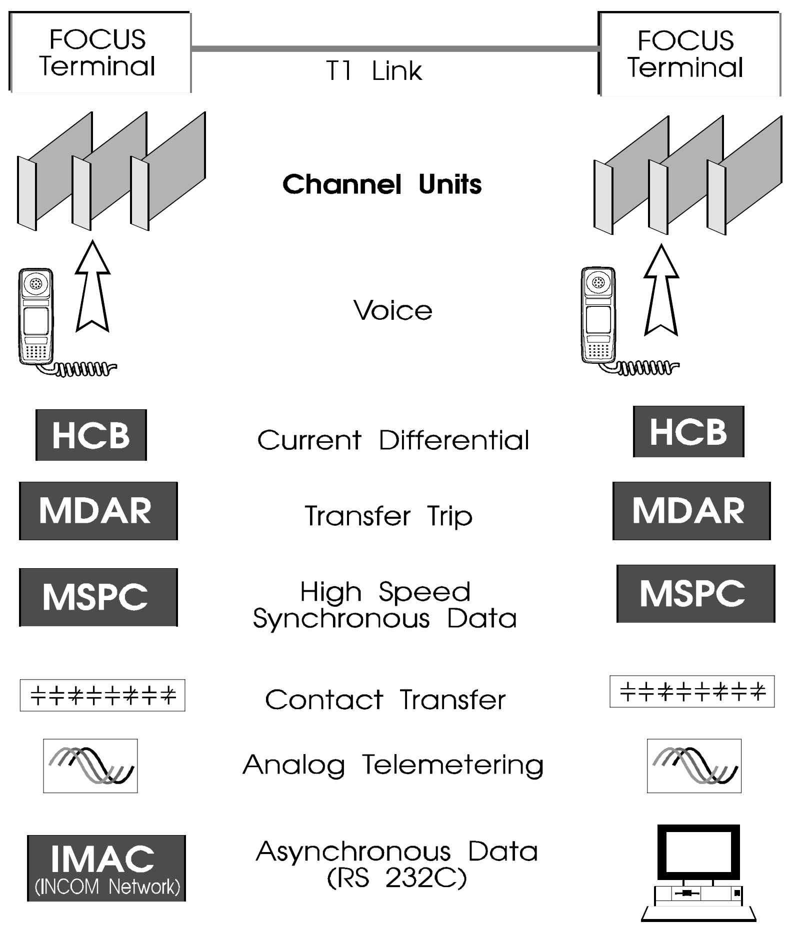

Figure 19. Types of FOCUS Channel Modules

FCB Interface Module

The FCB interface module takes the fiber optic signal from an FCB/HCB system and allows it to be transmitted over the fiber T1 network. This module would be used where there is considerable distance between the HCB and the FOCUS chassis. If the FOCUS chassis were mounted in a communication building across the switchyard from the relay building, then this module allows the HCB to communicate with FOCUS using fiber optics across the substation. This system will require the use of an FCB next to each HCB.

High Speed Data Module

Although the high speed data module can be used for any general form of digital communications it can also provide a very high speed secure channel for relays that can make use of its data capabilities. Modern relays are being designed to take advantage of the extra bandwidth a digital channel offers. Among these are the MSPC segregated phase comparison relay and the LCB current differential relay.

Contact Transfer Module

The contact transfer module can take in up to eight contacts and transfer the status of those contacts to the other end. It uses one DS0 time slot. The status transfer module should not be used for any critical relaying function. It is designed with no channel monitoring, and will not block operation during channel trouble conditions.

Analog Telemeter Module

The analog telemetering module will allow up to four slow speed analog functions to be transmitted to the other end of the link. It also requires only one DS0 time slot. The inputs will come in a variety of levels to accept most popular types of voltage or current loops.

General Communications Functions

RS-232 Data Module

The RS-232 Channel module will provide for low speed data communications. It will have two RS-232 channels per card with each channel taking one time slot. It will provide for asynchronous communications from 300 to 9600 bps, and synchronous communications from 300 to 19,200 bps. The RS-232 module will support four of the most popular handshaking lines. These are DTR, DSR, CTS and CTR.

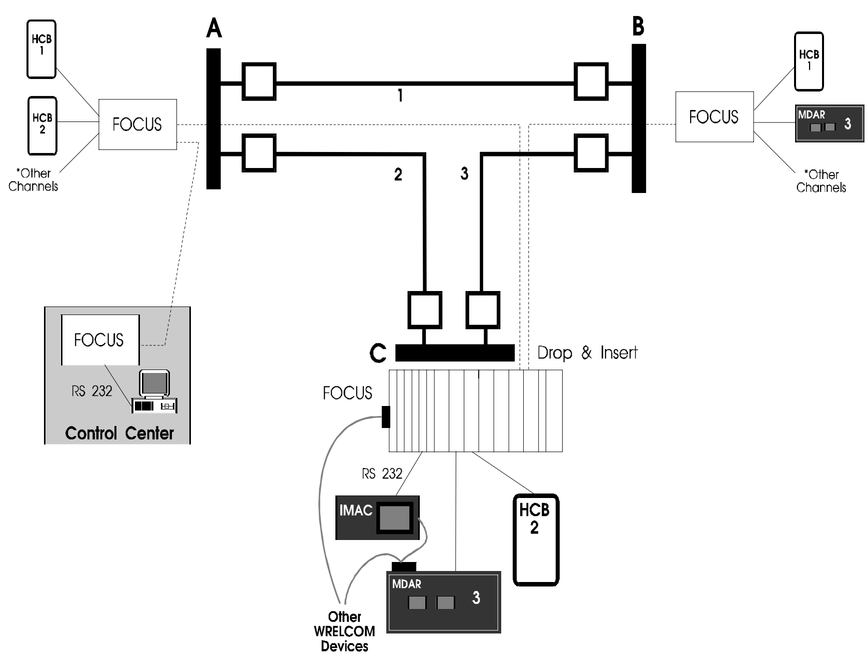

Figure 20. Example of a FOCUS Application

4-Wire Voice Module

The 4-Wire Voice Module can be obtained with or without E/M signaling. There are Two four wire voice channels per module and each requires a single time slot. The 4-Wire Module may also be used for relaying. If there is an existing audio tone used for relaying to be transmitted, then this module without signaling is the one to apply. With signaling this module will be applied to supply a trunk line between two PBXs.

2-Wire Voice Module

The 2-Wire Voice Module will provide for the connection of a standard telephone between two points or for the use of extending a telephone channel from a PBX. This module will have two 2-wire voice channels and each will require a single time slot.

High Speed Data Module

The High Speed Data Module will provide one single channel per module. It will allow for synchronous data transmission speeds of 64 or 56 kbps.

CONCLUSIONS

Twelve years ago the first relay was introduced that used fiber optics for its channel. It proved that relay system security and dependability was significantly improved by the use of fiber. Its only negative feature is that a pair of dedicated fibers are required to provide the communications. The industry has been experimenting with various forms of fiber channels since then. Fiber channels have failed to become the industry standard, partly due to the high cost of fiber, but mostly the high cost of installing the fiber. However, the fact that fiber costs and installation costs have been reduced greatly has made fiber much more attractive. Another big reason for fiber becoming more attractive is that it can become a large source of revenue for utility companies. Also the introduction of products such as FOCUS will drive the use of fiber because they more efficiently use the bandwidth.

This paper has attempted to give the reader some of the fundamentals associated with fiber optic communications. This by far is not a complete treatise on the subject, and it is suggested that the reader obtain one of the references in order to get more complete information. The paper has also attempted to give an initial insight into how digital channels operate. Also described is a new generation of digital fiber optic equipment that will revolutionize the way power system communication engineers look at reliability and security. The channels offered will eliminate most all the past problems associated with pilot wire type of relay systems and other forms of pilot relaying. The relay engineer can now for the first time be very comfortable with his relay channels. These engineers will come to expect a new level of dependability and security, which up until now could only be a dream. The new equipment offered makes it possible to make better use of the fiber bandwidth, and gives the engineer the ability to develop complicated networks for all types of data and voice communications.

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