FIBER OPTIC TECHNOLOGY

INTRODUCTION

The technology base of Fiber Optics has literally exploded during the past few years. Applications of fiber optic systems have evolved from image transmission with coherent fiber bundles to decorations such as fiber optic lamps, to turn signal status indicators and finally to data transmission. It is the area of data transmission that potentially holds the most interest for engineers in the EMC field. The wide band width of fiber optics may permit a glass fiber slightly larger in diameter than a human hair to replace a microwave link. Properly jacketed for environmental protection, hundreds of parallel channels of fiber optics each transmitting several GHz of data can be envisioned in a cable no larger than RG-58 coax. Considering the decreasing availability of the RF spectrum for microwave links and the complexities and cost associated with millimeter waveguides (considered until recently the next major advance in communications technology) it is easy to understand the tremendous efforts long haul communication companies are directing towards fiber optic research and development. Military laboratories and aerospace companies are also devoting significant resources in fiber optic technology anticipating a reduction in the impact of electromagnetic compatibility overhead on advanced systems. Aerospace interest is easily explained when one considers the growing complexity and importance of electronic systems employed in an environment of lightning, EMP, and ever increasing RF field levels while at the same time the shielding effectiveness of yesterday's metal air frame is being reduced by the application of nonconductive composite materials.

For the EMC engineer, fiber optic information transfer has the following significant characteristics:

a. The interface routing component is a non-conductor (glass or plastic) and, therefore, does not generate nor intercept RF energy.
b. Variations or mismatch in receiver termination impedances do not create significant reflections, ringing, or changes in the information power transferred.
c. Adjacent signal channels do not exhibit inductive or capacitive effects. In addition, the length or configuration of the interface component does not affect the impedance of the transmitter or receiver elements.
d. Data coupling into or out of a shielded enclosure can easily be done with a fiber optic system while electromagnetic integrity is maintained with a simple waveguide filter.

These advantages result in a technique for transferring data which is essentially immune to RF interference. The LED or the photodetector at each end of the fiber optic link is subject to interference as is any solid state component. However, for a fiber optic system, one of the primary sources of RF interference coupling (the data interconnection lead) has been eliminated, leaving only powerline conducted or antenna radiated problems to contend with.

A BRIEF HISTORY

Fiber optics play a key role in the human eye, and as such, have been around as long as man himself. The first recorded scientific evidence of total internal reflection and light guiding was made by the Englishman, John Tyndall, in 1870. In 1951, significant scientific progress began when van Heel, Hopkins, and Kapany began transmitting images on flexible fiber bundles. The first clad fiber was attributed to van Heel. Soon afterward, glass was used to replace the original plastic cladding.

Dr. Charles Cao proposed transmitting data on optical fibers in 1968. In 1970, the Corning Glass Works announced 20 dB/km fibers, a significant reduction from the pre-1970 level of 1000 dB/km. Bell Laboratories and Corning obtained 4 dB/km fiber losses in 1973 and during the summer of 1974 Bell Labs achieved a 2 dB/km fiber.

HOW AN OPTICAL FIBER WORKS

An optical fiber is essentially a long cylindrical mirror which accepts a cone of light at one end, transmits the light through the fiber by multiple reflections and shines the light out the other end from a cone similar to the acceptance end. The fiber is composed of a core and a cladding, both of which are optically transmitting materials. The core has an index of refraction N_1, which is greater than the index of refraction of the cladding, N_2. An angle 2θ defines the light acceptance cone of the fiber. The sine of half this angle θ, has been designated the *numerical aperture* of a fiber. A relatively good description of the numerical aperture is given by the values of N_1 and N_2, the refractive indices of the core and cladding respectively, that is $\sin\theta = \sqrt{N_1^2 - N_2^2}$

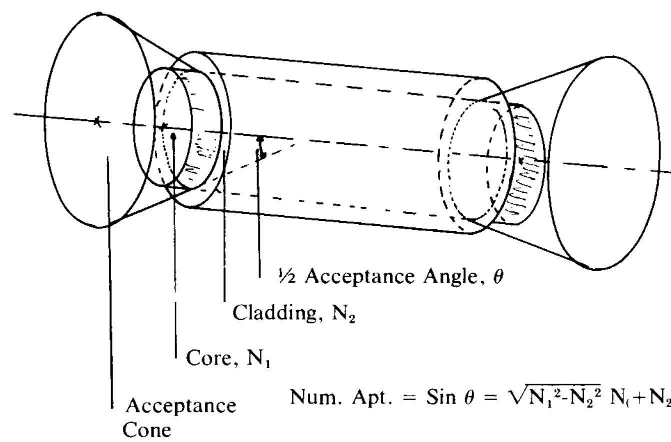
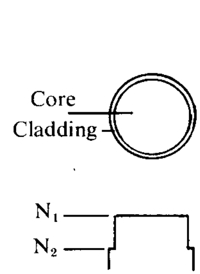


Figure 1 Optical Fiber Perspective View

Practical value of N, (the index of refraction) vary from approximately 1.2 to 1.7 and values of 2θ, (the acceptance angle) vary from a few degrees to 90°. Primary limiting factors for choices of core and claddings are the thermal and physical compatibilities of various glass and plastic materials.

STEP INDEX AND GRADED INDEX FIBERS

The fiber described above is a step index fiber. The name derives from the fact that at the core cladding interface the index of refraction changes as a step function.



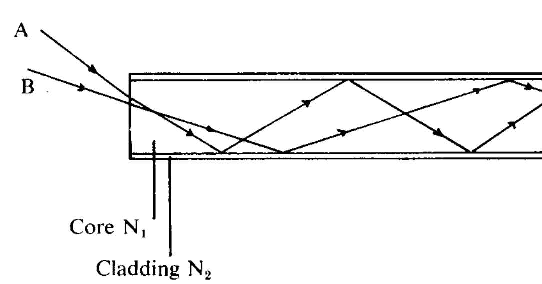


Fig. 2a Step Index Profile   Fig. 2b Cross Section Optical Fiber

Light propogates in a step index fiber by multiple reflections at the core cladding interface. A light ray entering the fiber at a higher angle (Ray A, Fib. 2b) will travel further in the core than a light ray entering the fiber more nearly parallel with the fiber axis (Ray B, Fig. 2b). Traveling further, Ray A will arrive at the terminal point later than Ray B. This time dispersion limits the bandwidth of most step index fibers to a few ten's of hundreds of megahertz per kilometer.

A graded index fiber consists of a cone cladding arrangement where the index of refractions decreases gradually from the core to the external portion of the cladding (Fig. 3a). This causes light to propogate through the fiber in a sinusoidal fashion (Fig. 3b).

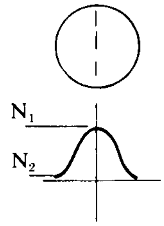


Fig. 3a Graded Index Profile

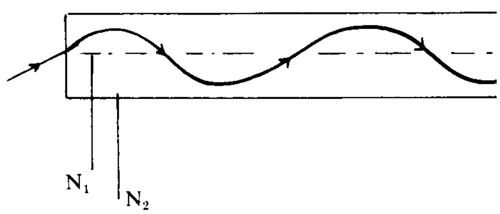


Fig. 3b Cross Section Graded Index Fiber

Light travels faster near the periphery of the fiber and consequently higher order modes (light rays entering the fiber at high angles) tend to arrive at the exit end of the fiber at nearly the same time as light propogating an axis at the center of the fiber. The net result: dispersion in graded index fiber is significantly lower than step index fibers (on the order of lns/km permitting data rates in the range of GHz/km).

SINGLE MODE FIBERS

Step index fibers constructed with a very core (on the order of 1-2 wavelengths of light) and a very slight difference between N_1 and N_2 (the core and cladding refractive indices) will support only a single mode of light energy.

Dispersion is almost nonexistent in single mode fibers. Data bandwidths in excess of 10 gigabits/sec are anticipated for single mode fiber systems. The numerical aperture is very low and highly coherent, high radiance sources, (i.e., lasers or laser diodes) are needed to drive single mode fibers.

FIBER OPTIC DATA TRANSMISSION SYSTEMS

A fiber optic data transmission system is comprised of three basis elements:

a. An electrical to light transducer (typically a LED or a laser diode).
b. A fiber optic cable.
c. A light to electrical transducer (a photodetector).

Other significant components are LED to fiber connectors, fiber to photodetector connectors and fiber-to-fiber splices or connectors.

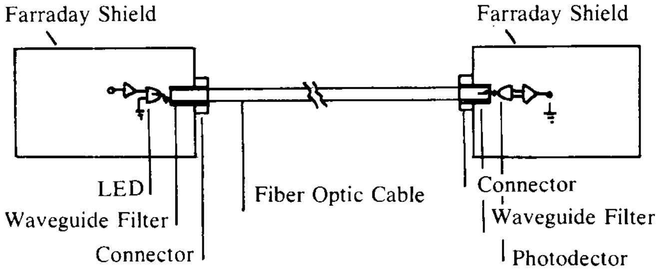


Figure 4 Fiber Optic System

LIGHT SOURCES

There are a wide range of light sources suitable for use in fiber systems. High and medium radiance LEDs which can be modulated at a few hundred MHz have been developed. High radiance LEDs (termed Burrus LEDs) were developed for efficient coupling into single fiber systems. Larger area medium radiance LEDs are used for coupling into fiber bundles with more than one fiber per data channel. Inexpensive medium radiance LEDs that can be modulated up to 50 MHz are available. Laser diodes are becoming an important fiber optic source. Although limited to room temperature operation at this time, significant breakthroughs are being made in reducing current densities and extending modulation rates into the GHz range. High temperature laser diodes should be available within one or two years. The companies most actively developing LEDs for fiber optic systems are RCA, TI, Spectronics, Bell Northern (of Canada), Bell Laboratories, and ITT.

LEDs operated at high current levels have shown a tendency to decrease output power by a factor of 3 dB over a period of 3000-5000 hours. A slight derating has resulted in device lifetimes in excess of 10,000 hours which is considered acceptable for most applications. Also, LED optical output power drops on the order of 2 to 4 dB as temperature is increased from 30°C to 80°C. Significant progress is being made in explaining and reducing the degradation phenomena.

Frequency response and electrical to optical conversion efficiency in LEDs are significantly affected by minority carrier lifetimes. Unfortunately, longer carrier lifetime enhances efficiency but slows down frequency response. Short carrier lifetimes increase frequency response but decrease efficiency.

PHOTODETECTORS

Photodetector technology is relatively mature. Devices are available that couple efficiently with fiber optic systems. Primary candidates are silicon PIN and avalanche photodetectors (APDs). The photodetectors are operated in a reverse bias mode and photons impacting the PN junction cause an increase in reverse current. The low power photodetector and the high gain amplifier at the receiver end of a fiber optic link represent a very significant potential interference problem. Fortunately, the photodetector and amplifier package can easily be shielded and the fiber optic cable can be routed through a simple waveguide filter.

Avalanche photodetectors are 10 to 15 dB more sensitive than PIN photodetectors, but require a 100 to 200 volt reverse bias and are very sensitive to temperature variations.

FIBER OPTIC SYSTEMS EXAMPLE

A typical GaAs LED available at this time from several companies will deliver approximately 1 mw of optical power. A 45 mil diameter fiber bundle (approximately 175 individual 3 mil fibers) with a numerical aperture of .6 will couple to the LED with approximately 4 dB of loss. Output coupling loss to the photodetector is about 1 dB. The sensitivity of a PIN photodiode coupled with a low noise bipolar amplifier is approximately -60 dB at 1 MHz, -50 dBm at 10 MHz and -40 dBm at 100 MHz (assuming a 10^{-8} bit error rate). This results in an available optical margin of 55 dB at 1 MHz, 45 dB at 10 MHz and 35 dB at 100 MHz. Fibers which couple efficiently to the LED mentioned above have been fabricated with losses as low as 100 dB/km. Table I summarizes fiber optic link length versus modulation frequency for various loss fibers.

TABLE I

FIBER ATTENUATION	SYSTEM LENGTH		
	1 MHz (55 dB margin)	10 MHz (45 dB margin)	100 Mhz (35 dB margin)
1500dB/km (.45dB/ft)	122 ft	100 ft	77 ft
1000dB/km (.3dB/ft)	183 ft	150 ft	116 ft
500dB/km (.15dB/ft)	366 ft	300 ft	233 ft
200dB/km (.061dB/ft)	900 ft	730 ft	573 ft
100dB/km (.03dB/ft)	1833 ft	1500 ft	1166 ft

Table I represents the low cost, medium performance fiber optics systems which have already been used to retrieve instrumentation data during EMC screen room testing, missile radiated field susceptibility testing, and lightning effects testing. Obviously, for short lengths and low data rates, optical dispersion is not a problem for these systems.