Technical English

For Information and Communication Engineering

2011/9/11

Unit Sixteen

Optical Communication Components

概述

- 光纤作为通信传输媒介的基本原理
- 均芯光纤和渐变折射率光纤
- 传输引起的失真和误码
- 多模和单模光纤
- 光纤作为调制和检测元件

terrestrial	地面的
celestial	天体的
transparent	透明的
opaque	不透明的
refraction	折射
cladding	包层
exponentially	按指数规律地
homogeneous	均匀的，同质的
gradient	梯度
graded-index fiber	渐变折射率光纤
evanescent	短暂的，很快消失的
impinge	撞击
traverse	跨越，横过
incident	入射
intermodal	模态间的
intramodal	模态内的
dispersion	色散，散开

axis	轴
coaxial	同轴的
radius (pl. radii)	半径
repeater	中继器
overlap	重叠
diameter	直径
silica	硅石，二氧化硅
conduit	管道
immune	免疫
cross talk	窜音
hazard	危险
fusion	熔合，核聚变
detector	检波器，检测器
on-off modulate	启闭调制
bias	偏置
threshold	阈值
incoherent	非相干的

emission	发射
sensitivity	灵敏度
ambient	周围的
aging	老化
emanate	散发，发出
birefringence	双折射
polarization	极化，偏振
acousto-optic	声光的
diffract	衍射，绕射
grating	光栅
photodiode	光二极管
avalanche	雪崩（效应）
bulky	笨重的
valence	（原子的）价
accelerate	加速
quantum	量子

As discussed earlier, the atmosphere cannot be used as a transmission channel for terrestrial communications using light beams. The most promising channel is the optical fiber waveguide. An optical fiber essentially consists of a central transparent region called the core which is surrounded by a region of lower refractive index called the cladding (see Figure 16.1).

一个中心透明的称为纤芯的区域和一个环绕纤芯的称为包层的折射率较低的区域

Caption of Figure 16.1

Figure 16.1 A typical optical fiber consisting of a transparent material of refractive index n_1 and surrounded by a cladding of a slightly lower refractive index n_2. Typical dimensions of the core and cladding are 50 and 125 μm, respectively. Most of the propagating energy is confined to the core region and the field decays exponentially in the cladding.

传播能量的大部分被限制在纤芯内，包层中的场按指数律衰减。

从中心向外具有递减梯度的

The core could either be homogeneous or could have a gradient in refractive index with the refractive index decreasing away from the center of the core. In the former type of fiber, also referred to as homogeneous core fibers (see Figure 16.2), the guidance of light occurs through the phenomenon of total internal reflection at the core-cladding interface. In the latter type of fibers, also referred to as graded-index fibers (see Figure 16.3), the guidance of light occurs through continuous refraction of light rays towards the center of the core.

由光束朝纤芯中央连续折射而产生光导

由于在纤芯包层的界面处的全内反射现象而形成光导

Caption of Figure 16.2

以大于临界角射到纤芯—包层界面处

Figure 16.2 A homogeneous core optical fiber in which the refractive index in the core is constant. Light rays impinging on the core-cladding interface at an angle greater than the critical angle are trapped inside the core of the waveguide. In such a fiber rays traveling at larger angles to the axis have to traverse a larger path and hence take a longer time than those rays which propagate with lesser angles to the axis.[1] This leads to a substantial amount of broadening in a pulse propagating through the fiber.

与轴线成较大角度传播的光线比起那些以较小角度传播的光线来，要经过较长的路径，因此需要用较多的时间

Caption of Figure 16.3

… 光线朝纤芯中央连续折射而被束缚在纤芯内

Figure 16.3 A graded index optical fiber in which the refractive index in the core decreases continuously away from the axis. Figure 16.3(a) shows a typical variation of refractive index across the core of the optical fiber. Light rays in such a fiber are trapped by a continuous refraction towards the center of the core, which leads to a periodic focusing of the rays, as illustrated in (b). In such a fiber, even though rays making larger angles with the axis traverse a longer path length, they do so in a region with a lower refractive index and hence at a higher speed of propagation: this leads to a smaller value of pulse dispersion in such fibers as compared to homogeneous core fibers.[2]

即使与轴线夹角较大的光线要经过较长的路径，但是在折射率较低光速较大的区域内传播，…

存在着不改变场结构并以固定的相位和群速传播的特殊的场分布

In an optical waveguide, there exist specific field distributions which propagate without changing their form and with a definite phase and group velocity. These field configurations are referred to as the modes of the optical waveguide. These modes are characterized by different propagation constants and different group velocities. In a multimode waveguide, there exist a large number of these propagating modes while in a single-mode waveguide there exists only one mode.

Each mode has most of the energy inside the core, but due to the evanescent fields outside the core, a part of the energy is also traveling in the cladding. By making the cladding sufficiently thick, the fields of the mode at the cladding-air boundary can be made small, thus making it easy to handle and support without causing much disturbance to the modes.

可使传播模式的场在包层一空气界面处很弱，使得光纤便于处置和支撑而不会严重地扰乱传播模式

As already discussed, in a fiber optic communication system the information is coded in the form of discrete pulses which are transmitted through the fiber. The information capacity of the system will be determined by the number of pulses that can be sent per unit time. For the information to be retrieved at the output end, the various pulses must be well resolved in time.

各个脉冲必须能在时间上被正确分辨

In an optical fiber due to various factors like the differences in group-velocity between the different modes and the dependence of the propagation constant of a mode on wavelength, a pulse of light broadens as it propagates through the fiber.[3]

在光纤中由于不同模式之间的群速度不等，以及各模式的传输常数依赖于波长等因素，光脉冲会在光纤传输过程中变宽。

Hence, even though two pulses may be well resolved at the input end, because of broadening of the pulses they may not be so at the output (see Figure 16.4). In such a case no information can be retrieved at the output. Thus for a given broadening, the pulses have to be separated by a minimum time interval which would determine the ultimate information-carrying capacity of the system.

脉冲之间必须以一个最小的时间间隔分开，这个时间间隔就确定了系统的最大信息容量

Caption of Figure 16.4

在光纤输入端每个脉冲宽度为τ_1的一串脉冲经传输后，变成一串宽度为τ_2（$>\tau_1$）的脉冲。

Figure 16.4 A series of pulses each of width τ_1 (at the input end of the fiber) after transmission through the fiber emerges as a series of pulses of width τ_2 ($>\tau_1$). The broadening in the pulses is caused by the different group velocities of the various modes and by the dependence of the propagation constant on wavelength. If the broadening is large, then adjacent pulses will overlap at the output end and may not be resolvable. Thus, pulse broadening determines the minimum separation between adjacent pulses, which in turn determines the maximum information-carrying capacity of the fiber.

脉冲展宽决定了相邻脉冲间的最小间隔，也决定了光纤的最大信息容量

每一种模式一般都以不同的特征群速度传播

When a pulse of radiation is injected into a fiber, it excites various modes of the fiber. Since each mode propagates with, in general, a different characteristic group velocity, the incident pulse of light broadens as it propagates through the fiber. This is referred to as intermodal broadening. When the fiber can carry only one propagating mode, i.e., in a single-mode fiber, this broadening is absent, but due to the dependence of the propagation constant on wavelength, there is still some broadening; this is referred to as intramodal broadening.

Both intermodal and intramodal dispersions arise as a result of (a) waveguide effects and (b) material effects; the latter due to the finite bandwidth of the source and the fact that at different wavelengths the refractive indices are different.[4]

后者是由于光源为有限带宽，以及对不同波长的光有不同的折射率而产生的一种效应

使用激光器的系统与使用LED的系统相比其材料色散更小

It may be mentioned here that since lasers have much smaller spectral width as compared to light-emitting diodes, the material dispersion is much lower in a system employing lasers as compared to one using LEDs. For example, with an LED, the pulse broadening due to material dispersion may be ~4 nsec/km, whereas with a laser this would be less than 0.2 nsec/km.

The broadening of a pulse of light as it propagates through an optical fiber can also be visualized by using the concept of geometrical optics. When a pulse of light is injected into a homogeneous core optical fiber, it excites rays traveling at different angles with the axis. As can be seen from Figure 16.2 since rays making larger angles with the axis have to traverse a longer optical path length, they take a longer time to reach the output end.

由于与轴线夹角较大的光线必须经过较长的光程，因此它们要用更长的时间到达输出端

Consequently the pulse of light broadens as it propagates through the fiber. In contrast, in a graded index fiber, even though rays making larger angles with the axis have to traverse longer path lengths they do so in a medium with a lower value of refractive index (see Figure 16.3).

尽管与轴线夹角较大的光线必须通过较长的光程，但它们是在折射率较低的媒介中传播

Thus the longer path length can be partially compensated by propagation at a higher velocity. Hence the broadening of a pulse must be much lower in a graded index fiber as compared to a homogeneous core fiber. In fact this is indeed the case, and for high-bandwidth applications, graded index fibers are more suitable than homogeneous core fibers.

可以制成只存在一种传播模式的光纤

It may be mentioned here that in optical fibers having very small core radii and small index difference between the core and cladding, it can be so arranged that only one mode of propagation exists in the fiber. Such fibers are therefore referred to as single-mode fibers. Because of the presence of just one mode, the dispersion in these fibers is very small and is only due to intramodal broadening. Such fibers are indeed expected to be used in future super high bandwidth systems.

In addition to the extremely large information-carrying capacity of a system using lightwaves, communication or transmission through optical fibers has several other additional advantages over the conventional metallic systems like the coaxial cable, etc.

与同轴电缆等传统金属系统相比，通过光纤通信或传输还有另一些优点

因为实际可获得的光纤传输损耗极低

(i) Because of the extremely low transmission loss of practically available fibers, one can have much greater distance between repeater stations, resulting in substantial cost savings.

(ii) Optical fibers are typically about 100 μm in diameter and are basically made of silica or glass. This results in a heavy reduction in weight and volume of space required, which is an important consideration for laying in already crowded available conduits. This saving in weight and volume is also important for shipboard applications and data handling using optical fibers in aircrafts.

直径大约是100微米

不受电磁干扰影响

(iii) Optical fibers are immune to electromagnetic interference and there is no cross talk. This is an important consideration for secure communications in defense.

(iv) Optical fibers can be used in explosive as well as high-voltage environments due to the absence of any hazard due to short circuits, etc.

由于不存在任何由短路等原因而造成的危险

In addition to the main application in telecommunications, optical fibers are also expected to play an important role in computer links, space vehicles, industrial automation and process control, etc. In fact, recently optical fibers have been used to carry data and control information within big fusion lasers at Lawrence Livermore Laboratory and Los Alamos Scientific Laboratory and also for monitoring underground nuclear explosions at the Nevada test site. The additional advantages of using optical fibers include lower cost and immunity from noise.

光纤已经被用来 … 传送数据和控制信息，也用于 … 监控地下核爆炸。

What we have discussed above is just one of the components of a lightwave communication system. In addition to this, one requires modulators, which would code the information into the lightwave, and detectors, which could detect the pulses of light at the receiver and decode the information. We will discuss briefly the principle behind modulators and detectors.

人们还需要能把信息编码成为光波的调制器和能在接收端检测光脉冲并把光脉冲解译还原成信息的检测器

通过改变其某个输入参数如输入电流来直接调制

Light sources can either be modulated directly by varying some source input parameter like input current, or the light output can be modulated externally by passing it through devices known as modulators. The most promising source to be used in optical fiber communication systems, namely, the semiconductor laser sources, can be modulated easily by varying the input current.

光源必须被键控调制

In fact, in digital systems, the source has to be on-off modulated, and practically, the semiconductor sources can be on-off modulated at high speeds with rise times of less than a nanosecond. The on-off modulation is done by biasing the laser diode slightly below the threshold value, which is typically ~100 mA. At this stage, the laser diode operates as an LED and emits incoherent light at a low optical output power.

键控调制是通过把激光二极管偏置在稍低于门限值上来实现的，门限值一般为100毫安左右。

将二极管激光器从非相干光发射状态转换成具有较大输出光功率的相干光发射状态

An additional current (~20 mA) is added by a high-speed driver, which switches the laser diode from incoherent emission state to a coherent emission with large output optical power. By keeping the "off state" slightly below threshold, the delay between the applied electrical pulse and the resulting optical output pulse is minimized; this delay must indeed not be more than the bit interval so that the optical pulses accurately reproduce the input signal.[5]

这一延迟必须不大于比特之间的间隔从而使光脉冲能精确重建输入信号

An important factor to be taken care of is the temperature sensitivity of the output optical power. In the above-mentioned scheme of operation, this fact can be taken care of by varying the DC bias through an optical feedback circuit so as to take care of both slow changes in ambient temperature and the gradual aging of the laser itself.[6]

以便兼顾环境温度的缓慢变化和激光器本身逐渐老化这两种因素

The monitoring of the output power is usually done by collecting the light emanating from the backside of the laser, the light from the front surface being coupled into the fiber itself.[7]

通常由收集激光器背面射出的光来实现输出功率监控，激光器前面发出的光则全部耦合到光纤中去。

For nonsemiconductor laser sources, an external modulator is used for modulation. The external modulators make use of various properties possessed by different materials. Thus, certain crystals have a birefringence which changes in the presence of an applied electric field. Thus, the state of polarization of a beam can be changed by passing it through such a crystal. If the crystal is placed between crossed polarizers, one would have an intensity modulation.

放在正交的偏振镜之间

Similarly, acousto-optic modulators are based on the interaction of an acoustic beam with the light wave. The propagating acoustic wave creates a refractive index grating which in turn diffracts the optical wave.

传播的声波产生一个折射率光栅，反过来使光波发生衍射。

光波通信中应用的三种重要检测器是光电倍增管，PIN光二极管和雪崩光二极管。

At the receiving terminals or at repeater stations, one requires optical detectors which receive the input optical signal and convert it into electrical signals. The three important detector types that find use in lightwave communication are the photomultiplier, the PIN photodiode, and the avalanche photodiode. Even though photomultipliers possess large gains, the latter two are expected to find more widespread application because they are less bulky, do not need high bias voltages, and are much cheaper.

由一个具有开阔中心区域的反偏P-N结构成，为了接收入射光，该区域涂有抗反射的涂层

The simplest solid-state photodetector consists of a reverse-biased *p-n* junction with an open center area that is anti-reflection coated to receive the incident light. The absorbed photons excite electrons from the valence band into the conduction band. The electrons and holes so generated are separated by an applied electric field to induce a photocurrent across the junction.

由此产生的电子和空穴被外加电场分离，产生通过P-N结的光电流。

In order to detect very low optical powers one uses the avalanche photodetector. In this device, the electron-hole pair produced by a photon of light is accelerated in the device and is made to release more electron-hole pairs, thus leading to a gain.

光子产生的电子–空穴对在这种器件中被加速，释放出更多的电子–空穴对，以此获得增益。

为了适应系统的信息率

The photodetectors required in a fiber optic communication system must have a high responsivity at the operating wavelength and must also have sufficient bandwidth in order to accommodate the information rate of the system. The most promising photodetector for the 0.80μm wavelength region seems to be silicon photodiodes. They have very fast response times (≤0.1nsec). The quantum efficiency (the ratio of primary photoelectrons generated to the photons incident on the detector) is also large.

所产生的一次光电子与入射在检测器上的光子之比

结合课文的思考题

- **What are the differences between homogeneous core fiber and graded index optical fiber?**
- **What are the advantages of graded index optical fiber?**
- **How does inter-symbol interference (ISI) occur in an optical fiber communication system?**
- **In addition to being transmission media, what else can optical fibers be used for?**

Exercises

- **Together with the already proven modulation bandwidth capability of fiber cable this property provides a totally compelling case for the adoption of fiber communication in the majority of long-haul telecommunication applications.**
  - **A. an absolutely convincing example**
  - **B. an entirely conceivable condition**
  - **C. a very important situation**
  - **D. a highly competitive case**

Exercises

- **Unfortunately, we will see that it is not as easy to distinguish between psychologically valid and invalid AI programs as it is to distinguish between physically valid and invalid jumper making procedures.**
  - **A tell whether or not AI programs are of importance to psychology**
  - **B provide psychological differences between a valid AI program and an invalid AI program**
  - **C give valid reasons to distinguish psychologically different AI programs**
  - **D separate psychologically valid AI programs from psychologically invalid ones**

Exercises

- **We are to develop a code such that fewer bits are assigned to code words representing gray levels having higher probability of occurrence, and vice versa.**
  - **A. in other words, gray levels that more frequently occur are given more bits**
  - **B. and more bits are used for gray levels of lower probability of occurrence**
  - **C. otherwise, more bits are needed in the similar case**
  - **D. in other words, more probable gray levels require shorter code words**

Exercises

- **We shall use this parameter as a measure of degradation during the evaluation of different quantization systems later in this chapter.**
  - **A. an action of processing**
  - **B. a degree of enhancement**
  - **C. an amount of impairment**
  - **D. an effect of interference**

Exercises

- **What is fascinating about all this from the perspective of computer architecture is that, on the one hand, the basic building blocks for today's computer miracles are virtually the same as those of the IAS computer from 50 years ago, while on the other hand, the techniques for squeezing the last iota of performance out of the materials at hand have become increasingly sophisticated.**
  - **A. in view of computer architecture**
  - **B. with proposed computer architecture**
  - **C. taking computer architecture into account**
  - **D. from various aspects of computer architecture**