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# Digital Microwave Communication

## Principles V1.1

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**Key word:**

Microwave antenna ODU IDU fading anti-fading route  
site antenna height

**Abstract:**

This document describes basic concepts of the microwave and microwave communication to help technical support staff learn microwave products and improve their ability to maintain microwave equipment.

There are nine chapters in this document. First chapter is an overview about the microwave communication; succeeding chapters introduce the digital microwave communication equipment, split microwave, typical networking modes and application and site types of the microwave, the relay site, transmission theory of the microwave which includes fading in the transmission process, technology against fading, microwave equipment protection modes, interference and anti-interference technology.

The last four chapters relate the microwave engineering calculation, microwave engineering design requirements, microwave engineering design methods and issues that should be attended to in engineering design. As the fundamentals of microwave engineering design, these four chapters are optional in reading.

**Abbreviations:**

None

**References:**

None

# 1 Microwave Communication Overview

## Objectives:

- To understand what is microwave communication
- To know the challenges and opportunities for the microwave communication
- To have an overall concept about the microwave communication

## 1.1 Basic Concepts of Digital Microwave

Microwave is electromagnetic wave with frequency from 300MHz to 300GHz and it is a finite frequency band of the entire electromagnetic wave spectrum. According to the microwave transmission feature, microwave can be viewed as plane wave. Along the transmission direction, the plane wave has no longitudinal components of electric field and magnetic field. Both electric field and magnetic field are vertical to the transmission direction. Thus, the plane wave is called transverse electromagnetic wave and marked as TEM wave. For the application of each frequency band in the microwave spectrum, see figure 1.1.

frequency	30	300KHz	3	30	300MHz	3	30	300GHz	3THz
wavelength	10Km	1	100m	10	1	100mm	10	1	100μm
name	VLF (very long freq)	LF (long freq)	MF (middle freq)	HF (high freq)	VHF (very high freq)	UHF (ultra high freq)	SHF (super high freq)	EHF (extra high freq)	Optical wave
Main purpose	navigation		broadcast			Satellite Communication Microwave Communication			
	wireless		Television						

Figure 1.1 application of each frequency band in the microwave spectrum

In figure 1.1, VHF and LF are ground wave which is very capable of diffraction and can diffract hundreds of kilometers; they are mainly used in radio and navigation. MF is used in broadcast and is less capable of diffraction than VHF and LF. HF is not ground wave, and it is reflected to the ionosphere. VHF and UHF are used in TV. Though UHF is used in TV, (that is, the microwave is involved) it is not called microwave. After the microwave, it is optical wave which is also a type of electromagnetic wave.

Digital microwave communication refers to a type of communication mode which uses microwave (frequency) to carry digital information through the electric wave space, transmit independent information and conduct

regeneration. Microwave is weak in diffraction and it is only line-of-sight communication, therefore, it has a limited transmission distance. In long-distance transmission, relay is needed to connect sites. Thus, it is called microwave relay communication.

Microwave communication uses microwave as the carrier of signals, which is similar to optical fiber communication that uses light as the carrier of signals. Simply speaking, transmitting module and optoelectronic inspection module used for receiving in the optical fiber transmission system are similar to the transmitting and receiving antenna. Compared with the optical fiber communication with wire channels, microwave channel is wireless and microwave communication is much more complicated.

## 1.2 Microwave Development Course

Microwave communication technology comes into being half a century ago. It is a wireless line-of-sight communication means that propagates information in the radio-frequency band around the ground. Original microwave communication systems are all analog, and same as the coaxial cable carrier transmission system at that time, they are the major transmission means of the communication network long-distance transmission trunk. In the year of 1958, China began to study, develop, introduce and apply the analogue microwave communication technology. In the 1970's, China developed the low- and medium-capacity (such as 8Mb/s and 34Mb/s) digital microwave communication system, which was the outcome of communication technology from the analogue to the digital.

In the late 1980's, SDH was widely used in transmission system and SDH high-capacity digital microwave communication system of  $N \times 155\text{Mb/s}$  was developed. Now, digital microwave communication, optical fiber communication and satellite communication are considered as the three major means of modern communication transmission. Following sections describe microwave development history both in China and the world.

### 1.2.1 Microwave Evolution in the World

In the year of 1947, Bell lab built the first analogue microwave trial circuit (TD-X) between New York and Boston. This circuit used vacuum tube to amplify signals and adopted the frequency modulation (FM) mode. In the year of 1950, 4 GHz TD-2 system carried commercial telephone services for the first time. Since early 1950's, except America, the backbones of Australia, Canada, France, Italy and Japan were all installed with microwave-relay system similar to the TD-2 system. In the year of 1979, radio-channel capacity of Japanese commercial system was up to 3600 telephone channels, and till 1980, American commercial system AR6A adopted single-sideband modulation technology and arranged 6000 telephone channels in 30 MHz bandwidth of 6 GHz frequency band, which made the transport cost of each channel to the minimum unprecedented. To improve the voice quality, in the late 1960's, digital radio-relay came into being for the first time. To improve the frequency spectrum efficiency, high-status modulation modes 64QAM, 128QAM, 512QAM appears and the frequency spectrum efficiency is raised to 10bit/s/Hz. In the year of 1988, based on the

American SONET, the ITU formulated the SDH transmission network standard. Compared with the former PDH, SDH unifies the standards of Europe and North America and made intercommunication of STM-1 and higher rate in the world become available. SDH system adopts synchronous multiplex and flexible mapping structure. It can add/drop lower-order tributary signals directly to/from higher-order tributaries; avoid multiplexing of many hierarchies and simplify the equipment. Moreover, SDH system provides sufficient overhead bytes, which strengthens the operation, management, maintenance and provision of the network. Therefore, SDH was rapidly developed in the 1990's.

## 1.2.2 Microwave Evolution in China

### (1) Analogue Microwave Evolution

China already began to develop analogue radio communication system of 60 channels and 300 channels since 1957 and began the research of 600 channels in 1964, 960 channels in 1966. And in 1986, China developed 1800 channels analogue microwave system (sixth five year state key technologies R&D program). Based on those achievements, China built analogue microwave circuits of more than 20,000 kilometers.

### (2) PDH Digital Microwave Evolution

PDH is formulated by CCITT (the previous name of ITU) in 1960's. China introduced a set of PDH microwave equipment from abroad in late 1960's. In the year of 1979, China built the first trunk PDH microwave circuit (between Beijing and Wuhan, introduced from abroad by State Electric Power Ministry). In the year of 1986, China independently developed 4 GHz 34 Mbit/s PDH microwave system and built it between Fuzhou and Xiamen. During 1987 and 1989, the former Telecommunications Ministry built 6 GHz 140 Mbit/s PDH microwave circuit between Beijing and Shanghai. In 1992, China independently developed 6GHz 140Mbps PDH microwave system (achievement of seventh five year state key technologies R&D program) and built it between Wuchang and Yangluo in Hubei province. After 1995, low and medium capacity PDH microwave systems needed in mobile communication coverage are greatly developed. Split microwave system, which is easy to install and dismantle, gradually replaces trunk microwave system.

### (3) SDH Digital Microwave Evolution

SDH (synchronous digital hierarchy) was developed in the world in 1992. The first SDH microwave circuit in China was introduced and built by Jilin Broadcast Television Bureau in 1995. During 1995 and 1996, the former State Telecommunications Ministry began to introduce and build SDH microwave circuit. In 1997, the 6 GHz SDH microwave circuit (achievement of ninth five year state technologies R&D program) developed by China independently passed the verification and was accepted in Shandong. After the year of 2000, Information Industry Ministry discontinues to build SDH microwave used in national backbone public network. Due to the industry features and their own demands, industries such as broadcast television, coal, oil, water and natural gas pipe have already become the main force of the SDH microwave. SDH

minimized split microwave systems are already being applied in mobile, emergent and metro networks.

## 1.3 Characteristics of Digital Radio Communication System

Radio communication system, especially the digital radio communication system, has the following advantages:

Can be rapidly installed

Can use the existing network infrastructure repeatedly (digital radio uses the infrastructure of the analogue radio)

Can cross complicated terrains (rivers, lakes and mountains)

Can use point-to-point radio transmission structure in the remote mountains

Can rapidly restore the communication after the natural disasters

Can protect hybrid multiple transmission media

Those advantages not only apply to the fixed nodes or temporary nodes and feeder routes in the urban areas, but also apply to very long long-distance routes.

For example, Russian Telecommunications build a very long long-distance route (totally more than 8000 km) of SDH digital microwave radio-relay system. This network uses the existing infrastructure, have total capacity of eight radio frequency (RF) channels (six primary channels and two protection channels) and each channel carries 155 Mbit/s.

Another example, Canada uses optical fiber transmission system and radio transmission system together to constitute a transmission network, to overcome the difficulties of geographical conditions.

High capability SDH microwave circuit of China should be Beijing-Guangzhou backbone microwave circuit built in 1998, which occupies two frequencies and is configured in  $2 \times 2 \times (7+1)$  with a total transmission capacity up to 4.8 Gbit/s.

In metropolises and urban areas, digital microwave is always considered as the only optional means that can parallel optical cables in terms of building digital nodes and distributing networks. In fact, it is very expensive to bury underground cables in the metropolises and towns and it is unlikely to get approved to trench in downtown areas, particularly in the developed countries such as European countries and America. It is said that, in developed countries, 80%–90% of the transmission used for mobile coverage adopts digital radio system.

In most parts of the world, radio-relay links may be the only available high-capacity transmission medium in crossing thousands of miles of wood

areas, mountains, prairies, deserts, wetlands and other rough areas. Furthermore, for the power consumption of radio-relay links is very low, solar power already becomes a major factor in such rough areas using digital radio-relay systems.

For the microwave circuit is unlikely to be damaged by human activities and natural disasters, therefore, microwave system is an indispensable part to constitute China communication networks and ensure the security of communication networks.

Currently, microwave is still a most promising means of communications. In 1976 when the earthquake occurred in Tangshan, all the coaxial cables between Beijing and Tianjin were broken, but the six microwave channels were free from any damage. Therefore, if network planning is carefully and reasonably carried out and proper information volume is used to cover the land, radio-relay links together with other modern transmission media can support and supplement optical fiber transmission networks.

Microwave yet has some disadvantages. In microwave transmission,

- ✧ Line-of-sight transmission conditions should be ensured
- ✧ Transmission distance between two stations should be not too long
- ✧ Frequencies need to be applied for
- ✧ Communication quality is greatly affected by the environment and
- ✧ Communication capacity is limited

## 1.4 Challenges and Opportunities for Digital Microwave Communication

### 1.4.1 Optical Fiber Communication—Biggest Challenge for Digital Microwave Communication

Rising of optical fiber communication is the most scientific event in the twentieth century. Since the optical fiber transmission theory is proposed in 1970's and the optical fiber is practically used in 1980's, the optical fiber communication is greatly developed. Due to its huge bandwidth, minimum loss and lowest cost, optical fiber communication becomes a major means of the backbone transmission and enormously impacts the digital microwave communication.

**Challenge 1: can the backbone digital microwave systems be used as protection for backbone optical fiber systems?**

Since the beginning of 1990's, administration of telecommunications begins to use high-capacity optical fiber systems as the major transmission means of the national information highway, which becomes an overwhelming trend. In the middle and late 1990's, when China administration of telecommunications notes the huge capacity of the optical fiber communication, it also observes the great influence of the optical fiber systems on the telecommunication when the

systems are affected by natural disasters and human destructive acts. To ensure the normal running of communications, about ten national backbone SDH radio communication circuits are established to protect the backbone optical networks. However, in the twenty-first century, optical networks are sufficiently built from west to east and from north to south, the previous problems of optical fiber communication can be completely solved by redundant circuit, and the significance of using digital microwave systems as the protection of optical communications is reduced.

### **Challenge 2: can the capacity of digital microwave systems be increased?**

To increase the capacity of digital microwave systems, microwave R&D engineers adopts a series of advanced technologies:

- ✧ High-status modulation demodulation, 64QAM/128QAM/256QAM/512QAM
- ✧ XPIC—a cross-polarization interference counteract technology, which can realize co-channel frequency multiplex. Then, the transmission capacity can multiple under same radio-frequency bandwidth
- ✧ New efficient correction coding technology, such as TCM, MLCM and RS
- ✧ A series of anti-multi-fading technologies, such as frequency field equalization, time field equalization, space diversity and all kinds of diversity technologies
- ✧ Other new technologies, such as ATPC, transmitting power spectrum molding technology

It is said that, at the end of 1990's, some research institutes claimed that they already achieved the technology that under 28 MHz channel bandwidth, using high-status modulation-demodulation 1024QAM, XPIC and other advanced technologies to transmit STM-4 and make the total transmission capacity up to 4.8 Gbit/s in 500 MHz frequency band (such as L6 GHz frequency band). However, due to many reasons, this technology is not commercialized in use. Though capacity of 4.8 Gbit/s of the microwave communication systems is very remarkable, it is far less than the capacity of optical fiber communications which is up to dozens of or even hundreds of Gbit/s in a single fiber.

## **1.4.2 Opportunities for Digital Microwave Communication**

As a radio transmission means, digital microwave transmission have the advantages that the optical fiber cannot parallel in terms of flexibility, anti-disaster and mobility. At present, the opportunities of digital microwave can be included as follows: used as dedicated network or the backup and supplement of the dedicated optical fiber transmission. China dedicated networks, such as broadcast television, oil, natural gas pipe, coal and water, do not need high capability transmission, normally, an STM-1 or several STM-1s. Those networks are either built with optical fiber communication circuits, or only built with single-line optical fiber communication links. They do not have the advantage like the telecommunication does which is built with sufficient optical



networks from west to east and north to south. Therefore, those networks must be built with SDH or PDH microwave circuits used

- ✧ To transmit data services and telegraphy
- ✧ As the protection for the optical transmission systems in natural disasters
- ✧ In some situations that the optical transmission systems are inapplicable

In China, 2 G and 2.5 G mobile communication stations use most PDH microwave communication circuits. Along with the award of 3G license, the transmission capacity is to be expanded. In addition, participation of fixed network operator may further raise the fever of mobile coverage. Succeeding to the optical fiber transmission, the digital microwave transmission is surely to be in increasing demands and the SDH microwave may be in great demand, too. When China telecommunication products, especially mobile communication systems are expanding to the overseas countries, digital microwave transmission products is also exported.

Other methods of microwave communications, for example:

- (1) Point to multi-point microwave communication system (PMP): it has two categories of user line type and relay line type, the radio user loop in the microwave frequency band can belong to the PMP. PMP is mainly used in remote areas such as countryside, islands, and dedicated communication networks.
- (2) Microwave spreading data transmission system, such as point-to-point 2.4GHz spreading microwave, point to multi-point 2.4GHz spreading microwave data network.
- (3) Temporary microwave communication, which adopts upper frequency band point-to-point microwave communication system and can easily settle burst matters in the communications.
- (4) Local multi-point distributed service, which works at the frequency band from 26 to 28 GHz and can be used in the future wideband services access, it is called wireless fiber.

Those various microwave communication methods may last perpetually for their diversity and flexibility.



## 1.5 Microwave Frequency Band Choice and RF Channel Arrangements

Frequency bands frequently used in microwave transmission include 7G/8G/11G/13G/15G/18G/23G/26G/32G/38G (defined by Rec. ITU-R). Each frequency band is used as follows:

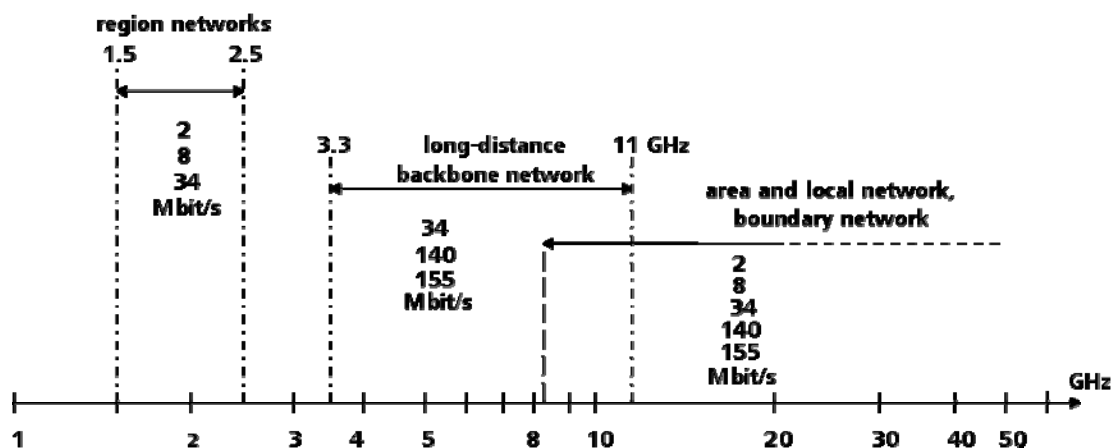


Figure1.2 the use of commom frequency band

(1) For long-distance PDH microwave circuit (more than 15 km), use 8 GHz frequency band. If the distance is not more than 25 km, use 11 GHz. Choose specific frequency band based on the local weather condition and microwave transmission cross section.

(2) For short-distance PDN microwave circuit (normally used in the access layer, within 10 km), consider using 11 GHz, 13 GHz, 14 GHz, 15 GHz and 18 GHz.

(3) For long-distance SDH microwave circuit (normally exceeding 15 km), use 5 GHz, 6 GHz, 7 GHz and 8 GHz. If the distance is not more than 20 km, consider using 11 GHz. Choose specific frequency band based on the local weather condition and microwave transmission cross section.

Frequency bands 7G, 8 G, 11G, 13G, 15G, 18G, 23G are not contiguous, for the microwave frequency resources are internationally defined and radar needs to use some frequency bands. The microwave used in transmission is above 4G, 2G is used by mobile communication. Microwave communications previously use 1.5G, and later ITU-T decides to allocate 2G to mobile communication and 9G to meteorologic radar.

Radio resources are restricted by the administrations but the optical cable is not. Microwave frequency needs to be applied for but it does not need to be applied for in a certain period. In the past, 1.8G and 2.4G are used as spreading frequencies such as microwave oven, Bluetooth. 1.8 G and 2.4 G can be transmitted in the noise, but now the interference is too heavy and 2.4 G cannot be randomly used.

In each frequency band, various frequency ranges, transmitting and receiving (T/R) spacing and channel spacing are defined. The channel spacing is equal to channel bandwidth. In using a certain frequency band, there are specifications for the center frequency, T/R spacing and channel spacing. And the specification can be looked up in relevant frequency specifications.

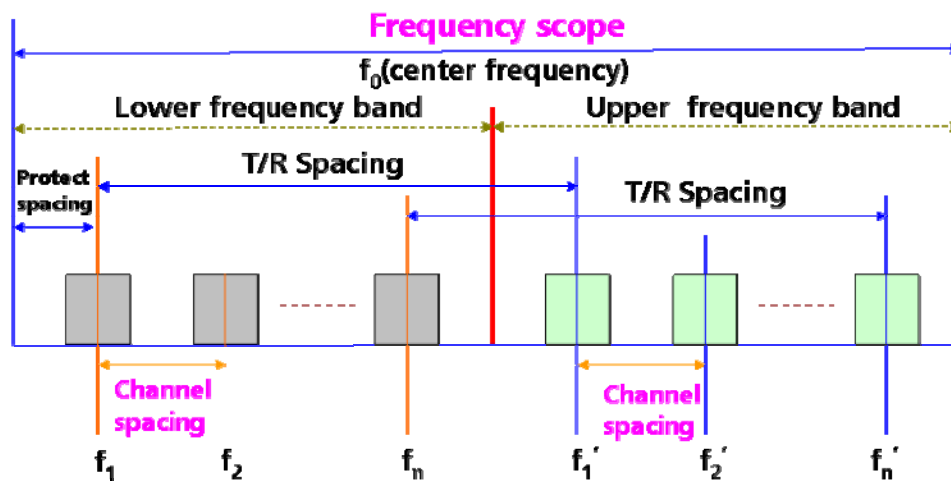


Figure 1.3 simple concepts of microwave frequency band arrangements

After deciding the microwave frequency band, configure the RF channels. To configure RF channels is to subdivide the specific frequency band, to make the bands adapt to frequency spectrum that the transmitter needs. Those subdivided frequency bands are called “channel”. Normally, any channel is expressed by the center frequency it is configured and an ordinal number. The width of the channel is decided by the spectrum of the signals transmitted, that is, the capacity and the modulation mode adopted.

In configuring RF channel, following factors should be considered:

- (1) Utmost economy and efficiency of the RF frequency
- (2) Enough spacing between transmitting frequency and receiving frequency in a microwave station to avoid serious interference generated by transmitter to receiver
- (3) In multi-channel working system, adjacent channels must have enough frequency spacing to avoid interference generated by each other
- (4) Enough guard bands should be reserved at the edge of the distributed frequency band to avoid generating interference with the system working on the adjacent frequency band
- (5) Most RF channel arrangements are based on the homogeneous patterns

ITU-R F.746-3 “Radio-Frequency Channel Arrangements for Radio-Relay Systems” recommends that homogeneous patterns are preferred as the basis for radio-frequency channel arrangements. Normally, the basic channel spacing is 2.5 MHz and 3.5 MHz. Digital microwave systems that adopt such channel spacing support the bit rate of both North America and Europe. In the pattern of 3.5 MHz, it may be subdivided into 1.75 MHz spacing to meet the transmission requirement of 1E1 and 2E1 in the low capacity mobile coverage.

## 1.6 Digital Microwave Communication System Model

Digital microwave communication system model:

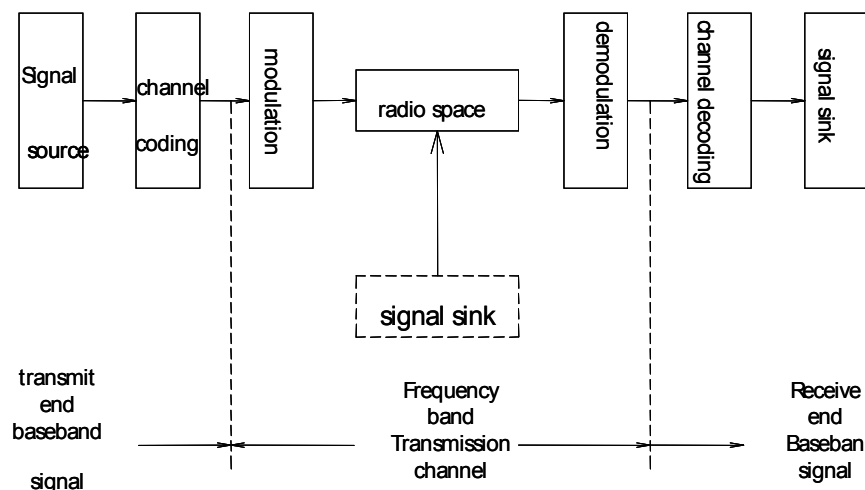


Figure 1.4 Digital microwave communication system model

Signal source of the transmit end is the equipment that provides original signals, it outputs digital signals.

Channel coding is to improve the reliability of transmitting digital signals. For noise and interference may inevitably exist in the channel, the digital signals transmitted may generate error bit. To make the code element automatically checked and corrected at the receive end, channel coder is used to add some additional code elements to the input digital hierarchy based on certain rules, and form new digital hierarchy. At the receive end, signals are checked based on the rules of the new digital code element hierarchy.

Modulation is to modulate the digital signals to the carrier of higher frequencies to make it adapt to radio channel transmission.

Functions of demodulation and channel decoding at the receive end are opposite to that of modulation and channel code at the transmit end.

### 1.6.1 Modulation Method of Digital Microwave

Digital signal unmodulated is called digital baseband signal. For the baseband signal cannot be transmitted in the radio microwave channels, it must be converted to frequency band signal, that is, implement digital modulation to the carrier based on the baseband signals. After the modulation, intermediate frequency (IF) signal is obtained. Normally, frequency of the upper IF signal is 350 MHz, and the lower 140MHz. In some circumstances, frequency of the upper IF signal is 850 MHz, and the lower 70 MHz.

To transmit the signal by the microwave, it should be converted to RF signals by the upconversion. Upconversion is a process to mix the IF signals and a high-frequency local oscillation signal and then get the upper sideband signal after the frequency mixing. Down-conversion is a reverse process of the upconversion with the same principle, but it gets different combination of local

oscillation signal and microwave signal, namely, obtains the lower sideband signal after the frequency mixing. Slight shift of local oscillation signal may cause large frequency shift of the emitting signals and the receiving signals. Therefore, their frequency stability is dependent on the frequency stability of the local oscillation signals.

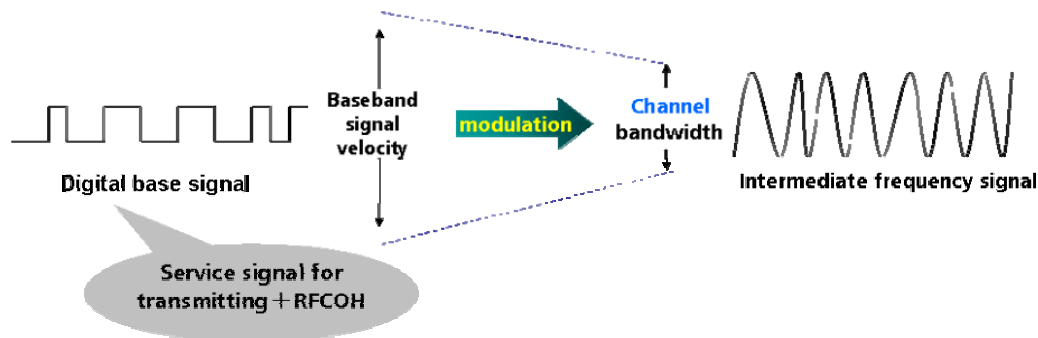


Figure 1.5 Modulation process of digital microwave signal

Modulation process of digital baseband signal can be simply expressed as

$$A * \cos(W_c * t + \phi)$$

Amplitude      frequency      phase

Frequently used PSK and QAM modulation method in digital microwave communication

- Amplitude shift keying (ASK): using digital baseband signal to change carrier A,  $W_c$  AND  $\phi$  are not changed
- Frequency shift keying (FSK): using digital baseband signal to change carrier  $W_c$ , A and  $\phi$  are not changed
- Phase shift keying (PSK): using digital baseband signal to change carrier  $\phi$ , A and  $\phi$  are not changed
- Quadrature amplitude modulation (QAM): using digital baseband signal to change carriers  $\phi$  and A,  $W_c$  is not changed

Currently, PSK is a critical modulation used in low and medium capacity radio communication systems. It has better anti-interference performance and is a very simple modulation and cost-effective. Current low and medium capacity digital radio communication systems use quaternary phase shift keying (4PSK or QPSK) modulation. Typical manufacturers include NEC, Ericsson and Nokia.

FSK is also a critical modulation used in low and medium capacity radio communication systems. But its anti-interference performance and decoding threshold is not better than that of PSK, and it occupies larger channel bandwidth. Current low and medium capacity digital radio communication systems use quaternary FSK (4FSK) modulation. Typical manufacturers include DMC and Harris.

MQAM is a carrier keying mode largely used in high capacity digital radio communication systems. This mode has higher frequency spectrum utilization and when the modulation of more than binary, the signal vector set is reasonably allocated and the mode can be easily carried out.

PDH microwave systems mainly use PSK, 4PSK (4QAM) and 8PSK and some systems also use MQAM such as 16QAM. SDH microwave systems typically use MQAM (usually, 32QAM, 64QAM, 128QAM and 512QAM). QAM modulation has higher frequency band utilization. Waveforms of typical modulations are as follows:

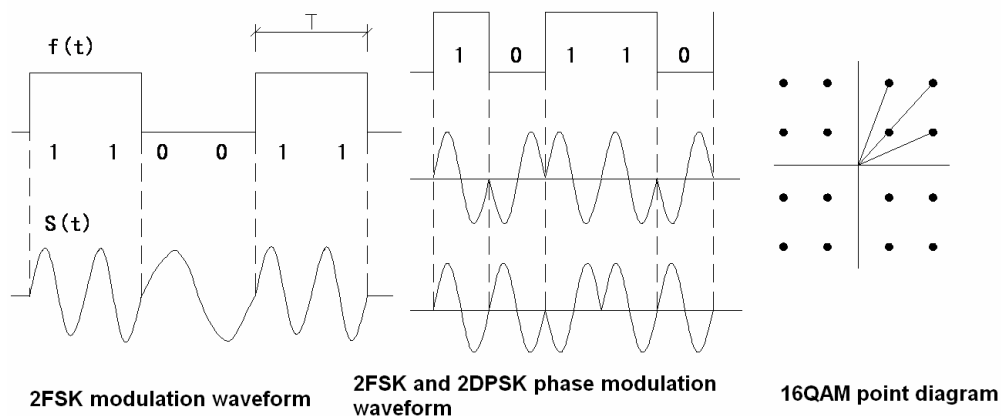


Figure 1.6 Waveform of typical modulations

## 1.6.2 Channel Utilization of Each Modulation

Channel utilization is typical concept used to compare the advantages and disadvantages of each modulation. Channel utilization is defined as: the ratio of signal baseband bandwidth to transmission channel bandwidth (bit/s/Hz). For binary digital signal, the frequency band utilization of the baseband transmission channel is  $2F_B/F_B=2(\text{bit/s/Hz})$ .

For high-frequency channel, “baseband signal” is dual-sideband signal that is already modulated.

In practice, for the baseband transmission channel is not ideally rectangular, the channel bandwidth should be properly widened, and the nominal digital microwave channel utilization is smaller than the theoretical value. Following is the theoretical values of high-frequency channel utilization of each modulation and nominal digital microwave channel utilization.

Table 1.1 Ratio of channel utilization of typical modulations

Modulation modes	Bandwidth utilization of baseband transmission channel	Bandwidth utilization of high-frequency channel	Bandwidth utilization of nominal microwave channel
4FSK	2	<1	<2
4PSK	2	1	2
8PSK	2	1.5	3
16PSK	2	2	4
16QAM	2	2	4
64QAM	2	3	6

## 1.7 Digital Microwave Frame Structure

In digital microwave system, to transmit digital orderwire, wayside information, ATPC information correction bit, channel switching, some complementary bits should be added to the main data flow from the SDH multiplexing equipment, that is, radio frame complementary overhead (RFCOH).

Each manufacturer arranges the frame structure based on the transmission rate, modulation and correction modes adopted and types of complementary information needed, therefore, the radio frame structure of equipment manufactured by different manufacturers are different. Following figure shows the frame structure of equipment using multi-level coded modulation (MLCM)

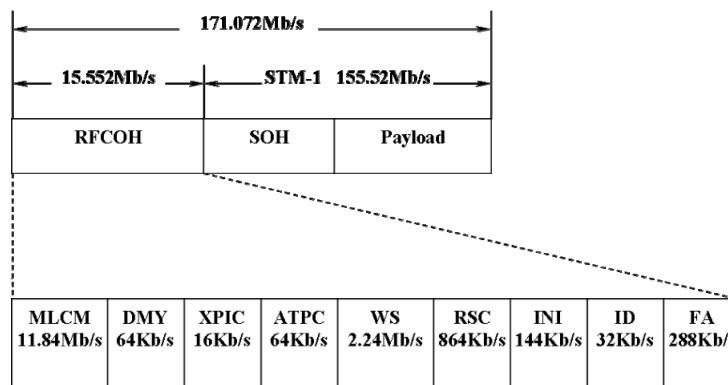


Figure 1.7 Radio frame overhead of equipment using MLCM

RFCOH: radio frame complementary overhead

MLCM: multi-level coded modulation

DMY: Dummy

WS: wayside services

XPIC: cross polarization interference counteract

RSC: radio service

INI: N:1 switch instruction

ID: Identification

FA: Frame synchronization

ATPC: automatic transmitter power control

Total rate of the supervision bit that is added for multi-level code is 11.84 Mb/s. The WS is 30 PCM telephone channels and the nominal rate is 2.048 Mb/s. To use the same clock as the main data system, before the radio frame multiplexing, use positive justification to adjust the nominal rate to 2.24 Mb/s, and then enter it to the microwave multiplexing circuit. There are total 13 channels of RSC and control signals, each channel is 64 kb/s, total rate is 832

kb/s. Convert the rate to be 864 kb/s and enter it to microwave multiplexing circuit. The 13 channels include two user channels which can transmit voice or data signals, the other channels are auxiliary switching signal: four channels are used in main channel service switching information and other six channels are system monitor channels. ID is used to separate different microwave channels.

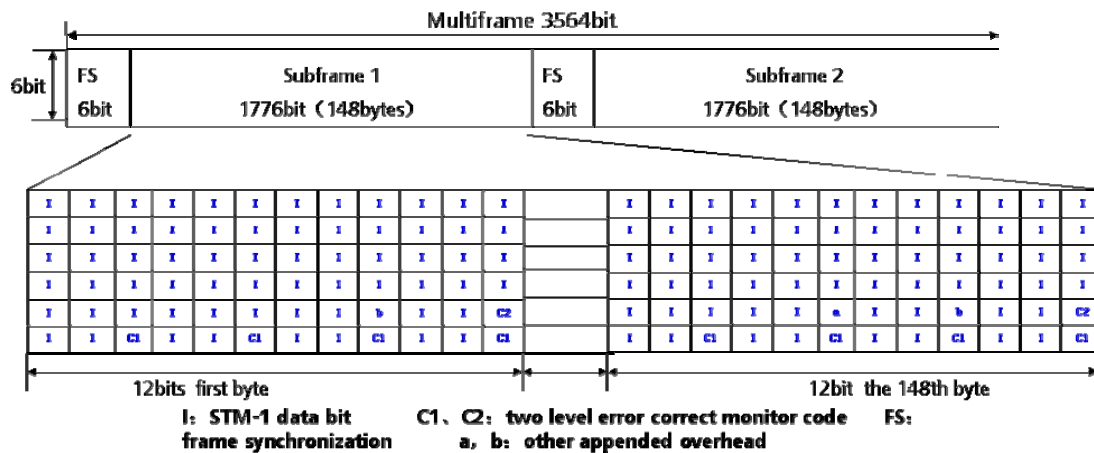


Figure 1.8 Microwave frame when MLCM is used

The frame structure of SDH is a block by byte and it has specific alignment. Microwave frame is different from others for it is by bit and its alignment is determined based on specific applications and without any order.

I indicates information bit, C1 and C2 indicate correction coding supervision bit of first level and second level. FS indicates frame synchronization bit, "a" and "b" indicate other complementary overhead bits.

Have a think:

What do you learn in this chapter?

1. What is the meaning of microwave?
2. What is digital microwave communication?
3. What are the challenges and opportunities for microwave communication at the present?
4. How to arrange the microwave RF channels?
5. What is the basic model of microwave communication?
6. What are the modulations of microwave?
7. What is microwave frame like?

## 1.8 Conclusion

This chapter explains the concepts of microwave and digital microwave communications, the development course and features of microwave communication. It describes the current challenges and opportunities for microwave communications, introduces the arrangements of microwave RF channels and microwave modulations, and explains the microwave frame structure.

## 2 Introduction to Digital Microwave Equipment

Objectives:

To know the classification of microwave equipment

To understand roles, constituents and performance indexes of antenna and feeder, outdoor unit (ODU) and indoor unit (IDU) of split microwave equipment

To learn split microwave equipment installation and antenna adjustment

To have an overall idea of microwave equipment

### 2.1 Digital Microwave Equipment Classification

Based on different classification methods, the digital microwave equipment can be classified based on the following modes:

Table 2.1 Microwave equipment classification

Mode	Digital microwave		Analogue microwave
Multiplexing mode	PDH	SDH	Eliminated
capacity	2–16E1 34M	STM-0 STM-1 2 x STM-1	
Structure	All-indoor microwave		
	Split microwave		
	All-outdoor microwave		

Currently, common classification method is, based on structure, to classify the microwave equipment into split microwave, all-indoor microwave and all-outdoor microwave.

All-indoor microwave is commonly called big microwave. Its RF unit (RFU), signal processing unit (SPU) and multiplexer reside indoor, only the antenna is outdoor. It has a high transmission capacity and is suitable to backbone line transmission, but its cost is high.



### Structure of subrack

(7+1)\*155M

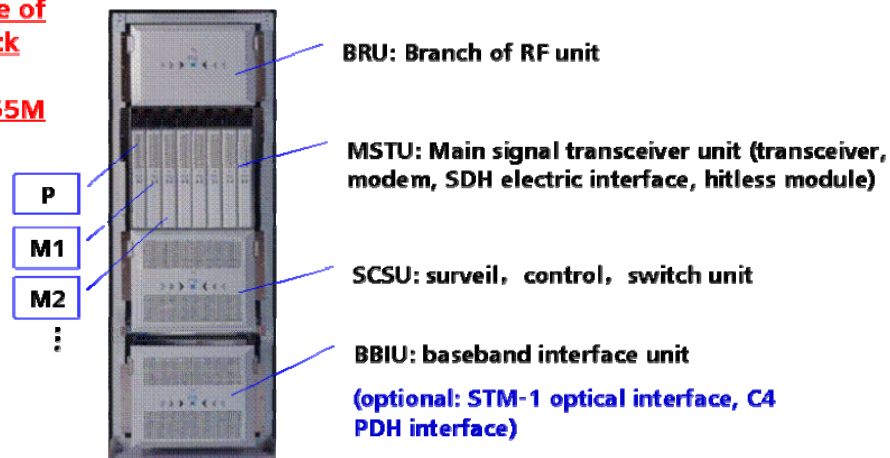


Figure 2.1 All-indoor microwave

All the units of all-outdoor microwave reside outdoor. All-outdoor microwave is easy to install and saves equipment room space. For it is outdoor, it is easily damaged.

- All units are outdoor
- Easy to install
- Save equipment room

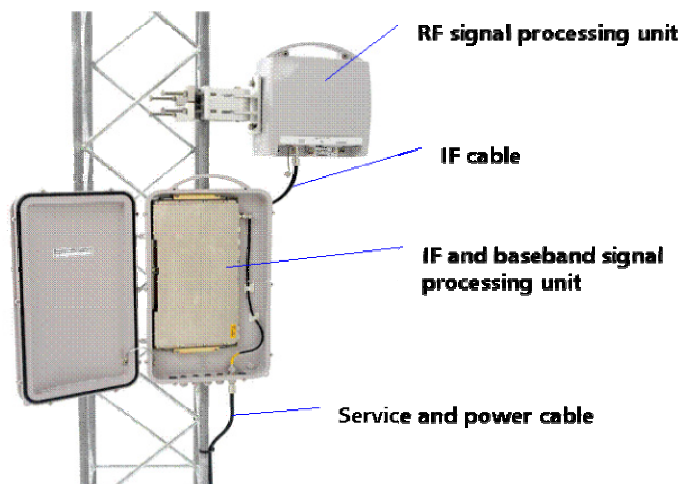


Figure 2.2 All-outdoor microwave

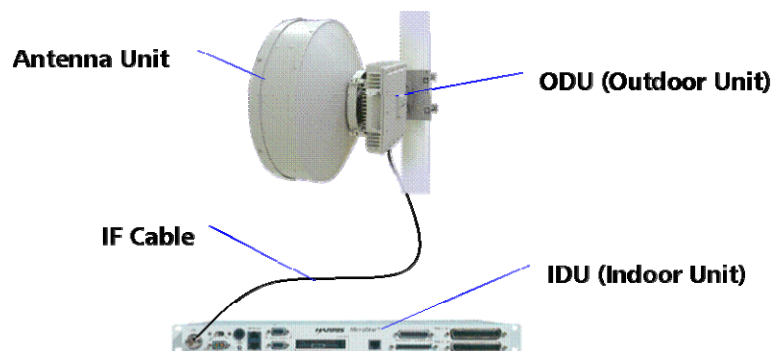


Figure 2.3 Split microwave

Split microwave equipment consists of ODU and IDU. The antenna and ODU are connected by waveguide pipe, and the IDU and ODU are connected by IF cable. IF cable is used to transmit the IF service signals between IDU and ODU and the IDU/ODU communication control signals and provides power to the ODU. Split microwave equipment has a low capacity and is easy to install and maintain and available in quickly building networks. It is the most widely used microwave equipment for the present.

## 2.2 Microwave antenna and feeder

### 2.2.1 Microwave antenna

The antenna is used to directionally radiate the microwave power emitted by the transmitter ODU and transmit the microwave power received to the receiver ODU. Commonly used microwave antenna includes parabolic antenna and cassegrain antenna. The diameter of the microwave antenna produced by China is 0.3, 0.6, 1.2, 1.6, 2.0, 2.5, 3.2m, and that is imported from abroad is 0.3, 0.6, 1.2, 1.8, 2.4, 3.0m. There are many types of antennas. Antenna of different diameters has different specifications for different frequencies. Ericsson Mini-link has 46 types of antennas.



Figure2.4 Parabolic antenna



Figure2.5 Cassegrain antenna

N channels in the same frequency band can share the same antenna.

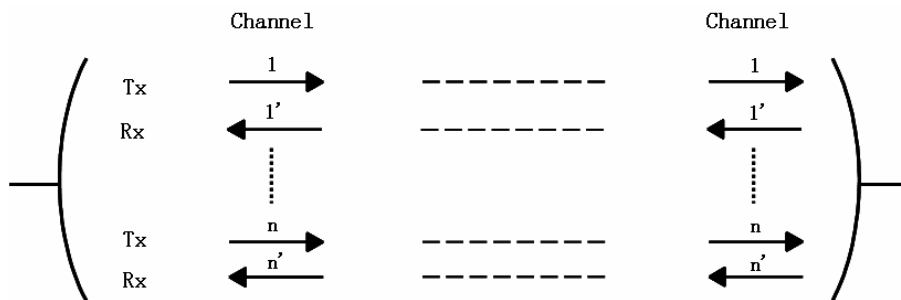


Figure2.6 same antenna shares N channels

In a radio-relay system, the requirements for the antenna are that the antenna should be highly efficient, the sidelobe level should be low, cross-polarization discrimination should be high, voltage standing wave ratio should be low and the working frequency band should be wide. The main parameters of the antenna are as follows:

#### (1) Antenna gain

Gain is a major parameter of the antenna. When the size of the antenna is certain, the antenna gain directly reflects the efficiency of the antenna.

The gain is the ratio of the input power  $P_{io}$  of isotropic antenna to the input power  $P_i$  of the surface antenna when the surface antenna and isotropic antenna produce the same electric field at the same place.

Antenna gain of the microwave antenna is expressed by:

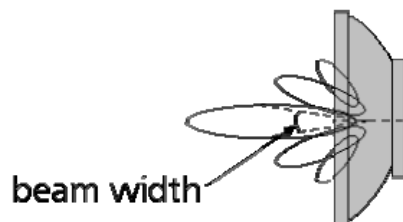
$$G = \frac{P_{io}}{P_i} = \left( \frac{\pi D}{\lambda} \right)^2 * \eta$$

In the formula, D is the diameter of the parabolic antenna,  $\lambda$  is the working wavelength,  $\eta$  is a surface usability coefficient, which is decided by the antenna processing accuracy and the active loss, normally,  $\eta$  ranges from 0.45 to 0.6. The gain given in the antenna indexes is the maximum radiation direction (main lobe) gain and expressed by dB.

$$G \text{ (dB)} = 10 \log G = 10 \log [(\pi D / \lambda)^2 * \eta]$$

#### (2) Half-power angle (3 dB beam width)

Deviate to the two sides from the main lobe, when the direction is deviated to the point where the power decreases half, the point is called the half-power point. And the separation angle between the two half-power points is half-power angle.



Half-power angle is expressed by:

$$\theta_{0.5} = (65^\circ \sim 70^\circ) \frac{\lambda}{D}$$

From this formula, you can see that, when the antenna diameter is certain, the higher the working frequency is, the smaller the half-power angle is, and the higher the power integration is. When the working frequency is certain, the larger the antenna diameter is, the smaller the half-power angle is.

### (3) Cross-polarization discrimination (XPD)

XPD is, for a radio wave transmitted with a given polarization, the ratio at the reception point of the power received with the expected polarization to the power received with the orthogonal polarization. The XPD should be high to suppress the interference from the orthogonal polarization signal. High capacity radio-relay system (SDH microwave system) widely uses co-channel orthogonal polarization frequency multiplexing to improve communication capacity and save frequencies and it has strict requirement for the XPD (such as the XPD should be larger than 40 dB).

$$XPD=10\lg P_0/P_x$$

In the formula,

“ $p_0$ ” is the receiving power to the normal polarization wave

“ $p_x$ ” is the receiving power to the abnormal polarization wave

In actual microwave circuit, due to multi-path propagation effect and rain, XPD may degrade. For frequency band lower than 10 GHz, the main cause to XPD degradation is multi-path effect. For the two orthogonal polarization signals reach at different angles in communication, and the influence of the geographical and meteorologic conditions on the two orthogonal polarizations are not totally relevant, which cause the XPD to change in actual practice. Even though there is no fading or there is up fading, the XPD is tested to be distributed logarithmically and normally rather than a constant value.

### (4) Antenna protection ratio

Antenna protection ratio is the attenuation of the antenna reception capability in some direction to the antenna reception capability in the main lobe direction. For protection ratio of 180°, it is also called front/rear ratio. Antenna protection ratio is an import index in the microwave communication.

### (5) Voltage standing wave ratio

The connecting impedance between the antenna and the feeder should be matched and the voltage standing wave ratio at the input must be smaller. The standing wave ratio of normal antenna is between 1.05 and 1.2.

## 2.2.2 Classification of Microwave Antennas

Based on installation method, microwave antenna can be classified as hanging antenna and seating antenna.

Based on electric feature, it can be classified as standard antenna and high-performance antenna.

The front and rear of the high-performance antenna is larger than that of the standard antenna with more than 10 dB.

### 2.2.3 Feeder System

Feeder system consists of the feeder connecting branching system to antennas and the waveguide components, and it has several installation methods. Currently, elliptical waveguide is commonly used.



(a) Elliptical waveguide



(b) Flexible twist waveguide

Figure 2.7 Typical feeders

Elliptical waveguide has lower loss in certain length and is suitable for long feeders. Normally, it is used in frequency band from 2 to 11GHz and it is the most typical microwave feeder. Now, elliptical waveguide is widely used in frequency band ranging from 4 GHz to 15 GHz as the feeder for it makes the layout and installation of the feeders easier. The entire feeder system includes elliptical waveguide, elliptical-rectangular converter, sealing section and air-filled waveguide section. To protect feeder, the feeder must be charged with dry gas. In installing the elliptical waveguide, you must follow the product specification; otherwise, the standing wave ratio of the feeder might be affected.

Flexible twist waveguide is used to connect the ODU and the antenna. It is easy to install and can ensure the connection accuracy, and it has function of twisting. The disadvantage of the flexible twist waveguide is huge loss.

Coaxial cable has huge loss in certain length. It is better to use the coaxial cable in occasion that the antenna is near the transceiver. Normally, it is used in the frequency band lower than 2 GHz. currently, it is seldom used.

There are two ways of connecting elliptical waveguide and branching system:

- a) Waveguide: using hard waveguide, E bend and H bend or flexible waveguide.
- b) Coaxial: using coaxial cable

In addition, the access layer typically uses portable PDH and SDH microwave systems and adopts indoor/outdoor structure. The indoor unit and the outdoor

unit (transceiver) are connected by IF cable. Outdoor unit and antenna are connected by flange interface (the feeder loss is reduced) or flexible waveguide of 0.6–0.9 m (the caliber is more than 1.2 m).

Following figures show how the PDH/SDH microwave antenna is connected to the ODU (transceiver):



Figure 2.8 Antenna connected to ODU

## 2.2.4 Branching System

Normally, in microwave communication, many channels share the same set of an antenna and feeder system, which needs branching system to separate them. The branching system consists of circulator, branching filter, terminator and connection waveguide. The filter is installed in the rack.

Branching filter consists of bandpass filter, it only allow designed certain frequency band to pass and the frequencies that outside the band cannot pass the filter. The terminator is used to absorb the emitting waves, and the loop makes the signals progress in a certain direction.

## 2.3 Outdoor unit (ODU)

ODU is used to convert IF and RF signals, process and amplify the RF signals. Specification of the ODU is related to the RF frequency and independent of the transmission capacity. For an ODU cannot cover a frequency band, normally, a frequency band can be subdivided into three sub-bands: A, B and C. Different sub-band matches different ODU. Different receiving/transmitting spacing also matches different ODU and different higher-lower station matches different ODU. Therefore, ODU types= quantity of the frequency band × quantity of receiving/transmitting spacing × quantity of sub-band ×2 (for different

manufacturers, different ODU with different capacities may have different types). Currently, ODU has many types but small batches. Small manufacturers produce ODU and larger manufacturers integrate ODU. For specific functional module structure inside ODU, see the following table.

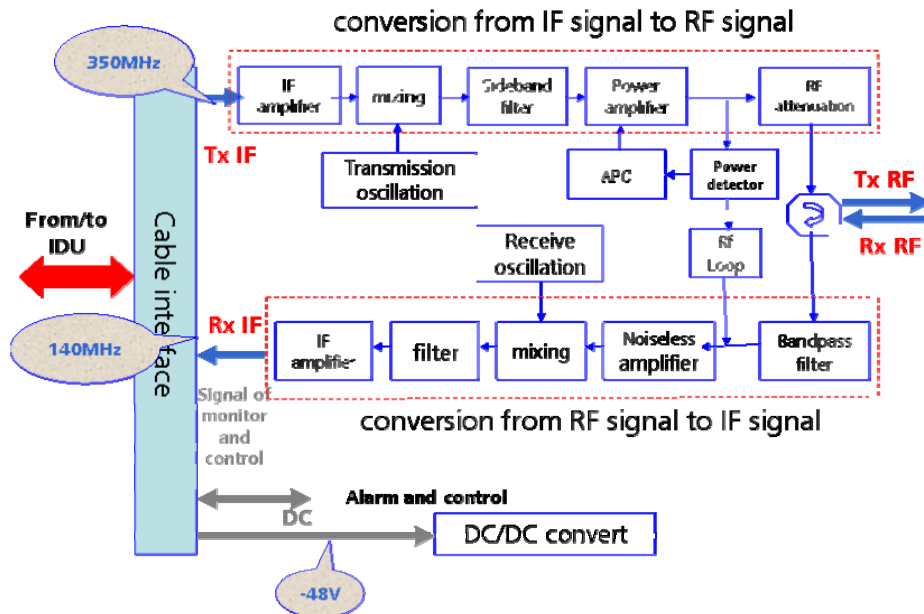


Figure2.9 inner structure of ODU

In Figure 2.9, ODU consists of transmitter and receiver which achieve the conversion from IF to RF and RF to IF respectively.

## 2.3.1 Constituents of Digital Microwave Transmitter and Major Performance Indexes

### 2.3.1.1 Functions and constituents of transmitter

Main functions of transmitter are as follows:

- (1) Generate proper local oscillation (LO) within the RF band.
- (2) Use the local oscillation signal from the local oscillator to convert the adjusted IF signal from the adjuster to the required frequency in transmitting.
- (3) Achieve pre-distortion of IF and RF of signals to compensate the non-linearity of RF amplifier.
- (4) Achieve amplification of linear RF



- (5) Conduct RF filter to eliminate useless frequencies (harmonic mirroring frequency, local oscillator leakage, stray outcome) to keep the frequency spectrum within required frame. In the branching system, the local carrier is combined with other carriers together and sent to the antenna.

Following is the system frame of a typical microwave transmitter

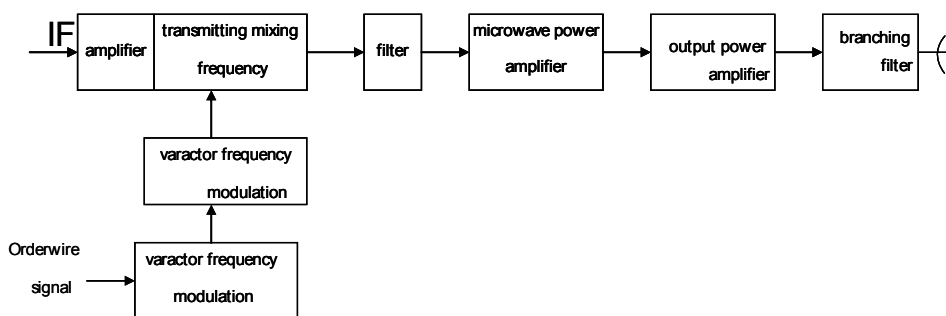


Figure2.10 system frame of receiver

After being amplified by the IF amplifier of the transmitter, IF adjusted signal from the adjuster is transmitted to the transmitting frequency mixer, and after transmitting mixing frequency, adjusted IF signal is converted to a frequency of the RF band. To suppress local oscillator leakage and stray outcome, equalization frequency mixer is preferred in use. Unilateral filter obtains a sideband after frequency mixing. Microwave power amplifier is used to amplify the signals with weak level (-30 dBm to -50 dBm) output by the transmitting frequency mixer to the required level. Typical RF power amplifier is GaAs FET device. For the SDH microwave system normally uses high-status modulation mode, it has strict requirement for the linearity of the amplifier. Typical amplifier works at output power far lower than the compression point of 1 dB, that is, backoff measures should be taken. But if the backoff quantity increases, the cost of the amplifier increases, therefore, pre-distortion is adopted to compensate the residual non-linearity. In normal transmission conditions, ATPC is used to low the output power, and then the power is amplified to the required transmitting power by microwave power amplifier, later, the power is transmitted to branching system, antenna and feeder by the sub-channel filter. RSC is transmitted by multiplexing modulation.

### 2.3.1.2 Major Performance Indexes of the Transmitter

- (1) Working Frequency Band



Currently, the working frequency bands mainly used in China backbone microwave system are 4 and 6 GHz. Frequency bands 7, 8 and 11 GHz are mainly used in branch lines. Frequency bands higher than 13 GHz are mainly used in access layer such as station access.

#### (2) Output power

Output power refers to the power at the output port of the transmitter, ranging from 15 to 30 dBm.

#### (3) Frequency stability

Each channel of the transmitter has nominal RF center working frequency. The stability of the working frequency depends on the frequency stability of the transmitting local oscillator. If the working frequency of the transmitter is unstable, and there is offset, the amplitude of the effective signal demodulated may decrease, and bit error rate may increase. Currently, the local oscillator frequency stability of the microwave equipment is normally about 3–10 ppm.

#### (4) Transmitting frequency spectrum frame

Spectrum of signal transmitted must comply with certain limitations to prevent over-wide bandwidth from being occupied, and then over-high interference may be produced to the adjacent channels. The limitation range of the spectrum is called frequency frame.

## 2.3.2 Constituents and Major Indexes of Receiver

### 2.3.2.1 Constituents of Receiver

The theory of receiver is: to use low-noise amplifier to amplify the RF signal from the antenna and convert RF frequency as follows before the demodulation. The system frame is shown in Figure 2.11.

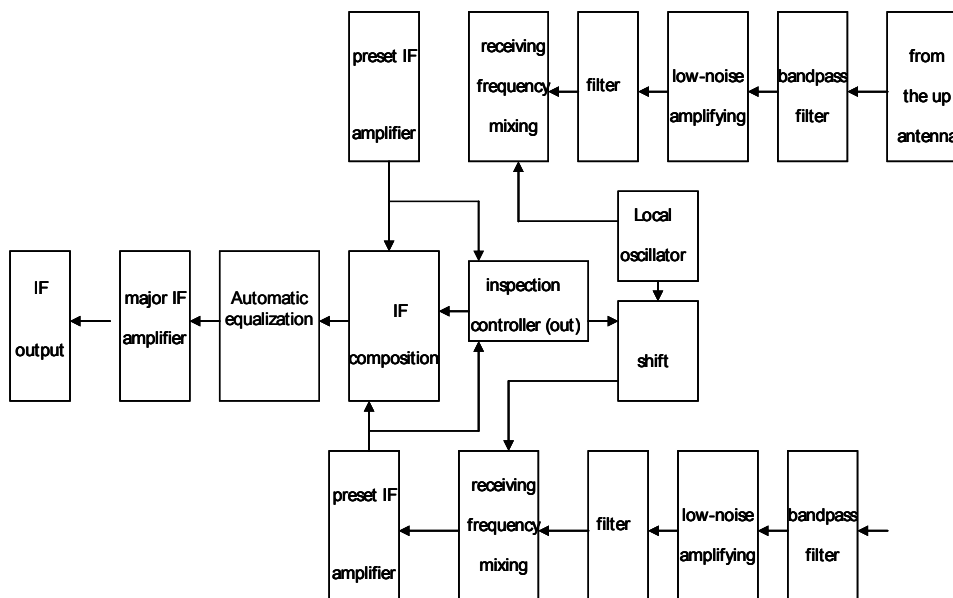


Figure 2.11 System frame of receiver

Direct wave from the upper antenna and the lower antenna and the electric wave that reaches the receiving point by means of all paths pass two same channels: bandpass filter, low-noise amplifier, mirror-suppressing filter, receiving frequency mixing, preset IF amplifier and then they are composed and amplified by the IF amplifier and then the IF modulated signal is output.

In the receiver:

- (1) Use LAN with low noise coefficient to pre-amplify the RF signals.
- (2) Use local oscillator to convert the RF signals from the antenna via the branching filter components to IF signals.
- (3) Use variable gain amplifier to amplify the IF signals to maintain the level unchanged when the propagation fading changes.

For most receivers, the gain is carried by the major IF amplifier, its variable gain is used to compensate the RF signal fading caused by propagation. The reason why IF amplifier is set with automatic gain control circuit is to make the level of the signal that is transmitted to the modulator keep unchanged. The gain change of amplifiers is achieved by many levels. The gain of those levels can vary with proper controlling voltage, while the controlling voltage is the function of the IF signal amplitude at the output end of the amplifier. In fact, part of input signals is led out, detected by the diode, filtered by AGC filter (this filter can prevent signals outside the usable spectrum from affecting the total frequency

response of the amplifier), after being amplified, it is used as controlling voltage of the variable gain section. This method is to extract some signals from the feedback path and the middle layer to control the variable gain and then to make the IF output level unchanged.

(4) IF channel filter

### **2.3.2.2 Major Performance Indexes of the Receiver**

(1) Working frequency

Receiver and the transmitter cooperate in work. For a regenerator section, the transmitting frequency of the former microwave station is the receiving frequency of the same channel of the local receiver, and use of the frequency band is the same as that of the transmitter.

(2) Frequency stability of the receiving oscillator

Requirement for the frequency stability of the receiving oscillator is consistent with that of the transmitter. Normally, it is 3–10 ppm.

(3) Noise coefficient

The noise coefficient of digital microwave receiver is normally 2.5–5 dB, and it is 5 dB less than that of the analogue receiver.

(4) Passband

To effectively suppress the interference, obtain the best signal transmission, choose suitable passband and the amplitude feature of the passband. The passband feature of receiver depends on IF filter and the passband of normal digital microwave equipment can be 1–2 times of transmission code element rate.

(5) Selectivity

To ensure that the receiver only accepts signals of local channel, the receiver should be able to suppress the interference of other signals outside the passband, especially to suppress the interference of the adjacent channels, mirroring interference, and interference between receiving and transmitting of the receiver.

(6) Automatic gain control range

On the basis of the received level under free space transmission, when the received level is higher than the reference level, it is called upward fading, and when it is lower than the reference level, it is called downward fading. Supposed the upward fading of the digital microwave system is +5 dB and the downward fading is -40 dB, that is, the fading has a dynamic range of 45 dB. The requirement for automatic gain control is when the received level undergoes variation within this range; the rating output level of the receiver does not change.

## 2.4 Indoor Unit

IDU performs the functions of service access, service scheduling, multiplexing and modulation and demodulation. It is the major part of a microwave system. If an IF board is equal to the line board of optical network equipment, IDU is similar to the box-shape equipment of optical network. It has service boards (SDE, SD1, SLE, SL1, PH1 and PO1), cross-connect board (PXC) and SCC. The structure of IDU internal function modules is shown in figure 2.12.

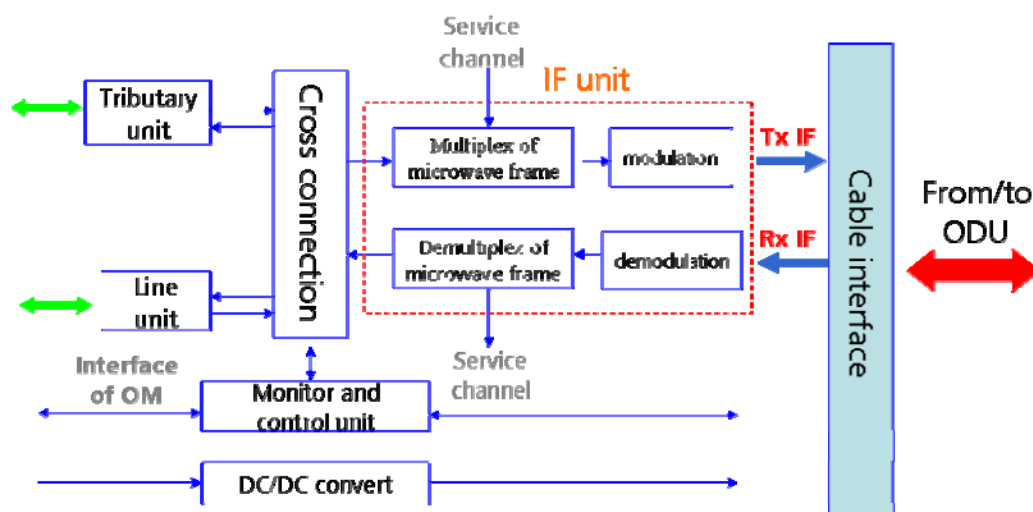


Figure2.12 IDU internal structure

## 2.5 Installation and Adjustment of Split Microwave System

Split microwave system can be divided into two parts: outdoor installation and indoor installation. Indoor installation is similar to that of box-shape equipment. This section describes outdoor installation which mainly consists of antenna and ODU installation. There are two methods of outdoor installation: integrated mounting and separate mounting. Integrated mounting does not need feeder,

and it directly connects ODU to the antenna. Separate mounting uses feeder to connect ODU to the antenna. See figure 2.13.

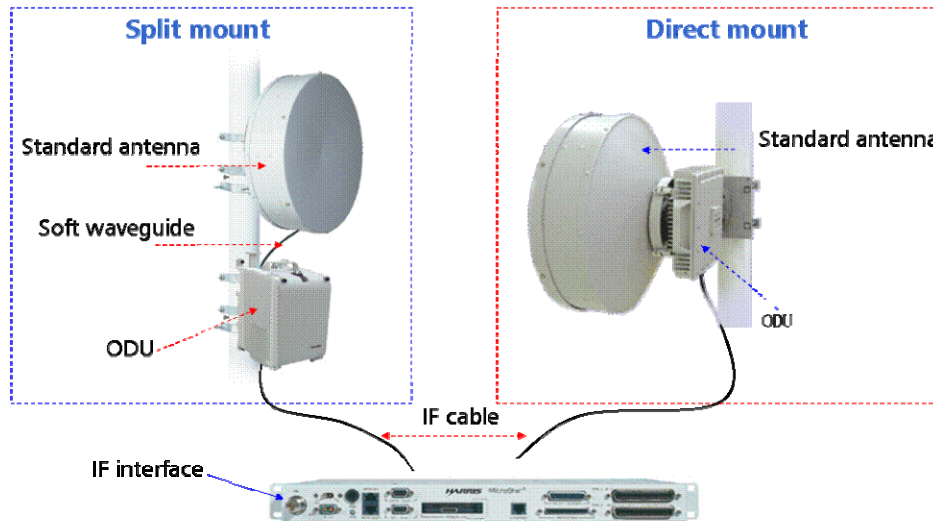


Figure 2.13 Outdoor installation

When the antenna is mounted, the key process is to adjust the directional angle of the antenna.

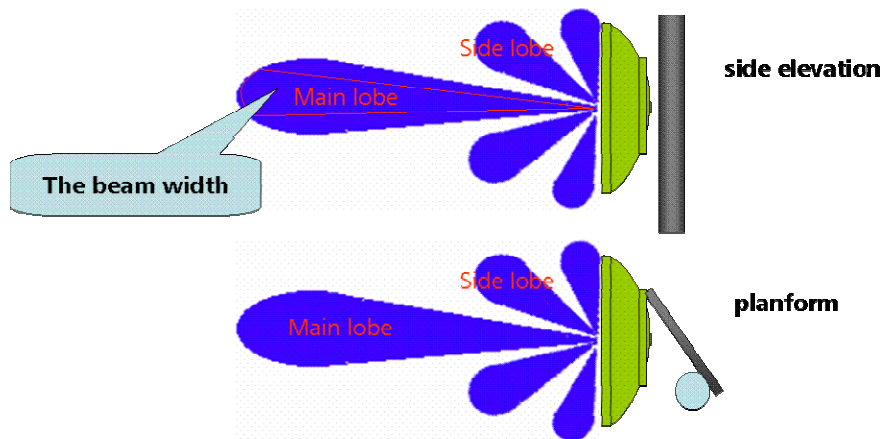


Figure 2.14 Antenna side view and top view

In the process of adjusting the antenna, you may find voltage wave in figure 2.15, under this condition, the point of the maximum voltage is the main lobe position of the pitching or horizontal direction. Then you need not adjust this direction within great extent, and you only need slightly adjust the antenna to the point where the voltage is highest. The method of adjusting the pitching direction of the antenna is same as that of adjusting horizontal direction. When the antenna is not accurately adjusted, you can only test lower voltage in a

direction. Then, you need briefly adjust antennas of the two ends and make them leveled.

In the process of adjusting the antenna, if you find the received signal indicates the point of maximum voltage, that position is the main lobe position of pitching or horizontal direction. . Then you need not adjust this direction within great extent, and you only need slightly adjust the antenna to the point where the voltage is highest. The method of adjusting the pitching direction of the antenna is same as that of adjusting horizontal direction. When the antenna is not accurately adjusted, you can only test lower voltage in a direction. Then, you need briefly adjust antennas of the two ends and make them roughly leveled and then adjust them carefully. Typical errors occur in the process of antenna adjusting is shown in figure 2.16, that is, the antenna is adjusted to the side lobe, which makes the received signal level falling short of the design indexes.

#### Tips:

When antenna at two ends are leveled, they may become slightly upward and 1–2 dB is wasted to prevent refraction interference.

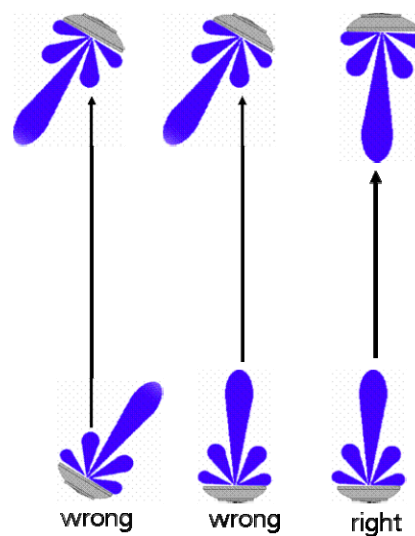
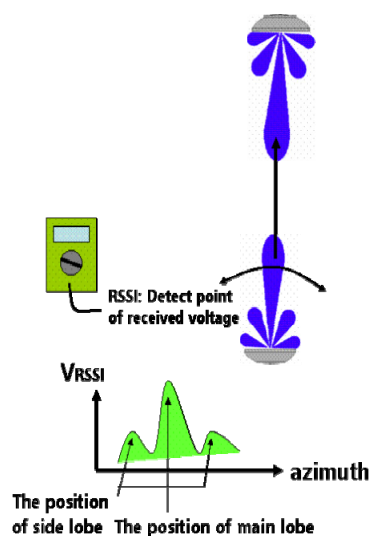


Figure 2.15 Voltage wave in adjusting antenna      Figure 2.16 Typical errors in adjusting antenna

Have a think:

What do you learn in this chapter?

- (1) The classification of microwave equipment
- (2) Antenna and feeder system and branching system of split microwave system
- (3) ODU constituents, functions and performance indexes of split microwave system

- (4) IDU constituents of split microwave system
- (5) Installation and adjustment of split microwave system

## 2.6 Conclusion

This chapter mainly describes digital microwave equipment, and attaches great importance to explaining functions of each components, antenna and feeder system, constituents and performance indexes of ODU and IDU, split microwave system and antenna adjustment.

# 3 Microwave System Networking and Application

Objectives:

- To know the typical networking modes of microwave system
- To understand all types of stations of microwave system
- To learn classification of relay station
- To learn microwave application

## 3.1 Microwave System Typical Networking Modes and Station Types

### 3.1.1 Typical Networking Modes

Microwave network is similar to the optical network in terms of structure. The basic structure is shown in figure 3.1.

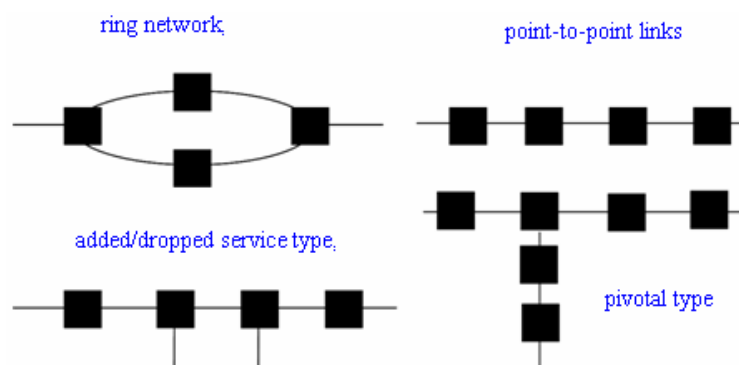


Figure 3.1 Microwave typical networking mode

### 3.1.2 Microwave Station Types

Based on station types, the microwave station can be classified as:

**Terminal station:** stations located at two ends of the microwave link, the communication is unidirectional and voice channels need to be added/dropped.

**Relay station:** stations in the middle of any two stations of a microwave link, the communication is to directions and the voice channels can be added/dropped (baseband transfer) or cannot be added/dropped (IF or RF transfer).

**Pivotal station:** the station located in the middle of the microwave link, the communication is to more than three directions, and voice channels need to be added/dropped.

Based on communication frequency, stations can be classified as:

**Upper station:** station where the receiving frequency is higher than transmitting frequency.

**Lower station:** station where the receiving frequency is lower than transmitting frequency.

Obviously, due to microwave frequency configuration, upper and lower stations are arranged alternatively. See figure 3.2.

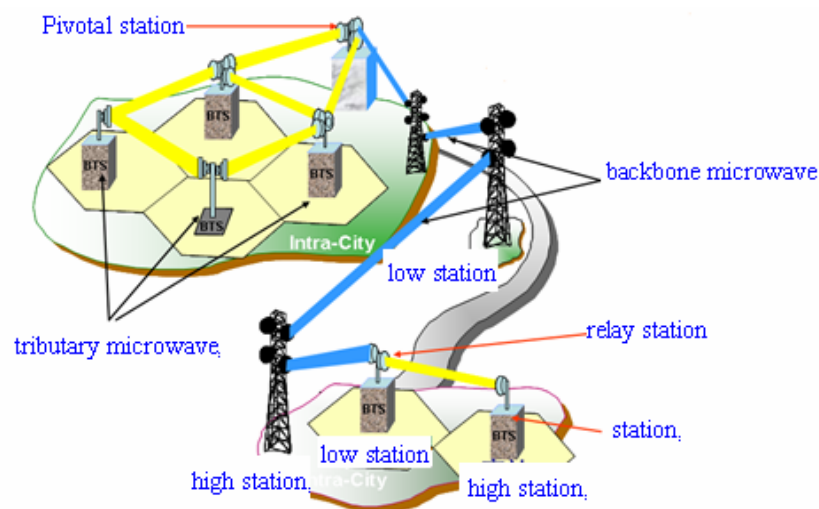


Figure3.2 microwave station types



## 3.2 Relay Station

Microwave frequency band has higher frequencies. The microwave beam is transmitted along a straight line and it is incapable of diffraction when it encounters obstacles. Therefore, there should be no obstacles in the line-of-sight range between two communication points. Otherwise, a microwave relay station should be added at the obstacle point or other suitable place to communicate the two communication points.

Microwave relay station can be classified into two types: passive relay station and active relay station.

### 3.2.1 Passive Relay Station

Passive relay station is like a beam diverter, it makes the microwave beam surpass the obstacle and form path. There are two models of passive relay station: one model of station is formed by two back-to-back parabolic antennas connected by a section of waveguide, the other is one or two metal planes which is smooth to some extent, has proper available area, and a suitable angle and distance for two communication points.



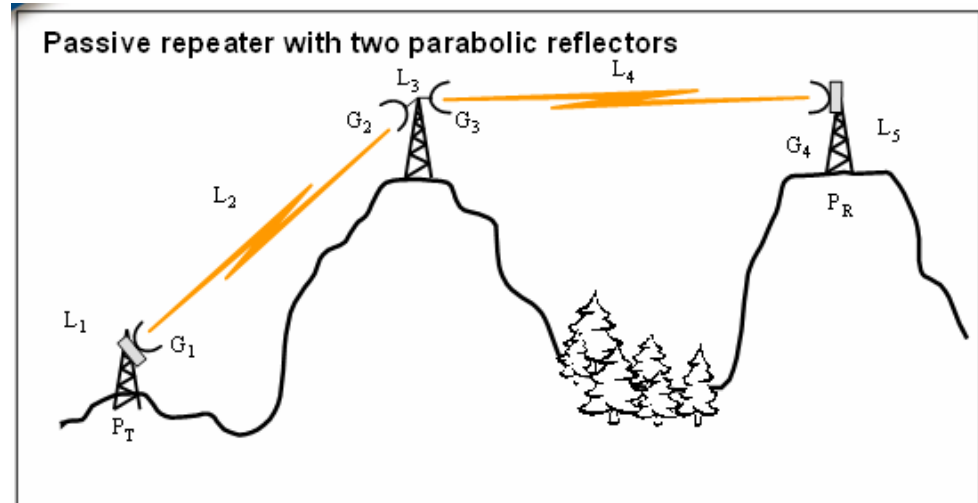
Plane reflectors



Double Parabolic reflectors

Figure3.3 Passive relay station

### 3.2.1.1 Dual Parabolic Antennas Passive Relay Station



$P_T$ : output power of transmitter (transmitting power)

$P_R$ : signal power of the input end of the receiver (received power)

$L_1$ : feeder loss from the transmitter to the antenna

$L_2, L_4$ : free space loss from the passive relay station to two communication points

$L_3$ : feeder loss between antennas at the passive relay station,

$L_5$ : feeder loss from the receiving antenna to the receiver

$G_1 \sim G_4$ : the gain of antenna

Figure3.4 Dual parabolic antennas passive relay station

(1) The received power can be expressed by:

$$P_R = P_T - L_0$$

$$L_0 = L_1 + L_2 + L_3 + L_4 + L_5 - G_1 - G_2 - G_3 - G_4$$

In the formula:

$P_T$  is transmitting power

$L_0$  is line net loss, that is, the net loss between the transmitter and the receiver

From the formula, to increase the received power, the output power of the transmitter and gains of the four microwave antennas should be increased and feeder losses and the free space loss between two paths should be reduced.

(2) Methods to Increase  $P_R$

When the microwave equipment and the model are selected, the output power of microwave transmitter and the sensitivity of the receiver are fixed. When relative location of the transmitting antenna and the transmitter and that of the receiving antenna and the receiver are fixed, the feeder loss  $L_1$  and  $L_5$  are constant. Therefore, to improve the received power, you can only increase the gains of the four parabolic antennas, reduce the free space loss and make the two parabolic antennas closer to reduce the feeder loss  $L_3$ .

### (3) Parabolic antenna gain

Parabolic antenna gain can be expressed by:

$$G=20\lg D+20\lg F+17.8$$

In the formula:

D: diameter of the caliber of the parabolic antenna (m)

F: working frequency (GHZ)

G: antenna gain (dB)

Normally, passive relay station uses large diameter parabolic antenna. But if the caliber diameter of the parabolic antenna is enlarged unrestrained, the passive relay station may cost a lot and be difficult to install and erect. At the same time, the half-power angle of the parabolic antenna beam may be small, the antenna installation may become complicated and the adjustment of the antenna may be not accurate (for the half-power angle of parabolic antenna beam is in reverse proportion to the diameter of the parabolic antenna). Therefore, ground microwave passive relay station is improper to use parabolic antenna with too large diameter.

For passive relay station, fading margin is not large and there are four antennas, the gain maybe quadrupled to affect the received power.

### (4) Free space loss

Free space loss of the path can be expressed by:

$$L=92.4+20\lg D+20\lg F$$

In the formula:

L: free space loss (dB)

F: working frequency (GHZ)

G: antenna gain (dB)

For communication line that has passive relay station, the total free space loss is the sum of the free space loss from the passive relay station to the two communication points, that is,  $L=L_2+L_4$ . This means that the total free space loss of the passive relay station is related to the relative position of the passive relay station to the two communication points. Therefore, to improve the efficiency of the passive relay station, the distance between the passive relay station and any of the two communication points should be narrowed if possible. The closer the passive relay station next to the communication point, the less the  $L_2$  or  $L_4$  is.

The worst condition is that the passive relay station is located in the right middle of the two communication points, because the free space loss is the maximum in this condition.

#### **3.2.1.2 Plane antenna passive relay station**

A metal plane that is smooth to some extent, has proper available area, and a suitable angle and distance to two communication points, is also a microwave passive relay station. The station uses the reflection function of the metal plane to change the propagation direction of the microwave beam and round the obstacle to achieve communication. The PR is calculated by the same formula that is previously described in parabolic antenna passive relay station.

### 3.2.1.3 Comparison between two passive relay stations: parabolic antenna and plane antenna

- 1) Plane antenna is more efficient, for the gain of the antenna is used two times in receiving and transmitting. This is a remarkable advantage of this station.
- 2) Parabolic antenna passive relay station is easy to install and adjust; it works in a more stable way. While the plane antenna passive relay station, due to large reflection area, is of dozens of square meters, it is not easy to install and adjust. When there is a strong wind, it may not work stably.
- 3) Parabolic antenna passive relay station is not limited by the separation angle of the receiving and transmitting paths at the relay station, while the plane antenna passive relay station is limited by this separation angle. When the angle is more than  $100^\circ$ , two plane antennas are used, which makes field selection, installation and adjustment more difficult.
- 4) Parabolic antenna passive relay station can use polarization selector to convert the horizontal and vertical polarization waves transmitted from the previous station at the relay station, to reduce the fading caused by propagation condition change. Especially when the passive relay station is located on the straight line of the path, polarization conversion can reduce multi-path fading of the path.
- 5) Based on requirement of transmitting signals and suitable terrain condition, three parabolic antennas passive relay station can be built. While the plane antenna passive relay station cannot achieve this.
- 6) In view of the cost, dual parabolic antennas passive relay station cost less than the plane antenna passive relay station, especially much less than dual plane antennas passive relay station. Dual plane antennas passive relay station has strict requirements for the site location, if it is adopted, the wind loading should be considered, and then investment needs to be increased to ensure stable work of the dual plane antennas passive relay station.

## 3.2.2 Active Relay Station

There are two types of microwave active relay station: RF direct station and regenerative relay station.

### 3.2.2.1 RF Direct Station

RF direct station is an active, bidirectional, non-frequency-shift RF relay system. For it amplifies signals directly on the RF, it is called RF direct station. It can be used as a relay station that needs not add/drop voice channels in the microwave system. It can be used to solve the block problem caused by mountains and large building, and it can also be inserted in the newly built and already established microwave to increase fading margin.

RF direct station is highly applicable due to following characteristics:

- (1) It has large gains and good transmission performance.
- (2) It has high reliability and can cooperate with the terminal equipment of any manufacturers.
- (3) It adopts many types of energy to supply power, such as DC, AC, solar energy, wind and heat.
- (4) It needs low cost and is flexible in choosing sites. Normally, RF direct station is installed in the outdoor stormproof box and is attached to iron tower next to the antenna to narrow the feeder line. For RF direct station, equipment room, power line and railway are unnecessary. Its total cost is 50%-80% less than that of the regenerative relay station. In addition, when selecting the site, you only need to consider the optimal position for transmission without worrying about factors such as transport, power supply and so on.
- (5) It is easy to install and maintain, and expansion and frequency conversion of the RF direct station is very simple.

### 3.2.2.2 Regenerative Relay Station

Regenerative relay station is a high-frequency repeater with high performance. Regenerative relay station is similar to back-to-back terminal station, including an entire set of RF unit with regenerative microwave signals. It can extend the signal transmission path and change transmission direction to round obstacles,

but it is incapable of adding/dropping voice channels. It can be used to break the distance limit of microwave transmission system or divert the transmission direction to round line-of-sight obstacles, and the signal quality is not degraded. It receives signals, fully regenerates and amplifies the signals and then transmits the signals.

### 3.3 Digital Microwave Application

Microwave system is mainly used in the following scenarios:

Mobile base station return transmission: after field mobile base station receives radio signals, the signals need to be returned to BSC to enter into the core network for transmission, and this process is called “mobile base station return transmission”.

Supplementary network of optical network: due to geographical condition and other reasons, it is difficult to lay fiber cables between optical network and BSC, and then microwave transmission is needed.

Critical link backup: between two major transmission sites, to reduce the impact on the transmission to the minimum when the fiber cables are broken, microwave transmission is used as a backup for the optical transmission.

Enterprise private network: due to limitations of some special industries, such as oil transport pipe or the relay of the TV signals in the field, fiber cables cannot be laid due to certain limitations, and then microwave transmission is adopted.

VIP customer access: due to cost limitation, between the HQ of large enterprises and their subsidiaries, fiber cables cannot be laid in wide area, and then microwave transmission is adopted.

Currently, microwave system is frequently used in mobile base station return transmission. In the networking of wideband radio access, the topology structure should be chosen based on actual requirements. Topology structure on the basis of PMP is traditional and frequently used, and the network model can be ring network which is similar to the optical ring network. Topology structure based on TDM/IP is original and effective. The two structures both have their advantages and have different application environments; they can supplement each other. Microwave ring network topology structure is also called consecutive point topology structure.

Have a think:

What do you learn in this chapter?

- (1) Network structures of digital microwave systems
- (2) Models of digital microwave stations
- (3) Characteristics of relay stations
- (4) Application of digital microwave systems

You should pay more attention to the characteristics of relay stations.

### 3.4 Conclusion

This chapter mainly describes typical networking modes of microwave systems, models of microwave stations and characteristics of relay stations, and the application of the digital microwave systems.

## 4 Microwave Propagation Theory

Objectives:

To understand microwave propagation in free space

To know the influence of ground reflection and troposphere on the electric wave propagation

To learn the fading caused by aerial and ground effect

To understand the impact caused by fading and statistical features of fading

Microwave communication is based on the carrier of microwave and realized by line-of-sight communication in the atmosphere. The major theory foundation of microwave communication is electromagnetic propagation, which includes: Huygens-Fresnel theory, concepts of Fresnel zone, interference and polarization of electric waves, co-oscillation and absorption of materials. We should learn all those theories first to further study microwave communication.

### 4.1 Electric Wave Propagation in Free Space

#### 4.1.1 Free Space

Free space is also called ideal medium space, it equals to the ideal space in vacuum status. This space is full of homogeneous and ideal medium, for this medium, the conductance  $\sigma=0$ , dielectric constant  $\epsilon=\epsilon_0=10^{-9}/36\pi$  F/m and magnetic capacity  $\mu=\mu_0=4\pi\times10^{-7}$  H/m. in this space, electric waves are not



affected by factors such as obstacles, reflection, diffraction, scattering and absorption.

#### 4.1.2 Propagation Loss of Electric Waves in Free Space

For magnetic wave that propagates in free space, reflection, diffraction, absorption and scattering do not occur. That is, the total energy is not lost. But when electric wave propagates in free space, it is attenuated for energy is diffused to the space, likes a single bulb lighting in the air, the light is homogeneously spreading around, and the place that is far away from the bulb obviously is of less energy. The diffusion loss of electric wave is called free space loss. Based on the energy-flux density and antenna theory, the propagation loss of electric wave in free space is expressed by:

$$L_S = P_t / P_r = (4\pi df/c)^2$$

or  $L_S \text{ (dB)} = 20\log(4\pi df/c)$

In the formula:

$L_S$ : free space loss (dB)

$d$ : distance from the emitting source of electric wave to the receiving point (m)

$f$ : working frequency of electric wave (Hz)

$c$ : speed of light  $3 \times 10^8$  (m/s)

If the unit of  $d$  is km and that of  $f$  is GHz, the formula can be:

$$L_S \text{ (dB)} = 92.4 + 20\log d + 20\log f$$

## 4.2 Influence of Ground Reflection on the Electric Wave Propagation

Due to different terrain conditions, different relay sections have different influence on electric wave. Major influences are reflection, diffraction and ground scattering. For the ground scattering has little influence on the main waves, it can be ignored. The influence of reflection is that the ground can reflect some of the signals from the antenna to the receiving antenna (water surface and smooth ground have strong influence of reflection), which interferes the direct waves, and at the receiving point, vector of these signals is added to the vector of the direct waves, as a result, the receiving level sometimes is more than the receiving level of the free space and sometimes is less than the receiving level of the free space.

## 4.2.1 Concept of Fresnel Zone

### 4.2.1.1 Huygens-Fresnel Principle

Huygens formulates electro-magnetic wave character theory, based on Huygens' theory, Fresnel formulate the concept of Fresnel zone which further explains the reflection and diffraction of electric waves and is proved in practice. The basic idea of Huygens principle is: light and electric-magnetic wave are both a kind of oscillation, the medium around them are flexible, and therefore, the oscillation of a point can be transmitted to the adjacent particle and spread around, and then it becomes the wave that is transmitted in the medium. Therefore, it can be considered that the oscillation of a point source is transmitted to the adjacent particles and forms secondary wave source and then tertiary wave source and so on. If the wave transmitted by the point source is spherical wave, then the wave before the secondary wave formed by the point source is spherical wave and that before the tertiary wave is also spherical wave, and the other is by analogy. In microwave communication, when the size of transmitting antenna is less than the microwave relay distance, the transmitting antenna can be considered to be a point source.

### 4.2.1.2 Fresnel Ellipsoid

Supposed, for a microwave relay section, the transmitting point is T and the receiving point is R and the distance between stations is  $d$ , if on a flat surface, the distance from a moving point P to two fixed points (T and R) is a constant, the track of this point is an ellipse. And in the space, the track of this point is a rotary ellipsoid. In electric wave propagation, when the constant is  $d+\lambda/2$ , the ellipsoid obtained is called first Fresnel ellipsoid, and when the constant is  $d+2\lambda/2$ , the ellipsoid obtained is called second Fresnel ellipsoid..., when the constant is  $d+N\lambda/2$ , the ellipsoid obtained is called Number N Fresnel ellipsoid.

### 4.2.1.3 Fresnel Zone

If the Fresnel ellipsoid intersect with the waves transmitted from T or R, on the intersect interface, a series of circles and rings can be obtained and the center is a circle which is called the first Fresnel zone, the annulus (external circle minus internal circle) next to the first Fresnel zone is called second Fresnel zone and others by analogy. These rings and circles can be approximately considered as plane area graphics that are vertical to the ground and the ray between T and R. In practice, the influence of Fresnel zone on the project can be ignored.

### 4.2.1.4 Fresnel Zone Diameter

The distance from any point on the Fresnel zone to the link between R and T is called Fresnel diameter and is represented by  $F$ . when the point is on the first Fresnel zone, the diameter is called the first Fresnel zone diameter.

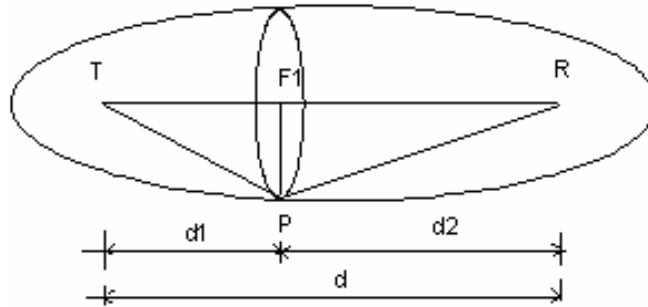


Figure4.1 First Fresnel zone diameter

Based on definitions of Fresnel ellipsoid and Fresnel zone, the first, second... and number N Fresnel zone diameter can be approximately expressed by:

$$F_2 = (2\lambda d_1 d_2 / d)^{1/2} = (2)^{1/2} F_1$$

$$F_1 = (\lambda d_1 d_2 / d)^{1/2}$$

...

$$F_n = (n\lambda d_1 d_2 / d)^{1/2} = (n)^{1/2} F_1$$

In the formula:

The meanings of  $F_1$ ,  $\lambda$ ,  $d_1$ ,  $d_2$ ,  $d$  are as previously explained, and unit of  $F_1$ ,  $\lambda$  is m and the unit of  $d_1$ ,  $d_2$ ,  $d$  is km.

#### 4.2.1.5 Relationship between Field strength of Receiving Point and Energy of Each Fresnel Zone

Based on analysis, phases of field strength produced by adjacent Fresnel zones in the receiving point R are opposite. That is, the field strength produced by the second Fresnel zone is opposite to that produced by the first Fresnel, and the field strength produced by the third Fresnel zone is opposite to that produced by the second Fresnel.

Take the first Fresnel zone as a reference, the field strength produced by the zone with odd number makes the field strength of the receiving point strengthened, and that produced in by the zone with even number makes the field strength weakened. Field strength of the receiving point is sum of the vectors of the field strength of each Fresnel zone at the receiving point. In practice, for the slant of each Fresnel zone to the receiving point is different, thus Fresnel zones interfere with each other. The result of the vectors overlapped together is: the field strength of the receiving point which is obtained from all the Fresnel zones in the free space is approximately equal to the field strength produced by the first Fresnel zone at this point in the space.

#### 4.2.2 Influence of Ground Reflection on Receiving Level

To make explanation more simple and easy to understand, the convex of the earth is ignored, that is, distance between stations is considered to be short and the ground is with little fluctuation.

#### 4.2.2.1 Clearance

Actual microwave propagation may be blocked by buildings, trees and mountains. If obstacles are high enough to enter the first Fresnel zone, additional loss is caused and the receiving level decreases, and then the transmission quality is affected. To avoid the phenomenon, the clearance is introduced.

The vertical distance from the obstacle to line section  $AB$  is called clearance of the obstacle in the path, and line section  $hc$  that is vertical to the ground is used to indicate the clearance, see figure 4.2. If the first Fresnel diameter of this point is  $F1$ ,  $hc/F1$  is the relative clearance of this point.

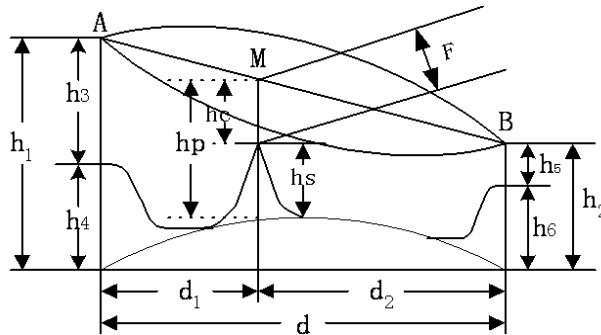


Figure 4.2 Definition of clearance—schematic

#### 4.2.2.2 Loss caused by Knife-edge Obstacles on the Path

In actual microwave project, knife-edge obstacles always block the transmission path. The knife-edge obstacles cannot block all the Fresnel zones, at the receiving point, there is only partial Fresnel zone energy is diffracted and make the receiving point have somewhat level. The level must be lower than that in the free space. Loss caused by the knife-edge obstacles is called additional loss. When the peak of the obstacle just falls down on the link between the transmitting and receiving points, that is,  $H_c=0$ , the additional loss is 6 dB. When the peak of the obstacle surpasses the link between the two points, the additional loss may rapidly increase. When the peak of the obstacle is below the link between the two points, additional loss may vary slightly around 0 dB, at this time, the transmission loss (or receiving level) on the path is close to that of the free space.

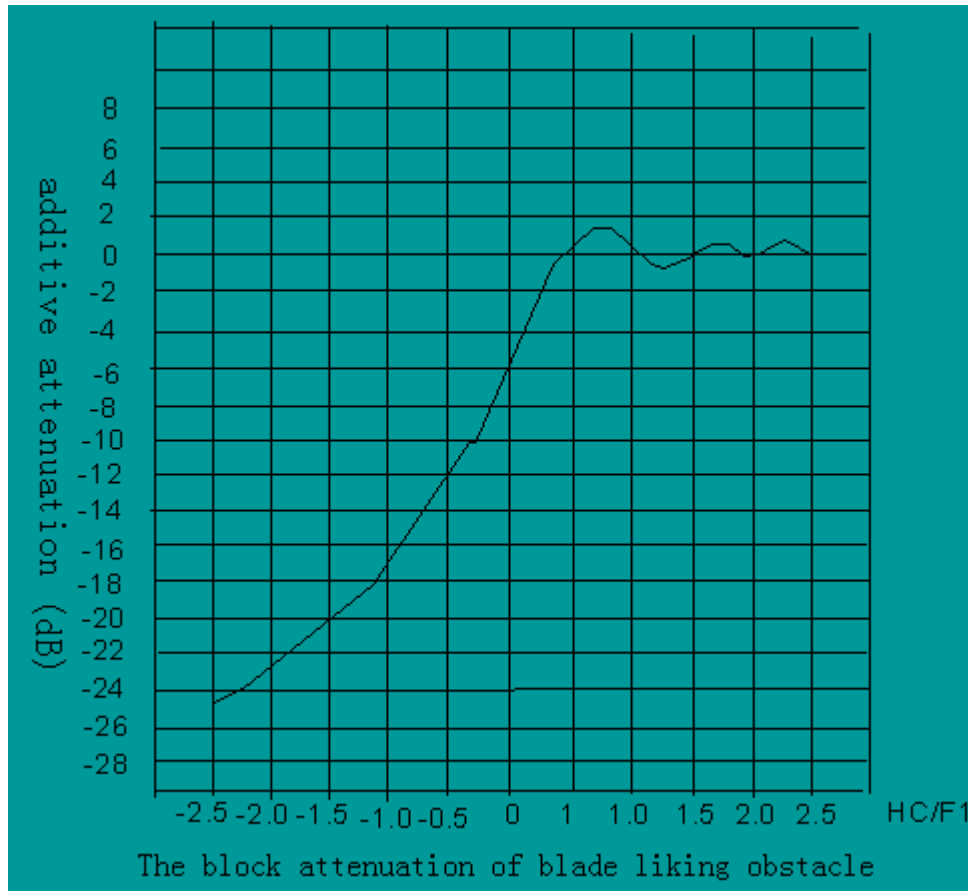


Figure4.3 Loss caused by knife-edge obstacle

#### 4.2.2.3 Reflection of Flat Terrain to Electric Waves

Flat terrain indicates that the earth curvature is not considered and the terrain between two points is considered to be flat. In actual microwave communication project lines, the receiving and transmitting antennas are leveled to make the receive end receive stronger direct waves. But based on the Huygens theory, some electric waves are always sent to the ground, therefore, at the receiving point, besides the direct waves, there are reflected waves reflected by the ground and meeting the reflection conditions (angle of arrival equals to angle of reflection). We can use the following geometrical relationship to deduce the expression of virtual value of the composite field strength.

If: transient value of field strength of direct wave is expressed by:

$$e_1 = 2^{1/2} E_0 \cos \omega t$$

Transient value of field strength of reflected wave is expressed by:

$$e_2 = 2^{1/2} E_0 \Phi \cos (\omega t - \psi - 2\pi (r_2 - r_1) / \lambda)$$

In the two formulas:

$e_1, e_2$  are the transient values of field strength of direct wave and reflected wave respectively.

$E_0$  is the effective wave of the field strength of waves propagates in free space.

$\Phi$  is the modulus of reflectance.

$\psi$  is the phase angle of reflectance (when the angle of arrival formed by the incoming wave and the ground are small,  $\psi$  is close to  $180^\circ$ )

$r_2 - r_1$  is the progressive error of the field strength of reflected wave and the direct wave.

By deduction, the effective value of composite field strength is:

$$E = (E_0^2 + E_0^2 \Phi^2 + 2 E_0^2 \Phi \cos(\psi + 2\pi(r_2 - r_1)/\lambda))^{1/2}$$

$$= E_0 (1 + \Phi^2 - 2\Phi \cos(\psi + 2\pi(r_2 - r_1)/\lambda))^{1/2}$$

The ratio of composite field strength  $E$  to the field strength of free space is called fading factor  $V$  when the ground influence is considered. The  $V$  is expressed by:

$$V = E/E_0$$

$$= (1 + \Phi^2 - 2\Phi \cos(\psi + 2\pi(r_2 - r_1)/\lambda))^{1/2}$$

Expressed in dB:

$$V \text{ dB} = 20 \log V$$

When the ground influence is considered, the actual receiving level is:

$$PR \text{ (dBm)} = PR_0 \text{ (dBm)} + V \text{ dB}$$

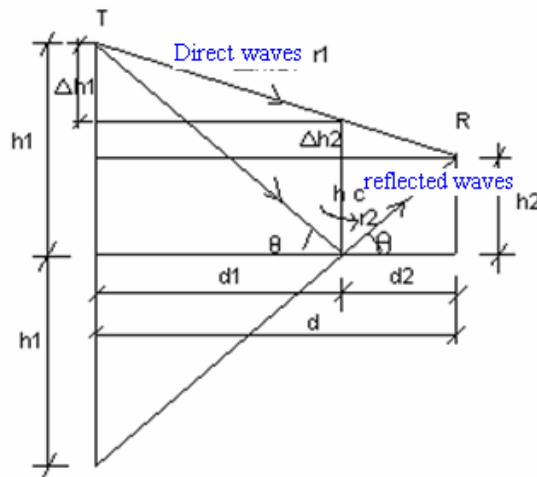


Figure 4.4 Influence of terrain on electric waves

#### 4.2.2.4 Using Fresnel zone concept to analyze the influence of ground reflection

When section distance  $d$  is longer than antenna height ( $h_1$  and  $h_2$ ), the progressive error of direct wave and ground reflection wave can be approximately expressed by:

$$\Delta r = \lambda (H_c/F_1)^2 / 2$$

When  $\theta$  in figure4.3 is very small (that is,  $\psi$  is close to  $180^\circ$ ), following expression can be obtained

$$V = [1 + \Phi^2 + 2\Phi \cos(\pi (h_c/F_1)^2)]^{1/2}$$

This expression indicates the quantitative relationship between fading factor  $V$  and relative clearance  $h_c/F_1$ . In engineering, curve indicating the relationship between  $V$  and  $h_c/F_1$  is made to simplify the calculation of the additional loss caused by ground reflection.

$\Phi$  is related to ground conditions, see figure4.5.

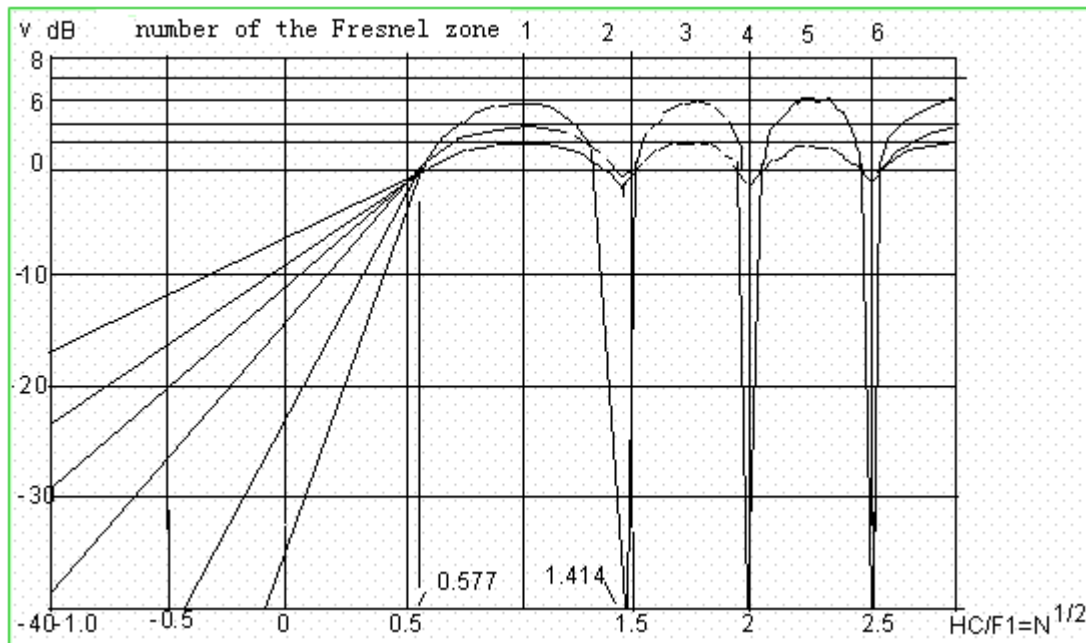


Figure4.5 Relation between VdB and  $h_c/F_1$

In the figure, “reflection loss” indicates that compared with incoming wave, the level that reflected wave attenuates; it is equal to  $20\text{LOG}$  and different from the fading factor in terms of concept.

In figure4.5:

If  $\Phi=1$ , the ground influence is considered, when the receiving level equals to the level of free space for the first time,  $H_c/F_1=0.577$ .

If  $\Phi < 1$ , when the receiving level equals to the level of free space for the first time,  $H_0/F_1 = 0.577$

When  $H_0/F_1 = 0.577$ , the clearance is called free space clearance which is represented by  $H_0$ .

It is expressed by:

$$H_0 = 0.577 F_1 = (\lambda d_1 d_2 / d)^{1/2}$$

#### 4.2.2.5 Classification of Microwave Lines

Normally, in the line-of-sight microwave communication, based on the clearance  $h_c$  of relay lines, the relay lines can be classified into three categories:

If  $h_c \geq h_0$ , it is called open line

If  $0 < h_c < h_0$ , it is called half open line

If  $h_c \leq 0$ , it is called closed line

Corresponding to the previous three conditions, the calculation method of fading factor  $V$  is:

Open line: for rough calculation, refer to figure 4.5

For knife-edge obstacles, refer to figure 4.5.

For half-open and closed lines caused by large highlands, mountains, the fading factor can be checked out in figure 4.5 or calculated by diffraction expression. Under condition of such lines, electric wave reaches the receiving point in the way of diffraction. Based on relevant theory, approximate diffraction expression can be obtained. There are three conditions:

A, when  $h_c = h_0 = 0.577 F_1$ ,  $V = 1$ , or  $V_{dB} = 0$ ;

B, when  $h_c = 0$ , for knife-edge obstacles:  $V_{dB} = -6dB$ ;

For large-size obstacles:  $V_{dB} < -6dB$ , based on expression C.

C, when  $h_c < h_0$ ,  $V_{dB} = V_{0dB} (1 - h_c/h_0)$

In the formulas:

$V_{dB}$  is the fading factor when diffraction is considered.

$h_0$  is free space clearance.  $h_0 = 0.577 F_1$

$h_c$  is clearance of the main ray of relay circuit (m)

$V_{0dB}$  is the level value of fading factor when the free space clearance is  $h_c = 0$ . It is calculated by parameter  $\mu$  that reflects the obstacle terrain.

$$\mu = 2.02 [K(1-K)/L]^{2/3}$$

In the formula:



$$K=d1/d$$

L is the link that parallel to the RT, draw tangent and secant lines over the obstacles based on  $(\lambda d)^{1/2}/2$ , the width of obstacles can be obtained.

For cross-section diagram of calculating terrain parameter  $\mu$ , see figure 4.6.

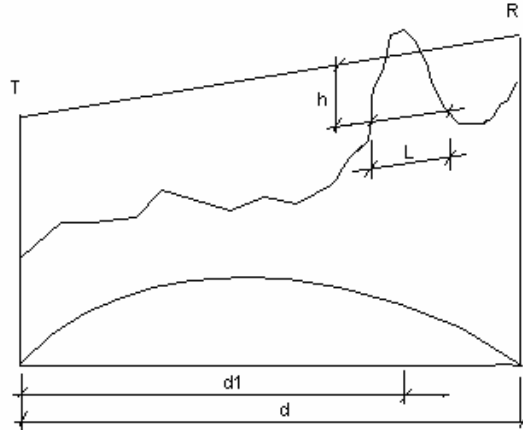


Figure4.6 Curve of determining terrain parameter  $\mu$

The relation between  $V_{0dB}$  and  $\mu$  is shown in figure4.7.

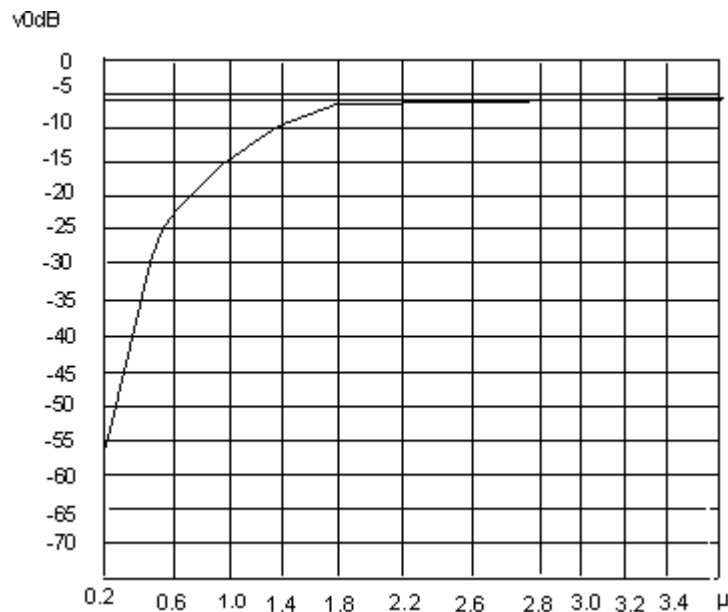


Figure4.7 Curve indicating relation of  $V_{0dB}$  and  $\mu$

### 4.3 Influence of Troposphere on Electric Wave

The most distinct influence of troposphere on the electric wave is the influence of atmospheric refraction on the electric wave propagation.

### 4.3.1 Ray Bend in Atmosphere

The propagation speed of electric wave in the free space is:

$$u=c=1/(\mu_0\epsilon_0)^{1/2}=3\times 10^8 \quad (\text{m/s})$$

In actual atmosphere, dielectric coefficient  $\epsilon=\epsilon_0*\epsilon'$ ,  $\mu=\mu_0$ , thus the velocity that electric wave propagates in atmosphere is:

$$u=1/(\mu_0\epsilon_0 \epsilon')^{1/2} = c/(\epsilon')^{1/2}$$

In the formula:  $\epsilon'$  is called relative dielectric coefficient.

Supposed the diffraction of atmosphere is  $n$ , it is the velocity that electric wave propagates in the free space to the velocity that electric wave propagates in atmosphere.

$$n=c/u=(\epsilon')^{1/2}$$

Indicated by reflection exponent  $N$ :

$$N=(n-1) \times 10^6$$

In free space,  $N=0$ . On the surface of the ground,  $N=300$ . “ $n$ ” is normally between 1.0 and 1.00045.

In atmosphere, in different heights, influenced by different pressure, temperature, and moisture, the atmosphere may vary. This variation is expressed by  $dn/dh$ . See figure4.8.

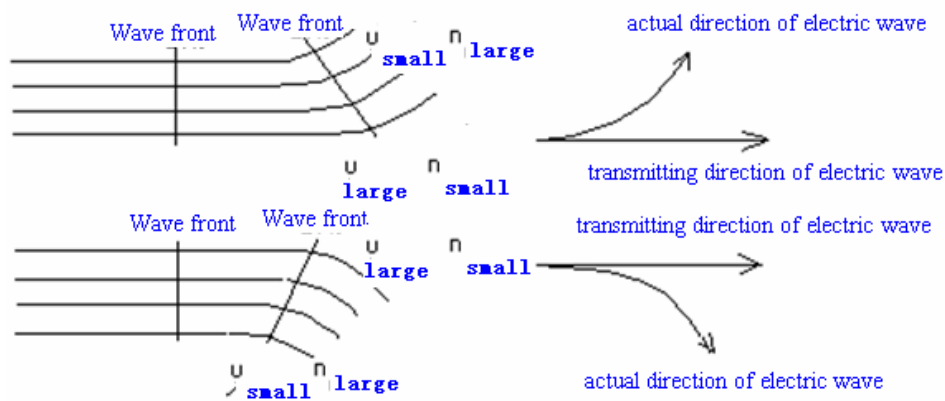


Figure4.8 variation of electric wave track influenced by atmosphere

When  $dn/dh < 0$ ,  $n$  is in reverse ratio to  $h$  in variation, which makes electric transmitting ray bend down.

### 4.3.2 Concept of Equivalent Earth Radius

To analyze influence on electric wave transmission, the concept of equivalent radius is introduced. After the concept is introduced, the electric wave is always considered to be a straight line and the actual radius of the earth is equivalent to  $a_e$ . Equivalent rule is that the clearance between the ray and the earth is unchanged before and after the equivalence. See figure4.9.

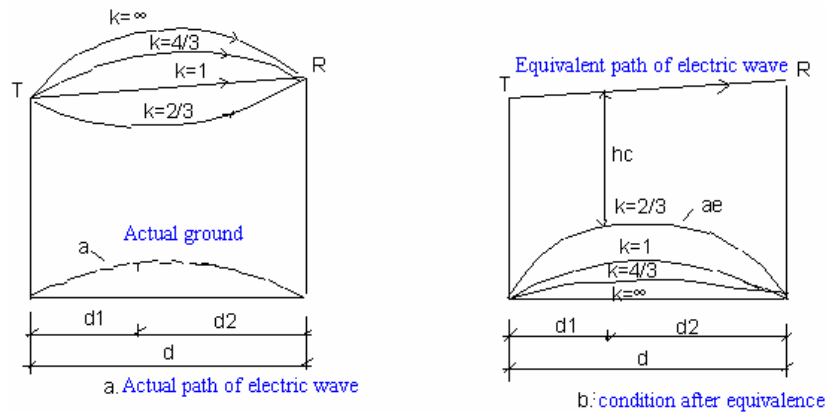


Figure4.9 Conditions after and before the equivalence—schematic

$K$  is defined as equivalent earth radius coefficient:  $K = ae/a$

In the formula,  $a=6370$  km

The relationship between  $K$  and the index of refraction is:

$$K = 1 / (1 + a \, dn/dh)$$

$K$  is a very important concept in microwave engineering, it must be considered.

### 4.3.3 Refraction can be classified into three categories based on the $K$ value

- (1) Non-refraction:  $dn/dh=0$ ; and  $k=1$  or  $a=a_e$
- (2) Negative refraction:  $dn/dh > 0$ ; and  $k < 1$  or  $a > a_e$ , the bending direction of the electric wave ray is opposite to that of the earth
- (3) Positive refraction:  $dn/dh < 0$ ; and  $k > 1$  or  $a < a_e$ , the bending direction of the electric wave ray is same as that of the earth

Based on a large amount of test result, the refracting index gradient is:  $dn/dh = -1/4a$

And then,

$$k = 1 / (1 + a(-1/4a)) = 4/3$$

In temperate region, when  $K=4/3$ , the refraction is standard refraction, and the atmosphere is called standard atmospheric pressure.  $a_e=4a/3$  is called standard equivalent earth radius.

At equator, standard equivalent earth radius is  $a_e = (4/3 - 3/2)a$ ;

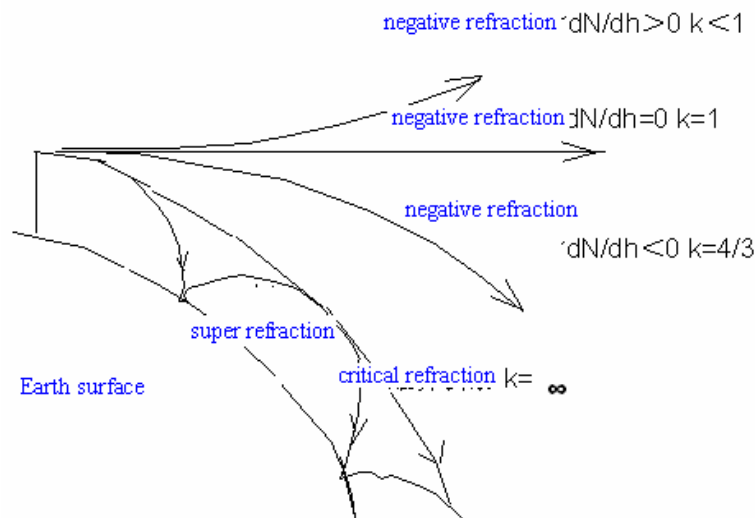


Figure 4.10 Classification of refraction—schematic

In engineering calculation, China uses  $K_{\text{standard}} = 4/3$ ,  $K_{\text{negative refraction}} = 2/3$ . When inter-station interference is considered,  $K = \infty$ , that is, influence of earth bulge on the electric wave propagation is not considered.

#### 4.3.4 The Meaning of K Value in Engineering Design

In engineering, to make clearance more economical and rational in use, you should control the antenna height based on the following requirements.

- (1)  $\Phi \leq 0.5$ , that is, for circuits that have small earth reflectance, such as mountains, cities, hilly grounds, to avoid over large diffraction, control the antenna height based on the following standards.

When  $K = 2/3$ ,  $h_c \geq 0.3F_1$  (for general obstacles)

$h_c \geq 0$  (for knife-edge obstacles)

In this situation, diffraction fading produced is not more than 8 dB.

- (2)  $\Phi > 0.7$ , that is, for circuits that have large earth reflectance, such as flat, water reticulation area, to avoid over large reflection fading, control the antenna height based on the following standards.

When  $K = 2/3$ ,  $h_c \geq 0.3F_1$  (for general obstacles)

$h_c \geq 0$  (for knife-edge obstacles)

When  $K = 4/3$ ,  $h_c \approx F_1$

When  $K=\infty$ ,  $h_c \leq 1.35 F_1$  (for when the clearance is  $2^{1/2} F_1$ , deep fading may appear)

If those requirements cannot be met, change the antenna height or change the route.

## 4.4 Fading caused by Several Atmospheric and Earth Effects

Microwave propagation must adopt direct wave and the field strengths of the receiving point is overlap of the direct space wave and earth reflected wave. Propagation medium is the low-altitude aerosphere and earth and objects in the route. When the time (season, day and night) and weather (rain, fog and snow) vary, atmospheric temperature, refraction and pressure, earth reflecting point and reflectance also change. This causes the field strength of the receiving point to change. The phenomenon is called electric wave propagation fading. Obviously, fading is very random.

The degree of fading is indicated by fading factor and fading reason attributes the earth and ground effect.

### 4.4.1 Fading Types

#### 4.4.1.1 Fast Fading and Slow Fading

Fading can be classified into slow fading and fast fading based on the duration. Long-duration fading is called slow fading and the duration is from several minutes to several hours. Short-duration fading is called slow fading and the duration is from several seconds to several minutes. Slow fading varies slowly, it is slowly formed and then slowly disappears, and it is always caused by atmospheric refraction changing slowly in a wide area. For in a wide area (such as a section of relay circuit), atmospheric refraction becomes bad and recovers in a relatively long time, and then slow fading is formed. Fast fading is closely related to multi-path propagation caused by thin layer in the atmospheric waveguide and turbulent current. In the range of microwave, if the paths of each ray in the previous multi-path propagation vary, the composite signals of the rays at the receiving point may vary and then fast fading is formed.

#### 4.4.1.2 Upward Fading and Upward Fading

Fading can be classified based on the field strength of the receiving point. When the received level is higher than the free space level, it is called upward fading, and when it is lower than the free space level, it is called downward fading

#### 4.4.1.3 Blinking Fading and Multi-path Fading

In engineering, fading is always classified into blinking fading and multi-path fading based on the physical causes of fading.

Blinking fading is mainly caused by local slight disturbance in atmosphere resulting in electric wave beam scattering. Each scattering wave has small amplitude and the phase varies along with the atmosphere. As a result, the composite amplitude at the receiving point is very small and does affect the

main waves. Therefore, this fading seldom affects the stability of the line-of-sight radio-relay circuits.

Multi-path is mainly caused by multi-path propagation, and it is the major cause of the deep fading of line-of-sight propagation channels.

For both analogue microwave and digital microwave, multi-path propagation objectively exists and affects microwave. But digital microwave is more sensitive to multi-path propagation than analogue microwave. Multi-path propagation is described in the following section.

Multi-path propagation is a kind of propagation phenomenon that when the electric wave leaves transmitting antenna, it arrives at the receiving antenna through more than two different paths. There are many reasons for multi-path propagation, for example, on the path where there is earth reflection, in addition to receiving the direct space wave from transmitting antenna, the receiving antenna also receives reflected waves from the ground. In addition, under certain weather conditions, there are various non-homogeneous objects in the atmosphere. For example, atmospheric waveguide or reflection, refracted waves received by receiving antenna, those are the causes of multi-path propagation.

In multi-path propagation, electric wave is transmitted to the receiving point along many paths. For non-homogeneous positions, interfaces and sizes are random; there is phase variance between each electric wave caused by progressive error, and the amplitude error caused by different reflection conditions is also random. Therefore, the composite interference field at the receiving point greatly changes, and this is multi-path fading. In the microwave frequency band, for the wavelength is very short, the phase variance  $\frac{2\pi}{\lambda}$  caused by progressive error changes greatly, thus multi-path fading is very remarkable in this frequency band.

## 4.4.2 Influence of Troposphere on Electric Wave Propagation

From the ground, upwardly, atmosphere can be divided into six layers in order: troposphere, stratosphere, mesosphere, thermosphere, ionosphere, and exosphere. Troposphere is low-altitude atmosphere ranging from the ground to 10 kilometers higher upward. Microwave communication works in this layer. Troposphere gathers 3/4 mass of the entire atmosphere. When the ground is exposed to the sun, the ground temperature increases, and heat emitted from the ground make the low-temperature atmosphere inflated, which causes the atmospheric density non-homogeneous, and then convection current is formed, thus this layer is called troposphere. The influence of troposphere on the electric wave has following types:

### 4.4.2.1 Atmosphere Absorption Loss

Molecule of any material is constituted by charged particles. Those particles have constant electro-magnetic resonance frequency. When the microwave frequency of these materials is close to their resonance frequency, those materials absorb microwave resonantly. Oxygen molecule ( $O_2$ ) in the atmosphere has magnetic-coupling polar and vapor ( $H_2O$ ) has electric-coupling polar, they can absorb energy from electromagnetic waves and then absorption loss is caused.

The maximum absorption peak of vapor is at  $\lambda = 1.3\text{cm}$  ( $f = 22.2\text{GHz}$ ), and that of oxygen is at  $\lambda = 0.57\text{cm}$  ( $f = 57\text{GHz}$ ).

Following figure shows the absorption loss of electromagnetic waves caused by atmosphere.

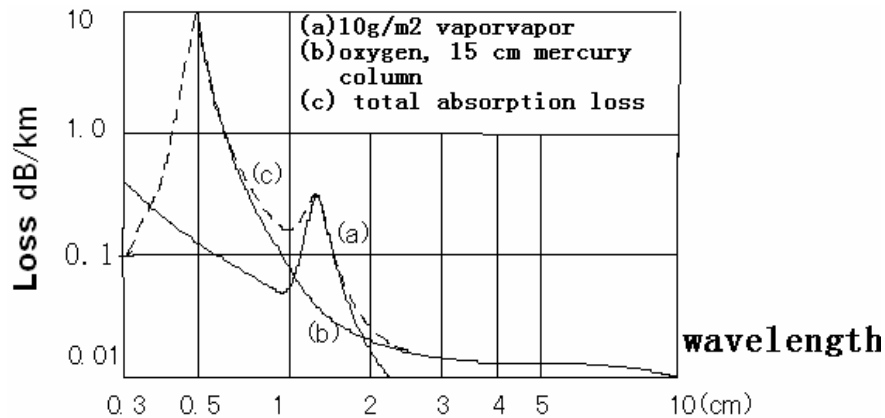


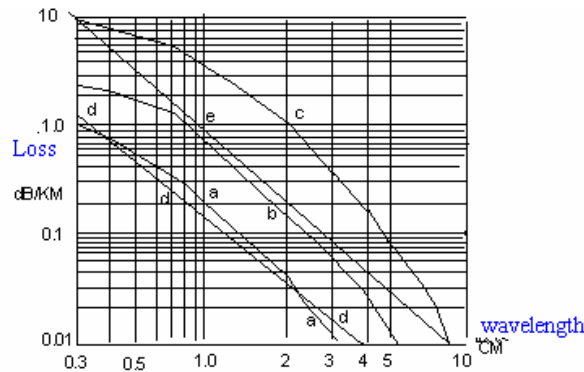
Figure4.11 Absorption of vapor and oxygen

The curve in the figure shows, when the microwave frequency is 12 GHz (wavelength is 2.5 cm), absorption loss of the atmosphere is about 0.02 dB/km. if the microwave station distance is 50 km, the attenuation of a relay section is 1.0 dB. Therefore, when microwave frequency is less than 12 GHz, compared with free space propagation loss, the absorption loss can be ignored.

#### 4.4.2.2 Scattering Loss Caused by Rain and Fog

Rain, fog and snow can absorb electric wave energy if the microwave wavelength is under 5 cm (frequency is 6 GHz), when the wavelength is longer than 5 cm, the absorption can be ignored. Generally, for frequency band is less than 10 GHz, fading caused by rain and fog is not serious; normally the fading between two stations is only several dB. For the frequency band is more than 10 GHz, distance between relay sections is limited by loss caused by rains, and it cannot be too long. See figure4.11.

Sometimes, moisture cluster, such as mist, is formed in the atmosphere, this non-homogeneous material can make the electric wave refracted, absorbed, scattered and reflected, mainly refracted.



Note: in the figure  
a indicates rainfall is 1 mm/h  
b indicates rainfall is 4 mm/h  
c indicates rainfall is 16 mm/h  
d indicates fog of 0.3g/m<sup>3</sup> (scale of visibility is 120 m)  
e indicates fog of 2.3g/m<sup>3</sup> (scale of visibility is 30 m)

Figure 4.12 scattering loss caused by rain and fog

#### 4.4.2.3 K Type Fading

It is an interference-type fading caused by multi-path transmission. This fading is caused by mutual interference of the direct wave and ground reflected wave (or diffracted wave under certain conditions) due to phase variance when the two kinds of waves arrive at the receiving point. The interference is related to progressive error. In troposphere, the progressive error varies with the K value; therefore, this fading is called K types fading. This fading is very serious when the transmission line crosses river, lake and smooth ground. Thus, in selecting routes, try to avoid river, lake and smooth ground if possible, if not, use high-low antenna technology to make the reflecting point more nearer to one end to reduce the impact of reflected waves, or use high-low antenna technology plus space diversity technology to reduce the impact of multi-path reflection.

#### 4.4.2.4 Waveguide Fading

Due to influence of all kinds of weather conditions, such as the ground is heated by the sun in the morning and become cold in the night, and in the high-pressure area, non-homogeneous objects are formed. When electric waves pass those non-homogeneous objects, super reflection phenomenon occurs and atmospheric waveguide is formed. Under such circumstances, you can deal with the waveguide fading only based on engineering experience.

### 4.4.3 Fading Rules (microwave frequency bands lower than 10 GHz)

Based on a large amount of test result, find fading of microwave frequency bands lower than 10 GHz follows the following rules:

(1) The shorter the wavelength is, the longer the distance is, and the more serious the fading is.



(2) Fading of propagation paths crossing rivers and plains is more serious than that of the paths crossing mountain areas.

(3) Fading occurs more frequently and is deeper in summer and autumn than autumn and spring.

(4) The field strength of received signals is more stable in sunny days and daytime than nights. When day and night shift, for example, from 05:00:00 to 09:00:00 in the morning, from 19:00:00 to 21:00:00 in the night, and from 00:00:00 to 03:00:00, deep fading frequently occurs.

(6) Signals received in rainy, foggy and windy days are more stable than in sunny days. When the sun shines again after rain and fog scatters, fast fading always occur.

## 4.5 Frequency Selective Fading

### 4.5.1 Multi-path Propagation of Electric Waves

#### 4.5.1.1 Basic Concepts

From the previous chapters, it is learned that for a relay section, in addition to receiving direct waves, the receiving point can also receive reflected waves from some point of the path. Atmospheric effect makes the atmosphere produce some random reflected waves and scattered waves that are independent of any fixed reflecting surface. That is, the receiving point can receive electric waves from many paths, this is multi-path propagation phenomenon.

Multi-path electric waves have random amplitude and phase at the receiving point, and the level of the receiving point is the vector sum of mutual interference of the waves, therefore, the receiving level produces multi-path interfering fading along with this multi-path propagation phenomenon. This phenomenon typically occurs in hot and humid summer, for example, in the basin of the Yellow river, it frequently occurs in July, August and September. This phenomenon is more apt to occur in plains and water reticulation areas than mountain areas.

#### 4.5.1.2 Further Analysis on Multi-Path Propagation

Multi-path fading can be classified into level fading and frequency selective fading.

Influence of level fading on digital microwave system is equivalent to receiving level decrease. Therefore, adequate level fading margin can effectively improve the level fading in multi-path fading channels. For level fading, its analysis model can be indicated by the sum of a constant field strength vector and the innumerable mutually independent random vector, and the modulus of this vector sum is subject to Rayleigh distribution.

Influence of frequency selective fading on digital microwave system is equivalent to signal-to-noise ratio decrease. Therefore, it is limited to enlarge fading margin to improve system bit error performance. The analysis methods normally use two-path model or simplified three-path model.

Multi-path propagation can be concluded to two types: one type of multi-path is formed by direct waves and reflected waves, and the other type of multi-path is formed by co-existing paths caused by low-atmosphere effect. Normally, the first type is major and frequently occurs. And the second type is not typical and does not frequently occur. But when ground reflected wave is very weak even feeble, influence of the second type becomes the major factor.

For multi-path interfering fading is produced by mutual interference of electric waves of different paths, therefore, theoretically, fading model for research should be based on several composite wave beams. However, fading caused by mutual interference of more than three beams has lower probability of making circuit quality bad; therefore, model for research of interfering fading is normally based on two beams.

## 4.5.2 Influence of Frequency Selective Fading on Transmission Quality of Microwave Communication Systems

### 4.5.2.1 Causing In-Band Distortion

In-band distortion indicates that amplitude frequency feature and time delay frequency feature of microwave signals (modulated waves) in the band are linear, the  $A(f)$ ,  $T(f)$  features of each frequency spectrum of the signal vary along with frequency, and this variation is called in-band distortion.

In-band distortion caused by frequency selective fading is related to transmission bandwidth of signals, while bandwidth of signals is determined by transmission capacity and modulation mode.

### 4.5.2.2 Making Cross Polarization Discrimination Decrease

For microwave signal under a polarization status (such as horizontal polarization), after being transmitted by the channel, due to the influence of the atmosphere on the electric wave transmission, the polarization side may be damaged and part of the energy may become orthogonal status (such as vertical polarization) to the signals. Then, when co-frequency reutilization scheme is adopted, interference between two channels of the same frequencies and with polarization orthogonal may be caused, this is called cross polarization interference (XPI).

XPI can be produced by the feature of antenna and feeder system at the receiving and transmitting ends. But XPI exists in the form of background interference (noise) and keeps unchanged. In the frequency band lower than 10 GHz, XPI is mainly caused by multi-path propagation.

Cross polarization discrimination (XPD) is normally represented by level value, that is,

$$XPD=10\lg(P/P_x) \text{ (dB)}$$

In the formula:

$P$  is power of the signal received by some channel of receiving end and having the same polarization with transmitting end.

$P_X$  is the XPI signal received by the channel.

If the XPD value is large, it indicates that energy is reduced when a polarization status is changed to orthogonal polarization status via transmission.

For frequency bands 4 GHz and 6GHz, the XPD of antenna and feeder system should be larger than 40 dB, but multi-path propagation might make the XPD become bad remarkably.

#### 4.5.2.3 Making Original Fading Margin of the System Decrease

When the frequency selective fading is not considered or the narrowband signals are transmitted in the system (frequency selective fading is ignored), anti-fading capacity of the system is represented by flat fading margin.

Flat fading margin is: compared with free space propagation condition, when thermal noise is increased (only thermal noise is considered), to make system work under the condition that the threshold bit error rate is not exceeded, thus adequate level margin must be reserved. For example, under the condition of free space propagation, for a digital microwave communication system, the receiving level is -35 dB, when the bit error rate is the threshold value  $P_e=10^{-3}$ , the receiving level is -80 dB and its flat fading margin is 45 dB.

When frequency selective fading is considered, that is, for high and medium capacity digital microwave communication system, concept of flat fading is not suitable. Because transport bandwidth of the digital microwave communication system is relatively wide and the wider the bandwidth is, the more serious the influence of frequency selective fading is, and then actual fading margin of the system is less than flat fading margin. This is because when in-band distortion is serious, sometimes the fading is not deep and the influence of thermal noise is not remarkable, but the bit error rate may quickly increase and when it exceeds threshold bit error rate, communication is interrupted.

Effective fading margin is always mentioned in digital microwave communication, it is level margin that must be reserved to make the system still work when the threshold bit error rate is not exceeded and frequency selective fading is considered in comparison to free space propagation.

For high and medium capacity digital microwave communication system, when flat fading margin is added, effective fading margin cannot be added (it is slowly added) in proportion to the flat fading margin. That is, only by means of increasing flat fading margin such as increasing transmitting power, performance of digital microwave communication system cannot obtain necessary improvement. You can adopt frequency diversity, space diversity and automatic equilibrium technologies to improve the capability of the system in terms of frequency selective fading.

## 4.6 Statistic Feature of Fading

### 4.6.1 Microwave Fading Model—Rayleigh Distribution Function

To understand the reliability of communications, you should understand possibility distribution of fading depth and fading duration. Fading depth

provides interruption level in propagation and fading duration provides interruption time.

Phase interference caused by multi-path transmission effect is the major cause of microwave transmission line-of-sight deep fading. Fading model is described by the sum of innumerable random vectors with independent phase. To analyze fading features in different conditions, probability theory is adopted, and many types of distribution functions that can indicate those features are cited. The typical function is Rayleigh distribution function. The modulus of the vector sum that can prove fading is subject to this general distribution. When the fading is serious, coherent multi-path vector occupies large proportion, and constant field strength is subordinated. In the Rayleigh distribution, the fading is fast and deep.

Simply, Rayleigh distribution is the probability of a value that the receiving level might be when there is fading. When the fading feature is subject to Rayleigh distribution, the probability of the receiving level lower than a certain level is:

$$P(E)=1-e^{-(E^2/E_e^2)}$$

In the formula:

$E^2$ —the square of previously defined effective value of the field strength, it corresponds to receiving power and sometimes it indicates the receiving power related to threshold condition.

$E_e^2$ —the effective guide average value of the field strength. It corresponds to average receiving power.

#### 4.6.2 Engineering Calculation of Rayleigh Fading Probability

Use Rayleigh fading distribution rules in the microwave communication, consider the condition of electric wave propagation, the probability of fading is:

$$Pr=KQfBdcW/W_0$$

In the formula:

Pr: Rayleigh fading probability, that is, not more than the probability of the receiving power when there is fading.

K: factor of environment condition

Q: factor of geographical condition

F: working frequency of microwave (GHz)

B, C: constant factor concerning weather and seasonal geography

D: distance between stations (km)

W: the received power when there is no fading

$W_0$ : the received power when there is fading

Based on decades of practices performed by national research institutes, in China, the values of constant factors are as follows:

No.		KQ	B	C
1	Mountain areas	$1.072 \times 10^{-2}$	1	1.3
2	Hilly areas	$2.75 \times 10^{-3}$	1	1.8
3	plains	$2.884 \times 10^{-3}$	1	2.2
4	Lake, sea, swamp lands	$2.63 \times 10^{-4}$	1	3.2

In actual engineering, when the fading depth is already known " $F_d(\text{dB})$ ", the probability of this depth to occur is:

$$P_r = KQr^B d^C 10^{(-fd/10)}$$

In the formula: meanings of the symbols are previously explained,  $10^{(-fd/10)}$  is the multiple of fading depth.

In engineering, when  $P_r$  value of each relay circuit meets the bit error rate index of the microwave channels, it is OK.

Have a think:

What do you learn in this chapter?

- (1) Electric wave propagation in free sapce
- (2) Influence of groud reflection on the electric wave propagation
- (3) Influence of troposphere on the electric wave
- (4) Fading caused by several atmospheric and ground effects
- (5) Frequency selective fading and its influence on microwave communication

Pay special attention to (4) and (5).

## 4.7 Conclusion

This chapter mainly describes the propagation principles of microwave, including propagation theory of free space, Huygens-Fresnel theory, Fresnel theory of electric wave propagation; interference and polarization of electric wave, electric wave reflection caused by non-homogeneous atmosphere, influence of troposphere on the electric wave, super refraction caused by irregular change of atmospheric medium gradient, reflection on different characteristic grounds, diffraction on smooth spherical surface, propagation in the presence of knife-edge obstacles and multi-obstacles, absorption of the electric wave by rains and fogs in atmospheric propagation, and loss theory.

For more information about microwave transmission, refer to following documents:

*Microwave Communication Engineering Design* Posts & Telecom Press  
edited by Post & Telecommunication Design Institute 1989-08

*Digital Microwave Communication Engineering* Posts & Telecom Press  
1991-11

*Digital Microwave Communication* Posts & Telecom Press edited by Wang Yunfei Gao Fengquan, Yin Minguang 1992-01

*Microwave Propagation Fading and Anti-Fading Technology* edited by Gao Yulong 1984-05

*Microwave Propagation* Posts & Telecom Press 1988-11

## 5 Anti-Fading Technology in Digital Microwave Equipment

- **Objectives**

To have a general understanding on anti-fading technology

To master principles and features of all kinds of anti-fading technologies

To master all kinds of protection schemes for digital microwave equipment

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Fading phenomenon in microwave propagation has impact on relay transmission. Based on the wave propagation statistical rules, all kinds of anti-fading technical measures are proposed; that is, anti-fading technology.

### 5.1 Overview

Multi-Path fading may cause fading and distortion of the transmission channel, which varies with the geographical environment and time. Hence, any kind of anti-fading measure must be adaptive.

To deal with flat fading, the automatic gain control circuit (AGE) of the intermediate frequency amplifier in the receiver and channel switching method are for common use.

To deal with frequency selective fading, the diversity technology and adaptive equalization technology are adopted. The following three measures are used for frequency selective anti-fading. These anti-fading technologies suppress amplitude dispersion and delay dispersion in different ranges of space, frequency and time. If these technologies are combined, a better anti-fading effect can be achieved.

#### 5.1.1 Purposes of Taking Anti-Fading Measures

(1) Compared to fiber transmission system, digital microwave relay system has the following two problems:

- Reduced received power due to multi-path fading

➤ Degraded circuit performance due to wave shape distortion

Hence, the designers of the microwave relay system should take proper anti-fading measures to meet indexes on general error performance parameters of the system, such as SES probability.

(2) ITU-T specifies the error performance indexes of the end-to-end digital channels within 27500km. ITU-R also responds and proposes similar suggestions. To meet these indexes, digital microwave relay system should take anti-fading measures to improve the system performance. During the design for systems and/or equipment, all kinds of anti-fading devices are important parts of the system. The stricter the indexes are, the more advanced anti-fading methods the system should be adopted.

(3) Another purpose of the anti-fading measures is to popularize and apply microwave relay links in relay segments where the propagation conditions are weak. For example, proper diversity receiver and effective equalizer can overcome the difficulty in long-haul across-the-sea spans. In these cases, microwave relay system is always the unique transmission medium to transmit services as required.

Any kind of anti-fading measure requires additional investment. Hence, both the price and performance need be considered to decide an anti-fading measure.

## 5.1.2 Classification of Anti-Fading Measures

The anti-fading measures can be classified based on two standards.

### 1、Based on physical features

Table 5.1 and Table 5.2 illustrate the anti-fading measures classified based on physical features. Category A relates to the equipment and category B relates to the system.

Table 5.3 illustrates the classification based on functional features.

Table 5.1 Category A - anti-fading measure related to equipment

Adaptive equalization	Frequency domain equalization	
	Time domain equalization	Linear equalization
		Decision feedback equalization
Interference cancellation	XPIC	
	IC of other route	

ATPC
forward error correction (FEC)

Table 5.2 Category B - anti-fading measure related to the system

space diversity	Double space diversity
	Triple/quadruple space diversity
angle diversity	
frequency diversity	Same frequency band
	Cross-connect frequency band
multi-carrier transmission*	

\* Multi-carrier transmission is only used in areas where environments are bad.

## 2、Based on functional features

Multi-Path fading may cause power reduction or wave shape distortion when signals are received. The spectrums within the frequency range is fully (flat fading) or partially reduced (selective fading). As a kind of dominant fading in microwave system, flat fading may cause relative reduction of C/N and C/I. Selective fading is a kind of dominant fading in broad-band digital microwave system.

The anti-fading measures described in Table 5.1 and Table 5.2 are used for compensation in case of one or two preceding conditions.

Table 5.3 Classification based on functional features

Classification		Effect
(A) Anti-fading measure related to equipment	Adaptive equalization	Wave shape distortion
	Interference cancellation	Wave shape distortion
	ATPC	Power reduction
	forward error correction	Power reduction
(B) Anti-fading measure related to the system	Space diversity	Power reduction and wave shape distortion
	Angle diversity	Power reduction and wave shape distortion
	frequency diversity	Power reduction and wave shape distortion
	Multi-Carrier transmission	Wave shape distortion

### 5.1.3 Evaluation on Anti-Fading Measures

The improvement factor of anti-fading measures is defined by  $I = P/P'$ . P refers to the system interruption probability in a given fading depth in when there is not anti-fading measure. P' refers to the system interruption probability in a given fading depth when there are anti-fading measures.

The value of I relates to the degree of performance degradation. As shown in Figure 5.1, when there is space diversity, if the system has large fading margin, the improvement effect is also great.



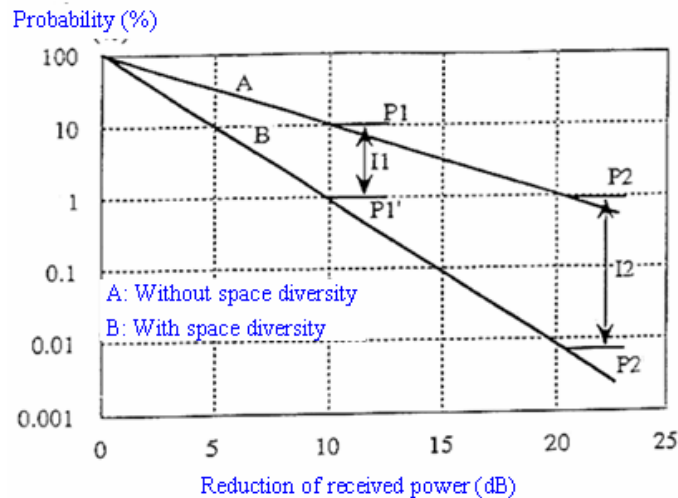


Figure 5.1 Space diversity improvement factor

Each anti-fading measure has its own improvement factor. However, the improvement effect for two different anti-fading measures is not presented by multiplying two improvement factors. For example, if space diversity and adaptive equalizer are combined, the combined effect exists. The improvement factor is bigger than the product of two factors.

## 5.2 Adaptive Equalization

In a digital microwave system, to compensate signal distortion caused by multi-path fading and reduce the system interruption time, the adaptive equalizer is widely used. Based on different working frequencies and places, the equalizer is classified into two types.

Adaptive frequency domain equalizer (AFE): used in intermediate frequency (IF) to control transfer function of the channel

Adaptive time domain equalizer (ATE): used in time domain to directly reduce intersymbol interference (ISI) caused by bad transfer function

Compared to AFE, the equalization capability of ATE is stronger. Some SDH microwave systems just use ATE, rather than AFE. However, most SDH microwave systems use both AFE and ATE, which may cause combined effect.

### 5.2.1 AFE

Frequency equalization uses the frequency characteristics of an adjustable network to compensate distortion of amplitude frequency characteristics and phase frequency characteristics of actual channels. Currently, the common equalizer is intermediate frequency adaptive equalizer, which is a kind of bandpass equalization.

Intermediate frequency adaptive equalizer (IF-EQL) consists of correction network (equalization circuit), equalization characteristic detector and controller.

IF-EQL is classified into IF tunable equalizer and IF adaptive amplitude frequency slope equalizer.

Figure 5.2 illustrates the principle of tunable equalizer:

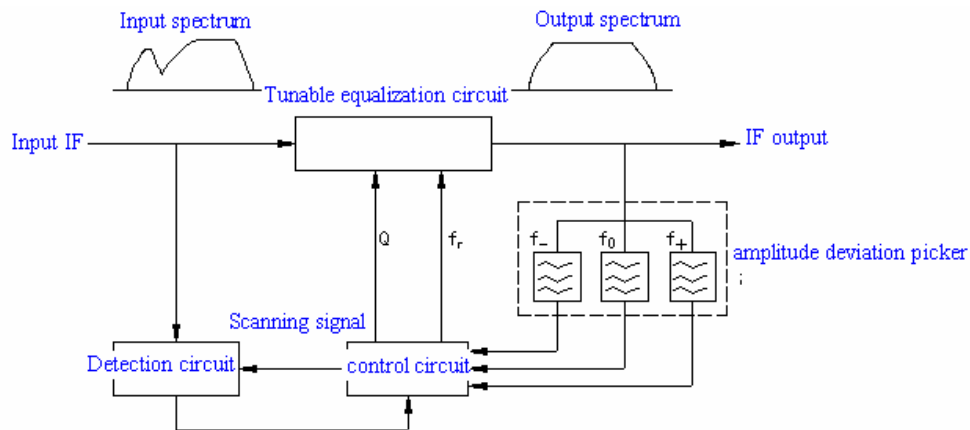


Figure 5.2 IF tunable adaptive equalizer

### 5.2.1.1 Slope Frequency Domain Equalizer

When multi-path fading exists, slope frequency domain equalizer is used to compensate the slope asymmetry in frequency response to microwave channels. The equalizer introduces a tool to correct the amplitude slope and thus recovers symmetry of power spectrum density of received signals.

Principle of slope frequency domain equalizer: Use a set of narrow-band filters to monitor output power spectrums at three places. According to the tested slope direction, a detection signal at the opposite direction is generated to mix with the original signal. Thus the amplitude frequency characteristics can be recovered to be flat.

Note: During spectrum monitoring, information about group delay distortion cannot be obtained. Hence, the improvement effect of the equalizer is limited.

### 5.2.1.2 Gap Frequency Domain Equalizer

The transfer function should be close to the reciprocal of the channel characteristic that complies with the propagation model of two rays. In this way, the actual transfer function can obtain flat amplitude frequency characteristics.

Principle of gap frequency domain equalizer: As a part, the resonance filter is used to control its gradient coefficient and center frequency and thus trace the fading gap. This kind of circuit always shows concave-down group delay characteristic. Hence, when the channel encounters the minimum phase fading, the signal distortion will reduce. However, if the channel encounters non-minimum phase fading, group delay distortion will double. In this event, the system characteristic curve of the minimum phase fading can be reduced, but the characteristic curve of the non-minimum phase fading is not improved.

In Figure 5.2, the control signals of most frequency domain equalizers are extracted from signal spectrum by using three bandpass filters. Hence, the many hardware devices are involved and the control accuracy is bad. Currently, the control signals of some frequency domain equalizers are extracted from baseband signals; that is, time domain controls equalization of frequency domain.

## 5.2.2 ATE

ATE is used in time domain to directly reduce intersymbol interference (ISI) caused by distortion of amplitude and group delay. The following formula describes the discrete input/output relation of general channel response, visually presenting basic principle of ATE:

$$x_k(\tau) = \sum_{-\infty}^{+\infty} h_i(\tau) a_{k-i} + n_k$$

In the preceding formula:

$X_k(\tau) = x_k(kT + \tau)$  is the received composite signal at the sampling moment:  $kT + \tau$

$a_k$  refers to the transmitted data symbol at  $kT$ .

$n_k$  refers to the sampling value of additive white Gauss noise (AWGN)

$h_i(\tau), i = -\infty, \dots, +\infty$  is the sampling value of general channel pulse response at the sampling phase  $\tau$ .

The preceding equation describes two reasons for the quality reduction of transmitted symbols: additive noise and interference from previous and later symbols. Only when pulse response  $h(\tau)$  meets the Nyquist rule, may non-intersymbol interference be implemented. Actually, though the transmitting and received filters are designed to form the Nyquist filter, time-varying multi-path propagation of attribute microwave channel destroys this characteristic, thus causing severe intersymbol interference. To avoid intersymbol interference, an adaptive equalizer should be added out of the receiver.

For the microwave equipment in QAM mode, different information is transmitted through orthogonal phase carriers. Hence, distortion caused on the propagation channel can interfere in mutual orthogonal carriers. Time domain equalization is performed between orthogonal carriers to eliminate such orthogonal interference.

Figure 5.3 illustrates the principle of an IF adaptive transverse equalizer:

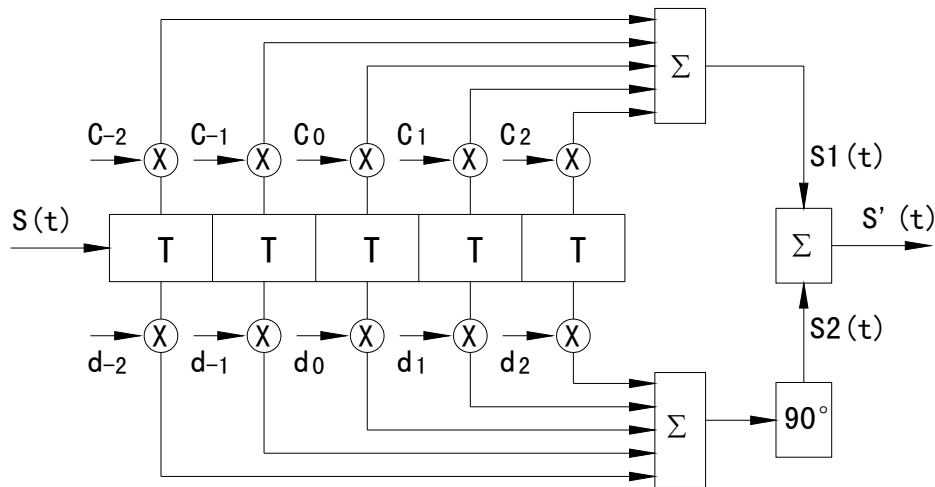


Figure 5.3 Principle diagram of an IF adaptive transverse equalizer

T refers to the delay line and every class of delay is a bit.

The ATE can equalize non-minimum phase fading when the reflected wave is stronger than direct wave:  $\rho > 1$ .

In actual use, both the AFE and ATE are used.

### 5.3 Cross-Polarization Interference Counteract (XPIC)

In a common microwave radio transmission system, the frequency of two polarization waves are allocated in different interleave mode. The interference between two polarization waves is small. However, in SDH microwave transmission, to improve the spectrum utilization, the co-channel or channel-insertion cross-polarization frequency regeneration mode is adopted.

In a light-of-sight propagation route, in the event of multi-path fading, dispersion on the nonuniform layer and ground or rain and fog, the cross-polarization signals may severely cause interference to co-polarization signals. Hence, the interwave interference compensation technology of cross-polarization should be introduced.

Orthogonal polarization Interference Counteract (OPIC) can be implemented in radio frequency, intermediate frequency and baseband frequency. The latter two frequency bands are more common. After the XPIC is adopted, the XPI can be improved by about 20 dB.

Figure 5.4 shows the principle of XPIC (NEC3000 series SDH microwave equipment):

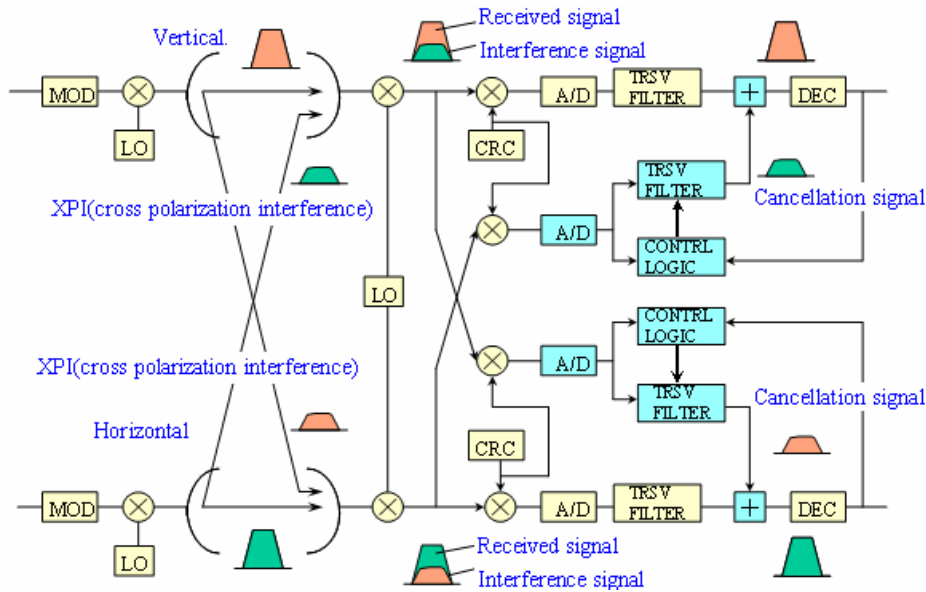


Figure5.4 Principle of XPIC

## 5.4 Automatic Transmit Power Control (ATPC)

As a key technology in digital microwave area, ATPC helps the output power of a transmitter operates in a normal value (or minimum value)  $P_{nom}$  in most cases. When the level of the remote receiver reduces, the reverse communication service channel is used to control the transmitter configured in the feedback loop and thus the output power can gradually reach  $P_{max}$ .

Characteristics of ATPC: The output power of a microwave transmitter can automatically trace the receiving levels at the receive end within the range controlled by ATPC and vary with the levels. In normal propagation conditions, the output power of a transmitter is fixed at a low level that may be about 10–15 dB lower than the normal level. When the level is lower than the lowest received level specified by ATPC and the receiver detects propagation fading in the event of propagation fading, ATPC uses the RFCOH byte to control the peer end transmitter and thus increase the transmitting power till a rated power value. Usually, the time rate occurring on severe propagation fading is short; that is, lower than 1%. After the ATPC is adopted, the transmitter operates at the power 10–15 dB lower than the rated power in most time (over 99%).

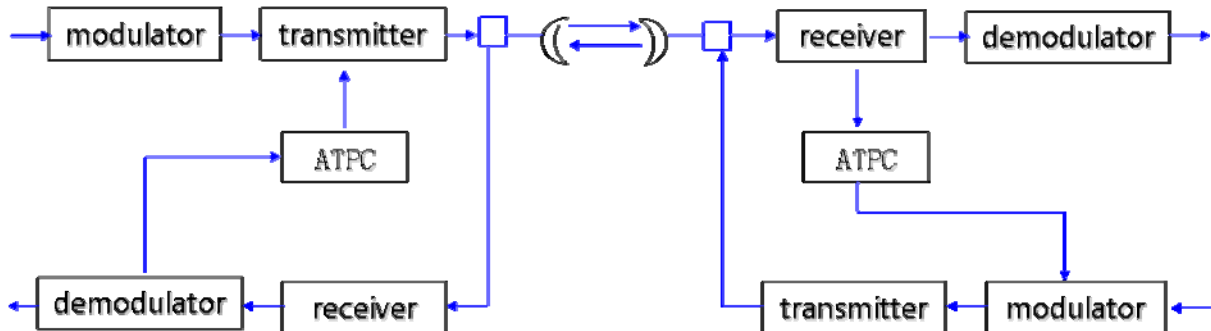


Figure 5.5 Principle of ATPC

According to the change rate of the transmitting power of a transmitter, ATPC is classified into mutation ATPC system and progressive ATPC system. For the mutation ATPC system, when the received level of a receiver reduces to the startup threshold level of ATPC, the transmitting power of a transmitter operates at a high level at once. When the received level increases to a set upper level, the transmitting power operates at a low level at once. For the progressive ATPC system, when the received level ranges between two thresholds, the level of the transmitting power changes gradually.

To adapt the change of electric wave fading, the trace speed of the ATPC system should be 100 dB/s. In addition, any bit error should not occur due to the ATPC during the operation of ATPC. In common frequency heteropolarizing frequency reuse mode, two polarizations should start ATPC at the same time, thus avoiding one in a high level and the other in a low level. Otherwise, severe interference may occur.

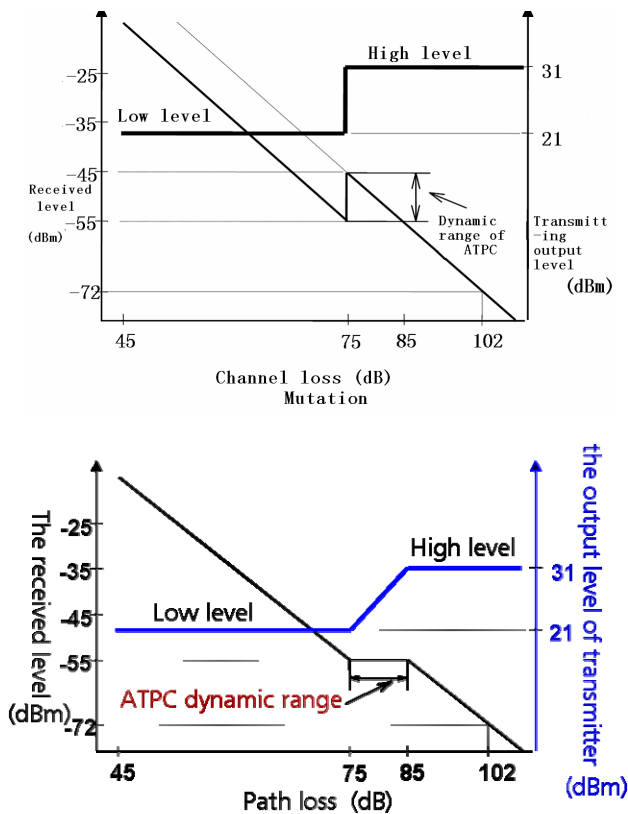


Figure 5.5 Mutation and progressive ATPC systems

Advantages of using ATPC are as follows:

(1) In the event of strong fading, output backoff (OBO) can be reduced. In the middle-high BER area ( $10^{-9} \leq \text{BER} \leq 10^{-6}$ ), the gain of an available system is added and the impact on BER performance due to bad linear performance of a transmitter can be omitted.

(2) Joint adaptive DC feeding may be provided. As a result, power consumption of high-power amplifiers is obviously reduced and the power consumption of the radio frequency amplifiers is equal to 50% of the normal

level, which facilitates to largely improve the mean time between failures (MTBF) of FET power device.

(3) The upward fading problem of the receiver is removed.

(4) The impact due to adjacent channel interference (ACI) is reduced and the performance improvement is interrupted.

(5) At the crowded railroad terminals, the reduction of nominal received level is prone to frequency coordination.

These advantages are very important for the new generation SDH microwave system.

## 5.5 Diversity Reception

Diversity reception: a resultant [signal](#) is obtained by combining or selecting signals, from two or more independent sources, that have been modulated with identical [information](#)-bearing signals, but which may vary in their [fading](#) characteristics at any given instant. [Diversity](#) reception is used to [minimize](#) the effects of fading.

### 5.5.1 Classification of Diversity Reception

Diversity reception is classified into the following types:

(1) Space diversity (SD): a method of [transmission](#) or reception, or both, in which the effects of [fading](#) are minimized by the simultaneous use of two or more physically separated antennas, ideally separated by one or more wavelengths. As the antennas are separated physically, the correlation is small. The count of antennas decides the count of diversity.

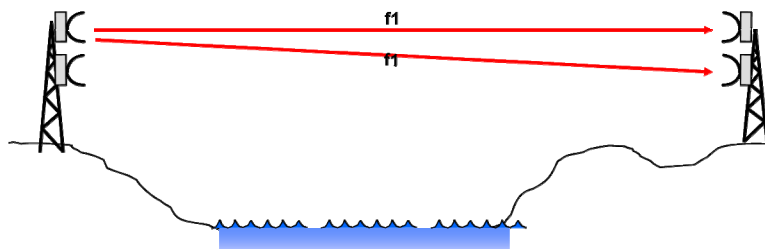


Figure 5.6 Space diversity

Space diversity can effectively solve K type fading caused by interference from the ground reflected wave and direct wave and interference fading caused by the troposphere. The space diversity can save frequency resources, but the equipment involved is complex. Two or more sets of antennas and feeders are needed.

(2) Frequency diversity (FD): [Transmission](#) and reception in which the same [information signal](#) is transmitted and received simultaneously on two or more independently [fading carrier](#) frequencies to reduce the effects of fading.

The frequency diversity uses the irrelevance of fading in different frequencies; that is, a feature with low probability of co-interruption on two frequencies. In SDH microwave systems, the main reason for circuit interruption is not the reduction of signal level, but the occurrence of frequency selective fading. Frequency diversity improves the digital microwave system much greater than the analog microwave system. As shown in the trial result on an actual microwave circuit ranging from 5925 to 6425 MHz, the correlation of flat fading depths of signals between two channels at a spacing of 60 MHz is high and the correlation coefficient is 0.97. However, the selective fading is seldom irrelevant and the coefficient is only 0.05. This is the reason for high improvement coefficient of frequency diversity in microwave systems.

In frequency diversity systems, the correlation of two diversity received signals (frequency correlation) should be small. Only in this event, deep fading on two frequencies can be avoided in a given path and good diversity effect can be implemented. The bigger the spacing of two frequencies is, the smaller the correlation of deep fading at the same time.

When the diversity in the same frequency uses 2% of the working frequency as a frequency spacing, the diversity improvement effect can be obtained.

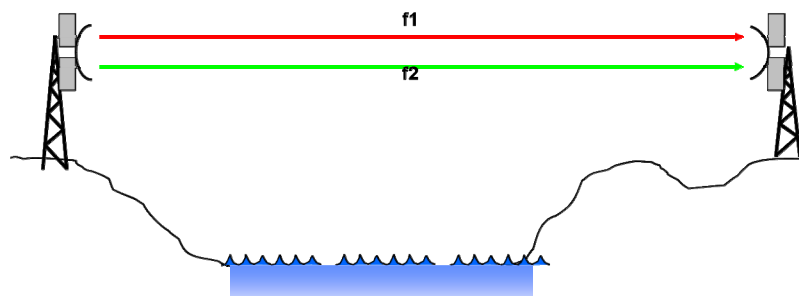


Figure5.7 Frequency diversity

Frequency diversity has obvious effects and needs an antenna and a feeder only. However, the utilization of its frequency bands is low.

(3) Polarization diversity: [Diversity transmission](#) and reception wherein the same [information signal](#) is transmitted and received simultaneously on orthogonally polarized waves with [fade-independent propagation](#) characteristics. Compared to other diversities, the effect of polarization diversity is smaller. The example is seldom seen.

(4) Angle diversity: Diversity reception in which beyond-the-horizon tropospheric scatter signals are received at slightly different angles, equivalent to paths through different scatter volumes in the troposphere. The second beam can be provided by an independent antenna or dual-feed antenna. The structure of angle diversity consists of two antennas installed side by side. They have different elevation angles or directions. Figure 5.8 is a typical structure. The main antenna is parallel with the main radial, and the beam of diversity antenna is elevation angle  $\theta$ .



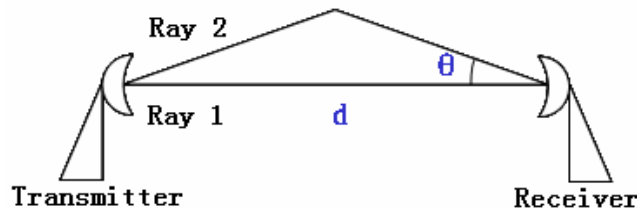


Figure 5.8 Angle diversity

Space diversity with the angle diversity has much better improvement effects than space diversity without the angle diversity, especially when a big upright space between two antennas cannot be ensured in paths with strong ground reflection. Currently, a large number of test results related to the angle diversity system exist. These results show that the performance of angle diversity and space diversity is equivalent when the performance of a digital microwave system depends on the amplitude dispersion. However, when the performance depends on the thermal noise effect, space diversity is better.

### 5.5.2 Description of Space Diversity

Frequency diversity and space diversity are used more widely. However, current frequency resources are more insufficient and frequency diversity has a good effect only when the frequency spacing is big. Hence, space diversity is applied more often and thus is described as follows.

Space diversity needs several antennas in the same tower. When deciding the antenna spacing, analyze and check whether multi-path fading on the specified path is caused by aerosphere or ground reflection.

For the path with weak ground reflection on foothills, when space diversity focuses on air multi-path fading, use the following formula:

$$\rho_c = \exp[-0.0021fS\sqrt{0.4d}]$$

$\rho_c$  refers to the correlation coefficient of two antenna signals and the value ranges from 0.4 to 0.6.

S refers to the upright spacing between the center of the upper received antenna and lower received antenna; that is, “diversity antenna spacing” (m).

In engineering practice, the value of S can be calculated simply as follows:

$$S \geq (100-200)\lambda$$

For plain areas and water circuit, the “half lobe distance” principle is adopted to calculate the spacing as follows:

$$S_1 = \frac{\lambda d}{4h'_2} \quad h'_2 = h_2 - \frac{d_2^2}{2kR_0}$$

$$S_2 = \frac{\lambda d}{4h_1'} \quad h_1' = h_1 - \frac{d_1^2}{2kR_0}$$

$S_1$  refers to the diversity antenna spacing of the received station and  $S_2$  refers to the diversity antenna spacing of the transmitting station (m).

$h_1$  refers to the height from the received antenna to the mountaintop and  $h_2$  refers to the height from the transmitting antenna to the mountaintop (m).

When the preceding formulas are adopted, pay attention to the following two issues:

a. When the clearance of a long path is small, the frequency is low and the height difference of antennas on both ends is big, the values calculated by using the preceding formulas will be big. Select a proper value according to the formula:  $S \geq (100-200)\lambda$ .

b. When the clearance of a short path is big and the frequency is high, the values calculated by using the preceding formulas will be small. Select a value according to the formula:  $S \geq (100-200)\lambda$  and the value can be taken as the integer multiple of "half wave distance".

In common engineering application, the spacing of space diversity for a digital microwave system can range from 8 to 12m and 10m is available. Space diversity largely reduces the received power and improves signal distortion. Space diversity reduces impact on flat fading and in-band amplitude dispersion and thus improves the transmission quality of digital microwave circuits.

Space diversity is further divided into the following:

(1) Standard space diversity:

Standard space diversity is a common receiving mode of the SDH microwave system. A transceiver unit needs one transmitter and two receivers (one is diversity receiver). Each station needs two antennas, including one main antenna (receiving and transmitting the main signal) and one diversity antenna (receiving diversity signal).

(2) Hybrid diversity:

Hybrid space diversity is a common receiving mode of the PDH microwave system (one transceiver unit has one transmitter and one receiver). One station uses one antenna (one antenna can receive and transmit two main signals) and the other station uses two antennas (each can receive and transmit one main signal).

(3) Non-standard space diversity:

Non-standard space diversity is also a common receiving mode of the PDH microwave system (one transceiver unit has one transmitter and one receiver). Each station uses two antennas (one antenna can receive and transmit one main signal).

Figure 5.9 is the sketch map of common space diversity in engineering design:

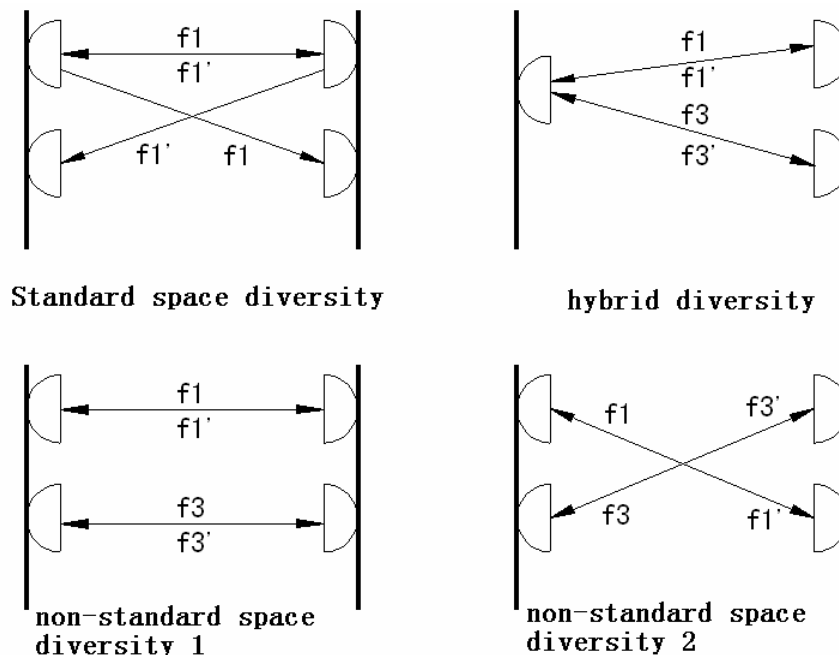


Figure 5.9 Classification of space diversity

### 5.5.3 Compound Mode of Diversity Signals

There are two modes to process receiving signals from different diversity paths: switching diversity and compound diversity.

Switching diversity is to choose one of the two signal paths based on maximum signal-to-noise ratio or minimum bit error rate. Integrated diversity is to compound two signals based on certain rules. Based on different rules, there are following compound modes: maximum power compound (co-phase compound), maximum signal-to-noise ratio co-phase compound and minimum chromatic dispersion compound. The advantages and disadvantages of each diversity signal compound modes are described as follows:

#### (1) Switching Diversity

For switching diversity, in switching, there are problems of amplitude and phase jump and waveform distortion. This diversity mode is very simple and it is mainly used in PDH microwave communication and normally realized in baseband.

#### (2) Maximum Power Compound

It is also called co-phase compound, this compound ignores frequency selective fading and only considers the flat fading caused by multi-path effect. It is ineffective to enhance receiving level. This compound mode does not consider separate signal-to-noise ratio of the two receiving signals. If the signal-to-noise ratios of the two paths are different, the signal-to-noise ratio of the compound signal may decrease.

Maximum power compound is easily realized in IF.

#### (3) Maximum Signal-to-Noise Ratio Co-Phase Compound

To ensure optimal signal-to-noise ratio of the diversity receiving compound signal, you can adopt maximum signal-to-noise ratio co-phase compound. The advantage is that when a receiving signal tends to be 0, the signal-to-noise ratio of the compound signal is not less than the signal-to-noise ratio value when single antenna is used to receive signals.

#### (4) Minimum Chromatic Dispersion Compound

In the condition of wideband modulation, frequency selective fading cannot be ignored for its influence is even more serious than flat fading. At this time, the main objective of space diversity is to overcome frequency selective fading and thus minimum chromatic dispersion is adopted.

The disadvantage of minimum chromatic dispersion compound is that the compound output power is less than that of co-phase compound, which may cause thermal noise to increase and deteriorate bit error rate.

## 5.6 Microwave Equipment Protection Mode

Currently, there are two protection mode widely used in microwave equipment: hitless switch module (HSM) and hot standby (HSB). Normally, the two are combined in use to protect microwave equipment.

### 5.6.1 HSM

As it is described previously, FD and SD are channel backup. When the signal of some channel is unavailable, it can be replaced by the signal of another channel, and at the receiving end, active/standby channels switch independently. After demodulating RF signals, local IF board not only sends signals to its own multiplexing module but also sends one signal to the backup IF board.

Multiplexing module selects and receives the signal of the best quality of all the signals, and then hitless switch of the baseband signal can be performed. Transmitting process of FD and SD are the same, both are cross dual fed. The difference is, when it is SD, ODU of the backup channel does not transmit signals but only receives signals; when it is FD, only an antenna is needed, and the two ODUs transmits same services with different frequencies.

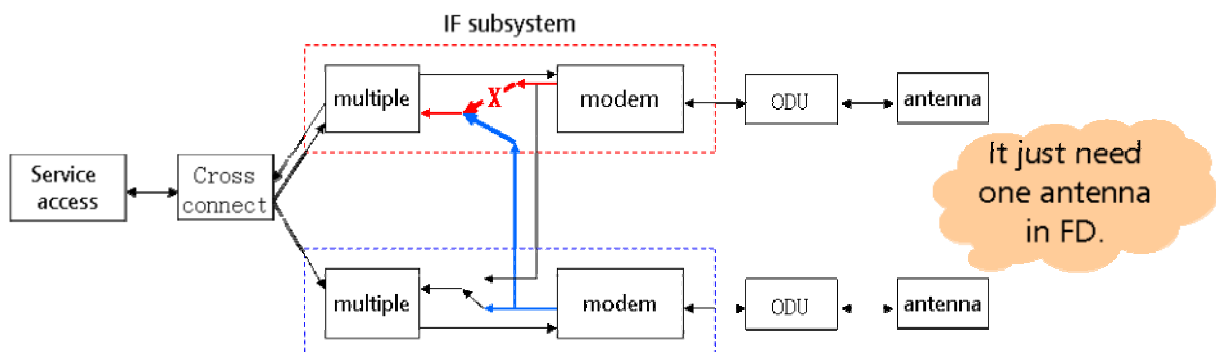


Figure5.10 HSM protection mode—schematic

## 5.6.2 HSB

HSB is similar to 1+1 hot standby of the cross-connect board and SCC in optical network equipment, it realizes the backup of IF board and ODU to be dual fed and selective receiving. The receiving end completes selective receiving at the cross-connect side, and HSB can be mixed with FD or SD to provide protection. Normally, cross-connect board only receives one signal and when this signal fails, the cross-connect board is switched to another signal. Therefore, HSB switching may damage the service.

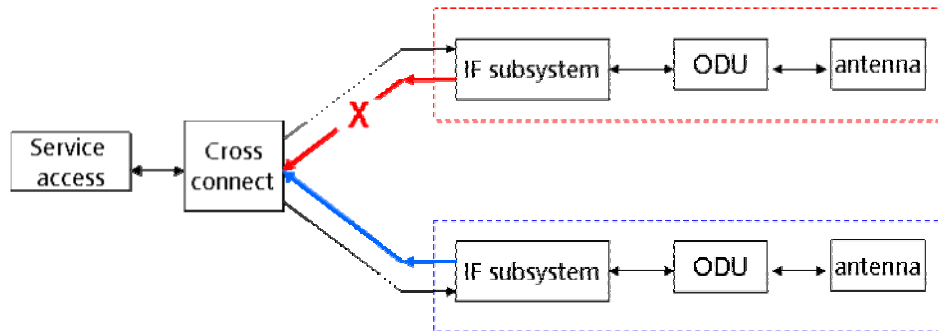


Figure 5.11 HSB protection mode—schematic

There are two ways to realize HSB:

- ✧ Add a hybridizer between two ODUs and the antenna, and then you can achieve 1+1 HSB protection by using one antenna and use FD technology at the same time.
- ✧ Use two antennas to achieve 1+1 HSB protection. You can use FD and SD technologies to improve system availability.

See figure 5.12.

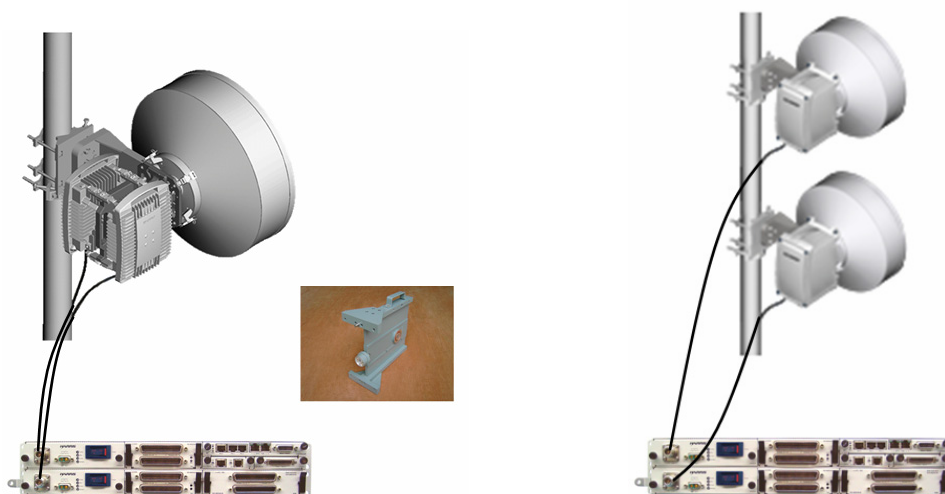


Figure 5.12 connection of single antenna and two antennas used in HSB

It should be emphasized that HSM switching is completed in IF board and can achieve hitless switching, while HSB is completed in cross-connect board and may damage services.

### 5.6.3 Classification of Digital Microwave Equipment Protection Modes

Classification of microwave equipment protection modes is shown in table 5.4. 1+0 non-protection is that both receive and transmit ends use one IDU and one ODU. For connection of other protection modes, see figures 5.13–5.16.

Table 5.4 Classification of Digital Microwave Equipment Protection

Configuration	Protection mode		Remark	Application
1+0	NP	Non-protection		Terminal of the network
1+1	HSB	Equipment protection	Intra-frequency	circuits where distance between the stations is short
1+1	HSB+FD	Channel protection, equipment protection	Inter-frequency	Select proper mode based on geographical conditions and customer's requirement
1+1	HSB+SD	equipment and antenna protection	Intra-frequency	
1+1	FD+SD	protection of channel, equipment and antenna	Inter-frequency	
N+1	FD	Channel protection, equipment protection	Inter-frequency	High capacity backbone transmission

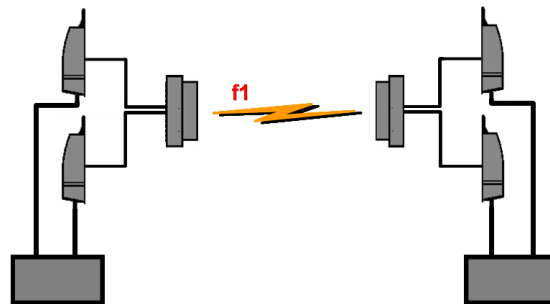


Figure5.13 HSB

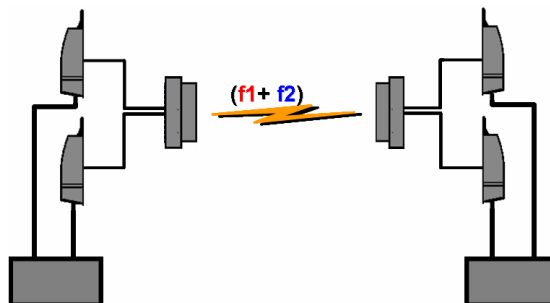


Figure5.14 HSB+FD

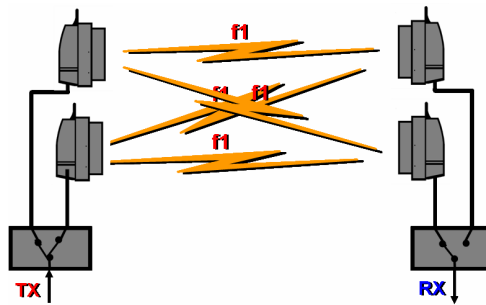


Figure 5.15 HSB+SD

In figure 5.15, if frequency transmitted by each antenna is inter-frequency, it is HSB+SD+FD.

In figure 5.16,  $M_n$  is the active channel and  $P$  is protection channel. They both include independent demodulator and modulator, receiving and transmitting units. When failure or fading occurs to the active channels, signals may be switched to standby channels, channel backup is inter-frequency backup and this protection mode (FD) is mainly used in all indoor microwave equipment. This protection mode is always called  $N+1$  ( $N \leq 3, 7, 11$ ) protection and different manufacturers support different specifications.

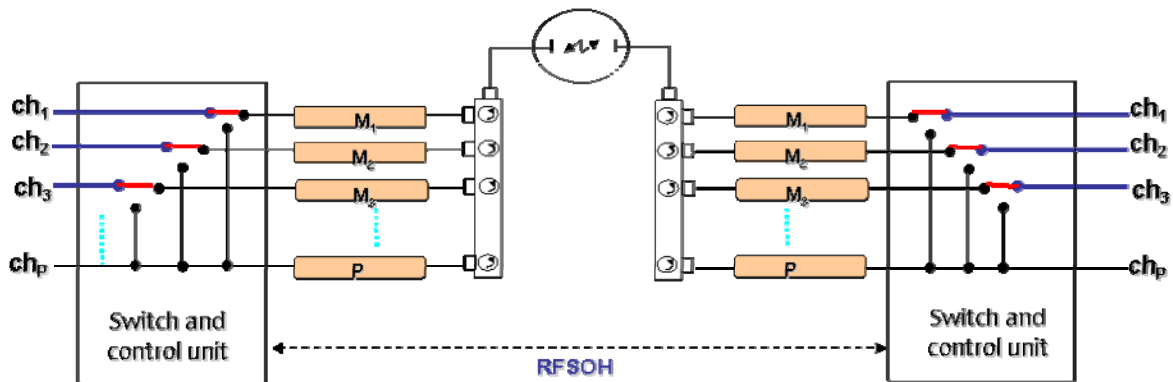


Figure 5.16 N+1

## 5.7 Interference and Main Methods against Interference

### 5.7.1 Interference Source

Interference on the communication system is from all kinds of sources which mainly are:

- (1) Circuits thermal noise, which is caused by thermal disturbance of the electrons in conductor.
- (2) Inner noise of electric devices, which is mainly caused by shot effect when charges inside devices move discontinuously.
- (3) Thermal radiation noise of objects (including absorption noise) which is caused by thermal radiation of objects.

- (4) Space interference, a noise radiation from universal objects
- (5) Atmospheric noise, which is caused by electric discharge in the atmosphere and is in the shape of pulse.
- (6) Industry interference, electric radiation from electrical equipment, such as electrical spark interference.
- (7) Radio station interference, signal radiation from other radio stations.
- (8) All kinds of interference produced inside receiver, such as alternating current hum, compounding noise, micro-phonic effect, non-linear result and oscillator phase jitter and so on.

## 5.7.2 Basic Methods of Communication System against Interference

Major factors that affect communication quality are defects (including failure) in equipment and interference. Quality of communication equipment can be improved under the development of scientific technology. But interference always exists and it is accelerated to some extent when the electric equipment is widely used. Influence of interference on communications is increasingly aggravated. Thus it becomes more crucial to prevent communication systems against interference.

Anti-interference in communication systems already becomes a specialized subject which attracts a great deal of scholars and engineers. Currently, research on communication technology is always research on the anti-interference technology (or closely related to anti-interference technology). Summarizing existing anti-interference methods, the basic methods are:

- (1) Amplifying the power of transmitting signals; improving the level of input signals of the receiving end

This method is very effective but limited by many aspects such as equipment size, weight and power-consumption quantity. In addition, amplifying transmitting power may aggravate interference on other radio stations or lines. Therefore, radio management administrations always set strict limitations on the maximum transmitting power of stations.

- (2) Using directional antenna to conduct space selection

Directional antenna is good for improving the strength of available signals and it can suppress interference from other directions on some particular high-level interference at the same time. You can also use directional suppression method to weaken the strength of signals. But complex and huge antennas are always required in this method, thus the method is also limited to great extent.

- (3) Using narrowband filterer to conduct frequency selection

This is the basic method to prevent communication systems against interference, almost all the communication equipment adopt this method. Narrowband filterer is complicated in crafts. When working frequency is higher, satisfactory attenuation feature cannot be guaranteed. Therefore, it should cooperate with other anti-interference measures to achieve required anti-interference performance.

- (4) Using correlator to conduct waveform selection



If narrowband filtering considered to be processing signals in the frequency domain and then correlated receiving method is to process signals in the time domain. When the input signal of correlator and the interference level are both very low to ensure correlator is under linear working status, its anti-interference ability is always superior to narrowband filtering. Thus, this method attracts more and more attention. However, when input interference level exceeds the linear working area of correlator, anti-interference performance may obviously degrade. Therefore, it is always used together with narrowband filtering.

(5) Improving modulation and demodulation

Based on different features of interference, narrowband modulation (such as single sideband modulation), wideband modulation (such as frequency modulation), frequency-expanding communication technology and digital modulation technology are used to improve anti-interference ability. Technology of this aspect is rapidly developed now.

(6) Using error correction and detection technology to check errors

This is an effective anti-interference measure which is developed in digital communication technology, and it is greatly used in communication systems that have strict requirement for reliability.

**Have a think:**

What do you learn in this chapter?

- (1) Objectives, classifications and evaluation of measures against digital microwave fading
- (2) Principles and features of technologies related to protect equipment
- (3) Diversity
- (4) Protection modes of microwave equipment
- (5) Interference and main methods against interference

Diversity is very import, you should pay more attention to this section.

## 5.8 Conclusion

This chapter first describes the fading of digital microwave transmission and objectives, classifications and evaluation of measures against fading, and then explains theories and features of anti-fading technologies related to microwave equipment, diversity technologies related to systems, and protection modes of microwave equipment, at last, it introduces the interference in microwave propagation and main anti-interference methods.