Basic Principles of Microwave Communication

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Abstract. Microwave is a form of electromagnetic radiation with one meter to the one-millimeter range. It has the excellent capacity to carry a lot of information and is a good choice to deal with data crisis. It can be used in many fields, and the development of microwave technology is being studied extensively. Microwaves can be used in scientific research, and the structure of the internal substances can be analyzed according to the different degrees of microwave absorption by different substances. Also, the microwave physiotherapy instrument created by microwave technology can kill some diseased cells and play a therapeutic role. This thesis will discuss and introduce some basic knowledge and equipment of transmission line theory, waveguide theory and microwave chemistry, to have a basic understanding of microwave technology. The results show that microwaves should have optical characteristics, skin effects, and other properties. Antennas, radars, transmission lines, and remote sensing measurement applications are all related to these characteristics.

1. Introduction
With the rapid development of electronic equipment and the substantial increase in the amount of data transmitted, microwave technology provides people with a choice when choosing information transmission.

Microwave is a high-frequency electromagnetic wave, the frequency range is $3 \times 10^8$ to $3 \times 10^{12}$ Hz[1]. According to the wavelength, microwave can be divided into decimeter wave, centimeter wave, millimeter wave and submillimeter wave. The British physicist J. C. Maxwell[2] proposed the concept of displacement current in 1862. Then in 1865, Maxwell used the term electromagnetic field for the first time in his thesis and proposed a system of electromagnetic equations, proving that light is a kind of electromagnetic wave. In 1885, H. Hertz published an article that divided waves into meter waves and decimeter waves[3], and invented a parabolic reflector antenna.

According to different communication methods and transmission media, microwave communication can be divided into atmospheric line-of-sight terrestrial microwave communication, tropospheric over-the-horizon scattering communication, satellite communication passing through the ionosphere and outer free space, and space mainly propagating in free space Communication. Microwave communications can be divided into analog microwave communications, which are mainly used to transmit multi-channel carrier telephones, carrier telegraphs, and TV programs.

Microwave technology is a basic course for electronic majors. The purpose of this thesis is to analyze some fundamental theories such as transmission line theory, waveguide theory, and microwave networks. It links the past and the future for the development of microwave technology.

2. Characteristics of Microwave
Microwave has several unique characteristics. Firstly, the propagation mode of microwave and light is very similar, so Microwave has a strong light transfer characteristic[4]. They are all spread in a straight line. And when the microwave encountered an object which has a large size of its wavelength,
it will be reflected. When the size of the conductor is almost the same as the wavelength of the microwave, it can produce radiation effects, the antenna and radar system are designed based on this characteristic.

Another obvious feature of the Microwave is the skin effect[5]. Skin effect means that when a conductor transmits electromagnetic waves, as the frequency of the electromagnetic wave increases, the conductivity of the conductor decreases, causing the electromagnetic wave to only propagate on the surface of the conductor. The microwave has a very high frequency, so the skin effect will be more obvious.

Also, the Microwave can penetrate the ionosphere[6]. There is an ionosphere in the range of 60 kilometers to 400 kilometers above the earth. The ionosphere absorbs waves with longer wavelengths, such as short-wave signals, which are easily absorbed in the ionosphere. Microwaves can penetrate electromagnetic layer because of their short wavelength and high frequency. Therefore, it is possible to use the microwave to realize satellite communication.

3. Signal transmission & common components

3.1 Transmission line theory

In the microwave band, any conductor used to guide the electromagnetic wave along with the directional transmission, the medium can be called a transmission line, it has a more complex transmission structure, as the Microwave frequency increases. The transmission line guides the directional transmission of electromagnetic power, so that signal transmission can be carried out between the signal source and the load. It sounds like a low-frequency circuit, but there are also some differences. In DC and AC low-frequency circuits, the length and shape of the wires have little effect on the circuit analysis and can be ignored. If the effects of wires cannot be ignored, using resistance, inductance or capacitance can also design an equivalent circuit. Microwave transmission has different transmission line structures. The difference between microwave transmission and DC low-frequency transmission can be found by introducing different transmission line structures.

As shown in Figure 1 and Figure 2, the transmission line used in the microwave low frequency is a twin-conductor cable, which is composed of two or more conductors[7].
In the medium and high frequency regions, microstrip lines are generally used for transmission. As shown in Figure 3, the ‘conductor’ strip and ‘ground’ are both conductors, with a dielectric substrate in the middle, which is often used in microwave integrated circuits [8].

Waveguides [9] are commonly used in the high-frequency region and are composed of a single metal tube. Different waves are generated according to the shape of the cross section. For example, as shown in the Figure 4, the Microstrip has a rectangular cross section and is called a rectangular waveguide. Similarly, if the cross section is circular, it is called a circular waveguide.

From the above three sets of transmission lines, we can find a difference between microwave transmission and DC low-frequency wire transmission. Microwave transmission is not necessarily two conductors, it can also be a single conductor, or it may be dielectric conduction. The direct current wire transmission must be a two-conductor system.

3.2 Waveguide theory:
Broadly speaking, all material structures that can guide electromagnetic waves to propagate in a certain direction are called waveguides. Therefore, another concept of guided waves has also been proposed. Guided waves are usually relative to electromagnetic waves in unbounded space, and refer to electromagnetic waves guided in a certain direction by a waveguide. For instance, if the current source does not radiate toward the unbounded space but radiates toward the inner space of the waveguide, the radiated electromagnetic wave will be guided and propagated due to the limitation of the waveguide, and then a guided wave will be formed.

As mentioned above, the loss of the two-conductor transmission line increases with the increase in frequency when propagating microwaves.
Figure 5 is a simple equivalent circuit. When the frequency increases, the skin effect on the surface of the wire is significant, and part of the electromagnetic power propagates to the inside of the wire to increase the internal loss. The resistance power is calculable by the formula:

\[ P_L = \frac{R_2}{2} \int \mathbf{H} \cdot \mathbf{H} \, ds \quad (1) \]

Where \( S \) is the Poynting vector, \( R_2 \) is the surface resistance of the wire, \( \mathbf{H} \) is the tangential magnetic field on the surface of the wire. The formula of surface resistance can be written as:

\[ R_2 = \frac{j \mu \pi}{\sigma} \quad (2) \]

Assume that the tangential magnetic field \( \mathbf{H} \) does not change, when the frequency \( \mathcal{f} \) increases, the surface resistance \( R_2 \) increases, resulting in an increase in \( P_L \).

In order to overcome the problem that the loss of the two-conductor transmission line increases with the increase in frequency when propagating microwaves, the high frequency and low consumption characteristics of the waveguide transmission line can perfectly solve this problem.

Assume the waveguide in figure 6 shows an ideal conductor, which has the ideal mediums inside. So, the Electric displacement vector \( \mathbf{D} = \varepsilon \mathbf{E} \), where \( \mathbf{E} \) is the Electric field intensity. Magnetic flux density \( \mathbf{B} = \mu \mathbf{H} \), where \( \mathbf{H} \) is the magnetic field intensity. According to Maxwell’s general equation, the electric field strength \( \mathbf{E} \) in the waveguide can be written as \( \nabla \mathbf{E} = -j \omega \mathbf{H} \), and the magnetic field strength \( \mathbf{H} \). Electric field strength and magnetic field strength have nothing to do with time, only a function of \( \mathbf{u} \). Substitute two equations, \( \nabla \nabla \mathbf{H} = (j \omega \varepsilon) (j \omega \mu) \mathbf{H} = \omega^2 \mu \varepsilon \mathbf{H} \). Wavenumber \( K \) can be used to present as \( K = \omega (j \mu) \), so \( \nabla \nabla \mathbf{H} = \omega^2 \mu \varepsilon \mathbf{H} = K^2 \mathbf{H} \), and this function is called Vector wave equation. Similarly, \( \nabla \nabla \mathbf{H} \) can be written as \( \nabla \nabla \mathbf{H} = K^2 \mathbf{H} \).

3.3 Microwave network basics:

The two-port network has two reference planes \( 1 \) and \( 2 \). The normalized voltage wave propagating inside the network is the incoming wave, which is from point \( 1 \) and point \( 2 \). The normalized voltage wave propagating to the outside of the network is called the outgoing wave and is represented by \( 1' \) and \( 2' \).

Another important parameter is the scattering parameter. Scattering parameter is the most used and most important parameter among various network parameters. It essentially describes the power
transmission and reflection characteristics of electromagnetic force caused by the uneven area represented by the network.

When Input is connected to a wave source and Output is connected to a load, the wave source generates an incident wave at point 1. If the impedance of network port 1 is mismatched, a reflected wave will be generated at 1, and the remaining wave of port 1 will continue to transmit and produce an incident wave at port 2. If the impedance mismatch between port 1 and 2, reflected waves will be generated again, and the reflected waves will be reflected to port 1. The remaining part will continue to be transmitted in 2.

Important properties of two-port networks generally include: reversibility, symmetry, loss lessness and power conservation. If the network is perfectly matched, it must be completely transmitted, and vice versa. And the smaller the reflection, the better the transmission power.

Applications belonging to the two-port network include microwave filters and mode converters, which are used to transform one electromagnetic wave mode in a waveguide into another, polarization converters, which are used to change the polarization properties of electromagnetic waves in the waveguide. Phase shifters, ferrites and isolators are also common applications for two-terminal networks[10].

4. Conclusion
In this paper, we study many characteristics of microwave. By studying the transmission line theory, it is found that different models are suitable for different frequency bands, and the similarities and differences between microwave transmission and low-frequency current transmission are discovered. Through the waveguide theory, the shortcomings of the two-conductor transmission line transmission were discovered, and a method to make high-frequency microwave transmission more efficient was found. Although microwave technology has broad prospects in various fields, the application of microwave technology is still in the accumulation of experiments, and accurate detection methods need to be verified. We need to consolidate and strengthen theoretical research while conducting various series of experiments. Experiments and perfecting various theories can create more microwave instruments and equipment suitable for national defense, military, or civilian use. Microwave technology has shown its charm in many aspects, and we need to fully integrate it into our lives. We can learn from various research results that microwave technology can be used in conventional industrial production in the next few decades. But as far as we know, due to the particularity of microwave, no scientist has found a reasonable theory to explain it, so microwave technology still has blind spots in certain fields. The application of microwave technology is still at a huge turning point, and its development is very malleable.

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