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The Application of Information Theory on Antenna

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Abstract

Antenna can be viewed as a communication system which plays an increasingly important role in our daily life due to the rapid develop of science and technology recently. As for a communication system, we need to pay attention to its validity and reliability in order to transmit information as both fast and great as possible. According to Shannon theorem, there is a limit on the transmission rate of information in the channel, and we call the limit as channel capacity. To increase the rate of undistorted transmission information, we need to improve the channel capacity according to Shannon Second Formula. At the meanwhile, the requirement of channel effectiveness makes us need to improve the efficiency of the antenna. However, there are contradictions between these two indicators. That is to say, the increase in channel capacity leads to the decrease of antenna efficiency, while the improvement of antenna efficiency must be at the expense of small channel capacity. Therefore, the optimal balance between the channel capacity and the antenna efficiency is found through MATLAB simulation, so as to provide better design ideas for the antenna designers.

Keywords

Channel Capacity, Antenna Efficiency, Shannon Formula

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1. Introduction

Since Shannon published his paper "A Mathematical Theory of Communication" in 1948, information theory has played an important role in modern society [1]. With the widely application of the mathematics of computer and the rapid development of social informatization, information industry has become one of the pillar industries, which make society presents fast growing, high efficiency and other characteristics [2]. The basic task of information theory proposed by Shannon is to improve the reliability and effectiveness of the communication system, and its main characteristics are the successful application of theory [3]. Nowadays, information theory has been widely used in data compression, cryptography, statistics and signal processing [4].

Antenna is a converter that transmits a guided wave propagating through a transmission line into an electromagnetic wave propagating in an unbounded medium (usually free space), or doing the opposite. Which is a important unit used in radio equipment to transmit or receive electromagnetic waves. Radio communications, radio, television, radar, navigation, electronic countermeasures, such as remote sensing, radio astronomy engineering system, all using electromagnetic waves to transmit information, rely on the antenna to work. In addition, antennas are also needed for non-signal energy radiation in the transmission of energy by electromagnetic waves. The same antenna can be used as both transmitting antenna and receiving antenna. The basic characteristic parameters of the same antenna as transmitting or receiving are the same [5].

Antenna, as a special information communication system, also need to consider the effectiveness and reliability in the process of its transport information [6], and in this paper, we will discuss the application of information theory in the field of antenna design.

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2. Theory

2.1. Index of Antenna

The way of communication is divided into two types: wireless communication and wired communication. The first one is mainly accomplished by fiber and cable, but due to its limited transmission distance, the other mode of communication has more extensive applications. Satellite, radar, radio, television and other radio equipment in our daily life, are used to convey information sent by electromagnetic wave. We call theses devices for transmitting and receiving electromagnetic waves as antennas [7]. Due to antenna can transmit and receive information, we can view the antenna as a channel.

In order to have a good command of the performance of antenna, we define antenna bandwidth and efficiency to measure antenna [8].

(1) Bandwidth B

It can be defined as a certain frequency range of the antenna meets certain specified standard. The middle point frequency of this frequency range is called the central frequency, which is used as the bandwidth of the antenna, and the antenna performance parameters within this bandwidth conform to the prescribed standard [4]. The expression can be described as follow:

$$B = f_h - f_l \tag{1}$$

where f_h and f_l represent the highest and lowest frequencies that can be passed by a signal.

In our real life, people tend to design and use broadband antennas, because of more information it can transmit. However, the increase of bandwidth makes it more difficult to design and manufacture antennas.

(2) Efficiency η_A

Antenna efficiency is usually expressed as the ratio of the antenna radiation power to the transmitting power, which is one of the important indexes for measuring antenna performance. Its expression is:

$$\eta_A = \frac{P_r}{P_{in}} = \frac{P_r}{P_r + P_l} \tag{2}$$

where P_r is antenna radiation power, is P_{in} transmitting power and P_l is loss power.

As it known to us, we measure the performance of a product by measuring its efficiency in the most cases, antenna is not an expectation. Therefore, while designing a antenna, antenna designers tend to pay more attention to the two index mentioned above.

2.2. Information Theory

The symbol of information Theory is “A Mathematical Theory of Communication” published by Shannon in 1948. The mathematical basis of information theory is communication, its probability theory as the main mathematical tools, each of the key links in the communication is studied in detail, in the form of theorem is given limit of source coding, channel coding theory, gives a measure of information, for a variety of specific communication technology provides the theoretical guide [9].

In order to study the reliability and validity of information transmission, we introduce the concept of channel capacity. The channel capacity is used to represent the maximum amount of information in a unit time.

When the signal of input channel is waveform signal, the noise of channel is additive gaussian noise. According to Shannon formula, the equation can be obtained:

$$C = B\log_2(1+\frac{S}{N}) \quad (bit/s) \tag{3}$$

where C is the channel capacity, which used to represent the maximum amount of information in a unit time. B is transmission bandwidth, and S/N is the signal-to-noise ratio.

In the general communication system, the noise encountered is mostly machine thermal noise (Gaussian white noise). According to the nature of Gaussian white noise [10], $N = n_0 B$ where n_0 is the unilateral power spectral density of noise. From this, formula (3) can be further written as:

$$C = B\log_2(1+\frac{S}{N}) = B\log_2(1+\frac{S}{n_0 B}) \quad (bit/s) \tag{4}$$

3. Application

3.1. Channel Capacity

According to Shannon second theorem, as long as the information transmission rate is less than the channel capacity, there exists a class of coding, which makes the error probability of information transmission arbitrarily small. Otherwise, there is no channel coding method that makes errors arbitrarily small. Therefore, the maximum transmission speed of antenna V_m cannot exceed the channel capacity C. Namely:

$$C \geq V_m \tag{5}$$

Therefore, it is necessary to increase the channel capacity of antenna so as to increase the rate of transmitting information.

By observing equation (2), it can be found that the channel capacity of antenna is related to signal power, bandwidth and noise power spectrum density.

Further analysis can be concluded as follows:

(1) signal power

Under the condition that the noise power and bandwidth remain unchanged, according to the formula (4), the increase of the channel capacity will inevitably lead to the increase of the channel capacity.

In this and real life, the increase of the effective signal is bound to coincide with the increase of the information volume of transmission.

(2) noise power spectral density.

The increase of effective signal and bandwidth will lead to the decrease of channel capacity.

In this and real life, the increase of transmission loss is bound to coincide with the decrease in the amount of information transmitted.

(3) antenna bandwidth

In the case of the original signal and the noise power, assume that the bandwidth tends to infinity $\lim_{B\to\infty} C = \lim_{B\to\infty} B\log_2(1+\frac{S}{Bn_0})$, define $\frac{S}{Bn_0} = x$, then, we obtain:

$$\lim_{B\to\infty} C = \lim_{B\to\infty} B\log_2(1+\frac{S}{Bn_0}) = \lim_{x\to 0}\frac{S}{n_0}\log_2(1+x)^{(1/x)} \quad (6)$$

According to the knowledge of limitation, we put $\lim_{x\to 0} In(1+x)^{(1/x)} = 1$ into the equation above, then, we obtain $\lim_{B\to\infty} C = \frac{S}{n_0}\log_2 e \approx 1.44\frac{S}{n_0}$. That is to say, if we want to improve the antenna's maximum transmission rate, we should improve channel capacity by increasing the bandwidth of the antenna. However, channel capacity is closer to the limitation $1.44\frac{S}{n_0}$, with the increase of bandwidth. We can draw the picture of bandwidth and channel capacity:

As it depicted in the figure, we can safely draw the conclusion that with the increase of bandwidth in small scale, the channel capacity will increase while the bandwidth reach a large scale, it is unwise to use large bandwidth to get a large channel capacity.

However, as we discussed before, in the design of antenna, large bandwidth is often required, but large bandwidth is much more difficult to design antenna.

Therefore, it is necessary to find a suitable value, which can satisfy the high capacity of the antenna channel without making it so difficult to realize.

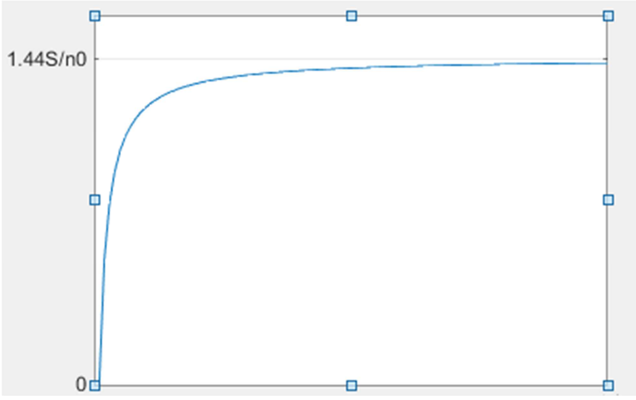

Figure 1. The relationship between bandwidth and channel capacity.

3.2. Antenna Efficiency

According to the formula (2), the antenna efficiency is related to the radiation power and loss power of the antenna. The radiation power of the antenna is the effective signal power in the process of information transmission. In order to simplify the model, we regard the antenna loss power as the interference generated by the internal noise in the information transmission process, which is the noise power. Therefore, we can simplify the formula (2) to:

$$\eta_A = \frac{S}{S+N} = \frac{S}{S+n_0 B} = \frac{1}{1+\frac{n_0}{S}B} \quad (7)$$

Therefore, the method of improving antenna efficiency can be obtained:

(1) increase the effective signal power.

(2) reduce the noise power spectral density.

(3) reduce bandwidth

Through the above analysis, it can be seen that, in the case of effective signal and noise unchanged, the increase of channel capacity needs to increase the bandwidth, while the increase of antenna efficiency needs to reduce the bandwidth. There is a contradiction between channel capacity and antenna efficiency. Therefore, this paper discusses how to alleviate the contradiction between the two to make the antenna performance better.

3.3. Find a Proper Bandwidth

In formula (4) and (7), define $k = \frac{S}{n_0}$, the equation can be rewritten as:

$$C = B\log_2(1+\frac{S}{N}) = B\log_2(1+\frac{S}{n_0 B}) = B\log_2(1+\frac{1}{kB}) \quad (8)$$

$$\eta_A = \frac{S}{S+N} = \frac{S}{S+n_0 B} = \frac{1}{1+\frac{n_0}{S}B} = \frac{1}{1+kB} \quad (9)$$

Choose bandwidth as the independent variable, the maximum channel capacity percentage of the antenna efficiency and channel capacity are the dependent variables, and the coefficients are respectively get different value, then obtain picture as follows:

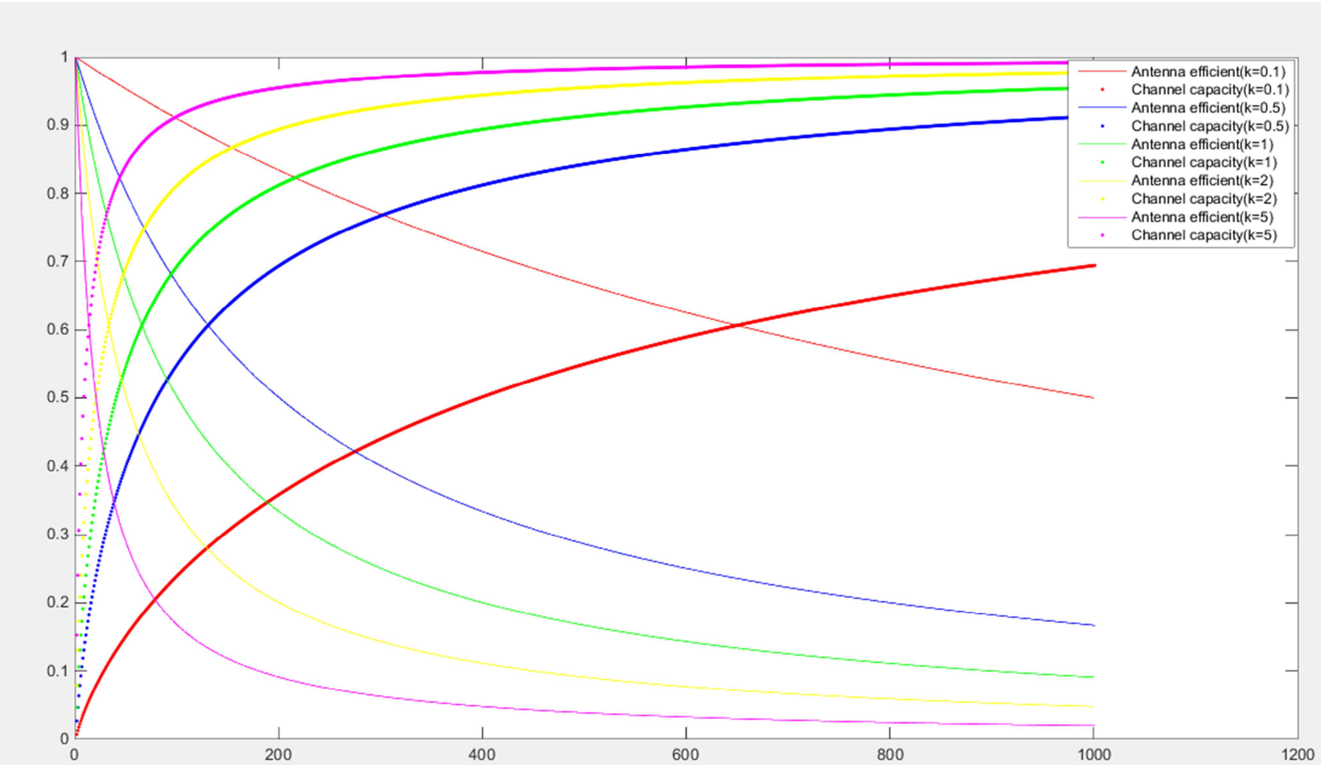

Figure 2. The relationship between bandwidth, channel capacity, antenna efficiency and coefficient.

As it can be seen from the figure, no matter what the value of the coefficient is, the equivalence point of efficiency and channel capacity is around 0.6. And the channel capacity and antenna efficiency are optimal at this time. When bandwidth exceeds this value, it will cause the loss of antenna efficiency in exchange for large channel capacity, while bandwidth less than this value, it will cause the loss of channel capacity in exchange for high antenna efficiency

According to formula (8), the coefficient is 0.6, then it can be obtained $B \approx \frac{2}{3k} = \frac{2S}{3n_0}$. In other words, the result is considered integrating channel capacity and antenna efficiency. When the bandwidth meets the above equation, the antenna performance is the best. Deformation of the equation:

$$\frac{S}{N} = \frac{3}{2} \quad (10)$$

That is, when the signal and noise are unchanged, the antenna performance is the best when the SNR is 1.5.

4. Conclusion

In this paper, according to the Shannon information theory formula and the expression of the efficiency of the antenna, it is concluded that under the condition of invariable in effective signal and noise, channel capacity and efficiency of the antenna bandwidth contradictions exist between the conclusion. The increase of bandwidth will result in the increase of channel capacity and the decrease of antenna efficiency, which will reduce the channel capacity and increase the efficiency. Validity and reliability of a win-win situation, in order to achieve the antenna based on the definition of channel capacity and efficiency of antenna type, deduced on the basis of the effective signal and noise, satisfy the antenna efficiency and channel capacity under the condition of good value formula of bandwidth. It provides convenience and theoretical basis for future antenna design.

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