Overview of UWB Feed

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ABSTRACT

This paper briefly introduces the UWB feeds. Firstly, it introduces the basic requirements of the feeds and the performance. Then it introduces the frequency-independent antenna, traveling wave antenna, combined feeds and tightly coupled antenna. It briefly describes the principles of UWB antenna and introduces the development status. Finally, it is concluded that the phase center of the combined antenna does not vary with the frequency, and combined antenna also has high gain, low sidelobe, which is more suitable for the feed of the reflector antenna.

KEYWORDS

Multi-Band Feed, UWB; Nested Combination, High Performance, Frequency-Independent Antenna, Tight Coupling.

INTRODUCTION

Ultra-wideband technology is called UWB technology for short. Reflector antenna plays an important role in various applications such as communication, navigation and remote sensing satellite earth station, spacecraft, the measurement and control of unmanned aerial vehicle, astronomical observation, high-power radar, ground-based line-of-sight microwave relay communication, satellite radio, television reception and so on. The feed is the core of the whole reflector antenna system, so the feed has stricter requirements: firstly, the feed has a higher aperture efficiency; secondly, in the working range, the radiation characteristics of the feed need to be stable, and low sidelobes are also needed; thirdly, the phase center should be stable even with the changing frequency because that defocusing will greatly affect aperture efficiency;

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Lastly, wider pattern bandwidth and impedance bandwidth are required. Only in this way the final reflector will have better performance. This paper firstly introduces the important indicators of UWB feed, then introduces several kinds of UWB feeds, and then uses these indicators to measure the advantages and disadvantages of each feed. Finally, the paper makes a summary and comparison, clarifies the use background of each feed in order to make some contributions to the future research work.

**IMPORTANT INDICATORS OF UWB FEED**

The antenna whose electrical characteristics remain unchanged or change little in a wide band is called broadband antenna. If \( f_U \) is the upper limit frequency of the antenna, \( f_L \) is the lower limit frequency of the antenna. Generally speaking, the antenna \( f_U / f_L \geq 2 \) belongs to the broadband antenna. For an antenna with \( f_U / f_L \geq 10 \), it is called an ultra-wideband antenna, usually called a broadband antenna.

There are usually two ways to express antenna bandwidth, one is called "relative bandwidth" and the other is called "frequency doubling bandwidth". Relative bandwidth is defined as the ratio of absolute bandwidth of antenna \( 2\Delta f \) to central frequency \( f_c \) in the working band.

\[
R = \frac{f_U - f_L}{f_c} = \frac{2\Delta f}{f_c} \quad (1)
\]

among them, \( f_U \) for the upper limit frequency of the antenna, \( f_L \) is the lower limit frequency of the antenna. Frequency doubling bandwidth is defined as the ratio of the upper frequency to the lower frequency in the working band.

\[
B = \frac{f_U}{f_L} \quad (2)
\]

Generally speaking, the relative bandwidth is often used for narrow-band antennas, while the doubling bandwidth is mostly used for broadband antennas. The antenna bandwidth mainly depends on the frequency characteristics of each performance parameter, so the main electrical parameters of the antenna have their
And the following are five Important Indicators of UWB Feed ².

**PATTERN BANDWIDTH**

When the frequency changes, a main lobe of radiation plot of the antenna may point offset, split or atrophy, and a side lobes increase. When the pattern deteriorates to the point that it cannot meet the electrical requirements, the available bandwidth of the antenna is limited, which is called pattern bandwidth.

**GAIN BANDWIDTH**

Usually the gain is defined to fall to 50% of the maximum gain value in the operating band, and the corresponding bandwidth is called the 3 dB gain bandwidth.

**INPUT IMPEDANCE BANDWIDTH (REFERRED TO AS IMPEDANCE BANDWIDTH)**

The impedance bandwidth of the antenna can be specified by the standing wave ratio on the feeder. The bandwidth of the antenna when the standing wave ratio is lower than a certain value is defined as the impedance bandwidth of the antenna. This representation method not only reflects the rate characteristic of the antenna impedance, but also shows the matching effect between the antenna and the feeder.

**AXIAL RATIO BANDWIDTH**

This is a very important technical indicator for circularly polarized antennas. When the frequency changes, the antenna polarization characteristics tend to change. Engineering, often in the angular range of the main valve half-power lobe width, the axial ratio|AR| ≤ 3, Decibel requirements determine the polarization bandwidth of the antenna.
PHASE CENTER

For a reflector antenna, the phase center of the feed is expected not to vary with the frequency. Because the focus of the reflector is fixed, if the feed phase center changes with frequency, the aperture efficiency will be reduced, so this is an important index for the feed.

COMMON UWB FEEDERS

FREQUENCY-INDEPENDENT ANTENNA

The effective working area of the antenna varies with the frequency, and the geometric and electrical dimensions of the effective working area remain unchanged with the frequency, so its frequency band can be set very wide. Since the shape of the antenna is determined only by the angle, the antenna has non-frequency-dependent impedance and non-frequency-dependent pattern characteristics. Because the antenna radiation area corresponding to different frequency bands is different, the phase center of the antenna as a feed will change. Common non-frequency-varying antennas include logarithmic periodic antenna, equiangular helical antenna and so on ³.

For logarithmic periodic antenna, Isbell described LPDA in 1960. The theoretical study of LPDA has been carried out both at home and abroad. In the early 1960s, R.L. Carrel et al. systematically analyzed LPDA based on the principle of transmission line and the theory of equivalent circuit. In 1967, S.P. Kosta used the general theoretical analysis of linear antenna array to analyse LPDA; R. L. Carrel showed the analysis method of LPDA and summarized the design steps of LPDA.

In the area of design optimization, in order to realize the miniaturization of LPDA antenna in China, He Shuai et al. extended the current path of LPDA oscillator by using curve elements, and realized the miniaturization of LPDA antenna. The standing wave ratio bandwidth is 290-1970 MHz, and the bandwidth is 6.8:1; the average gain in the whole bandwidth is 5.9 dBi; By optimizing the characteristic impedance of the antenna assembly line, the position of the oscillator and the short-circuit terminal, Zhou Jianhua et al. have weakened and eliminated
the resonance to ensure the uniformity of the antenna broadband performance. He proposed a kind of antenna which can work in 98-1000MHz band with a VSWR of less than 1.8 and an average gain of 8dB in the working band. Geng Jingchao et al. introduced a 1-6GHz broadband high efficiency direction finding antenna array composed of dual-polarized logarithmic periodic antenna elements. ATA ultra-wide feed consists of sawtooth logarithmic periodic oscillator, which covers 0.5GHz~11GHz. The echo loss is less than -15dB, the gain is 12dBi, and the lobe width of 10dB is 38 degrees. However, its phase center varies obviously with working frequency and its aperture efficiency is low.

The antenna characteristics of non-frequency-varying antennas are independent of frequency, so repeating the impedance characteristics and radiation patterns periodically. The impedance bandwidth of non-frequency-converted antenna can generally be more than 10 octave, the antenna sidelobe is low, the gain is easy to achieve high, generally up to 8-9 dB, and the directivity is good. However, due to its own reasons, the phase center varies with frequency, which is not suitable as a feed. It is more suitable for short-wave, ultra-short-wave, microwave and other bands of communication, direction finding, search, electronic countermeasures and so on.

TRAVELING WAVE ANTENNA

When the frequency of traveling wave antenna changes, although the electrical size changes, input impedance of traveling wave antenna is almost unchanged, so most of the energy of outward wave is radiated and only a few energy is reflected, and other electrical performance changes slowly. So it has a good impedance bandwidth. The traveling wave antenna we ofen heard are rhombic antenna, axial mode helical antenna and so on.

Spiral antenna has many broadband characteristics, like directional characteristics, impedance characteristics, and the bandwidth which can reach to (1.7-2.0): 1. Because of the continuous radiation of the current along the line, the incident power is low when it reaches the terminal. So the reflection caused by the terminal is inevitably small. At the same time, the reflected current radiates continuously along the line, and the reflection power to the input is very small. So the input impedance of the helical antenna is approximately equal to the characteristic impedance. In a wide range, the input impedance bandwidth of the antenna is quite wide. The current phase velocity can be automatically adjusted to the optimum endfire condition with the change of frequency in a very wide band.
which satisfies the axial radiation, so the bandwidth of directional pattern is wide. For its polarization characteristics, the line current phase shift constant does not change with frequency due to the automatic adjustment of the helical antenna, that is, the current distribution does not change with frequency, that is, the circular polarization characteristics do not change with frequency, so the polarization characteristics are also broadband.

**COMPOSITE ANTENNA**

Using multi-band feed technology, the working frequency band of antenna can be simply expanded. Generally, there are two kinds. The first one is to realize multi-band radiation in nested form. That is to say, different coaxial feeds are used to radiate in different frequency bands, such as nested combination of various antenna units, and the other is to share a horn radiation in several frequency bands, such as multi-band multi-mode horn and multi-band corrugated horn.

**COAXIAL NESTED FORM**

For coaxial nesting, in order to improve the performance of pattern and standing wave ratio, Hao Wenqian et al. used curve contour loading to load the external conductor, which effectively shortened the length of the feed and reduced the weight of the feed. Wang Junyi used the same method to improve the characteristics of high frequency end pattern beam equalization and broaden the beam. By adding a metal ring concentric with the inner and outer conductors and a corrugated groove on the outer wall of the aperture, it realized beam broadening and beam equalization of radiation pattern. In the design of coaxial feed, Qiu Jinghui et al. designed a four-cavity 60:1 bandwidth (1-60 GHz) UWB nested coaxial waveguide composite feed. The feed has reflection loss less than -10dB in the whole working frequency band. Zhan Ying et al. proposed a coaxial horn S/X dual-band common feed for dual-reflector antenna, which has simple structure and wide bandwidth. In terms of related theoretical research, Cheng proposed a mathematical model to analyze coaxial feeds solving the integral equation by Galerkin method. Luzhiyong used FDTD method to analyze the performance of coaxial feed. Yang Kezhong used the moment method to derive the mode ratio.
formula of coaxial multimode feed. Firstly, the field of the infinite plane at the wavelength of the feed inlet was calculated by using the geometric revolving blade theory (GTD), and then the radiation field was obtained.\textsuperscript{14}

Overseas, Rodney H. Jaeger\textsuperscript{15} et al. designed a coaxial cavity antenna with multi-polarization, high gain, broadband and low dispersion characteristics, which solved the problem of narrow E-plane and exhibited basically symmetrical E-plane and H-plane performances in relatively wide angle and wide bandwidth; James S. Ajioka\textsuperscript{16} et al. designed a coaxial cavity antenna with multi-ctave frequency range. Bandwidth antenna feeding system maximizes the efficiency of antenna by matching the effective feed aperture with the focus. Junbo Wang\textsuperscript{17} designed a set of nested, concentric slot cavities to increase the isolation between bands and slot staggered 45 degrees, which makes the isolation between bands better and the multiplexing performance better.

Domestic scholars improve their performance by changing the outline of the outer edge of coaxial feed and adding slots. At the same time, some scholars use moment method and FDTD method to solve the distribution of the outlet radial field and far-field radiation field. The theoretical results are in good agreement with the simulation results. The coaxial feeder abroad has complex structure, and its common features are nested format, small cavity spread high frequency, and large cavity spread low frequency. The difference is that different structures are used to match impedance and broaden the pattern. The feeds are all fed by a pair of orthogonal dipoles. And all the coaxial antenna can achieve multi-polarization, multi-band, high gain and phase center stable when the frequency changes.

**MULTI-BAND HORN**

For multi-band horns, Potter proposed a new horn design technique in 1963. This technique mainly according to excite $TE_{11}$ mode and $TM_{11}$ mode in the horn aperture with appropriate relative amplitude and phase to influence sidelobe suppression and beam width, and make the phase center coincides. Kralovec\textsuperscript{18} and Gothard\textsuperscript{19} have designed coaxial corrugated horns with similar and independent operating characteristics in broadband. The inner conductor is used to radiate high frequency band, and the space between the inner conductor and the outer conductor is used to radiate low frequency band. Hanlin\textsuperscript{20} et al. designed coaxial corrugated horns with good performance. The E-plane and H-plane patterns of rotational symmetry are radiated through longitudinal corrugated grooves on the inner surface of outer conductor in low frequency band and the rotational symmetry patterns are radiated through dielectric rod antenna in high frequency band.
Composited antenna has great potential in UWB because of its low dispersion and bandwidth expansion through nested structure. Composited antenna can be changed to satisfy the requirements. Composited antenna is an efficient antenna and can also be bipolarized by feeding. It can be used as interferometer, polarimeter, circular direction finding and ultra-wideband antenna.

TIGHTLY COUPLED ANTENNA ARRAY

Tightly coupled antenna array is based on the principle of coupling to widen the bandwidth. It chooses to strengthen the coupling to widen the bandwidth. That is to say, the reactance introduced by the ground surface is used to offset the reactance of the oscillator plane itself, so as to obtain a stable impedance characteristic close to the ideal radio current surface, thus achieving ultra-wideband performance.

Tightly coupled antenna arrays were proposed by Staiman et al. in the article of solid-state circuit source in 1960 that each unit was fed independently. Ben. A. Munk proposed in 2003 that the frequency doubling bandwidth could reach 9:1. In 2012, Moulder team made 4*4 tightly coupled antenna arrays, and the frequency doubling reached 21:1. They proposed adding a layer of resistive frequency selective surface between the oscillator plane and the reflector plate, the input resistance bandwidths can be widen. In China, in 2009, Yang Shiwen et al. produced a 1*8 linear array, which achieves 2-13.5 GHz working bandwidth.
| Types                      | Input impedance bandwidth(VSWR $\leq 1.5$) | Average gain | Patterns bandwidth | Radiation plot of the antenna. | Sidelobe | whether the phase center change with frequency |
|----------------------------|--------------------------------------------|--------------|--------------------|--------------------------------|----------|-----------------------------------------------|
| Non-frequency antenna      | 10($\geq 10$):1                           | 6~8dB        | Wide(3~4):1        | Directional                    | Low      | Y                                             |
| Traveling wave antenna     | (2~3):1                                    | 8~11dB       | Narrow             | Directional                    | High     | N                                             |
| Composite antenna          | Depending on needs                         | 6~8dB        | Wide               | Equal radiation patterns      | Low      | N                                             |
| Tightly coupled antenna array | (3~6):1                                   | 8~11dB       | Narrow             | Directional                    | High     | /                                             |

From the comparison of the Table.1 above, it can be seen that only traveling wave antenna and combined antenna are satisfied as feed in the condition of the phase center should not change with frequency. While the pattern of combined antenna is equal, which is more suitable for the feed of reflector antenna. The sidelobe of the tightly coupled antenna is too large and the pattern bandwidth is slightly narrow. For combined antenna, it can increase its input impedance bandwidth through nesting itself. So, it can be easily to satisfy the requirement. Although it has lower average gain than the tight coupling antenna, it is enough to use. Therefore, the study of composite antenna has significance and prospects. However, feeding the antenna is complex and it should be solved in the future.

**SUMMARY**

This paper firstly introduces the basic definition of UWB antenna and its important indicators. Then, according to the UWB principle divide UWB feed to four types: non-frequency conversion antenna, traveling wave antenna, combined...
antenna and tightly coupled antenna. By observing their gain bandwidth, impedance bandwidth, pattern bandwidth and phase center offset, it can be found that the phase center of coaxial feed antenna is not offset, so it has high efficiency, and it also has high gain, easily to achieve circular polarization. According to nesting the feed, it will have multi-band, which is of great significance for further study and research.

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