Satellite Communications Millimeter Wave and RF Technical Analysis

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Abstract. This paper introduces the development status and trend of millimeter band of satellite communication. Based on the analysis of the frequency division, spectrum advantages and transmission characteristics of EHF satellite communication, the new technologies adopted in EHF satellite communication are studied, and the special technology and application of the EHF radio frequency circuit are analyzed.

1. Introduction
Satellite communication is an important part of military communication system and a key means to realize informationized combat command. Currently, the frequency band below Ku is widely used in military satellite communications. With the development of communication demand, the frequency spectrum resources below Ku are less and less, and the interference is more and more strong. Therefore, the development of EHF frequency band with more spectrum resources and stronger anti-interference capability has become the inevitable direction of military satellite communications. In the 1990s, the United States pioneered the use of the Ka band in its global broadcasting system (GBS) to provide continuous, high-speed, one-way multimedia transmission to a wide range of users. In order to build a safe and reliable military satellite communications system, the U.S. department of defense launched the first "military star" strategic military communications satellite in 1994, with the operating frequency of 44GHz EHF band, capable of providing effective battlefield command and control services in a variety of combat environments. Since the beginning of the 21st century, out of the need for large capacity, high speed communications command means, the United States launched a true military satellite - WGS (broadband global satellite communications system). The system is the most advanced military broadband satellite communications system, capable of supporting two-way services on the ka-band and providing data return service for the global hawk. Later the United States and developed Advanced Extremely high frequency, the AEHF (Advanced Extremely High Frequency) satellite communication system as an alternative system, "military star" compared with "military star", the AEHF satellite of smaller volume, lower cost, but can provide larger capacity and higher data transmission rate, for the theater commander to provide communications services with high security and anti-interference characteristics, in order to meet the military for real-time image, battlefield maps and tracking data such as tactical communication needs.

2. Us Army EHF Satellite Communications System

2.1 "Military Star" System
Milstar satellite communication system is a strategic and tactical military satellite communication system Shared by the us navy, army and air forces. The system is divided into two generations, and from 1994 to 2003 deployed, launched five satellite, a total of two Milstar I (first generation) and three...
Milstar II (second generation), Milstar I contains data transfer rate of 75-2400 b/s of the low data rate (LDR) payload, and Milstar II not only contains a LDR repeater, and a data rate of 4.8 KB/s to 1.544 Mb/s data rate (MDR) in the payload. The specific index parameters of the system are shown in table 1.

### Table 1. Index Parameters of Milstar System

| Parameter                          | Milstar I | Milstar II |
|------------------------------------|-----------|------------|
| height                             | 36180km   | 36180km    |
| quality                            | 4500kg    | 4500kg     |
| Power consumption                  | 5kW       | 8kW        |
| lifetime                           | 10year    | 10year     |
| Communication capacity/single satellite | 0.5Mb/s  | 40Mb/s     |
| Data rate                          | 75-2400b/s | 4800b/s-1.544Mb/s |
| Payload                           | EHF(40GHz) | Line192 75-2400b/s |
|                                  | /         | Uplink line 32 |
|                                  | EHF(60GHz) | 4800b/s-1.54 |
|                                  | /         | 4800b/s-1.54 |
|                                  | SHF(20GHz) | Intersatellite communication link |
|                                  | /         | Intersatellite communication link |
|                                  | /         | Descending line 1 |
|                                  | UHF       | Line 6 narrow beam, line 2 wave point |

The Milstar system has an interplanetary communication line that eliminates the need for a ground relay station and allows communication and transmission of control data between any satellite in the constellation. As the system retains four UHF channels, it can also remain compatible with existing UHF users [3]. The system uses the EHF frequency band to provide 43.5 ghz-45.5 GHz upstream frequency and 20.2 ghz-21.2 GHz downstream frequency, which greatly reduces the size of satellite antennas and ground terminals and enables the use of antenna zeroing technology on the satellite. The system also adopts on-board processing technology, which can de-spread, demodulate and decode the interstellar signal, and then encode, modulate and spread the spectrum before the signal is transmitted to the ground terminal. On the one hand, the interference signal introduced by the uplink line is avoided, on the other hand, the complexity of the ground terminal is reduced. The satellite's interplanetary communication capability and on-board processing technology effectively guarantee the system's anti-interference, survivability and long-distance communication capability, and its on-board control system can flexibly allocate interplanetary and payload resources to fully meet the communication needs of tactical users.

#### 2.2 The AEHF System

The AEHF system is scheduled to consist of six stars. Aehf-1 was launched on August 14, 2010 by the shenzhou-5 carrier rocket. Due to the abnormal propulsion system, the satellite completed the orbit correction and entered the preset orbit on October 24, 2011. The satellite antenna there to carry a total of 14, namely 1 EHF upward phased array antenna, 2 SHF downward phased array antenna, 2 V (60 GHZ) link between the antenna and the one on/downlink transceiver global coverage horn antenna, 2 / downlink transceiver on zero antenna, on 6 / downlink transceiver with balance frame rotating disc type antenna, on the ground to form 194 coverage [4]. Aehf-2 and AE hf-3 were successfully launched in May 2012 and September 2013, respectively. In July 2015, the us air force announced that the AEHF constellation was entering the "initial operational capability" phase, which means the us military will gradually move away from its dependence on the previous generation of the constellation.
Milstar. The fourth satellite could be launched as early as December 2016, while the fifth and sixth satellites are expected to be launched in June 2018 and February 2019, respectively. The AEHF satellite USES xenon ion-fluid hall thrusters, which can carry less propellant to carry more payloads and expand coverage. In addition to interstellar communication and on-board processing technologies, the AEHF system also adopts key technologies such as phased array antenna, beam forming network and millimeter wave unit (AMU). The phased array antenna can quickly change the direction of the antenna beam and realize the instantaneous jump of the user beam. The beamforming network can provide the zeroing antenna for the AEHF satellite, and the antenna can be automatically zeroing without ground control and interference, so as to ensure the normal use of legitimate users in the beam coverage area. The radio frequency unit of AEHF system adopts millimeter wave circuit to realize the miniaturization and lightweight of modules, which greatly reduces the design cost and has significant economic benefits.

AEHF adopted, for example, compared Milstar II XDR data transmission mode, can provide higher data transmission rate, support for data, voice, video conference and image sensor business. Under the EHF spectrum, Milstar I system's total communication capacity is 75 KB/s, Milstar II to 100 MB/s, and the AEHF can exceed 1 gb/s. The interplanetary link communication rate in Milstar is 10Mb/s, while in EHF it can reach 60Mb/s. Table 2 shows the time difference of three generations of military stars when different information is transmitted.

| Table 2. Comparison of AEHF and Milstar Data Transmission Time |
|-----------------|-----------------|-----------------|
|                 | Milstar I       | Milstar II      | AEHF            |
| The tomahawk cruise missile's mission command | 100s            | 0.16s           | 0.03s           |
| 1.1mb air mission command                      | 1.02h           | 5.7s            | 1.07s           |
| 24MB size picture                              | 22.2h           | 2.07s           | 23.6s           |

3. The Features of EHF Frequency Band Satellite Communications

3.1 Operating Frequency

In the world, 18GHz ~ 300GHz is usually called EHF(Extremely High Frequency) band [6]. In terms of the current application, the research scope of EHF is mainly limited to 18GHz ~ 60GHz, and the Frequency band allocated for satellite communication is shown in table 3.

| Table 3. Frequency Bands Assigned to EHF Frequency Band Satellite Communications |
|-------------------------------|-----------------|-----------------|-----------------|
| Band range (GHz)          | 27.5~31.0       | 17.7~21.2       | 50.0~51.0       |
| Available bandwidth (MHz) | 3500            | 3500            | 1000            |
| service name               | Fixed service (up load) | Fixed service (down load) | Fixed service (up load) |
|                             | Mobileservice (ordinary) | Mobileservice (Air/sea) |

Compared with other frequency bands, the EHF frequency band has the following advantages when applied to military satellite communications:

1) wide available band, high data transmission rate. The higher the working frequency is, the wider the relative bandwidth is. For the center frequency of 40GHz, 10% of the relative bandwidth can
reach 4GHz. According to the communication principle, increasing the signal working bandwidth can improve the communication data rate and meet the needs of large capacity and high speed military communications.

2) small antenna size, high gain. The size of the antenna is inversely proportional to the working frequency, and the higher the working frequency is, the smaller the antenna size can be.

3) strong anti-interference performance. Due to high working frequency, relatively few interference sources, and high frequency loss, increased the difficulty of uplink interference. On the other hand, the working broadband of the EHF band is relatively wide, which is conducive to increasing the spread spectrum bandwidth and enhancing the anti-interference capability.

4) anti-interception capability. To improve the survivability of ground station, the interception probability or the maximum interception distance should be reduced. The effective interception distance of the interception receiver is approximately proportional to $f^{-3/2}$ (f is the working frequency). Therefore, the higher the working frequency is, the smaller the effective interception distance is and the stronger the anti-interception ability is.

3.2 Transmission Characteristics

The effects of typical satellite communication channels on electromagnetic waves are mainly attributed to ionospheric scintillation, multipath fading, atmospheric fading, rainfall fading and nuclear explosion scintillation. For the EHF frequency band, ionospheric scintillation and multipath fading have little influence, and they are mainly affected by atmospheric loss and rainfall loss. The attenuation of signals in different frequency bands in the atmosphere is different, among which the attenuation is small near 35, 94, 130 and 220GHz, which is called "atmospheric window"; while near 22, 183GHz, 60 and 190GHz, the attenuation appears maximum value due to the absorption of water molecules and oxygen molecules, which is called absorption peak [7]. In the EHF frequency band, the non-uniform transmission characteristics of signals in the atmosphere will cause the distortion and dispersion effect of broadband signal amplitude and phase, resulting in the increase of inter-symbol interference and the increase of bit error rate. Therefore, these factors must be considered in system design and compensated by appropriate modulation and reuse techniques.

In the EHF band, the rainfall loss is much larger than the atmospheric loss, which can seriously cause communication disruption. Rainfall loss is related to the size of rainfall and the height of the terrain. The greater the rainfall, the lower the terrain, and the farther the electromagnetic wave travels, the greater the rainfall loss. Antenna elevation Angle is also an important factor affecting rainfall loss. According to statistics, when the operating frequency is 30GHz and the elevation Angle is less than 20 degrees, the rainfall loss increases sharply. When the elevation Angle is 5 degrees and the rainfall is 100m/h, the rainfall loss is up to 120dB. Even under the rainfall rate of 20mm/h, the rainfall loss is up to 40dB. Therefore, in the EHF frequency band, the working elevation of the antenna is generally required to be greater than 20 degrees.

3.3 New Technology

Many new technologies are used on EHF frequency communication satellites, which can effectively improve the spectrum utilization, security level, anti-jamming ability and battlefield survivability of the system.

1) Multi-Beam Technology

Because of EHF band antenna size is relatively small, in order to improve the communication channel utilization, increase the coverage area, with the method of as shown in figure 1, the multiple antenna beam on the ground to form honeycomb communication area, using mutual isolation between beam, by way of FDMA, use the same carrier frequency in different beam, improve the utilization rate of the spectrum.
2) Interplanetary Link Technology

The EHF band satellite communication can achieve global communication without the relay of earth station, which relies on the interplanetary link technology. It uses the 60GHz interplanetary link, in the space through the forwarding between satellites to achieve direct communication between the ground terminal. At the same time, because the atmospheric attenuation above the earth has an absorption peak at 60GHz, the ground interference source is difficult to interfere and intercept the interplanetary link, highlighting the privacy of EHF frequency band satellite communications. In wartime, even if the satellite earth station was attacked, the entire system could operate autonomously because interplanetary communications were still present.

3) On-Board Processing Technology

To support multi-beam technology and interplanetary link technology, the EHF frequency band communication satellite needs control and signal processing capability of the satellite, and it needs a root according to the requirements of flexible configuration of beam coverage and channel resources, but also with modulation, demodulation, spectrum expansion, storage, exchange and other signal processing capacity, this is the on-board processing technology, it is an effective means to improve the satellite performance, but also reduce the complexity of the satellite ground terminal equipment.

4) Anti-Interference Technology

EHF frequency band has strong anti-interference ability due to its own spectrum characteristics. Its broadband characteristics provide rich spectrum resources for broadband spread spectrum technology. Under the condition of a certain SNR of the spread spectrum system, the wider the spread spectrum bandwidth is, the higher the processing gain is, and the stronger the allowable interference signal will be. Because the antenna size is small and the beam is narrow, it is suitable to use the multi-beam zeroing technology. By controlling the zero of the antenna, it can effectively avoid the reception of interference signals and improve the anti-interference ability of the system.

4. EHF Band Rf Technology

EHF frequency band satellite communication benefits from the high frequency band and has many advantages, but it also brings great challenges to the development of rf equipment in the system. Because the EHF band covers the millimeter band, the circuit design enters a completely new field compared with the low band, and the circuit performance is closely related to the material and process.

4.1 Millimeter Wave Circuit Technology

With the development of semiconductor technology, the performance of millimeter wave devices and chips represented by GaAs (arsenide GaAs) material has been greatly improved and widely used in
millimeter wave circuits. Low noise amplifier (LNA) is an important device to realize low noise amplification of signal. In millimeter-wave frequency band, the traditional fet LNA can no longer be used. Instead, the high electron mobility transistor (HEMT)LNA is used, which has the advantages of low noise coefficient, high efficiency, high gain and high operating frequency. In terms of power amplifier, with the progress of mm-wave monolithic integration technology and the improvement of power output of power amplifier MMIC chip, mm-wave solid state power amplifier (SSPA) is gradually replacing the traditional TWTA amplifier. In addition, the progress of PCB manufacturing process also provides the foundation for the realization of millimeter wave integrated circuit. At present, LTCC(low temperature ceramic co-firing) technology is developing rapidly in millimeter wave integration technology, and has the advantages of miniaturization, light weight and high density. As shown in figure 2, w.smon, j. kassner, o.itschke et al. of IMST GmbH center in Germany made the Ka band transmitting front end for satellite communication using LTCC technology. The module integrates 8×8 antenna array, rf circuit, local oscillator circuit, dc circuit and a water cooling cooling system into an LTCC substrate.

Now a very high degree of integration. Compared to low frequencies, millimeter wave circuit has two characteristics, one is that because of the short wavelength of their work, the machining precision of PCB and components of the installation precision is very high, in some key size of EHF frequency processing accuracy is less than 0.01 mm, and the amplifier, mixer element can only be used by the encapsulation of tube core, need to introduce micro assembly process complete chip assembly problem. Second, the high frequency circuits has greater influence on the distribution parameters on the circuit performance, in the circuit design, in order to obtain excellent circuit performance, no longer like low frequency circuits, extensive use of lumped capacitor, inductor and the filter element, using the form of microstrip structure device can be seen everywhere in the EHF frequency circuit, and once the microstrip circuit in the form of printed forms, difficult to debug, so need to design to complete the millimeter wave circuit design.

Master the electromagnetic simulation technology, use the simulation software for accurate simulation, improve the realization of the circuit.

4.2 Power Synthesis Technology
Mm-wave solid-state power amplifiers generally adopt monolithic integrated circuit (MMIC) as the basic module, and then combine the output of multiple basic modules to obtain higher output power through power synthesis technology. In EHF frequency band, power synthesizer mainly includes binary waveguide power synthesizer, radial cavity power synthesizer, waveguide inner space power synthesizer and quasi-optical/free space power synthesizer. FIG. 2 shows the principle block diagram of an 8-channel binary waveguide power synthesizer. The power synthesizer module is composed of 8 power amplifiers. The first two stages and the last two stages are realized by waveguide t-type coupler.

![Figure 2. Block Diagram of 8-channel Binary Waveguide Power Synthesis](image-url)
By the increase of the number of synthesis routes, the synthesis efficiency of binary waveguide power synthesizer will be lower and lower. The radial waveguide power synthesis technology can realize a multiplex synthesis, and all the synthesis units work in parallel. Figure 4 shows the structure model of a 4-path lumen power synthesizer.

4.3 Amplifier Simulation Pre-Distortion Technology

For the EHF solid state power amplifier, due to the wide operating frequency band and the possibility of multi-carrier signal amplification, the linearity requirement is high. Although linearity can be improved by power fallback, it will inevitably lead to increased power consumption, reduced efficiency and significantly increased cost. At present, the analog pre-distortion technology is often used in the pre-distortion processing of rf signal. The circuit is realized by the simulator, which can reach the millimeter-wave frequency band and improve the linearity of the power amplifier to some extent. It has the advantages of simple structure and can be used as an independent module.

Analog pre-distortion is the generation of pre-distortion signals complementary to the amplitude/phase characteristics of the power amplifier through the pre-distorter, and then the superposition of the pre-distortion signals through the power amplifier to compensate for the non-linear output of the amplifier. The principle is shown in figure 4. Because the amplitude and phase characteristics of the predistorter are related to the specific power amplifier used, it is necessary to master the nonlinear characteristics of the amplifier module before designing the predistorter.

![Figure 3. Radial Cavity Power Synthesizer Model](image)

![Figure 4. Working Principle of Simulated Predistortion](image)

The input rf signal is coupled by a coupler to a part of the signal into a nonlinear generator to obtain a nonlinear distortion signal, which is then adjusted by an adjustable attenuator and a tunable phase shifter, and synthesized by a synthesizer and an input signal at the straight end of the coupler to obtain the required pre-distortion signal of the amplifier.
5. Conclusion
Satellite communication is an important part of space and space integrated information network. EHF frequency band satellite communication has the advantages of large communication capacity, good confidentiality, strong survivability, anti-jamming and low probability of interception, etc., which is very useful for military satellite communication.

Advantage. At present, the working frequency of our army's satellite communication has covered UHF, C, Ku, Ka and other frequency bands, but the widely used working frequency is still below the Ku band. With the development of our army's second-generation military satellite communication system, the expansion to EHF band must be the inevitable choice for the development of our army's satellite communication. The rf front end of EHF frequency band is an important part of satellite and ground station equipment in the EHF frequency band satellite communication system, and the related technologies are difficult to implement. The research on the rf front end technology of EHF frequency band can provide a technical basis for the extensive application of EHF frequency band satellite communication in China.

6. References
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