Recent Progress and Future Development in Satellite Communication

Ju Han*

University of Electronic Science and Technology of China, No. 2006, Gaoxin District, Chengdu, Sichuan, 610041, China

*2614228H@student.gla.ac.uk

Abstract. In the era of high-speed communication, large-capacity broadband and multimedia personalization, satellite communication has become one of the most special ways of wireless communication. With the rapid development of satellite communication during recent years, many projects, like Oneweb, Starlink, and Telesat have been attempted. Based on higher and higher transmission speed demand, Satellite communication becomes a newly effective supplementation of traditional terrestrial station gradually. After nearly half a century of exploration, started from a live broadcast, broadband satellite constellation represented by Starlink had become mainstream application. The future communication system should be land, sea, and space integration. In this article, the phylogeny of SC, basic construct and some application will be discussed. Consider the specific applications, some challenges and future trend are also the focus. At the same time, the comparison between Satellite communication and terrestrial provision offers a thinking way of communication industry ecology. Nevertheless, the satellite communication system based on radio microwave communication still has some technical development problems and application difficulties, and it is necessary to seek breakthroughs in communication technology and hardware facilities.

Keywords: Satellite communication, Broadband satellite constellation, Satellite internet, Starlink.

1. Introduction

In 1965s, Analog Satellite communication first appeared, digital satellite communication, Narrow-banded Satellite communication system to Broadband Satellite communication system The Satellite communication consists of mainly three parts, transmitter, Antenna system (measurement and control antenna or data transmission antenna), and earth station. Satellite communication used in country defense, navigation, mobile device signal transmitter. All the evolution originates from one basic demand of human, the want of the sense of connection. It is a popular way to feel connected to the world through mobile device nowadays. However, the first trial of SC arrived at the live of the Tokyo Olympics in 1964s lately. Generally speaking, the development of satellite communication can be divided into several decades [1]. At the very early state, the service object of satellite was their professional operator. During 1950s to 1980s, international business communications services gradually expanded [1, 2] based on the evolution of international satellite (Intelsat). It is also a period when a broad company use appeared. The turning point came around 1990s, the invention of constellation of narrow-banded satellites signed the commercialization and privatization. In this new-21 century, high-through put satellite like KaSat, Taicom4, and Viasat [2] and the broadband constellation like telesat and Starlink implied the future trend of integration. To figure out some application, it is a basis to know its working principle and construct. With the artificial satellites as the transfer, radio wave can be transmitted through each earth station, space station, and spacecraft. In other words, satellite means another position of traditional earth station. Compared with traditional one, its communication function does not change, which covers aviation, fisheries, military, and environmental monitoring. Considering a whole system, it consists of three section, space ends, earth station, and user terminal. For space part, launch, insurance, and development are the major points. While construction and maintenance are what earth station should consider. The following part will review some application and solution for a highly integration communication system including satellite one during recent years.

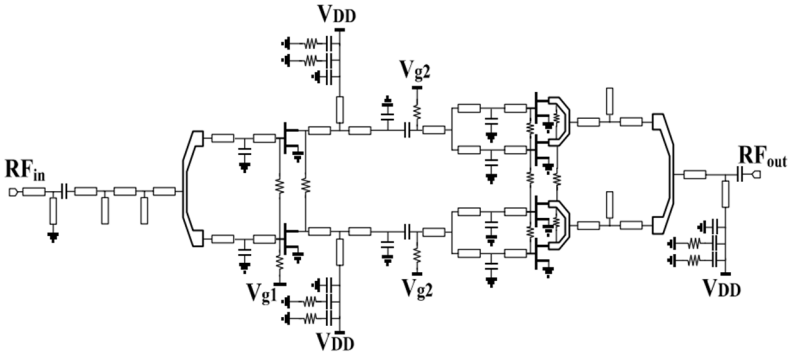


Figure. 1. Schematic of the GaAs p-HEMT Power Amplifier [3].

A Power Amplifier for 29GHz was invented to improve the efficiency of Ka-band satellite communication. Such improvement is necessary since the lower band is a kind of one-off resources. With decades of occupation of satellite orbits and communication bands, most of the low bands like S(2~4GHz), C(4~8GHz), and Ku(12~18GHz) have been saturated [3]. However, Ka-band (27~40GHz), as the newly popular and promising band, becomes a hot point not only for commercial but also military field. It is more obvious when it is compared with S-band, the data transfer efficiency of the former is hundreds of times that of the latter. Although there once was a misunderstanding that the fifth-generation wireless communication will be the most of the internet of thing and mobile one, satellite communication is a supplement in fact [3,4]. Furthermore, a power amplifier based on GaAs p-HEMT can even be the solution for the combination of 5G and satellite communication modulation. It is used in RF transmitter with a high gain and power added efficiency (PAE) at 5G mm-frequencies [2]. The schematic of this power amplifier is displayed in Figure 1. To ensure a large enough transconductance for the high gain, the drain and gate voltage bias are settled at 6V and -0.75V. At the output end, each transistor is chosen to have a width of 100μm. So that the peak of output power can achieve 25-dBm. In the driver stage, a width of 75μm for the transistor allow a better driving capability. Integrated with dc and RF pad together, a simulation and measurement results are shown as follows. Under a condition of 6-V direct current power supply, this power amplifier got a 16.1-dB peak gain at 28GHz. It is intuitionistic since the scatter parameter, S(2,1), the forward transmission coefficient which implies the gain of power reached the highest point. Attention, a certain degree of volatility ($\pm$0.5dB) around 30GHz is acceptable. The output power, gain, and PAE are graphed at Fig. 3. Corresponding to input power level, the measured saturation power is 29dBm, the OP1dB is 28.6dBm. The PAE at OP1dB is around 25%. So far, all the measurement data is in good agreement with simulation. Compared with other series of power amplifier like 0.25-μm GaAs pHEMT with a topology of 3 stage or 0.15- μm GaAs with 1 stage (1 way), this power amplifier reaches higher output power with smaller size [3-5].

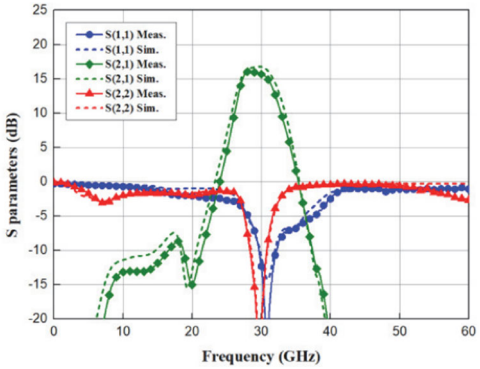


Figure. 2. Simulated and measured S-parameters of the proposed PA under 6-V supply voltage [3].

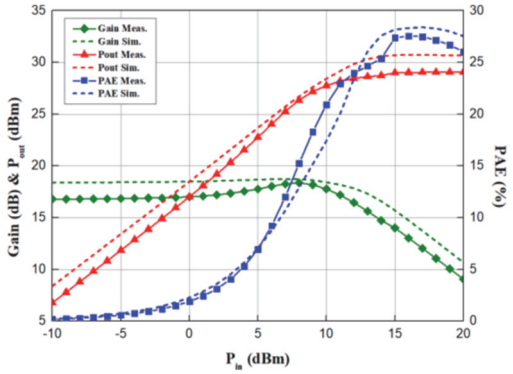


Figure. 3. Simulated and measured large-signal performance of the proposed PA at 29GHz under 6-Vsupply voltage [3].

2. Starlink

2.1 Definition

After a glance about satellite hardware and related improving scheme, a more conceptual application, Starlink is the main subject of this section. However, some extreme views have emerged during recent years [6]. On the one hand, some media do not believe such communication system cannot be realized because of expensive rocket launch costs and low-speed transmission efficiency. It is not something hard to understand. Since there is no any distinguish between terrestrial station except their carries. The launch of rockets carrying satellite and the distance of satellite and ground users. According to the information on the official website, this low earth orbit satellite constellation system can offer high speeds and latency as low as 20ms in most locations. Starlink subvert users' traditional image about satellite internet. It enables video calls, streaming, and other high data rate activities that historically have not been possible with satellite internet [6,7].

2.2 Non-geostationary satellite orbit (NGSO)

The high speed and low latency of Starlink profit from its Non-Geostationary-Orbit satellite constellation. This kind of satellite do not be fixed in one place, which is different from GSO. Therefore, this flexibility ensures its coverage expanded to the whole world. However, this flexibility also led to some challenges. The first one is the committed information rate and quality of service (QoS). Information rate commitment like Committed information rate (CIR), Example of QoS includes one-way packet latency, packet delay variance, and target packet error rate. The nature of nonstationary and time-variant connectivity among different network nodes makes guarantees mentioned above hard to be realized. However, terrestrial stations do not fulfil its duty that make every user in the world get access to internet no matter where they are. For those people who need to communicate with each other in remote area, NGSO provides a perfect supplementation although there are some drawbacks. As of 2018, almost half of the world's population is still not connected to the Internet [8]. To achieve a wider coverage, most of this satellite constellations are positioned at low earth orbit (LEO). Specifically, being popular on the market, four prominent NGSO systems including Starlink are introduced as below. Each of them has their own band (Ka or Ku), orbital planes, and altitude. The LEO constellation of Telasat [8] comprises of the least amount of satellite (117), which are only distributed in two orbits. While each orbit contains several planes with at least 10 satellite. Every satellite ensures the packet switching ability through intersatellite link and gateways. For OneWeb constellation, it has the least amount of satellites except Telasat(720). Its satellite planes are 18, each of them has a distance of 1,200km among ground. Since it consists of the satellite of first generation which do not allow intercommunication of adjacent satellite, at least of 50 gateways in earth station is necessary to ensure the coverage of corresponding gateway for users who are in the field of view under a satellite. Amazon's Kuiper system has the second most numerous

satellite (3236). But their orbits are the lowest, which do not exceed 700km. Considering Starlink, it has the most numerous satellites. At the same time, it applies optical intersatellite communication system to improve the service quality. To draw a small conclusion, the Telasat, Oneweb, and starlink are picked [8,9]. Those typical low-orbit satellite constellation have a common feature. Out of its low orbit, only a large enough number of satellites can form an internet that covers the whole world. For the Telesat constellation, his oblique circular orbit is used to focus on densely populated areas. The near-polar orbit covers both poles, providing signal coverage for remote areas. The overall number of beams is high. The OneWeb constellation is slightly different. It is networked in a near-polar orbit. Its 720 satellites covering the globe. The beam coverage is wide. SpaceX's Starlink constellation, which uses a hybrid network of four orbital surfaces, intends to launch more than 40,000 satellites to provide Internet services to the world. The bandwidth is large. Table 1 compares the beam characteristic among each of them.

Table 1. The beam characteristic comparison among three satellite constellations [6].

	User/Gateway beam downlink			User/Gateway beam uplink		
	SpaceX	OneWeb	Telesat	SpaceX	OneWeb	Telesat
Beams	>=8	16	>=16	>=8	16	>=16
Area	2800	75000	960	2800	75000	960
BW/MHz	250	250	-	125	125	-
	Gateway beam downlink			Gateway beam uplink		
	SpaceX	OneWeb	Telesat	SpaceX	OneWeb	Telesat
Beams	9	16	2	8	16	2
Area	780	3100	960	780	3100	960
BW/MHz	250	155	-	500	250	-

2.3 Related issues of Starlink

To be compatible with terrestrial station, Starlink have to comply with service level agreements (SLAs) to ensure an acceptable data transmission rate, packet loss rate, and packet latency, which belongs to QoS parameters. It is hard to satisfy committed information rate (CIR), excess information rate (EIR), and committed burst rate (CBS). For Metro Ethernet Forum (MEF)-based services, inter frame delay (IFDV), one-way frame delay (FD), and one-way frame loss ratio (FLR) are difficult to provide guarantees. The reason for the high difficulty is generated by Starlink's dynamic satellite constellation. Not only inter-satellite connection but also user terminal to satellite and gateway causes the fragility of stability. Moreover, the switch of users' terminal connection from NGSO (Starlink) to GSO or the mobility of user end which is fixed with an aircraft can also led to decline in the quality of satellite communication.

2.4 Solution of Starlink instability

There are four ways proposed in [8]. Whether it is to control data transmission protocol(24×7 flow admission), classify different priority for users traffic, or base on software defined network, the quality of service is definitely improved. Although it is a grand challenge to make NGSO match with users' terminal with its time-variant satellite constellation. Starlink has find the way to overcome the odds. According to [10], Starlink's satellite characteristics, such as its wide coverage (roughly 1000 km), improved anti-interference ability over ground base stations, and acceptable power budget of information transmission in passive radar systems, imply the viability and promising potential of this specific satellite application.

3. Starlink or 5G/6G ?

3.1 Starlink future trend

After introducing a series of low-orbit satellite communication systems, this subsection will enter the prediction of future development trends of satellite communications and some dialectical views on the satellite Internet [11]. SpaceX official media report in 2020 stated that Starlink could become a solution to replace Internet interfaces in areas with unstable, expensive, or even completely inaccessible, and to provide high-speed broadband Internet services. However, some self-media outlets have exaggerated their claims, saying that Starlink's 41,927 satellites will provide about 407Tbps, equivalent to nearly 400,000 5G base stations. Meanwhile, in the case of the United States, there are about 200,000 base stations on 4G networks in the country. That is to say, once Starlink is built, its capacity is equivalent to two satellite Internets that can carry the US region. Taking it a step further, the cost of Starlink terminals is extremely low, which do not exceed $500. Meanwhile, a 5G base station could cost thousands of dollars. So, part of the media says that when the Starlink deployment is complete, 5G will die. In fact, alarmism such as this is mostly media hype. In order to have a more comprehensive understanding of low-orbit satellite communication systems, the following will focus on low-orbit satellite communications represented by Starlink. At the same time, from a commercial point of view, the cost composition of the satellite communication industry chain is evaluated. Next, based on the analysis of the advantages and limitations of satellite communications, the complementary integration with 5G and 6G is explored.

3.2 Satellite Internet introduction

Satellite Internet is a network of a certain number of satellite units to provide communication services such as broadband Internet access to air and ground terminals [12]. According to the orbital altitude, satellite communication systems can be divided into low-Earth orbit satellites that are 300-2000 km above the ground, medium-Earth orbit satellites that are 2000-35786 km above the ground, geostationary satellites that rotate at the same speed as the earth, and inclined geosynchronous orbits with a certain angle. The sun-synchronous orbit tends to be in near-polar orbits below 6,000 km and nearly perpendicular to the Earth's equator. Among them, low Earth orbit and geostationary orbit undertake most of the navigation, topographic survey, communication tasks. Low-orbit satellites, due to their low-orbit speed characteristics, appear in the receiving range of ground communication terminals for about 10 minutes. Its essence is a kind of NGSO, so it also has the instability of NGSO mentioned in the second subsection. For the fixation of ground base stations, as long as the density of base stations is guaranteed, even if the user is in a high-speed moving state, stable Internet services can also be used. NGSO is different because the satellite signal base station itself is moving at a high speed, and the tunnel speed relative to the earth surface is more than 5.7 km/s.

3.3 Rise of Satellite Internet

With the upgrading of rocket launch technology and the customization of satellite integrated circuits, low-orbit satellites have been favored by major Internet, communication, and aerospace companies. At the same time, compared with high-orbit satellites, LEO's low cost and low latency also play a role in boosting. For satellite launch technology, the subversive innovations of Technologies such as Starlink's "One Arrow, Multiple Stars" and Rocket Recovery have greatly reduced the cost of satellite launches and the barriers to entry into the industry. In terms of satellite manufacturing technology, advances in technologies such as materials, power supplies, and process manufacturing have made it possible to miniaturize, modularize, and componentize satellites. This not only further reduces the cost of satellite communications, but also shortens the development cycle and lowers the industrial threshold. Advances in integrated circuits have enhanced on-board processing power and further miniaturized terminals while improving terminal performance. Advanced coding, modulation, multi-antenna beamforming, and complex frequency multiplexing methods in communication technologies [5,6] provide efficient means of communication for

infrastructure construction, including ground-based radar. Based on millimeter waves, the interstellar link of visible light communication has also matured this industry.

3.4 The industrial ecology of Satellite Communication

The satellite communication industry mainly includes four major links: satellite manufacturing, satellite launch, ground equipment, satellite operation and service. Manufacturing and launch are the focus of this section. The manufacturing process includes satellite platforms and satellite payloads. The satellite platform is mainly composed of structural system, power supply system, propulsion system, attitude control system, data management system and so on. The satellite payload determines the functions that the satellite can achieve after liftoff. Electronic components, transponder systems, and antenna systems will become the loads of different satellites. Launch services involve the manufacture and launch of rockets. SpaceX's disruptive innovation in this area is the use of a rocket to carry 60 satellites, each of which weighs at 500 pounds. Through the small- and large-scale effect, the launch cost of satellites is compressed. So far, the cost of satellite communication system is also gradually clear. The cost of ground end includes the construction cost of ground base station at the initial stage of system construction and the maintenance cost of ground end during system operation. The cost of space end includes the development, launch and insurance of satellites in constellation system and the update and maintenance cost during operation. Satellite launch, in-orbit attitude control and orbital transfer bring about the difference from the ground base station particularity. Strict reliability requirements make each communication satellite face tens or even hundreds of times the construction and maintenance costs of the ground base station.

3.5 The advantage and limitations of satellite communication

At present, the population coverage rate of mobile communication is about 70% [7], which seems to be able to meet the communication needs of most people. But in fact, due to economic costs and technical factors, only 20% of the land area is covered by signals [9,10]. The oceans, which cover about 70 percent of the planet's area, are not fully exploited. For example, in China's ocean area, only less than 5% of the area get access to signal. The advent of satellite communications has opened up a third type of base station in addition to sea and land. However, it cannot be ignored that satellite communication has some limitations that cannot replace land communication. For example, when the user is indoors, only the signal of the ground base station can penetrate the wall, providing an interface. Another flaw in satellite communications comes from its wide coverage area, which is too wide an area that actually has many invalid areas, and satellite signals may still exist even without users. The above two points are the problem of signal coverage of satellite communications. For the terminal of satellite communication, taking Starlink's phased array circular flat panel antenna as an example, not only is the size too large, the diameter is close to 0.5m, but also needs to carry the motor to adjust the attitude of the terminal. When considering commercialization for civilian use, its high construction and maintenance costs make the tariff of satellite communications much higher than that of 5G. However, the drawbacks of the appeal are not entirely unacceptable. Taking low-orbit communication satellites as an example, it is a complete upper-level replacement for high-orbit satellites, which not only has low cost, high transmission rate, and correspondingly reduced path loss. From the perspective of application, low-orbit satellites have unique advantages over ground mobile communication systems such as 5G [13,14]. The Satellite Internet can offer a connection experience similar to that of cities in dense rainforests, remote deserts, and the ocean. Based on their strong anti-interference capabilities and extensive coverage, satellites can offer emergency communication services in the case of natural disasters like earthquakes and tsunamis. It is an effective tool in these particular application circumstances, especially when compared to ground communication systems.

3.6 Complementary to 5G

Shannon's theorem proposes the relationship between the upper limit of the capacity of the point-to-point system in wireless communication. Increasing bandwidth will undoubtedly lead to more obvious communication capacity. Unfortunately, bandwidth is often non-renewable. This is especially evident in satellite communications. Therefore, for satellite communications, it is also necessary to improve the spectrum utilization rate and frequency multiplexing rate. On the one hand, you can increase the number of antennas and satellites, on the other hand, you can also increase the transmission power or optimize the coding modulation method. Even so, the path loss between satellites and ground terminals, and the absorption of rain and atmosphere are far greater than those of ground cellular mobile communication systems. When increasing power resistance losses, spectrum utilization and energy consumption per bit are pulled down. Compared with the cellular mobile systems of the same period, the gains outweigh the losses. So, coexistence with 5G is obviously a smart solution. In terms of the service objects of enhanced mobile broadband, the two show a large difference. 5G mainly serves urban users, while low-orbit satellites serve residential users in remote areas, marine, air and wilderness users. In the development of the Internet of Things, 5G is positioned in an economically developed and densely populated land, while satellite communications have a relatively low cost of global coverage [15, 16].

4. Conclusion

In the era of high-speed communication, large-capacity broadband and multimedia personalization, satellite communication has become one of the mainstream ways of wireless communication. This paper discusses the performance indicators of OneNet, Xinglian, Telephone Satellite and other projects. It also illustrates the necessity and inevitability of satellite communications becoming an effective supplement to traditional ground stations. In the future, satellite communication systems will be integrated on land, sea and air. At the same time, it will also be carried with 5G and 6G. At the same time, the comparison between satellite communications and ground supply provides a way of thinking for the ecology of the communication industry.

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