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Localization and Verification of Spaceborne Hydrogen Maser Plasma Preparation System

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Abstract

The BeiDou navigation satellite system is an important space infrastructure in China, which plays a great role in both civilian and military fields. The principle of navigation satellite is to perform the position calculation by measuring the time difference of the signals arriving at the user, and the spaceborne hydrogen maser is the benchmark of time on the star. The plasma preparation system is the key component of the spaceborne hydrogen maser, which is used to generate the atomic jump excitation signal and greatly influences and determines the lifetime and reliability of the spaceborne hydrogen maser. Therefore, it is necessary to perform the localization of the core devices. This paper presents the improvement and application validation work for the localization of the spaceborne hydrogen maser plasma preparation system.

Keywords: spaceborne hydrogen maser；plasma；transistor；application validation

1 Introduction

With the characteristics of low drift and high stability, the spaceborne hydrogen maser is widely used in satellite navigation and deep space exploration[1]. It is the core stand-alone machine of navigation satellites. The spaceborne hydrogen maser developed by the Shanghai Astronomical Observatory works by transmitting the detection signal to the physical part of the hydrogen maser through the circuit part[2], which excites the hydrogen atoms to jump and generates the error signal, and the circuit part receives the error signal, controls the voltage-controlled crystal to realize the closed-loop control of the hydrogen clock and outputs the 10MHz reference frequency signal[3].

The plasma preparation system is one of the key components of the spaceborne hydrogen maser, and its main function is to realize the ionization bubble lighting and maintain the ionization state of the hydrogen clock, which is an important component affecting the reliability and lifetime of the whole machine.

The RF signal in the plasma preparation system is generated directly through the Clapp oscillator circuit, which has the characteristics of high oscillation frequency, strong output power, and high-power consumption. For the core device High-power Transistor in this circuit, the No. 13 Research Institute of China Electronics Technology Group Corporation has carried out the localization work for a long time. In this paper, an improved oscillation circuit is adopted to match the localized transistor, and the corresponding application verification test is carried out to make the newly designed plasma preparation system have higher in-orbit operation reliability with guaranteed ionization efficiency.

2 Principle of plasma preparation system

The plasma preparation system generally uses RF signal excitation to induce induction of electrodeless discharge to achieve ionization of hydrogen gas. The specific principle is as follows: hydrogen gas is passed into a ionization bubble made of quartz, and a RF signal with a frequency of about 100 MHz and a power of about 10 W is generated by a Clapp oscillator circuit or a multi-stage RF amplifier circuit, which is introduced into the ionization bubble. The free electrons are accelerated and bombarded with hydrogen molecules under the action of the RF electric field, producing hydrogen atoms, hydrogen ions and more electrons, and the typical process is as follows[4].

$$H2+e=H++H+2e \quad (1)$$

The continuous acceleration and bombardment of electrons can constitute a continuous ionization within the ionization bubble. The hydrogen atoms generated by the electron bombardment ionization are generally in the excited state and will return to the ground state by spontaneous radiation while emitting optical radiation. The plasma preparation system first needs to ensure the ionization efficiency of the hydrogen molecule so that the effective flux of hydrogen atoms is maintained to meet the requirements of the atomic leap. This can be indirectly determined by the radiation spectrum and brightness (ionization bubble light intensity) [5]during the ionization of the molecule.

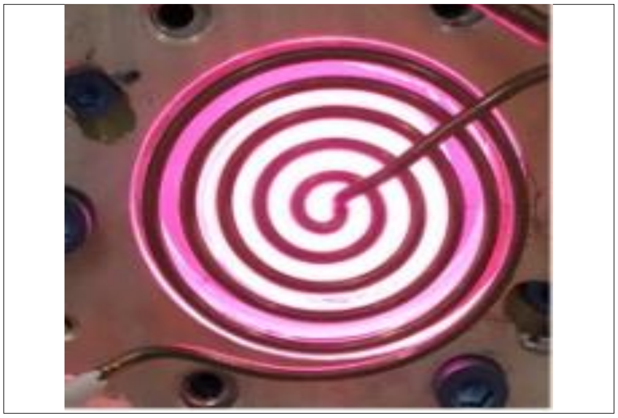

Fig.1 Ionization of hydrogen gas

The oscillation circuit consists of the amplifier circuit and the resonant circuit. Among them, the amplifier circuit adopts the form of the common base, and the common base amplifier circuit has low input impedance, high output impedance, no current amplification, high voltage amplification, good frequency characteristics, and is often used in wide-band amplifiers. The resonant circuit is in the form of LC, which forms positive feedback together with the amplifier circuit. Due to the low input impedance of the common base amplifier circuit, it makes the resonant circuit susceptible to the influence of transistor and circuit parameters, which affects the oscillation state of the whole circuit in the case of inappropriate parameters.

The specific circuit schematic is shown in Figure 2 below.

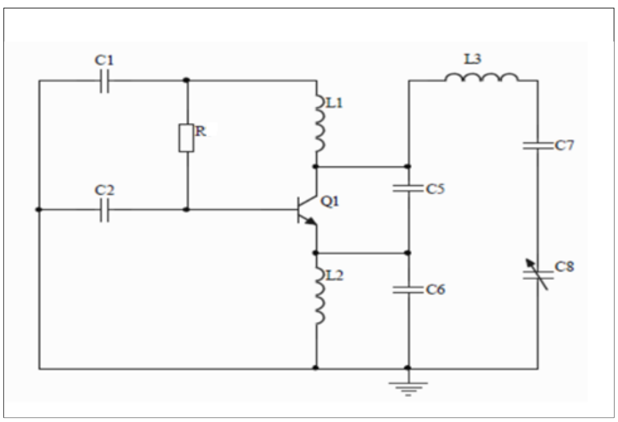

Fig.2 Oscillation circuit

In Figure 2, R is the base bias resistor of the triode to provide bias voltage for the base. C1 and C2 are bypass capacitors to derive the high-frequency oscillation. C5, C6,and L3 form a capacitive three-point oscillation loop, and the oscillation frequency is

$$f = \frac{1}{2\pi\sqrt{L_3 C_m}} \quad (2)$$

and Cm is the effective oscillation capacitor. The operating frequency of the ionization source should be located at 90-100MHz, and the working DC power is generally 15W[6], so a high-power microwave transistor is required. C7 can be realized by a section of distributed capacitance between the coaxial line core and the housing.

3 Localized circuit solutions

There are certain parameter differences between the nationalized transistors and the old state transistors, which cannot be directly replaced in-situ. In order to analyze the differences between the two transistors, the parametric performance of the transistors was tested and compared. The main differences of the two transistors were compared and then listed as shown in Table 1.

Table 1 Parameter comparisons of two transistors

Serial No.	Parameter	Symbol	Unit	Old state transistor	Localized transistor
1	Max. power dissipation	P	W	150	175 （Tc=25℃）
2	Collector-base breakdown voltage	V_{CBO}	V	60	90
3	Cut-off frequency	f	Mhz	250	＞300
4	Operating temperature	T	℃	-60~+125	-55~+200
5	Junction temperature	Tj	℃	160	200

Localized high-power transistor and old state transistor performance is similar, but the output characteristics are different, the localized transistor cannot be used on the original common base form oscillation circuit, in order to make the localized transistor can smoothly start and achieve the lighting of the hydrogen bubble, we will improve the original circuit, the common base circuit to common collector circuit. This change has been more mature on several oscillator schemes typical of RFLC, which can work well with the two transistors in the old and new states, and work more stable and simpler to adjust than the Clapp oscillator circuit. The schematic diagram of the common-collector oscillator circuit is shown in Figure 3 below.

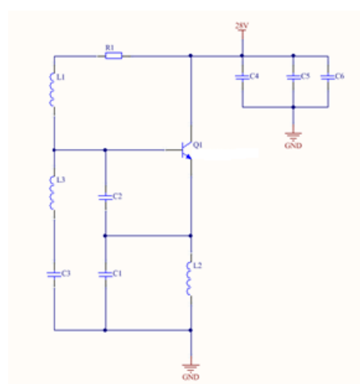

Fig.3 Common collector type oscillation circuit

In Figure 3, Q1 is the localized transistor, R1 is the bias resistor, which provides the bias voltage for the base. C1, C2, C3, and L3 form the oscillation loop, and C4 and C5 are the power supply filters.

The common collector oscillation circuit consists of the common collector amplifier circuit and the resonant circuit. Compared with the common base stage oscillation circuit, the characteristic is that the input impedance is higher, and the current can be amplified. The resonant circuit takes the form of LC, which forms positive feedback with the amplifier circuit. Since the input impedance of the amplifier circuit is high, the output impedance is usually also high, so the resonant circuit is less affected by the transistor and circuit parameters, and the frequency stability is higher.

The circuit is improved to accommodate both old and new state transistors, which is related to the characteristics of the circuit. The newly designed common collector type oscillation circuit has the same output power and close ionization bubble light intensity telemetry compared with the original common base oscillation circuit.

Therefore, the program has application experience and is less risky to use.

4 Localization application validation

To ensure the long-term reliable and stable operation of the spaceborne hydrogen maser, the Shanghai Astronomical Observatory conducted electrical performance tests, environmental tests ,and overall performance tests to verify the domestic high-power transistors on the common collector form oscillation circuit, and also compared the test results with the old state. Parameter pull-off tests were conducted on the newly designed circuit in combination with reliability requirements to verify the adaptability and reliability of the circuit.

According to the relevant requirements, the required test items for localized high-power transistors are detailed in Table 2 below.

Table 2 Localized high-power transistor test

Serial No.	Test Project	Voltage	Current	Resonant Frequency	Light intensity	Frequency stability
1	Preliminary performance test	Δ	Δ	Δ	Δ	
2	Thermal cycle test	Δ	Δ		Δ	
3	Thermal vacuum test	Δ	Δ		Δ	
4	Frequency Stability Test	Δ	Δ	Δ	Δ	Δ
5	Parameter pull-off test	Δ	Δ	Δ	Δ	

The integrated pull-off is mainly used to verify the circuit operation by changing the parameters of the components in the circuit. The integrated pull-off test results are detailed in Table 3.

Table 3 Comprehensive pull-off test results

Serial No.	C1/C2	Current	Resonant Frequency（MHz）	Light intensity	Operating mode
1	+10%	0.30A	91.00	1.97V	30℃@Atmospheric pressure
2	-10%	0.21 A	91.87	1.67 V	-20℃@Atmospheric pressure
3	+10%	0.25 A	91.35	1.54 V	25℃@ Vacuum
4	-10%	0.27 A	91.24	1.60 V	-15℃@ Vacuum

The atmospheric test, thermal cycle test ,and thermal vacuum test mainly verify the operation of the plasma preparation system during high and low- temperature conditions in both atmospheric and vacuum environments. The circuit operation is judged mainly by the telemetry parameter of ionization bubble light intensity.

Table 4 Operation under thermal cycle and thermal vacuum conditions

Serial No.	TEMP	Light intensity（V）	Pneumatic pressure	Voltage	Current
1	35℃	1.84	Atmospheric pressure	28V	0.39A
2	-25℃	2.07	Atmospheric pressure	28V	0.31A
3	25°C	1.74	Vacuum	28V	0.45A
4	-10°C	1.97	Vacuum	28V	0.41A

The long-term assessment examines mainly the work of the localized plasma preparation system in a single machine to determine whether there is an impact on the performance of the whole machine, which is compared by testing the frequency stability of the whole machine. The long-term assessment of the performance comparison results is detailed in Table 5.

Table 5 Long-term assessment performance comparison

Serial No.	Frequency stability	Old state transistor test data	Localized transistor test data
1	1s	6.38×10^{-13}	6.61×10^{-13}
2	10s	2.46×10^{-13}	2.47×10^{-13}
3	100s	8.15×10^{-14}	8.95×10^{-14}
4	1000s	2.77×10^{-14}	2.71×10^{-14}

The spaceborne hydrogen maser plasma preparation system using a localized high-power triode passed the above tests with no difference in stand-alone performance.

5 Conclusion

This paper presents the adaptive improvement ideas and application validation results of the localized application of the core components of the spaceborne hydrogen maser. The domestically produced plasma preparation system of the spaceborne hydrogen clock has passed all the required tests and experimental examinations and can work stably for a long time, which effectively improves the reliability of the spaceborne hydrogen clock for long-term operation in orbit.

References

Tao Shuai, Yonghui Xie. The Onboard Passive Hydrogen Maser for Navigation Satellite [J]. Science(in Chinese),2016,68(05):11-15+64+4.

Zhibin Pan, Yonghui Xie, Tao Shuai, Pengfei Chen, Chuanfu Lin. Development of mini space passive hydrogen maser [J]. Chinese Journal of Scientific Instrument（in Chinese）,2020,41(03):105-112.

Shuai T, Lin B J, Zhang J, et al. Performances and telemetries analysis of BD satellite passive hydrogen maser (in Chinese). Sci Sin-Phys Mech Astron,2021, 51: 019513, doi: 10.1360/SSPMA-2020-0226

Nina Ma, Jing Li. The Influence of Spectrum of Discharging Hydrogen Atoms on the Magnitude of Oscillating Signal of Hydrogen Maser[J].Journal of Astronautic Metrology and Measurement (in Chinese), 2016,36(01):38-41.

Pengfei Chen, Yonghui Xie, Tao Shuai, Yang Zhao, Yuxian Pei, Chao Shen, Xiaoyan Pan. Verification and Analyzing of the Reliability and Lifetime of Space Passive Hydrogen Maser[C](in Chinese)2017:3.

RIEHLE F. Frequency standards[M].Weinheim,Germany:Weily-VCH,2004:229-252