

Ku-band 500W Amplitude-phase Coherence Pulsed MPM for Ocean Exploration

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Abstract. The spatial high-resolution synthetic aperture radar (SAR) for ocean exploration puts forward higher requirement for output power and amplitude-phase consistency of the pulsed TWT amplifier. The kW class pulsed TWT amplifier based on broadband power combining is the key technology for space SAR applications. In this paper, the factors affecting the amplitude and phase consistency of MPM are studied, and a phase consistency compensation circuit was designed to improve the phase consistency of multiple sets of products. A microwave power model (MPM) with dual TWTs output integrated architecture was proposed which consists of two short travelling wave tubes (TWT), two solid-state power amplifiers (SSPA), and an electronic power conditioner (EPC). More than 45% efficiency is achieved in 15% duty cycle within 600 MHz bandwidth, and the phase consistency was less than ± 5 degrees. With the improvement of synthesis efficiency, higher synthesis power and higher sensitivity of ocean wide scanning and detection can be obtained

1 Introduction

Technology evolution promotes the rapid development of space remote sensing science, in the field of atmosphere and ocean exploration, C-band 100W and Ku band 120W pulsed TWT amplifiers are usually applied in SAR satellite system. C-band 100W pulsed TWT amplifier is used for atmospheric environment monitoring and prediction, and Ku band 120W pulsed TWT amplifier is used for ocean exploration. In order to obtain a wider scale of ocean exploration and higher sensitivity, the resolution of space SAR system is moving towards a higher sub meter level[1], which requires higher and higher imaging accuracy and resolution, it needs a mapping bandwidth of several hundred kilo-meters in the future large-scale ocean monitoring. The range resolution and mapping width of SAR depend on the system bandwidth and transmitting power[2]. The relationship of SAR imaging accuracy versus distance and transmitting is discussed in reference[2]. The pulsed traveling wave amplifier (PTWTA) for SAR system needs to have higher efficiency and power output. Due to the output power of a single TWT amplifier is not enough to meet the output power requirements of space SAR system, the power synthesis method is usually used in the system to achieve the required power output. At the same time, the inconsistencies of the phase and amplitude of each synthetic branch will distort the phase of the combined signal,

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resulting in the degradation of imaging quality. Therefore, PTWTAs are required to have high amplitude phase consistency.

Based on these important reasons above, pulsed MPM [3-5] with highly consistency has been used to implemented for space SAR system. In reference[3-5], the development of MPM technology was introduced, and the design principle of MPM was given. However, the low-power level MPM technology scheme of single travelling wave tube is adopted in the literature, which is used for communication and electronic countermeasures. And the design and control methods of amplitude and phase consistency are not involved in the references. In order to meet the demand of high power pulsed output for SAR satellite of ocean exploration, this paper proposed a dual TWTs pulsed MPM, and designed a continuously adjustable phase compensation circuit for power synthesis to achieve high amplitude and phase consistency of multi-channel TWT amplifiers. This MPM has been in orbit for more than three years was assembled in Academy of Space Electronic Information Technology (CAST) in 2017. Some advances to this MPM will be introduced here.

2 Principle

The schematic diagram of MPM was shown in Figure 1, the MPM consists of two mini TWTs, one EPC [6-7] and two solid-state amplifiers in one housing. The EPC receives the primary bus of satellite system, and converts it into various power supplies required by TWT and SSPAs, executes various tele-commands of the system, and feeds back its own state to the system through various telemetry information. The photograph of MPM was shown in Figure 2..

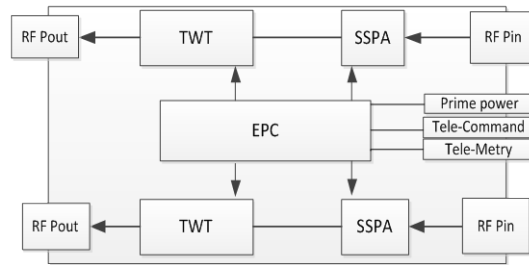


Fig. 1. MPM block diagram

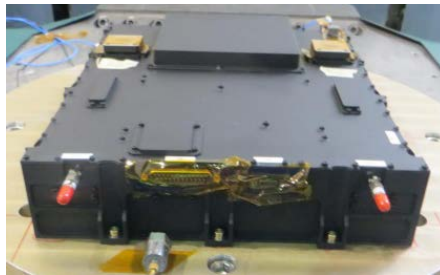


Fig. 2. Ku-Band Dual TWTs Pulsed MPM

Main performance of TWT was shown in Table 1. The mini TWT conduction cooled with four-stage collector design, the peak output power of TWT is greater than 550W, and

efficiency between 50-53% across the band, and the weight of single TWT is less than 1.1kg with an design lifetime is more than 8 years.

Table 1. TWT main characteristics

Parameter	Performance
Peak output power	$\geq 550W$
Cathode voltage	7.8kV
Duty cycle	15% max.
Power efficiency	50-53%
Phase coherence	$\leq \pm 25^\circ$
Weight	$\leq 1.1kg$

Table 2. EPC main characteristics

Parameter	Performance
Cathode voltage	up to 9kV
power capacity	up to 1300W
Power efficiency	$\geq 91\%$
PRF	3 to 10 KHz
Duty cycle	22% max.
Weight	$\leq 2.6kg$

EPC main performances were shown in Table 2. EPC power capacity was greater than 1300W and measured efficiency was higher than 91%. The power supply can drive the TWT working at pulsed repeat frequency (PRF) from 3 to 10 kHz for measured application requirements of satellite ocean monitoring.

SSPA can provide the maximum gain of 30dB, with output power was more than 25dbm, and the power consumption was less than 1W. It provided gain and temperature compensation to set and maintain the driving level of TWT within the allowable input range of the system.

3 Thermal design of MPM

Thermal design is very important for aerospace products, and it is the crucial consideration to ensure their long service life in orbit. The key to the thermal design of MPM is the reasonable distribution of heat conduction between vacuum devices and semiconductor devices. The maximum heat dissipation of MPM comes from the collector of TWT, while the heat consumption of semiconductor devices in EPC SSPA and are relatively smaller. At the same time, the maximum operating temperature of TWT and semiconductor devices are significantly different. Therefore, it is necessary to keep some devices with weak temperature tolerance away from TWT collector in thermal design.

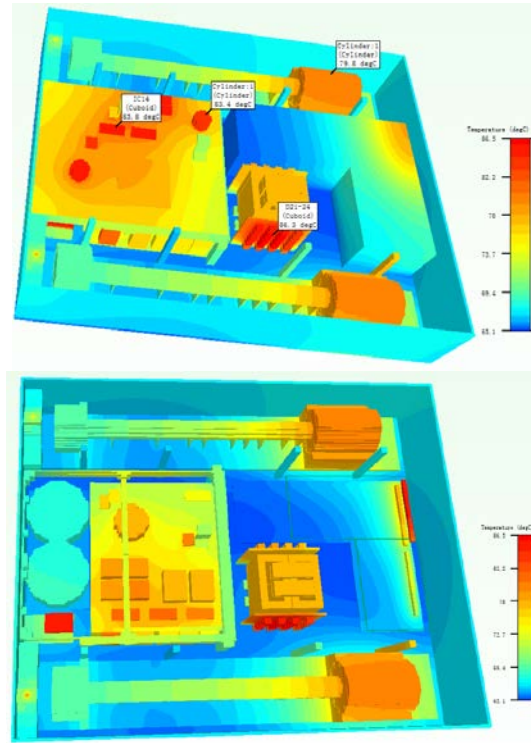


Fig. 3. MPM Temperature Distribution

The MPM temperature distribution of conduction cooling was shown in Figure 3. The mechanical structure model established by ANSYS and PROE software was used to simulate and optimize the thermal mechanical design parameters, which achieved efficient heat dissipation while maintaining the structural integrity and manufacturing robustness requirements.

The simulation results show that the highest temperature region of the whole module was located at the edge of EPC high voltage module. When the base plate temperature is 65°C, the highest temperature is 86.3°C. Reasonable device layout and thermal design ensure the working life of MPM.

4 Measurement

The consistency of amplitude and phase are two important factors in power synthesis. The efficiency equation was expressed as (1), and amplitude inconsistency and phase consistency are replaced by r and $\Delta\theta$ respectively. Figure 4 displayed the efficiency with different r and $\Delta\theta$ respectively. The results show that synthesis efficiency (η) increased with decrescent r and $\Delta\theta$. On the contrary, η decreased with increscent r and $\Delta\theta$.

$$\eta = \frac{P_{out}}{P_1 + P_2} = \frac{1 + r + 2\sqrt{r} \cos(\Delta\theta)}{2(1 + r)} \quad (1)$$

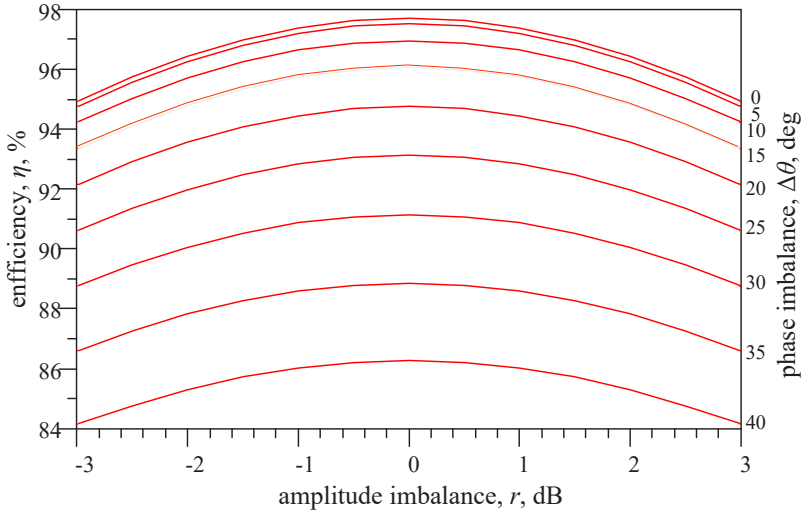


Fig. 4. Efficiency vs. r and $\Delta\theta$

4.1 Phase compensation chip

In order to ensure the phase consistency of any port, a new phase compensation circuit was proposed. And a RF chip with continuously adjustable time delay was developed in the MPM. The chip can obtain continuous time delay by adjusting the external supply voltage V_{cc} , which was integrated into SSPA and placed in each branch of the power synthesis network. The phase compensation and delay equations can be expressed as (2) and (3), $\Delta\theta$ can be gotten directly by modifying V_{cc} .

$$\Delta\tau = \tau(\Delta V_{cc}) = -\frac{\partial\phi(\omega)}{\partial\omega} \tag{2}$$

$$\Delta\theta = \int_{f_d}^{f_u} \tau(\Delta V_{cc})d\omega \tag{3}$$

The performance of the chip named p-c was shown in Figure 5 and Figure 6. The working frequency range of the chip is 5GHz to 18GHz. The delay increased continuously with increscent V_{cc} , when the supply voltage V_{cc} of the chip changes continuously from 0V to 8V. The phase compensation value of 0-26 degrees can be obtained by integrating in the bandwidth of 600MHz.

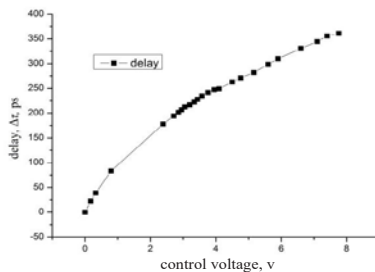


Fig. 5. Delay vs. control voltage

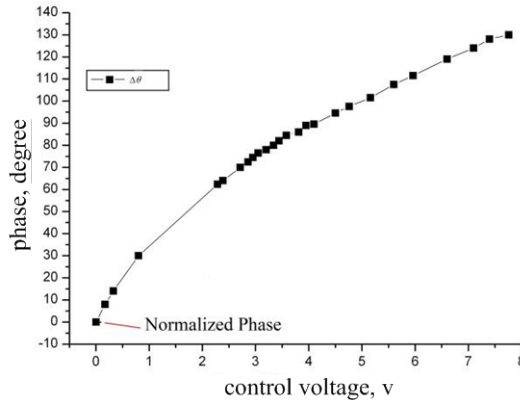


Fig. 6. Phase compensation vs. Voltage

Adjustment method was shown in Figure 7. When $\Delta\theta$ was confirmed, V_{cc} would be adjusted to a appropriate value and make sure phase consistency of different ports. After finishing phase compensation step, a 6-bit 360 degree digital phase shifter will be utilized to move the normalized phase to 0 degree.

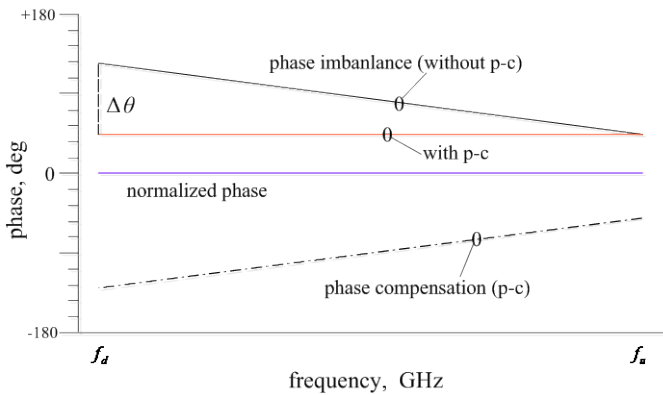


Fig. 7. Phase compensation

4.2 Amplitude phase consistency test

In order to verify the amplitude and phase consistency of MPM, two Ku-band 500W dual TWTs pulsed MPM products with phase compensation circuit are manufactured to verify the consistency performance in the working frequency band. Experimental results were shown in Figure 8 and 9. The amplitude coherence of different ports were less than $\pm 0.2\text{dB}$, and the phase imbalance of four output ports were less than ± 5 degree across the band. The RF output power and efficiency behavior versus frequency were given. The output power was greater than 550W with the efficiency of the MPM was higher than 45%. Table 3 displayed the summary of the measured performance of the Ku band MPM.

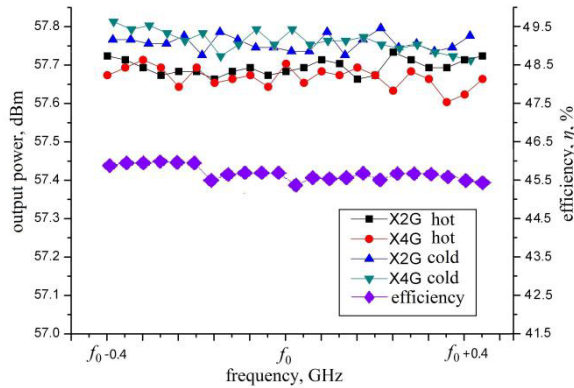


Fig. 8. Performance in thermal vacuum test

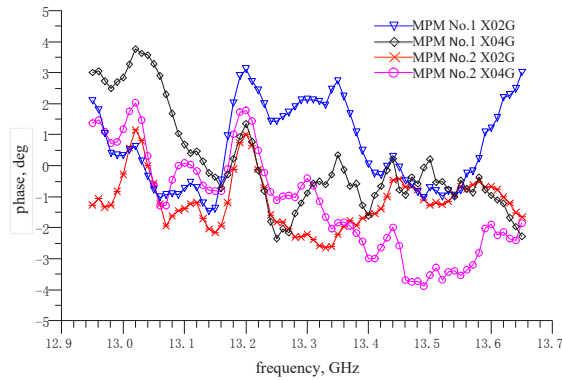


Fig. 9. Test result of phase coherence

Table 3. Main performance of MPM

Parameter	Performance
Operating frequency	Ku-band
Operating band width	≥600MHz
Gain flatness	≤0.3dB
Saturated gain	≥60dB
Peak power(single)	≥550W
Power efficiency	≥45%
Duty cycle	15% max.
Repeat frequency	3 kHz to 10kHz
Phase congruency	≤±5°
Random phase error	≤±2°
EPC related spurious modulation	≥55dBc
Pulse waveform drop	≤0.2dB
Bus voltage	38 to 45.5V
RF interface	Input: SMA Output: WR62
Mass	≤7.0kg

5 Conclusion

In this paper, a Ku-band 500W dual TWT pulsed MPM with high amplitude and phase consistency was proposed for aerospace SAR system, which has been in flight over two years. The mechanical structure model is established by ANSYS and PROE software, and the thermal mechanical design parameters are simulated and optimized to achieve efficient heat dissipation and ensure the long service life of MPM. The phase consistency compensation circuit was designed to improve the efficiency of power synthesis and the phase consistency of multiple sets of products. The design principle and parameter calculation for amplitude and phase consistency control are introduced in detail. The test results displayed that the circuit of amplitude phase consistency control and compensation method is simple, stable and universal. The phase compensation circuit proposed in this paper can be extended to the C-K frequency band, and has been applied to the development of power sources based on power synthesis in other frequency bands, laying a foundation for the practical application of wide-band power synthesis and amplitude phase consistency control of high-power pulse TWT amplifiers.

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