

DESIGN AND COLD-TEST OF AN S-BAND SPHERICAL PULSE COMPRESSOR FOR BEAM-TEST PLATFORM AT NSRL

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Abstract

To meet the requirement for high-peak-power S-band microwave pulses at the beam test platform of the National Synchrotron Radiation Laboratory (NSRL), a compact S-band spherical pulse compressor has been designed and fabricated. The compressor employs a dual-polarization mode coupler to excite two orthogonal operating modes in a single spherical resonant cavity, enabling dual-mode energy storage within a compact RF structure. The RF design, prototype fabrication, cold test, and tuning of the compressor are presented in this paper. Simulation results show good impedance matching and the expected power gain at the operating frequency. After tuning, the measured resonant frequency, coupling coefficient, unloaded quality factor, and power gain are 2998.2 MHz, 5.64, 99098, and 3.34, respectively, in good agreement with the design values. These results demonstrate the feasibility of the proposed S-band spherical pulse compressor for compact high-peak-power RF applications.

INTRODUCTION

RF pulse compression is an effective technique for converting long, low-peak-power microwave pulses into short, high-peak-power pulses, and has been widely used in linear accelerators and high-power microwave systems [1]. For beam test platforms, pulse compressors can provide higher RF peak power without a proportional increase in klystron output power, thereby reducing the cost and complexity of the RF power system.

Conventional SLED-type pulse compression systems generally employ two high- Q resonant cavities for energy storage. In comparison, a spherical pulse compressor can use two orthogonal polarization modes in a single spherical resonant cavity to realize dual-mode energy storage, which is equivalent to the function of two conventional cavities. This configuration offers several advantages, including a compact structure, high quality factor, and improved system integration [2]. Previous design and experimental studies of C-band spherical pulse compressors have demonstrated the potential of this scheme for compact high-peak-power RF systems [3, 4].

In this work, an S-band spherical pulse compressor is designed, fabricated, and cold-tested for the beam test platform of the National Synchrotron Radiation Laboratory (NSRL). The RF design of the pulse compressor is presented in the next section. The cold-test and tuning results are described subsequently, followed by a summary and outlook.

Table 1: S-band Spherical-Pulse Compressor RF Parameters

Parameter	Symbol	Value
Operating frequency	f_0	2998.2 MHz
operating mode	—	TE ₁₁₂
Input pulse width	τ_{in}	4 μ s
Output pulse width	τ_{out}	0.8 μ s
Compression ratio	C_r	5
Unloaded quality factor	Q_0	98700
Coupling coefficient	β	5.7
Peak power gain	G_{peak}	6.088
Average power gain	G_{avg}	3.35

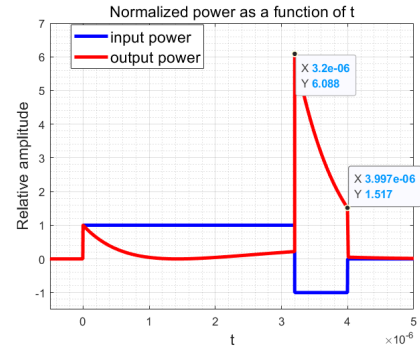


Figure 1: Theoretical waveform diagram of the pulse compressor performance.

RF DESIGN

The proposed S-band spherical pulse compressor consists of a dual-polarization mode coupler and a spherical resonant cavity. The input microwave is fed through a rectangular waveguide, converted into two orthogonal polarization modes in a circular waveguide, and coupled into the spherical cavity. During the filling process, the RF energy is stored in the two orthogonal modes. During the extraction process, the stored energy is released and combined with the phase-reversed incident wave, generating a compressed output pulse with higher peak power.

The design parameters were determined according to the requirements of the NSRL beam test platform. The operating frequency is 2998.2 MHz, the input pulse width is 4 μ s, the output pulse width is 0.8 μ s, and the target power gain is 3. The RF structure was optimized using HFSS, with emphasis on the resonant frequency of the spherical cavity, the excitation and frequency separation of the two orthogonal modes, and the impedance matching and coupling coefficient of the overall structure.

After optimization, the structure exhibits good impedance matching at the operating frequency. The two orthogonal op-

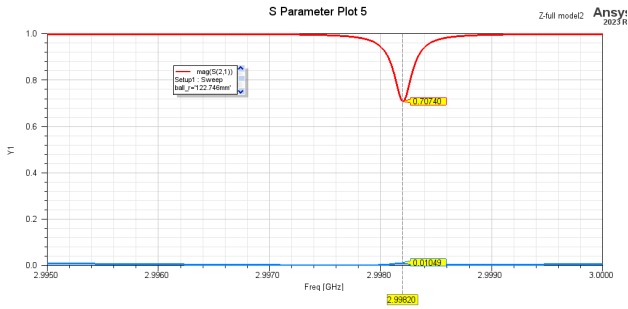


Figure 2: S-parameter curves of the optimized pulse compressor.

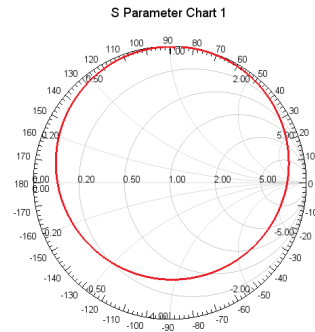


Figure 3: Smith chart of optimized pulse compressor.

erating modes are effectively excited in the spherical cavity. The simulated unloaded quality factor and coupling coefficient are 98700 and 5.7, respectively, corresponding to a calculated power gain of 3.35. The electric-field, magnetic-field, and surface power-flow distributions were also checked to evaluate the high-power performance. The results provide the basis for prototype fabrication and high-power experimental studies [5].

COLD-TEST AND TUNING

Based on the RF design, a prototype of the S-band spherical pulse compressor was fabricated. After fabrication, tuning and cold tests were carried out using a vector network analyzer. The measurements included the overall S-parameters, resonant frequency, coupling coefficient, unloaded quality factor, and the frequency separation between the two orthogonal polarization modes.

The initial cold-test results showed that the resonant frequency deviated from the design value due to fabrication errors, and a frequency separation existed between the two orthogonal polarization modes. The prototype was then

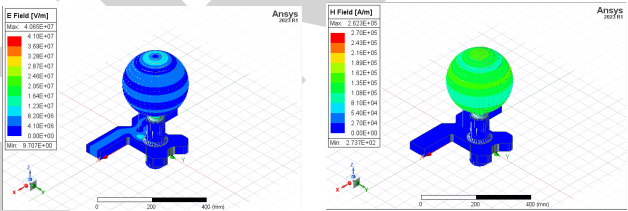


Figure 4: Simulated field distributions of the S-band spherical pulse compressor.

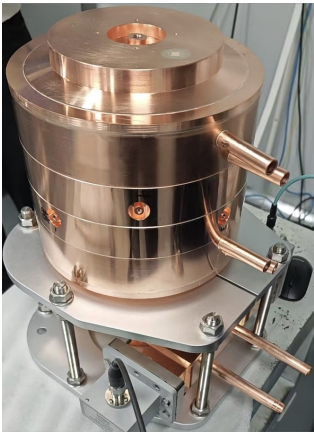


Figure 5: Pulse compressor after processing.

tuned to adjust the operating-mode frequency and compensate for the asymmetry between the two polarization modes, gradually bringing the structure close to the design condition.

After tuning, good impedance matching was achieved at the operating frequency, and the frequency separation between the two orthogonal polarization modes was significantly reduced. The coupling coefficient, unloaded quality factor, and power gain calculated from the measured S-parameters were 5.64, 99098, and 3.34, respectively, in good agreement with the simulation results. These results confirm that the prototype meets the main RF design requirements and provide a basis for subsequent high-power tests.

To further evaluate the pulse-compression performance of the fabricated S-band spherical pulse compressor, the

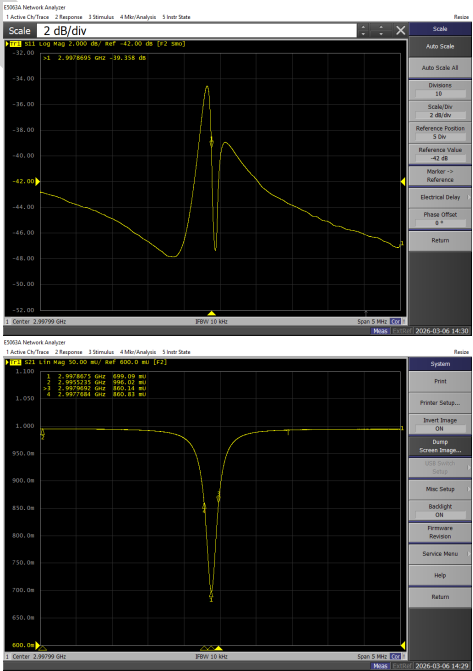


Figure 6: S-parameter curve after tuning of S-band spherical pulse compressor.

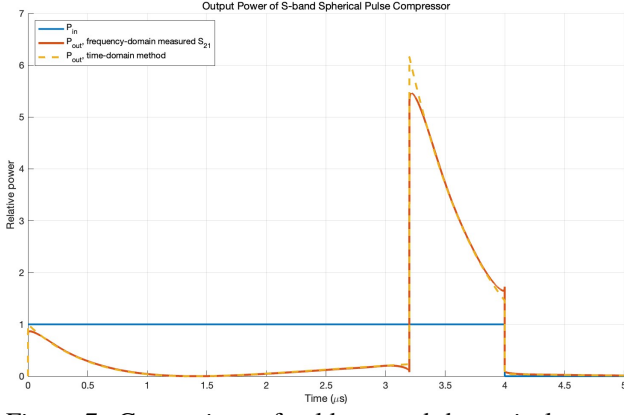


Figure 7: Comparison of cold-test and theoretical output waveforms of an S-band pulse compressor.

output waveform was reconstructed from the measured cold-test transmission coefficient. Let $F(t)$ and $G(t)$ denote the input and output waveforms in the time domain, respectively. Their corresponding incident and transmitted waves in the frequency domain are denoted by $a_1(f)$ and $b_2(f)$. Using the Fourier transform, the input spectrum can be written as

$$a_1(f) = \int_{-\infty}^{\infty} F(t) e^{-i2\pi ft} dt. \quad (1)$$

The output spectrum is then obtained by multiplying the input spectrum by the measured complex transmission coefficient $S_{21}(f)$,

$$b_2(f) = a_1(f) S_{21}(f). \quad (2)$$

Finally, the output waveform in the time domain is reconstructed by the inverse Fourier transform,

$$G(t) = \int_{-\infty}^{\infty} b_2(f) e^{i2\pi ft} df = \int_{-\infty}^{\infty} a_1(f) S_{21}(f) e^{i2\pi ft} df. \quad (3)$$

Based on the measured cold-test S_{21} curve, the actual output waveform of the S-band spherical pulse compressor was calculated and compared with the theoretical waveform. As shown in Fig. 7, the dashed curve represents the theoretical result, while the solid curve represents the waveform reconstructed from the measured S_{21} . The reconstructed waveform shows a compressed output pulse with good agreement with the theoretical prediction, indicating that the fabricated prototype achieves the expected pulse-compression behavior.

CONCLUSION

An S-band spherical pulse compressor has been designed, fabricated, cold-tested, and tuned for the NSRL beam test platform. By using a dual-polarization mode coupler and a single spherical resonant cavity, dual-mode energy storage is achieved in a compact structure. RF simulations indicate good impedance matching and the expected pulse compression performance at the operating frequency. The measured resonant frequency, coupling coefficient, unloaded quality factor, and average power gain after tuning agree well with the design values. Future work will focus on high-power tests to verify the performance of the compressor in the beam test platform RF system.

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