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CLIC Note 556

30 GHZ RF PULSE STRETCHER FOR CTF2

H.H. Braun, S. Döbert, P. Gu, I. Syratchev, I. Wilson, W. Wuensch

Abstract

A 30 GHz pulse stretcher was designed, manufactured, tuned, and installed within a period of about two months and was successfully used in CTF2 to investigate the pulse length dependence of maximum achievable surface gradient in one of the copper 30 GHz accelerating structures.

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A 30 GHz pulse stretcher was designed, manufactured, tuned, and installed within a period of about two months and was successfully used in CTF2 to investigate the pulse length dependence of maximum achievable surface gradient in one of the copper 30 GHz accelerating structures.

INTRODUCTION

The CTF2 operated for most of the time in 2002 as a high-gradient test stand for the development of 30 GHz accelerating structures. The nominal CLIC gradient is 150 MV/m. This high gradient is necessary to limit the length, and in consequence, the cost of the linacs but is very ambitious when compared to present day accelerators which run typically at gradients of around 25 MV/m. The confidence that such high gradients could be achieved was shaken three years ago when substantial damage of the copper surfaces of prototype 30 GHz accelerating structures was discovered after operating them in CTF2 at gradients of only 70 MV/m for pulse lengths of only 15 ns. The CLIC nominal pulse length is 130 ns, and the achievable gradient is expected to decrease with pulse length. Three years later, after a vigorous program of R&D, a novel 30-cell structure reached an average accelerating gradient of 125 MV/m in CTF2 with a peak gradient in the first cell of 150 MV/m when powered with 15 ns pulses, and on inspection was found to be undamaged. The irises (the place where the electric field is highest) were made from tungsten, a material with a high melting point that is reknowned for its resistance to damage from arcing. This same gradient has now to be demonstrated for a pulse which is almost ten times longer, and this will not be possible until CTF3 comes on line. In the mean-time, it was decided to build a 30 GHz pulse stretcher for the last run of CTF2 in 2002 to lengthen the available RF pulse from 15ns to 30 ns.

1 PRINCIPLE OF OPERATION

The layout of the pulse stretcher is shown in Fig. 1. It is very similar to SLED II [1]. The only difference is that the reflected and first round-trip (RT) signals are designed to be equal in amplitude and in phase. This is done by a proper choice of the iris reflection and the RF phase length of the delay lines.

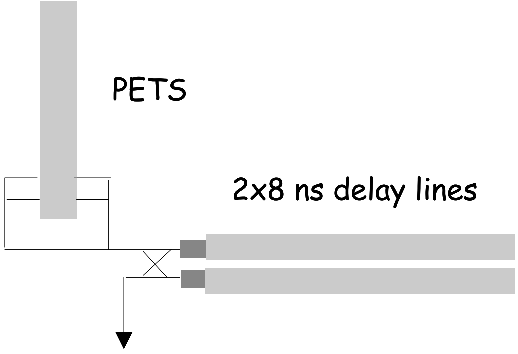


Figure 1. Schematic drawing of the pulse stretcher.

To equalize both amplitudes, the relationship between reflection coefficient "*s*" and the RT loss "*A*" in the delay lines should be as follows:

$$A = \frac{s}{1-s^2}, \qquad A = \exp(-2\alpha L) \quad (1),$$

where L is the length of the delay line and α is the attenuation. The RT efficiency (A^2) for different types of waveguides at 30 GHz is shown in Fig. 2. To minimize the production cost of the delay lines and RF components, it was decided to use a standard rectangular waveguide WR34 with an estimated efficiency A^2=0.68. To provide a 16 ns time delay, the total length of the single line was 1.97 m. Following (1), the reflection coefficient was chosen to be 0.56, see Fig. 3.

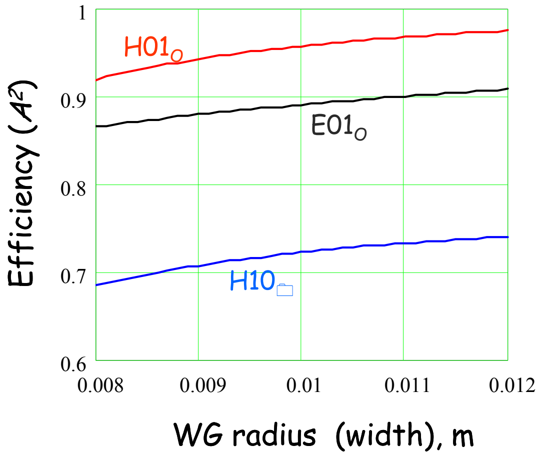


Figure 2. RT efficiency for different types of waveguides.

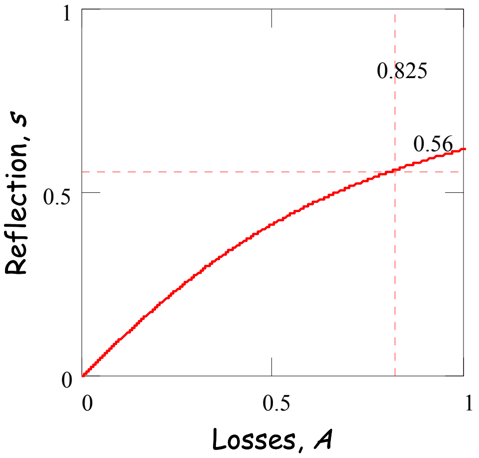


Figure 3. Reflection vs. RT loss.

The shape of the stretched pulse is shown in Fig. 4. The calculated efficiency of the pulse stretcher was 60%, including losses in all the components. This will provide a peak power of about 60 MW with a pulse length of 32 ns.

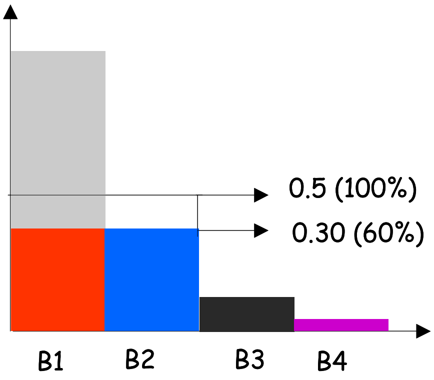


Figure 4. The shape of the stretched pulse.

To provide equal phases of the reflected and delayed parts of the pulse the length of the delay lines should be:

$$L = \frac{N\lambda_{WG}}{2} + \frac{\lambda_{WG}}{4} \quad (2).$$

(If this device were to be used as a compressor, the length of the delay line would be equal to an even number of half-wavelengths).

2 RF COMPONENT DESIGN

A 30 GHz 3-dB planar hybrid was developed (see Fig. 6) for this application. The design is similar to X-band NLC designs [2]. The electric field pattern in such a device is shown in Fig. 5. The S-parameters of the hybrid, shown in Fig. 7, were optimized with HFSS. The reflection coefficient of the inductive iris in the rectangular waveguide was also optimized with HFSS – see Fig.8.

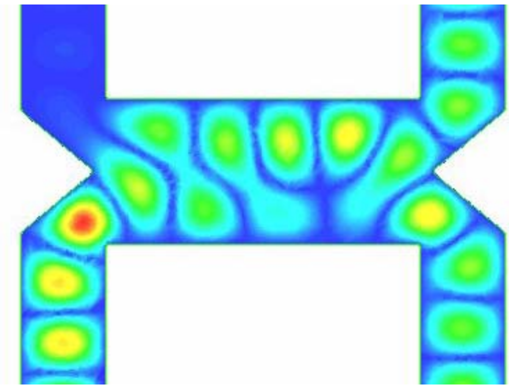


Figure 5. Electric field in 3 dB hybrid.

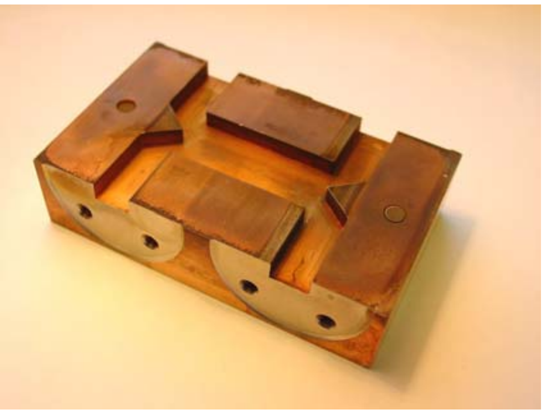


Figure 6. General view of the hybrid.

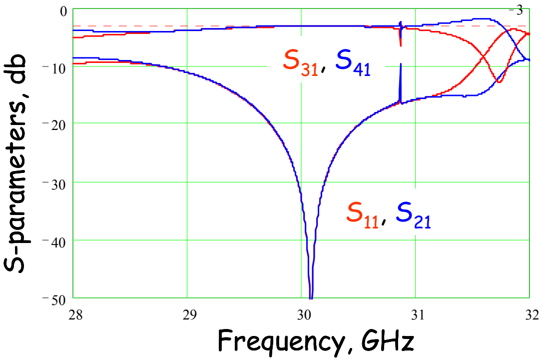


Figure 7. S-parameters.

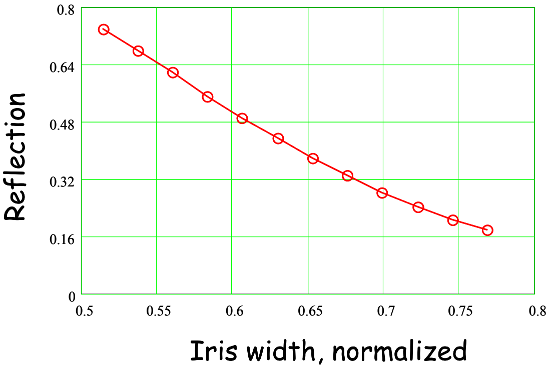


Figure 8. Reflection vs. normalized width.

3 PULSE STRETCHER TUNING

The pulse stretcher tuning was done into several steps. After measurements of the actual decay (-2.5 dB) and the delay (16.4 ns) of the single line, the reflection coefficient was re-adapted. The new values were: $A^2 = 0.563$ and $s = 0.535$. The hybrid showed a little imbalance (about 0.2 dB), however the matching remained within an acceptable level, less than – 25 dB. Finally the lengths of the delay lines were adjusted to provide synchronous RF phases of the reflected and delayed pulses. This was done by tuning the steady state transmission losses to a local minimum. Fig. 7 (left) shows the initial spectrum of the pulse stretcher. Fig. 7 (right) shows the spectrum after tuning. Note, that if the device were to be used as a compressor the tuning would be done to the local maximum. The shapes of the stretched pulse measured at a low RF power level are shown in Fig. 8 and Fig. 9. The measured efficiency was 57% (3% less than the design value).

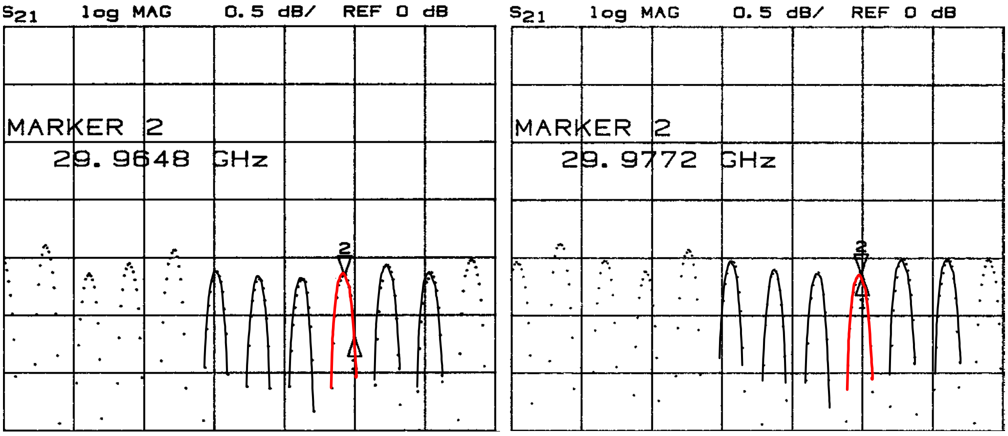
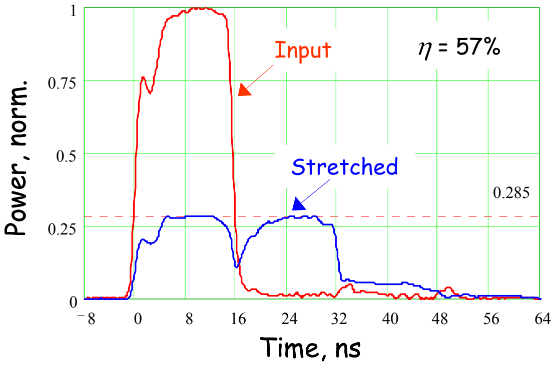


Figure 7. Spectra of the pulse stretcher before (left) and after (right) tuning of the delay line lengths.



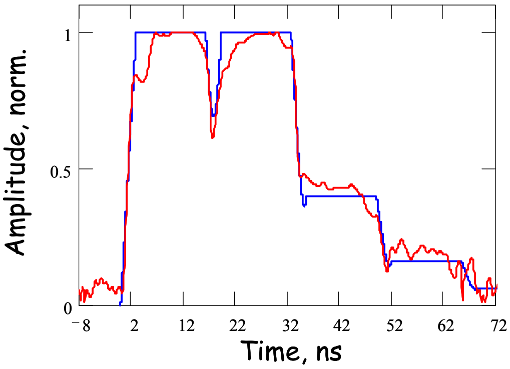


Figure 8. The shape of the stretched pulse measured at a low power level

Figure 9. Measured (dotted) and simulated (solid) envelopes of the stretched pulse.

4 HIGH POWER TESTS

The pulse stretcher was installed in CTF2 - see Fig. 10. A typical shape of a stretched pulse at high power is shown in Fig. 11. It clearly shows that the delay lines were properly tuned.

5 CONCLUSION

The pulse stretcher was designed, manufactured, tuned, and installed within a period of about two months and was successfully used in CTF2 to investigate the pulse length dependence of maximum achievable surface gradient in one of the copper 30 GHz accelerating structures.

6 REFERENCES

[1] P. B. Wilson, Z. D. Farkas, R. D. Ruth, "SLED II: A New Method of RF Pulse Compression", presented at the Linear Accelerator Conference, Albuquerque, New Mexico, September 1990; SLAC-PUB-3694;

[2] C. Nantista, W. R. Fowkes, N. M. Kroll, S. G. Tantawi, "Planar Waveguide hybrids for Very High Power RF", SLAC-PUB-8142, May 1999

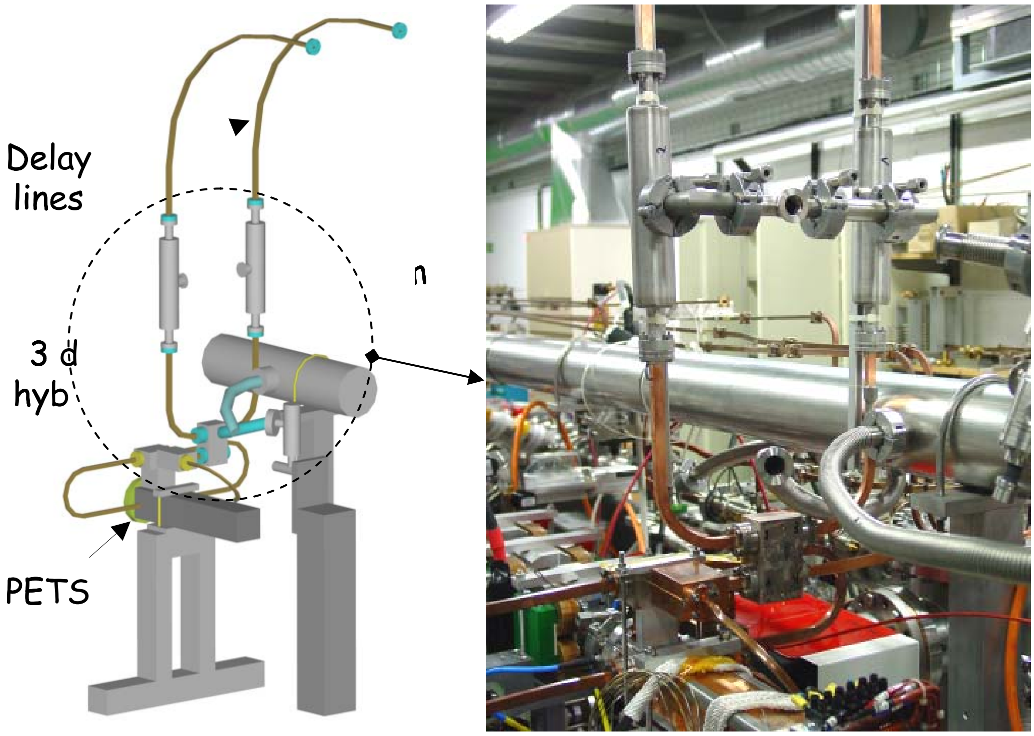


Figure 10. Pulse stretcher layout in CTF2.

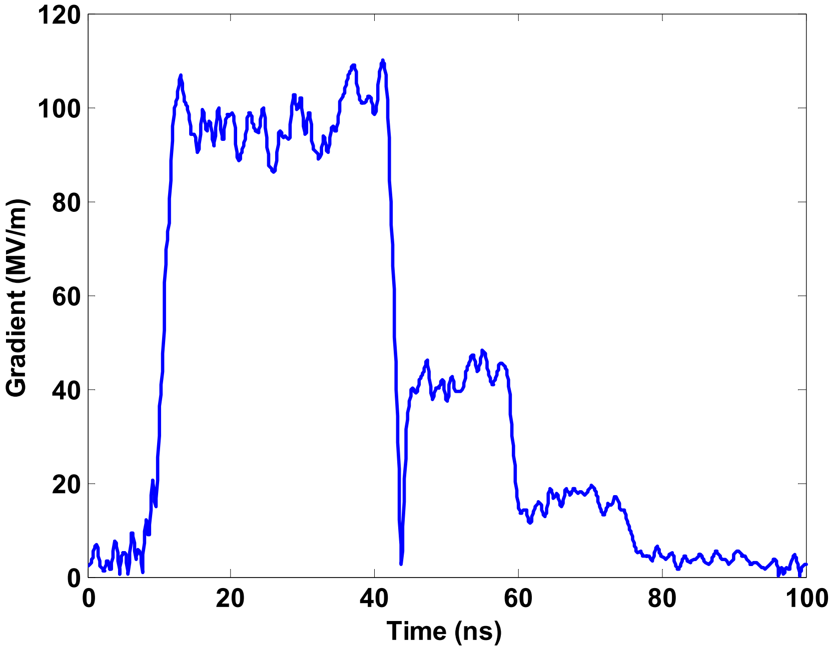


Figure 11. Measured envelope of the stretched pulse in CTF2.