Model Work on a Transfer Structure for CLIC

L. Thorndahl
CERN, 1211 Geneva 23, Switzerland

Abstract

The structure is needed to produce for acceleration in the CLIC (CERN linear collider) main linac [1] 12 ns, 30 GHz and 40 MW RF pulses. The structure input is four trains (spaced by 2.84 ns) of 11 drive bunchlets (10^{12}e, $\sigma < 1$ mm) separated by 33.3 ps. A novel concept based on a smooth beam chamber with coupling holes into waveguides and the TEM wave associated with the drive beam bunchlets is proposed and analysed in scale models. The TEM wave is simulated with transmission lines. The structure response is measured in the frequency domain and then multiplied with the bunchlet spectrum, yielding via a subsequent inverse Fourier Transform, the amplitude and phase versus time of the resulting 30 GHz pulse.

INTRODUCTION

The non-availability of 30 GHz power tubes with appropriate power levels (~ 100 MW) for achieving acceleration in colliding linacs has prompted the use of two-beam accelerators (TBA). In a TBA a primary (or drive) beam of relatively high current and relatively low energy is used to produce the necessary high frequency power for accelerating the secondary (or driven) high energy, low current beam. The high frequency radiation is generated during the interaction of the primary beam with some "extraction" structure. The properties of the CLIC drive beam have been discussed in detail elsewhere [2] and so this paper will be concerned primarily with the results of studies of the extraction cavity, or CLIC transfer structure (CTS).

It is intended that the CLIC drive beam will be fully relativistic (~ 5 GeV) and accelerated at 350 MHz using superconducting cavities such as those planned for LEP. Generation of the desired 30 GHz power for the secondary beam will be by direct deceleration of the tightly bunched ($\sigma_z < 1$ mm) primary beam in the CTS. A fundamental requirement of the CTS is that it should exhibit a very low shunt impedance [2].

A first version [3] [4] with an aperture of 4 mm was studied both with MAFIA codes and model measurements but had to be abandoned because of its high transverse and longitudinal resistive wall impedances. To reach acceptable impedances it was considered necessary to increase the aperture to at least 12 mm[1] with the unavoidable disadvantage of overmoded beam chamber.

DESCRIPTION OF A NEW CTS

The structure shown in Fig. 1 consists of a smooth round beam chamber containing coupling holes (at constant spacing, in the beam direction) into four rectangular waveguides. The TEM wave accompanying bunchlets has radial electrical fields and azimuthal magnetic ones at the holes causing constructive excitation of the TE_{10} backward mode in the waveguide (useful output) and non constructive excitation of the forward mode (not useful, terminated). The backward outputs from all four waveguides are intended for the acceleration in four modules of the main linac. The excitation of TE modes in the beam chamber is avoided by situating coupling holes always by pairs in symmetry with respect to the chamber axis.

The launching of TM_{01} backward waves is suppressed by offsetting in the beam direction by $\lambda/4$ the coupling holes of the top and bottom waveguides with respect to those on the left and right hand sides. Though there is no cancellation of TM_{01} forward waves, they are believed to be small in amplitude.

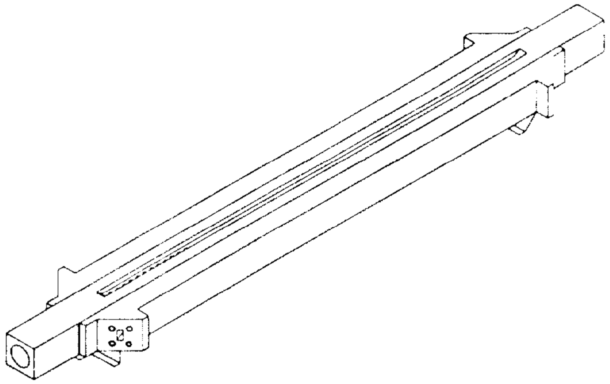

Figure 1 CTS with round beam chamber 16 mm Ø in the middle. The groove at the top is the TE_{10} waveguide with coupling holes into the beam chamber. The lids of the three other channels and an output flange are visible.

PRINCIPLE

The requirement that the structure should work as a "pulse stretcher" by extracting from a train of 11 bunchlets (lasting 333 ps) an RF pulse lasting 2.84 ns is met by using a backward wave in the waveguide as shown in Fig. 2 where a single bunchlet is followed as it crosses the structure. In the case of 11 bunchlets there is constructive superposition of 11 successive RF waves in the waveguide spaced in time by one RF period (33.3 ps) to create a rising flank (333 ps), a flat

---

[1] longitudinal/transverse impedance scales approximately with the inverse linear/inverse cube of the aperture size.

0-7803-0135-8/91$03.00 ©IEEE

top (2.5 ns) and a falling flank (333 ps) for the output pulse. Four successive pulses create a global pulse approximately 11 ns long to fill a module of the CLIC main linac.

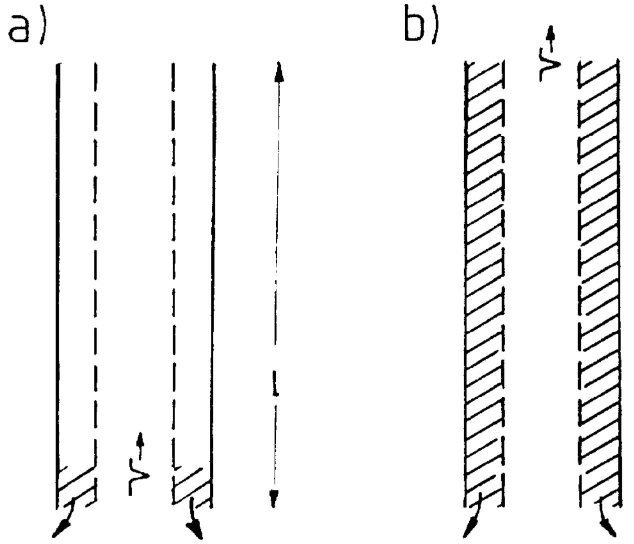

Figure 2 a) Arrival of a bunchlet at the structure. The waveguide is immediately energized and yields output power.
b) The bunchlet exits the structure ℓ/c later leaving the waveguide energized over its full length ℓ. It then empties in ℓ/β_{gr} c.
Total pulse length: $T = \ell/c(1 + 1/\beta_g)$
β_g: normalized group velocity in the waveguide.

There is a linear build-up through constructive interference of a wave sample in the waveguide as it experiences the first bunchlet through the Nth hole then the second through N-1th hole and so on up to the 11th bunchlet through the N-10th hole. The condition for constructive interference with a backward wave is:

$$\phi_b + \phi_w = 2\pi \qquad (1)$$

where ϕ_b is the spatial phase of the first longitudinal beam harmonic (at 30 GHz) and ϕ_w the phase advance of the waveguide TE_{10} mode between holes.

Phase diagram (Brillouin)

Figure 3 gives a simplified qualitative phase diagram of the CTS. The hole spacing (cell length)is chosen to fulfill the condition of constructive interference (1), as indicated by the two horizontal arrows at 30 GHz.

The two dotted arrows at about 27 GHz give the condition for constructive interference between the backward TM_{01} wave in the beam chamber and the forward TEM wave of the bunchlets.

The cut-offs of the TM_{02} and TM_{21} modes are situated above 30 GHz, the quadrupolar TM_{21} being the first one driven by the four-waveguide arrangement (but below cut-off).

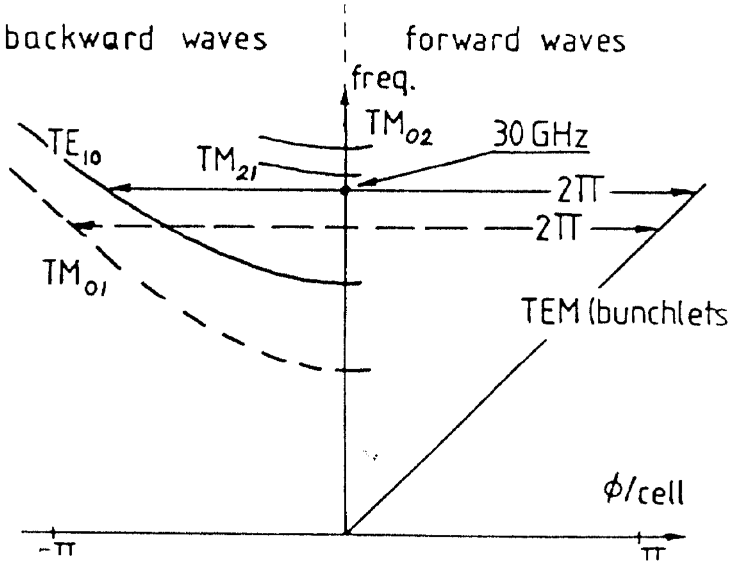

Figure 3 Simplified phase diagram for infinitely small coupling holes

MEASUREMENTS

The TEM fields of the bunchlets are simulated by two transmission lines situated near the top and bottom of the beam chamber so that their characteristic impedance is 50Ω. The lines powered in phase create at the hole positions, for a given total current on the two lines, TEM fields smaller by 24.2 dB than the same beam current situated in the middle of the chamber (See Fig. 4.). (The factor 24.2 dB was found with a separate two-dimensional resistive paper analog model.)

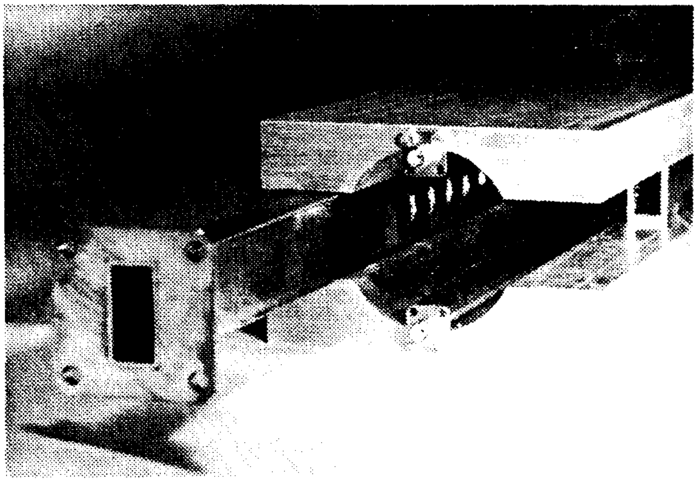

Figure 4 Simplified scaled CTS analog model with only two waveguides. TEM waves are excited with 50Ω transmission lines at top and bottom. Dimensions are larger by a factor 3.33. The operating frequency is thus 9 GHz. Hole diameter: 10.5 mm, hole spacing: 20 mm, 57 holes/waveguide, average beam chamber diameter: 53 mm.

This arrangement allows a network analyser measurement of the frequency response of the CTS, the output signal being the backward wave from the waveguide. (See Fig. 5.)

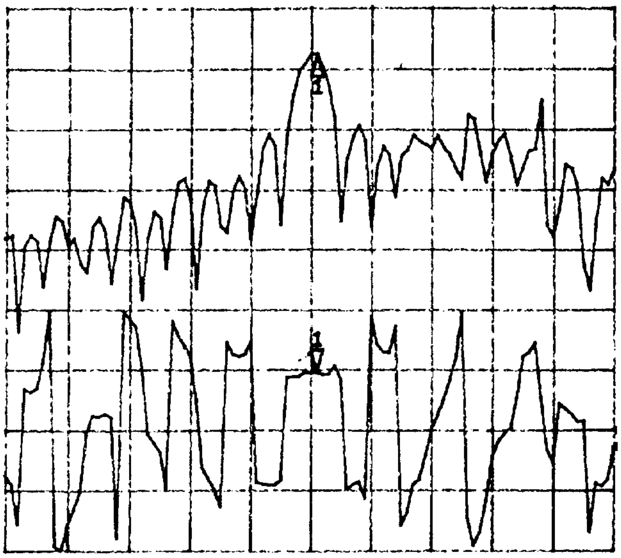

Figure 5 Frequency response of CTS model. Amplitude 10 dB/div. and phase 90°/div. Centre frequency 8.875 GHz, 0.2 GHz/div.

The TEM wave (from say the first bunchlet) scattering on the two rows of coupling holes inside this model creates in the beam chamber a TM_{01} backward wave containing about the same measured energy as the wave in one waveguide. This TM_{01} wave is detrimental since it interacts with the following bunchlets, creating an unwanted energy exchange. It can be suppressed by using two pairs of waveguides with coupling holes offset by $\lambda/4$, as described in the introduction and shown in Fig. 1.

Frequency scaling the measured CTS model response (9→30 GHz) and multiplying with the Fourier transform $F_b(f)$ of 11 gaussian pulses spaced by $t_0 = 33.3$ ps, charge $g = 160$ nC and $\sigma = 4$ ps,

$$F_b(f) = g e^{-2\pi\sigma^2 f^2} \sum_{N=1}^{11} e^{-2j\pi N f t_0} \qquad (2)$$

the CTS output spectrum can be calculated with an online desktop calculator.

By applying a subsequent inverse Fourier transform to the output spectrum we obtain the output pulse as a function of time, essentially a 30 GHz oscillation with a phase varying slightly with respect to an ideal 30 GHz source. (See Fig. 6.)

CONCLUSIONS

The model work and [5] show that the specified power level of 40 MW can be achieved with a simple CTS based on a smooth round chamber with coupling holes into parallel adjacent waveguides. Further work on the energy conversion efficiency and the influence of forward TE_{01} waves should by done.

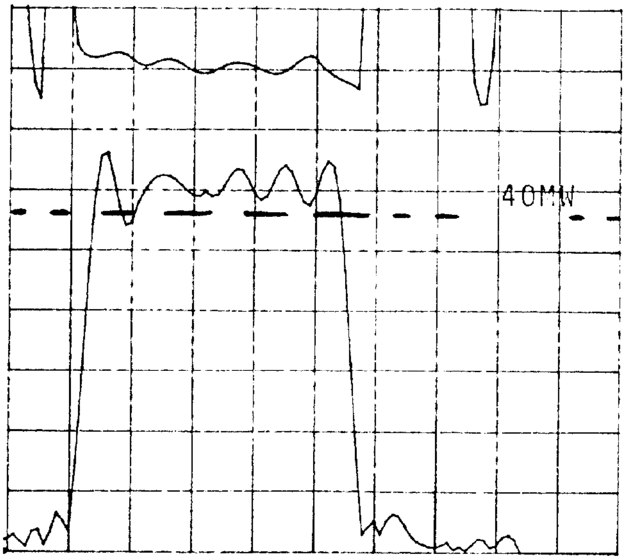

Figure 6 RF phase (20°/div) and amplitude (Amps into 50Ω, 160 A/div) of a CTS pulse caused by four trains of 11 bunchlets. The integration bandwidth for the inverse Fourier transformation is 1 GHz, corresponding approximately to the bandwidth of the driven main linac structure. The amplitude corresponding to the nominal 40 MW is indicated. Time scale 3.2 ns/div.

ACKNOWLEDGEMENTS

E. Jensen suggested the use of the backward TE_{10} wave instead of the forward one that required more structure length with more output pulse distortion. W. Wuensch solved the problems caused by the backward TM_{01} wave in the beam chamber with the proposal to annul it by having four parallel waveguides instead of two. G. Carron and C. Achard helped with model and drawing work. P. Martucci edited and typed the manuscript. Thanks to E. Jensen, W. Schnell, I. Wilson and W. Wuensch for many discussions.

REFERENCES

[1] W. Schnell, "The study of a CERN linear collider, CLIC", CERN-LEP-RF/88-48, presented at the Linear Accelerator Conference, Williamsburg, October 1988.

[2] W. Schnell, "A two-stage RF linear collider using a superconducting drive linac", CERN-LEP-RF/86-06, February 1986.

[3] T. Garvey *et al.*, "Studies of a frequency scaled model transfer structure for a two-stage linear collider", Proc. New Developments in Particle Acceleration Techniques (ED. S. Turner), CERN 87-11, Orsay, 1987.

[4] T. Garvey *et al.*, "A radio-frequency transfer structure for the CERN Linear Collider", CERN-LEP-RF/89-25 and CLIC Note 92.

[5] E. Jensen, "Design calculations of the CLIC Transfer Structure", this conference.