

## DESIGN OPTIONS FOR THE RF DEFLECTOR OF THE CTF3 DELAY LOOP

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### Abstract

Injection and extraction of bunch trains in the CTF3 Delay Loop for the recombination between adjacent bunch trains is performed by a specially designed RF deflector. A standing wave structure has been chosen. Three possible solutions have been studied and designed, and a comparative analysis is presented. All of them satisfy the essential requirements of the system up to the maximum foreseen energy with the existing klystron.

### INTRODUCTION

The process of bunch train compression in the DL is illustrated in Fig. 1 and more details can be found in [1].

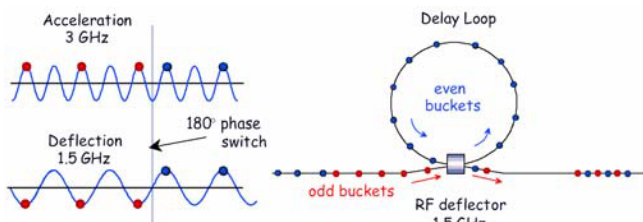


Figure 1: Sketch of the bunch frequency multiplication in the CTF3 Delay Loop.

Even and odd trains are deflected by kicks of the same amplitude but opposite sign. Only the even trains are injected into the ring so they are delayed to interleave the following odd train.

The frequency of the Delay Loop deflector (1.4995 GHz) has to be half the linac frequency as described in Fig 1. Other design parameters are the required deflecting angle, which is about 15 mrad, the maximum beam energy (300 MeV) and the RF power that the klystron can provide to the deflecting structure. The klystron is already available and its output power is 20 MW.

According to these specifications, a travelling wave (TW) type deflector should be a structure about 1.5 meter long, but this is not compatible with the available space and the large angles of the beam trajectories. So the adoption of a standing wave (SW) solution is necessary. In fact, the efficiency (i.e. the deflection obtainable with a given RF power) per unit length is higher for SW than for TW structures.

The major drawback of this choice is due to the fact that the voltage filling time of a resonant cavity is generally slow if compared to the RF pulse length (5µs). So the deflecting field is not constant during the passage of the train in the cavity and different bunches in the train sees different kicks. In order to reduce this spread of deflection angle between the head and the tail of the train, the Q of the cavity has to be reduced and this can be done externally loading the resonator. In Fig. 2 it is shown the time domain response of the cavity to a step pulse of 5µs.

The cavity Q is about 3000. The length of the train of bunches is also indicated and the resulting voltage spread is less than 1%, that is considered an acceptable value [2]. On the other hand it is not possible to further decrease the value of Q. Beyond a certain threshold the shunt impedance become too low and the field intensity in the cavity is no more sufficient to give the required angle to the beam.

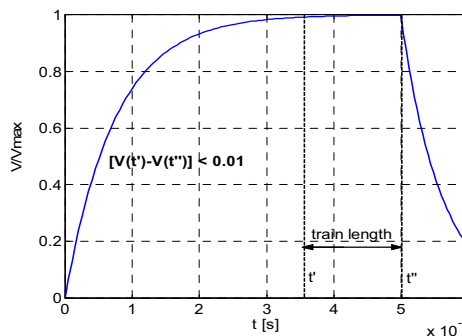


Figure 2: Cavity voltage as a function of time.

### POSSIBLE SCHEMES

Three possible solutions of a SW defector have been studied and their layouts are schematically represented in Fig. 3.

The first solution considered is the most standard one. A single cavity is excited through a coupling hole. The hole dimensions set the external Q of the cavity and its filling time as a consequence. A circulator has to be foreseen to protect the klystron from the power reflected at the cavity input.

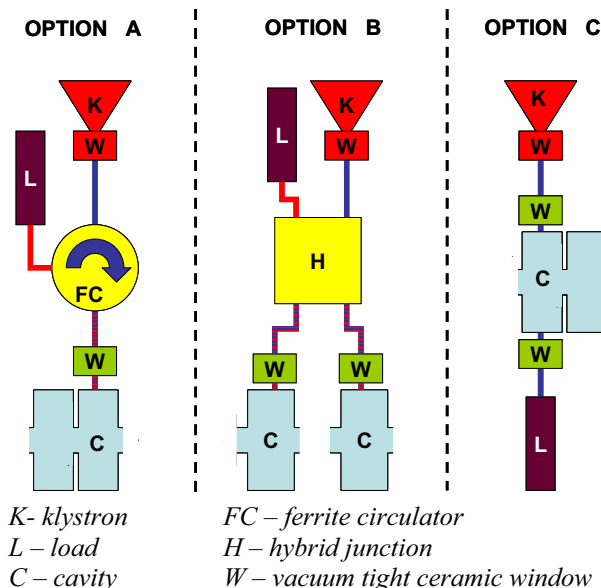


Figure 3: The three different options considered.

The second solution is based on the SLED principle used in the linac technology [3] and consists of two cavities coupled through a hybrid junction. The power reflected by the cavities adds out of phase at the klystron port of the hybrid, so there is no need of circulator and in phase at its fourth port, where it is dissipated on an external load. The two cavities system is also more efficient for a factor  $\sqrt{2}$  unless to use a double cell cavity in the previous scheme.

Finally, as third solution, a double cell cavity again is considered, but provided with two coupling holes of different size. On the side of the larger hole is connected the klystron, while on the other side is connected a load.

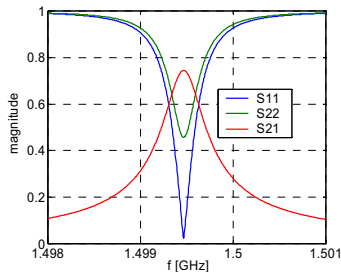


Figure 4: Scattering parameters of the option C cavity.

Tuning separately the size of the two holes it is possible to have no reflection at the klystron port for a pure sinusoidal excitation. In Fig. 4 it is shown that the reflection parameter  $S_{11}$  at the klystron port (blue line) is zero at the working frequency, therefore the input coupling coefficient is  $\beta=1$  in this case. At the same time the desired value for  $Q$  ( $\sim 3000$ ) has been obtained.

Each of the three structure proposed seems to be able to satisfy the essential requirements of the system. Driving the deflectors with the already commissioned klystron, the right angle of deflection can be obtained for beams of energy up to twice the nominal energy.

### SCHEMES EVALUATION AND THEIR COMPARISON

Another problem, arising with standing wave structure in this kind of utilization, is due to the RF power reflected at the cavity input back to the klystron. The need to over-couple the cavity ( $\beta > 1$ ) implies that the reflection coefficient is different from zero for the options A and B. In the examined case with  $\beta=5.6$ , the reflection coefficient is  $\rho=0.7$ , i.e. the 49% of the incident power is reflected back.

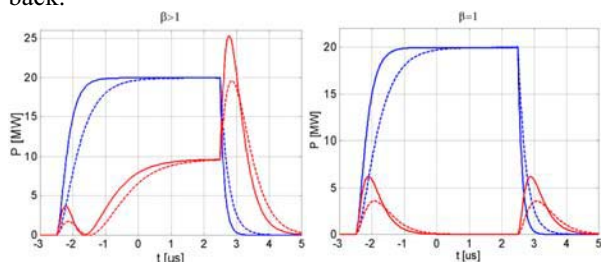


Figure 5: Time domain cavity response to a step input. Left:  $\beta > 1$ ; Right:  $\beta = 1$ . (Blue – RF input pulse. Red – cavity reflected power).

Moreover, when used in pulsed regime, the level of the reflected RF power is not a constant during the pulse length. Peaks of reflections are present correspondently to the transients of the pulse. The height of this peak depends on the loaded  $Q$  of the cavity and on the pulse rise time.

Fig. 5 shows the time dependence of the RF reflected power for two arbitrary slopes of the input pulse. This behavior is illustrated for both the cases  $\beta > 1$  (option A and B) and  $\beta = 1$  (option C).

The klystron needs to be isolated respect to this reflected power and, according to a conventional scheme, this is generally done by the use of a circulator. The first proposed solution is based on this scheme. Since the circulator is an expensive device it is preferable, if possible, choosing one of the two remaining options.

In the scheme of option C the amount of reflected power is considerably lower than in the other two, but, even with very slow rise time, the peak of reflections are scarcely below the tolerable klystron threshold. It has been considered too hazardous for the system reliability that the klystron was subjected to these repeated stresses; therefore this solution has been rejected.

On the contrary, in the scheme examined as second option, the reflected power cannot reach the klystron and it is dissipated on a load. From this point of view the hybrid junction has the same function of the circulator.

Finally, although two ceramic windows are necessary in this scheme instead of one, they can be dimensioned to be able to support half of the RF power respect to the scheme of option A.

From all these considerations the solution proposed as option B appears very promising and it has been decided to develop it more in detail.

### DEFLECTOR DESIGN

#### The cavity design

The cavity is externally coupled to a rectangular waveguide (WR650, the same standard of the klystron output) through a hole. The hole dimensions set the input coupling coefficient  $\beta$  and they have been chosen to obtain the wanted cavity loaded  $Q$ .

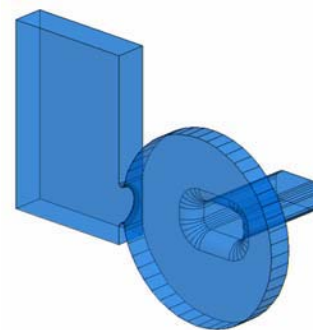


Figure 6: HFSS simulation: the loaded cavity geometry.

In Fig. 6 the geometry, which models the cavity coupled to the waveguide, used as input for HFSS [4] simulations is shown. From simulation results it is

possible to calculate the deflecting field seen by a particle crossing the cavity gap. In Fig.7 it is shown a representation of the magnetic field on the middle symmetry plane of the structure. The cavity, fed from the waveguide, resonates in the deflecting working mode, the  $TM_{110}$ .

Parasitic modes of the cavity can be excited by the beam. Apposite simulations have proved that the resonant frequencies of the modes most dangerous for the beam dynamics (monopoles and dipoles) are far enough from the lines of the beam power spectrum.

In particular, the vertical polarization of the  $TM_{110}$  results more than 40MHz apart from the horizontal one as it is visible in Fig. 8.

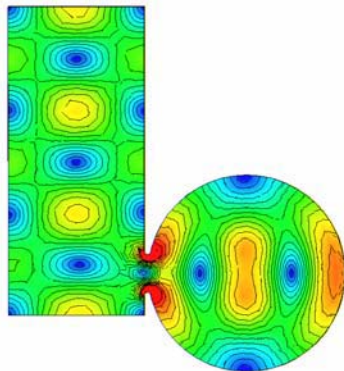


Figure 7: H field configuration of the  $TM_{110}$  mode in the deflecting cavity and in the feeding waveguide.

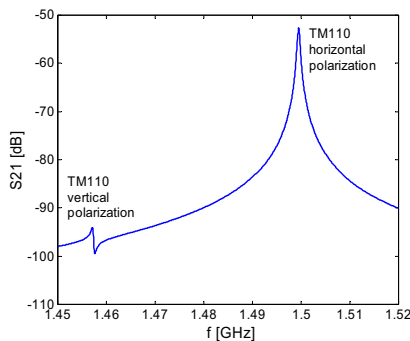


Figure 8: HFSS results: resonant frequencies of the vertical and horizontal polarization of the  $TM_{110}$  mode.

### The whole deflector design

The following step it has been to design a hybrid 3 dB coupler having well balanced outputs, no reflections at the input and a decoupled fourth port.

The hybrid splits the power coming from the klystron in equal parts at the two ports connected to the cavities. The phase relation between the voltages at these two ports is  $90^\circ$ , so the cavities are fed  $90^\circ$  out of phase each other. Then the cavities have to be placed an odd multiple integer of  $\lambda/4$  of the RF wavelength apart along the beam line in order that the kicks they deliver to the beam sum up in phase. For reasons of space the distance between the gaps has been chosen 250mm, i.e.  $5/4\lambda_{RF}$ .

Finally the feasibility of this innovative solution has been checked by means of simulations with HFSS code. Fig. 9 shows the full geometry used in the simulations.

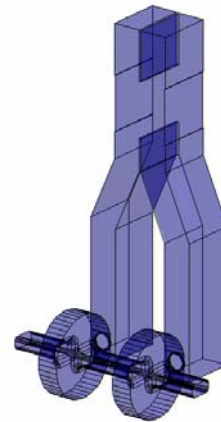


Figure 9: Model of the whole deflector structure.

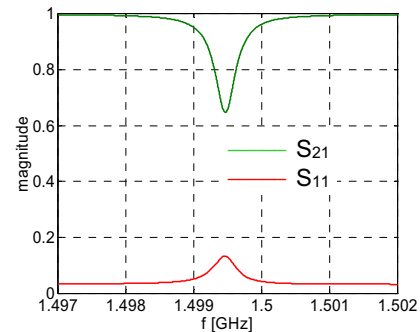


Figure 10: HFSS results: deflector frequency response; (Red – reflection at the klystron port. Green – transmission between klystron and load ports).

In Fig. 10 are reported the results concerning the frequency response of the whole deflector structure. The peak in transmission (see  $S_{21}$  curve) between klystron and load ports is due to the power dissipated into the structure, while the not completely flatness of the reflection response ( $S_{11}$ ) is probably caused by some small residual mismatches. However the effect of these mismatches is below the threshold reported in the klystron data sheet.

## CONCLUSIONS

Three different schemes to realize the RF deflector of CTF3 Delay Loop has been considered, studied and compared. The chosen solution fulfils all the requirements; first of all, it is able to provide the large angle of deflection needed and it has a bandwidth large enough for responding rapidly to the klystron pulse. Furthermore, the novelty of the idea makes the design very interesting and stimulating.

## REFERENCES

- [1] "CTF3 Design Report", CERN PS 2002-008 (RF), Geneve, (2002).
- [2] D. Alesini, F. Marcellini, "Beam Loading in the RF Deflector of the CTF3 DL", proc. of this conference.
- [3] Z. D. Farkas et al, "SLED: A Method of Doubling the SLAC's Energy", SLAC-PUB-1453 (1974).
- [4] <http://www.ansoft.com/products/hf/hfss/>.