FAST L-BAND WAVEGUIDE PHASE SHIFTER*

S. Kazakov[1,2], V.P. Yakovlev[1,3], S. Shchelkunov[4], A. Kanareikin[5], E. Nenasheva[6], J.L. Hirshfield[1,4]
[1]Omega-P, Inc., New Haven, CT 06511, USA
[2]KEK, Tsukuba, Ibaraki, 305-0801, Japan,
[3]Fermi National Accelerator Laboratory, IL, USA
[4]Physics Department, Yale University, New Haven, CT 06520, USA
[5]Euclid Techlabs LLC, Solon, OH 44139. USA
[6]Ceramics Ltd., St. Petersburg, 194223, Russia

Abstract

A conceptual design and electrical parameters of a fast phase shifter that employs ferroelectric ceramics are presented. The phase shifter is built into a standard air-filled WR650 waveguide. Calculations and measurements show the possibility of achieving a phase shift of 120°. Expected pulse power is 500 kW. This paper describes the first results of low power measurements on a one-third scale model of the phase shifter.

INTRODUCTION

During the operation of accelerators it is often important to rapidly change the phase and amplitude of the input RF wave that is fed to the acceleration structure. For this purpose a fast L-band phase shifter has been designed. The phase shifter is based on a new ferroelectric ceramic, whose permittivity changes with external application of an electric field [1]. The switching time depends on only the external HV circuit and can thus be less than one microsecond.

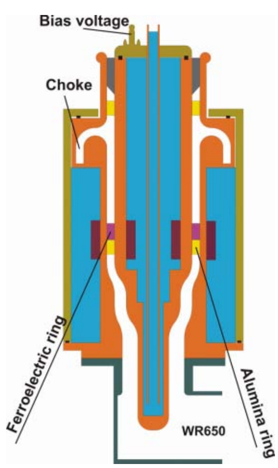


Figure 1: Coaxial ferroelectric phase shifter.

In [2], results of measurements of properties of large ferroelectric rings were presented, and designs of coaxial (Fig. 1) and coaxial-planar (Fig. 2) phase shifters were suggested. However, it emerged that these designs have a number of technical problems. The coaxial version is very complicated to manufacture, because it requires soldering of the large ceramic cylindrical surfaces to the coaxial walls. The coaxial-planar version is simpler to manufacture, but the large volume of ferroelectric ceramic leads to a high spectral density of parasitic modes that, in turn, leads to electric field enhancement and additional losses in the phase shifter.

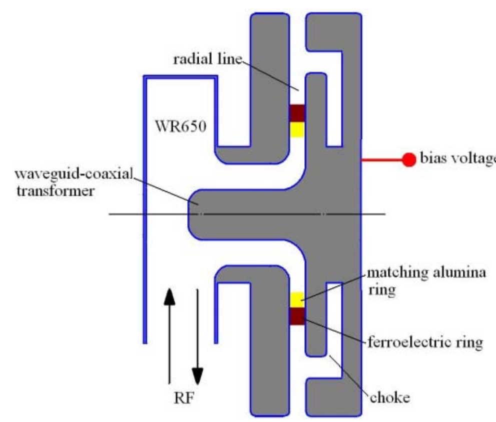


Figure 2: Coaxial-planar ferroelectric phase shifter.

A new design of the phase shifter is now suggested that has the advantages of the coaxial-planar design, but with a smaller volume of ceramics. The approach is to employ a single-mode ceramic waveguide. But, in order to reduce the RF fields in the device one should use a number of identical single-mode dielectric waveguides connected in parallel. In this situation the device has a sparse spectrum that can be controlled by changing its geometrical parameters.

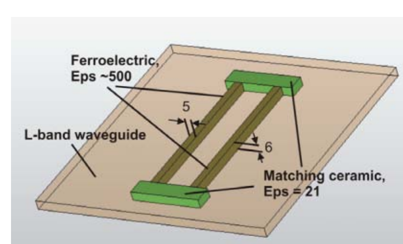


Figure 3: The new design of the planar phase shifter.

DESIGN AND MEASUREMENTS

The dielectric constant of the ferroelectric ceramics to be employed is about 500. For this dielectric constant

*Work supported by US Department of Energy
#sergey.kazakov@kek.jp

the maximum transverse cross section of a single-mode waveguide is about 5 mm × 6 mm. A geometry was found that allows one to match the empty waveguide to a multi-rod dielectric waveguide, one layer of which is shown in Fig. 3.

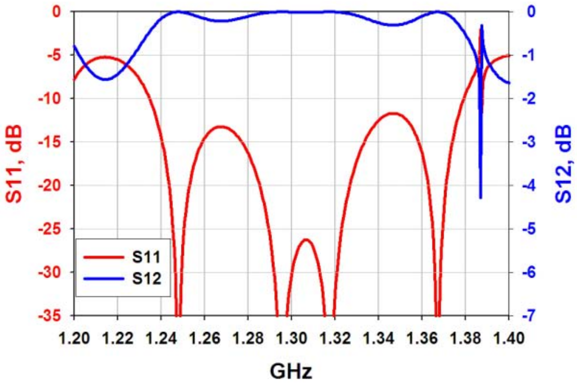


Figure 4: Frequency response of the new planar phase shifter.

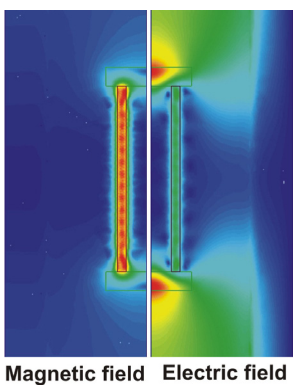
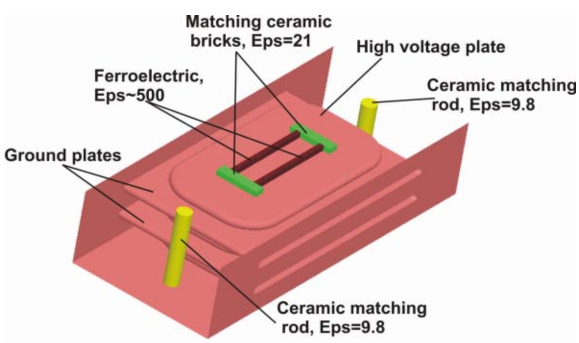
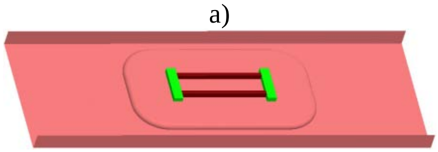


Figure 5: Field distribution in the phase shifter.



a)



b)

Figure 6: (a) Full: geometry of the three-layer phase shifter (top waveguide wall is removed); and (b) the assembly scheme of each layer containing two ferroelectric waveguides and two matching bricks.

The matching linear ceramics having a dielectric constant of 21 are placed before and after the ferroelectric waveguides. In Fig. 4, scattering matrix parameters are shown versus frequency for this structure. In Fig. 5 the field distribution is shown. One can see that the fields are concentrated in the ferroelectric slabs.

In Fig. 6a the full geometry of the phase shifter is presented. The waveguide is divided into three parts, and each part contains the assembly shown in Fig. 6b. There is a HV electrode between the assemblies, where the bias voltage is applied that changes the ferroelectric dielectric constant. In order to match all three parts to the WR650 waveguides, two cylindrical ceramic rods are used with a dielectric constant of 9.8. This matching scheme provides for equal power flow in all the three layers. The HV input for the bias is placed in the region where the RF fields are small, as seen in Fig. 7. Calculated reflections are shown in Fig. 8, while losses versus the ferroelectric loss tangent are shown in Fig. 10. Table 1 shows the phase shifter parameters.

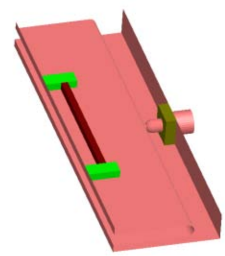


Figure 7: HV input.

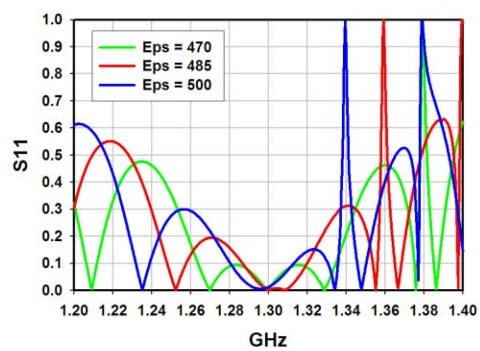


Figure 8: Calculated passband of the whole phase shifter.

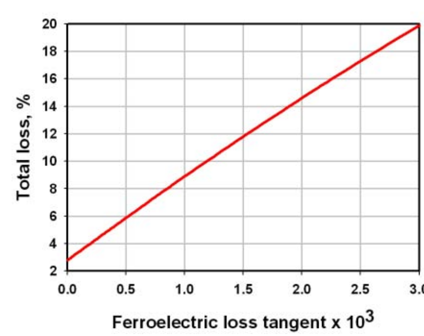


Figure 9: Calculated losses in ferroelectric versus the loss tangent.

Table 1: Phase shifter design parameters.

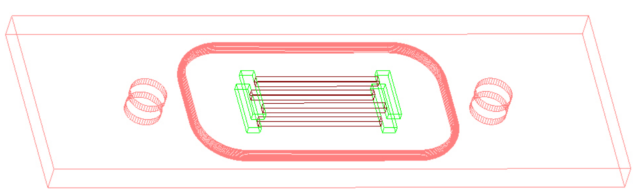
parameter	value
ferroelectric permittivity (V_bias = 0)	~ 460
∂phase (deg)/∂eps	4 deg
max. RF electric field (P = 500kW)	5.9 kV/cm
max. DC electric field (Δphase=120 deg)	15 kV/cm
total loss (%) for ferroelectric loss tangent δ	2.8 + 6.E3*δ

In order to check the design, a model was fabricated for one-third of the full design, namely a single layer. The model layout is shown in Fig. 10a, and a photo is shown in Fig. 10b. The model may be disassembled in order to test different ferroelectric rods. The first tests were made with rods without metallization of the contacting surfaces, with results that were far from those predicted. Previous experience with ferroelectrics showed that a good electric contact between the ceramics and the walls is essential. Thus, the next measurements were done when the surface of the ferroelectric was covered by liquid InGa alloy, and the results were close to those predicted. During the third measurement with gold-plated ferroelectric rods and matching slabs, the contact to the copper walls was provided by indium solder. Measured frequency response is shown in Fig. 11 that is close to what was predicted.

Figure 12 shows the measured output phase versus the bias voltage at 1300 MHz.

SUMMARY

A planar design of the fast ferroelectric fast shifter is presented. The phase shifter is built into standard WR650 waveguide. Calculations and experimental tests show that the device provides a phase shift of 120° without air breakdown, with an insertion loss of -0.64 dB.



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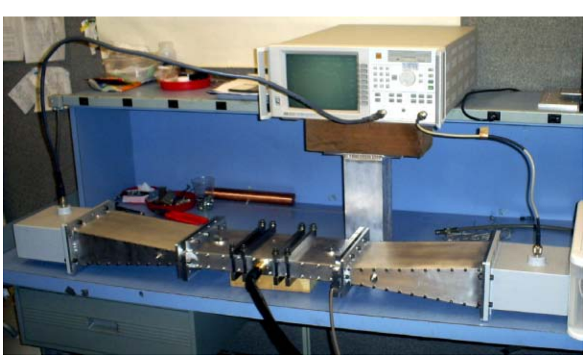
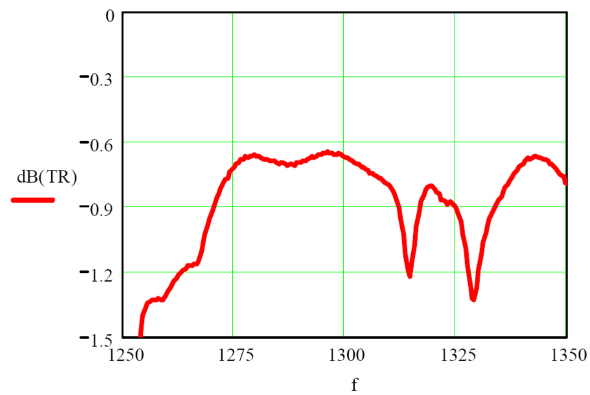


(b)

Figure 10: Sketch of the 1/3-model, and a photo.



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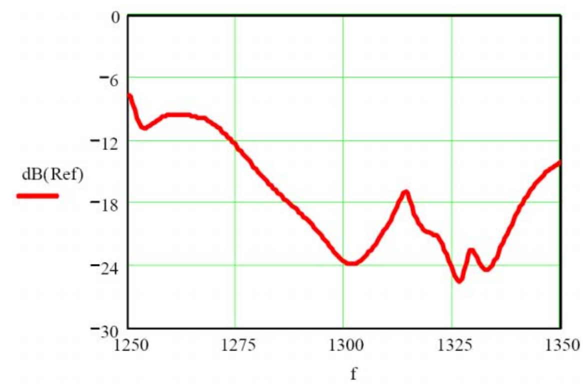

(b)

Figure 11: Measured transmission (a) and reflection (b) versus frequency.

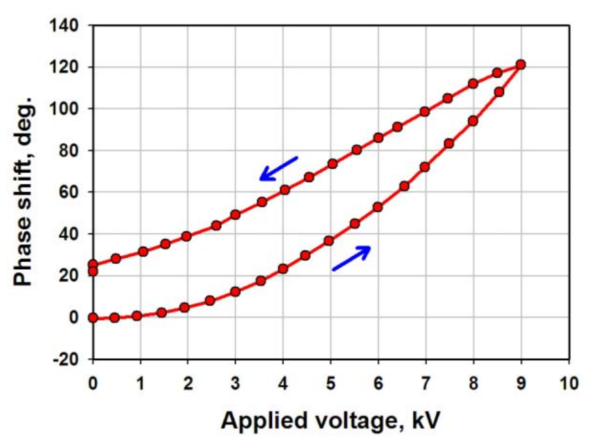

Figure 12: Phase shift versus bias voltage at 1300 MHz.

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[1] S.Yu. Kazakov, V.P. Yakovlev, S.V. Shchelkunov, A.D. Kanareikin, E.A. Nenasheva, and J.L. Hirshfield, "First Measurements of RF Properties of Large Ferroelectric Rings for RF Switches and Phase Shifters," PAC2007, Albuquerque, June 25-29, 2007.

[2] V.P. Yakovlev, S.Yu. Kazakov, and J.L. Hirshfield, "1.3 GHz Electrically-Controlled Fast Ferroelectric Tuner," EPAC2006, Edinburgh, June 26-30, 2006, pp. 487-489.