L-BAND 700 MHZ HIGH-POWER FERROELECTRIC PHASE SHIFTER*

S.Yu.Kazakov,[a,b] S.V.Shchelkunov,[c,#] V.P.Yakovlev,[a,d] J.L.Hirshfield,[a,c].
[a]Omega-P, Inc., 199 Whitney Ave., New Haven, CT 06511, USA
[b]High Energy Accelerator Research Organization, KEK, Tsukuba, Ibaraki 305-0801, Japan
[c]Beam Physics Laboratory, Yale University, 272 Whitney Avenue, New Haven, CT 06511, USA
[d]Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

Abstract

Measurements are reported for a one-third version of an L-band high-power ferroelectric phase shifter. The device is designed to allow fast adjustments of cavity coupling to an accelerator structure where microphonics, RF source fluctuations, or other uncontrolled fluctuations may cause undesired emittance growth. Experimental measurements of switching speed, phase shift, and insertion loss *vs* externally-applied voltage are presented. An average switching rate of ≤0.5 ns for each degree of RF phase has been observed.

INTRODUCTION

It is often necessary to rapidly change the phase and amplitude of the input RF that is fed to an acceleration structure. For this purpose a fast phase shifter has been designed for operation in L-band. The device is based on a new ferroelectric ceramic, whose permittivity changes with application of an external electric field [1]. The switching time depends on mainly on the external high-voltage circuit and thus can be less than ~100 ns. In an earlier publication, designs of coaxial and coaxial-planar phase shifters were described [2]. However, those have shown a number of technical problems. A new design is presented that is simpler to build, and has a small volume of ceramic, leading to a low spectral density of parasitic modes that in turn insures a low field enhancement and relatively low losses.

NEW PLANAR GEOMETRY

The new design employs a rectangular waveguide as a building block, inside of which ferroelectric ceramic bars are strategically placed. Fig. 1 shows the layout. To reduce RF field strengths, three identical waveguides within the WR650 perimeter are connected in parallel. This leads to a sparse mode spectrum that can be controlled by changing the waveguide geometry. The transverse cross section of each bar is 5 × 6 mm and is dictated mostly by the dielectric constant of the ferroelectric ceramics (ε ~460). Matching linear ceramic bricks having ε ~21 are placed before and after the ferroelectric bars. To match the empty entrance or exit waveguide to the resulting sandwich-like structure, dielectric roads (ε ~9.8) are inserted before and after the three-layer sandwich. This matching scheme provides for equal power flow in all three layers. In Fig. 2a the calculated scattering matrix parameters *vs* frequency are plotted. Fig. 2b and 2c show the field distributions.

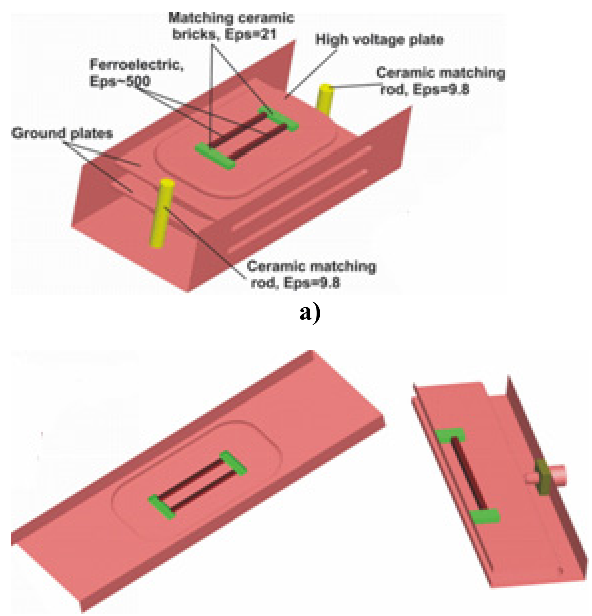

Figure 1: (a) Full geometry of phase shifter. (b) one-third section of phase shifter. (c) HV input.

MEASUREMENTS OF PHASE SHIFT FOR ONE-THIRD MODEL

In order to check the design, a model was fabricated for one-third of the full design [as in Fig. 1b]. The model could be disassembled in order to test a variety of ferroelectric bars. Tests were made with ferroelectric bars having gold-plated edges and matching slabs, and contact to the copper walls was provided using liquid InGa alloy or by indium solder. Results of measurements of phase shift are presented in Fig. 3; these are seen to be in good agreement with simulations.

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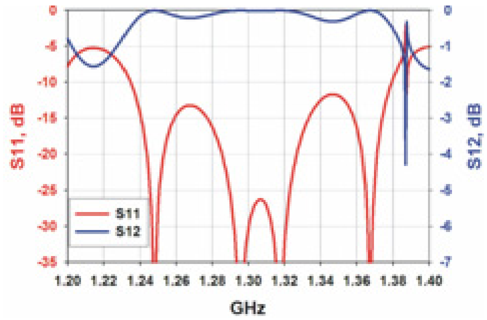
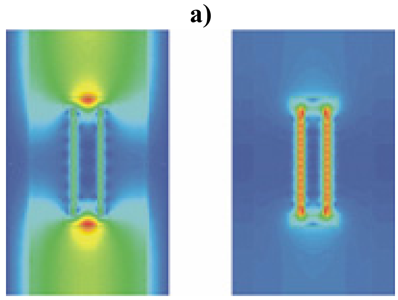
shchelkunov@bnl.gov

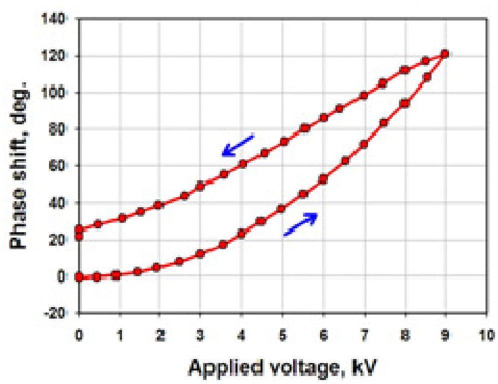


a)



b) c)

Figure 2: (a) Frequency response for one-third section. (b) Electric field. (c) Magnetic field.



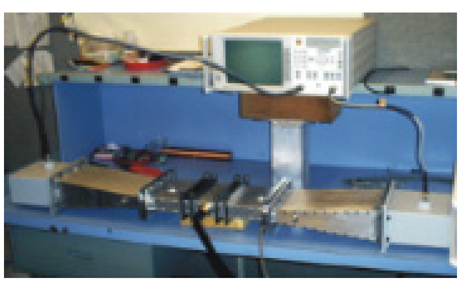


Figure 3: Measured phase shift of RF signal transmitted through one-third section *vs* applied bias voltage. Photo shows the experimental setup.

MEASUREMENTS OF SWITCHING SPEED FOR ONE-THIRD SECTION

A critical property of any tuner is its response time, which for many accelerator applications should be below 100 ns. This is clearly shorter than what can be achieved with a ferrite tuner. Measurements of response time were made using the arrangement shown in Fig. 4,

The signal from the RF generator at 1,290 MHz is split in two. One portion was directed through a phase shifter and attenuator directly to a mixer, while the second portion was fed through the tuner input port, passed through the tuner, picked up at the tuner output port, and then fed to the mixer. The resulting signal from the mixer was detected by a diode and monitored at an oscilloscope, and also captured by a computer for further signal processing (mainly FFT). The high voltage rise/fall times from the available pulse generator were in the range of ~100 ns.

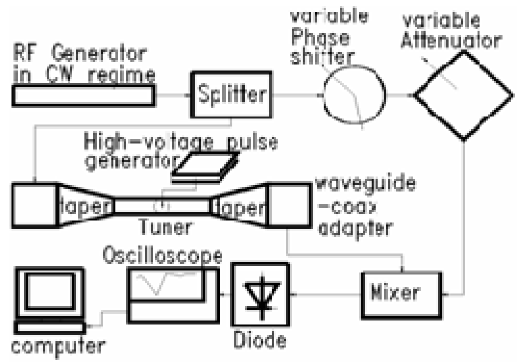


Figure 4:Setup for phase switch speed measurement.

A typical response is shown in Fig. 5. The red curve (convex) is the difference between data with RF off and RF on. The blue curve (also convex) is the processed red curve after direct and inverse FFT for filtering out of high frequency components; the black curve (concave) is the high-voltage pulse. The vertical scale for the latter is reduced by a factor of 2×10^5; its peak value was 9.7 kV. It is seen that the time delay between the peak voltage and the peak variation in phase is 28 ns. (This value excludes delays in cables.) Note the time scale is 50 ns per division. (The difference signal of 67 mV from the mixer corresponds to a phase change of 77º)

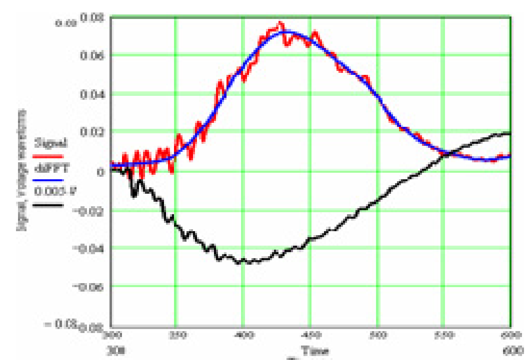


Figure 5: Time-response of the phase shifter.

From these data, one can infer that the response time to a step function voltage would be equal to or less than the delay time, namely approximately 30 ns. This could be interpreted to correspond to an average switching rate of less than 0.5 ns for each degree of RF phase.

MEASUREMENTS OF LOSS

The loss tangent of ferroelectric bars was measured for bars without gold-plated edges (manufactured from the same batch used to make the bars with gold-plating). The value of loss tangent was determined to be $\sim 2\times10^{-3}$, suggesting that the one-third scaled tuner section would suffer a transmission loss not less than ~0.7dB. In actuality, the measured transmission was lower, with lowest transmission loss only when using either freshly applied liquid InGa or soldering the bars to the waveguide walls (using In). However, it was impossible to apply more than 4 kV to the soldered versions without arcing; hence we discuss below only the structures assembled with liquid InGa. It was found that in the versions with fixed structure height, when the top and bottom walls are tethered by bolting to the side walls, the transmission dropped as the voltage grew, as shown in Fig. 6. However, in a test where the top wall was resting without tethering on the ceramic bars under 200-400 lbs load, the transmission did not drop as much. However, in general, the transmission level was reduced because of leakage radiation through the gaps formed between unbolted walls, or in some cases became even higher as shown in Fig. 7. This suggests the possible presence of piezoelectric effects that lead to the contraction of the bars and degradation in quality of the bar-wall surfaces contacts.

It is anticipated that successful brazing of the ferroelectric and matching dielectric bars will eliminate losses beyond those in the bulk ceramics and metallic walls, as well as to lead to transmission being independent of applied voltage.

CONCLUSION

Measurements for a one-third version of an L-band tuner give phase shifts in good agreement with theory, rapid (~30 ns) switching speed, but excessive insertion loss. Present understanding is that losses are partially caused by the poor contact between ceramic and the waveguide walls, and are not an intrinsic property of the phase shifter design or solely of the ferroelectric material. Lastly, the tuner was connected to a 1.3 GHz cavity and confirmed its capability for fast tuning of its resonance frequency [3].

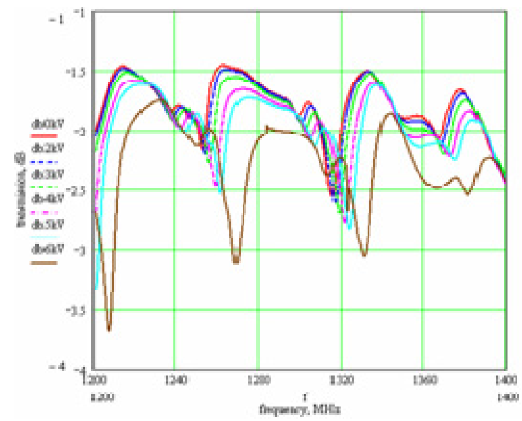


Figure 6: Transmission (dB) *vs* frequency (MHz). Transmission drops as voltage is increased in the versions with fixed structure height (the top and bottom walls are tethered by the side walls), suggesting a possible piezoelectric contraction of the bars.

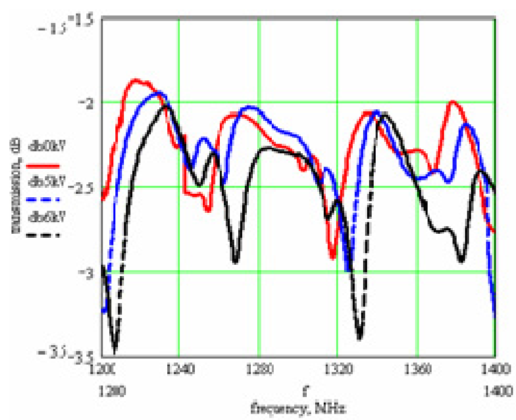


Figure 7: Same as Fig. 6, except in an arrangement where the top wall was resting (under 200 - 400 lbs load) on the ceramic bars and was not bolted to the side walls. Here, the transmission did not drop so much as in Fig. 6, or in some cases even increased. However, in general the transmission level was lower because of leakage radiation through the gaps formed between unbolted walls.

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