704 MHZ FAST HIGH-POWER FERROELECTRIC PHASE SHIFTER FOR ENERGY RECOVERY LINAC APPLICATIONS*

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Abstract

Development of a fast electrically-controlled 704 MHz phase shifter for Energy Recovery Linacs (ERLs) that employs an electrically-controlled ferroelectric element is described. The device is a refinement of an already tested prototype described elsewhere [1]. In the new design, ferroelectric assemblies behave as cavities configured as transmission elements within a coaxial waveguide. Each assembly is a ring-like ferroelectric ceramic with its height, inner and outer diameters, and the shape of edges adjusted to insure an operating mode free of interference from nearby modes, and with minimized field strength. Several assemblies installed in tandem serve to widen the passband and increase tunability. The device is to deliver fast (~100-200 ns) phase adjustment from 0-to-100 degrees when biased by voltages from 0-to-15kV; the design promises to handle 50 kW CW and 900 kW of pulsed power, as required by cavities in the BNL ERL. A scaled version is also considered to operate at 1300 MHz with capability to handel 500 kW of pulsed power.

INTRODUCTION

The device described here is a ferroelectric microwave component that controls reactive power for fast tuning of cavities and/or fast control of input power coupling. Its distinct feature is its predicted ability to operate at high power levels. In its present incarnation, the device is to be used as an RF circuit component that feeds cavities in an ERL; it can also be used as a component in a resonant delay line pulse compression or a delay line distribution system. Other high-power RF applications where the phase must be rapidly controlled are also possible.

The design is a new concept that is developed based on experience with its predecessors.

With regard to application to ERLs, a tuner [1] formed by two reflecting phase shifters attached to a 3-dB hybrid can be placed (Fig.1) between the superconducting (SC) cavity's coupling iris, and the cavity itself. The tuner can change the electric length of the line between the iris and cavity, thereby preserving the cavity resonance frequency, and keeping the cavity coupling to the feeding line always the same, in the presence of microphonics that detune the cavities. The coupling is chosen to minimize reflections; consequently, the power needed to operate is only to compensate for losses. However, should the tuner not be present, the coupling must be high enough to broaden the cavity bandwidth beyond the frequency range of rapid microphonics (as well as other factors [1]) that detune the cavity. With strong coupling, reflections occur and demand for an increased amount of RF power follows.

Another scheme is shown in Fig.2. It uses a tuner connected to a dedicated port; the tuner is based on only a single phase shifter. The efficiency of this scheme is nearly the same as the former one; one may argue however, that having a second port is a disadvantage. Still, careful investigation is required to choose one scheme over the other.

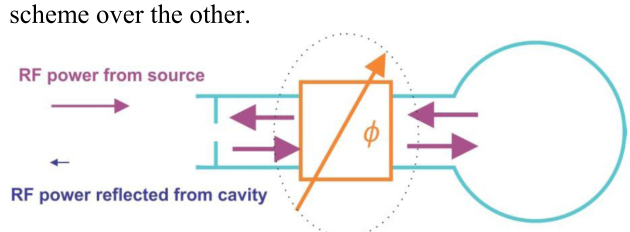

Figure 1: Schematic of a superconducting cavity fed through a fast, high-power tuner that is a combination of two phase shifters fed by a 3-dB hybrid (not shown).

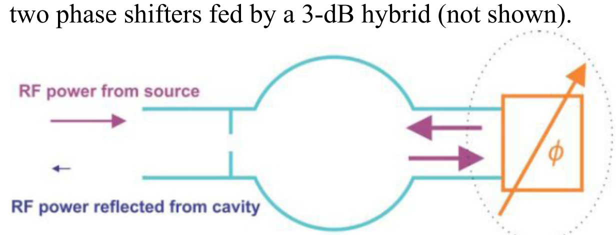

Figure 2: Schematic of a superconducting cavity using a tuner connected to a dedicated port; the tuner here requires only a single phase shifter

DESIGN OVERVIEW

The phase shifter schematic that shows the underlying principle is shown in Fig. 3. The shifter is based on a ferroelectric resonator. A donut-like ferroelectric resonator-insert (having its top and bottom metallized) is considered (Fig.4). The height, inner and outer diameters

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are dictated by the choice of frequency and dielectric constant. A wide variety of ferroelectrics is available [2], but many suffer from too much volume and high Ohmic losses [3]. Work continues to improve these materials and their surface metallization.

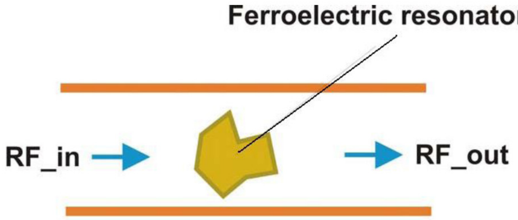

Figure 3: Phase shifter concept (see explanation in text).

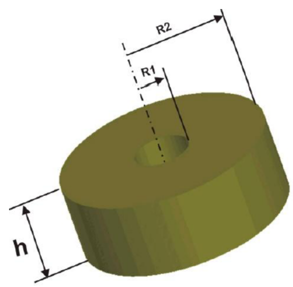

Figure 4: Ferroelectric ring is the resonator used in the design described in this paper.

Fig.5 presents the design suitable for the ERL at BNL [4]. The device is compact; the external dimensions are ~80 mm in diameter, and ~250 mm in length. The second port is shorted with a choke.

To build a tuner capable of sustaining 50 kW of average RF-power, two magic-T ports can be equipped with 5 phase shifters (as shown on the left-side of Fig 6); the resulting reflections are shown on the right-side.

PREDICTED ERFORMANCE

A figure of merit for the described device is the so-called power savings ratio, which is the ratio of RF-power required when no tuner is used to the power needed when the tuner is employed. Fig. 7 presents the power saving ratio vs. the loss tangent of the ferroelectric material.

With currently available ferroelectrics, a power savings ratio between 5 and 10 is expected. It is this substantial potential savings in RF-power when operating in a full-scale ERL containing many tens of SC cavities that provides strong motivation to develop this device.

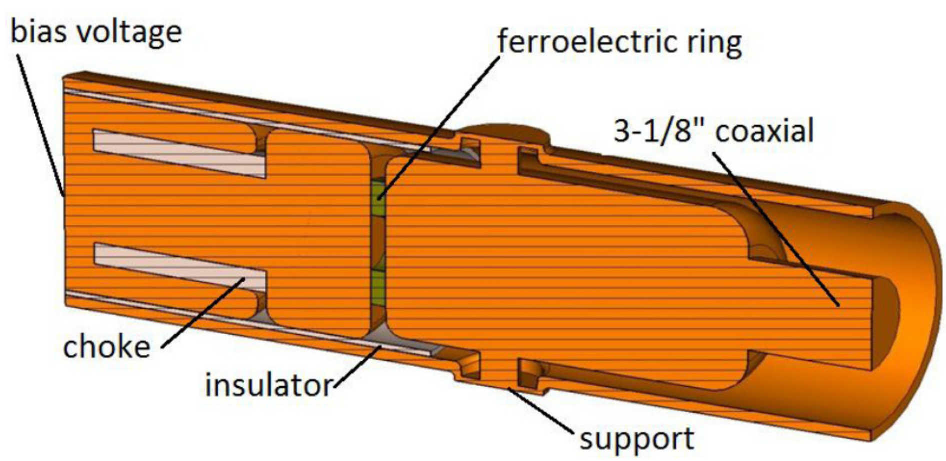

Figure 5: Design of each phase shifter.

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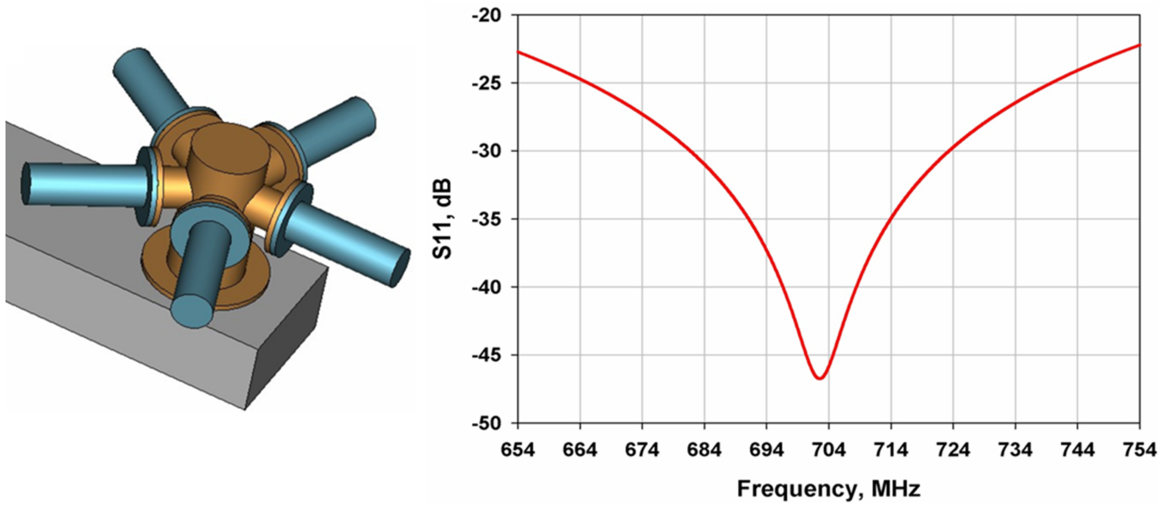

Figure 6. To comprise a tuner, each of two magic-T ports can be equipped with 5 phase shifters (one port is shown at left); the calculated resulting reflections are shown on the right.

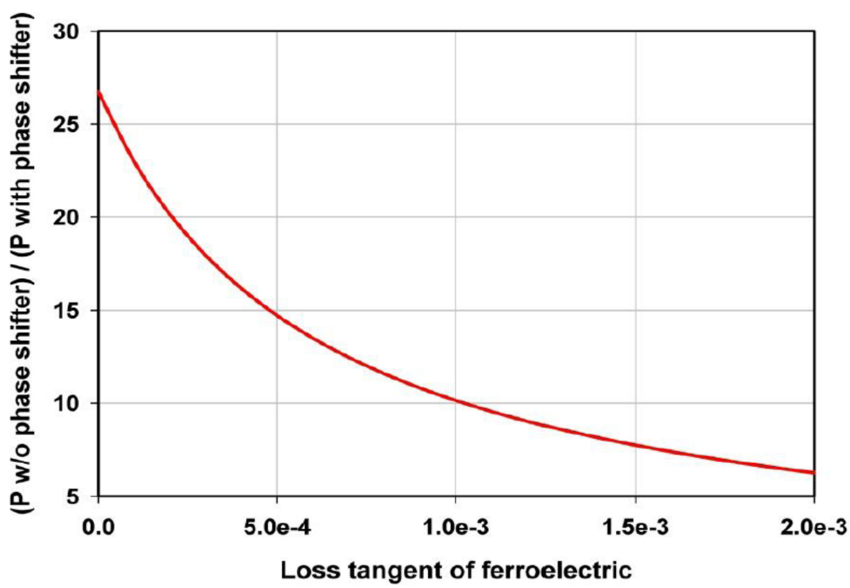

Figure 7. Power savings ratio vs. the loss tangent of the ferroelectric (see the text for explanations).

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