A MULTI-MODED RF DELAY LINE DISTRIBUTION SYSTEM FOR THE NEXT LINEAR COLLIDER

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Abstract

The Delay Line Distribution System (DLDS) [1] is an alternative to conventional pulse compression which enhances the peak power of an rf source while matching the long pulse of that source to the shorter filling time of the accelerator structure. We present a variation on that scheme that combines the parallel delay lines of the system into one single line. The power of several sources is combined into a single waveguide delay line using a multi-mode launcher. The output mode of the launcher is determined by the phase coding of the input signals. The combined power is extracted using several mode extractors, each of which extracts only one single mode. Hence, the phase coding of the sources controls the output port of the combined power. The power is then fed to the local accelerator structures. We present a detailed design of such a system, including several implementation methods for the launchers, extractors, and ancillary high power rf components. The system is designed so that it can handle the 600 MW peak power required by the NLC design, while maintaining high efficiency.

1 INTRODUCTION

During the past few years high power rf pulse compression systems have developed considerably. These systems provide a method for enhancing the peak power capability of high power rf sources. One important application is driving accelerator structures. In particular, future linear colliders, such as the proposed NLC, require peak rf powers that can not be generated by the current state-of-the-art microwave tubes. The SLED Pulse compression system [2] was implemented to enhance the performance of the two-mile linac at the Stanford Linear Accelerator Center (SLAC). One drawback of SLED is that it produces an exponentially decaying pulse. To produce a flat pulse and to improve the efficiency, the Binary Pulse Compression (BPC) system [3] was invented. The BPC system has the advantage of 100% intrinsic efficiency and a flat output pulse. Also, if one accepts some efficiency degradation, it can be driven by a single power source [4]. However, The implementation of the BPC [5] requires a large assembly of over-moded waveguides, making it expensive and extremely large in size. The SLED II pulse compression system is a variation of SLED that gives a flat output pulse [6]. The SLED II intrinsic efficiency is better than SLED, but not as good as BPC. However, from the compactness point of view SLED II is far superior to BPC. Several attempts have been made to improve its efficiency by turning it into an active system [7]. However, the intrinsic efficiency of the active SLED-II system is still lower than that of the BPC. The DLDS is a similar system to BPC, which utilises the delay of the electron beam in the accelerator structure of the linear collider to reduce the length of the over-moded waveguide assembly. However it still uses more over-moded waveguide than that required by SLED-II. To further enhance the DLDS we introduce in this paper a variation on that system which further reduces the length of the waveguide system by multiplexing several low-loss rf modes in the same waveguide, hence the name Multi-moded DLDS (MDLDS). The system has an intrinsic efficiency of 100%, and the total over-moded waveguide length is less than that required by the compact SLED-II system.

2 SYSTEM DESCRIPTION

Fig. 1 shows a schematic of the proposed system. Basically, four pairs of klystrons, operating at 11.424 GHz, feed a multi-mode launcher. The launcher, then, injects one of four modes into a large (12.7cm-diamter) waveguide delay line. The choice of modes is controlled by the relative phases between the four fr power sources. The four modes are chosen to minimize the losses in the delay line. These modes are TE_{01}, vertically polarized TE_{12}, horizontally polarized TE_{12}, and, finally, TE_{21}. The TE_{21} mode is quite lossy, and hence is extracted from the delay line immediately and is then converted to the TE_{01} mode in the circular waveguide that feeds the closest set of accelerator structures. The power carried by any of the other three modes is extracted at the appropriate point and then converted into TE_{01} mode to feed a set of accelerator structures.

The output pulse of the power sources is divided into four time bins, each with duration τ. The total rf power supply pulse width is 4τ. During the first time bin, the phases are adjusted to inject one of the polarizations of the TE_{12} mode. This signal does not get affected by any of the mode extractors. However, after the last mode extractor it gets converted into the TE_{01} mode, thus, feeding the most distant accelerator structure. Then, in the second time bin the second polarisation of the TE_{12} mode is injected. This signal is converted into the TE_{01} mode just after the first extractor. The second extractor extracts this signal. In the third time bin the TE_{01} mode is injected. The first extractor extracts that mode. Finally, in the forth time bin, the TE_{12} mode is injected, and extracted immediately to feed the closest set of accelerator structures.

In this manner, each of the four accelerator structure sets will see the combined power from the four power sources during the appropriate time-bins. This is equivalent to a pulse compression system with a compression ratio of four. Since, in this scheme, the electron (or positron) beam is moving in an opposite direction to the rf power, the total delay line length required between the feed points to the different accelerator structure sets is ~ *c τ/2*, where c is the speed of light in free space. For simplicity, we have assumed here that the group velocity of the rf signal and the beam velocity are both approximately equal to c; a more detailed analysis is presented in the section 3. Taking advantage of the finite time that electrons and positrons spend travelling between the accelerator structure sets reduces the total length of the waveguide required for this pulse compression system by a factor of two.

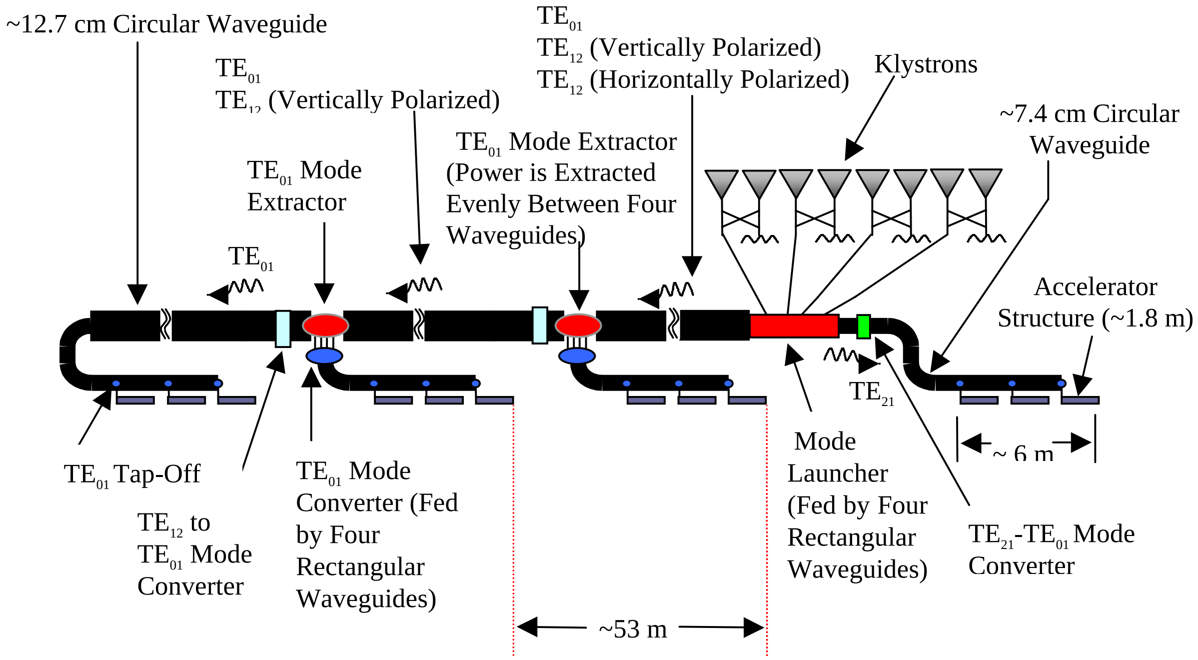

Fig.1 Multi-Moded Delay Line Distribution System

The power extracted from the rf delay line with the appropriate mode transducer is converted immediately into the TE_{01} mode and fed to three different accelerator structures. The manipulation and feeding is done with circular waveguides that have a diameter of 7.4cm. Each accelerator structure is fed with a different tap-off, a mode transducer from TE_{01} to TE_{10} in rectangular waveguide. Obviously, the first tap-off is a 4.77 dB transducer, the second is a 3 dB one, and the third is a low-loss mode converter.

Each power source (a pair of klystrons) will produce 150 MW for 1.5 µs. The total amount of power in any time bin is 600 MW for a duration of 375 ns. One of the design goals is to keep the surface electric field in this rf system below 40 MV/m. The total efficiency of the system should be above 85%.

3 TIMING

Because the rf power is being injected at different times into different modes that have different group velocities, one must pay a special attention to timing. The set of equation that need to be satisfied so that the each accelerator structure set get an rf pulse for a duration τ at the appropriate time are:

$$\tau = (\frac{L_1}{v_{TE01}} + \frac{L}{c}) + (\delta_2 - \delta_1),$$

$$\tau = (\frac{L_2}{v_{TE01}} + \frac{L}{c}) + (\delta_3 - \delta_2) + L_1(\frac{1}{v_{TE12}} - \frac{1}{v_{TE01}}),$$

$$\tau = (\frac{L_3}{v_{TE01}} + \frac{L}{c}) + (\delta_4 - \delta_3) + L_2(\frac{1}{v_{TE12}} - \frac{1}{v_{TE01}});$$

where L is the distance between accelerator structure sets, L_1 is the distance between the launcher and first extractor, L_2 is the distance between first and second extractor, L_3 is the length of the delay line after the second extractor, v_{TE01} and v_{TE12} are the group velocities of the TE_{01} and TE_{12} modes respectively, and δ_1 through δ_4 are the delays due to the transmission of power from the main rf delay line system to the accelerator structure sets, i.e., the delay through and after the extractors.

There are several choices for the lengths L, L_1 through L_3, and δ_1 through δ_4 that satisfy the above set of equations. An attractive choice is to set L_1 through L_3

$$\delta_2 - \delta_1 = L\left(\frac{1}{v_{TE12}} - \frac{1}{v_{TE01}}\right)$$

equal to L, $\delta_4 = \delta_3 = \delta_2$, and

This would lead to a fairly symmetric system.

4 LAUNCHER

Several ideas for the launcher have been proposed [8-9]. In all of them a fundamental property of the launcher has been preserved: the launcher has only four inputs and the launcher has to launch Four and only four modes. If this is preserved and the launcher is matched for all four different input conditions, because of unitarity and reciprocity the scattering matrix representing the launcher has to take the following form:

$$S = \begin{bmatrix} 0 & 0 & 0 & 0 & \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \\ 0 & 0 & 0 & 0 & \frac{-1}{2} & \frac{-1}{2} & \frac{1}{2} & \frac{1}{2} \\ 0 & 0 & 0 & 0 & \frac{-1}{2} & \frac{1}{2} & \frac{1}{2} & \frac{-1}{2} \\ 0 & 0 & 0 & 0 & \frac{-1}{2} & \frac{1}{2} & \frac{-1}{2} & \frac{1}{2} \\ \frac{1}{2} & \frac{-1}{2} & \frac{-1}{2} & \frac{-1}{2} & 0 & 0 & 0 & 0 \\ \frac{1}{2} & \frac{-1}{2} & \frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 & 0 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & \frac{-1}{2} & 0 & 0 & 0 & 0 \\ \frac{1}{2} & \frac{1}{2} & \frac{-1}{2} & \frac{1}{2} & 0 & 0 & 0 & 0 \end{bmatrix}$$

This form forces the isolation between inputs; i.e., if one of the four power supplies drops out or fails, the rest of the power supplies will not receive any reflected power.

In all cases of launcher designs four rectangular waveguides are coupled to a circular waveguide at four different places $\pi/2$ apart in azimuth the four waveguides supply equal amount of power with different phases, and the modes excited are TE_{11}, TE_{21} and TE_{01}. The TE_{11} modes are converted later to TE_{12} modes using a Marie' mode converter. A circular waveguide large enough to support the TE_{01} mode will support a set of TM modes and the TE_{31} mode. To avoid exciting these modes the launcher suggested in reference [8] perturbs the cross section of the circular guide to a cross like shape, thus allowing for only four modes to propagate. The launcher suggested in Ref. [9], uses longitudinal resonance coupling to avoid the excitation of other modes.

5 EXTRACTOR

The design of the TE_{01} extractor is quite complicated and will be a subject of further publications. However, A design based on the wrap-around mode converter [10] is possible. In this designs a rectangular waveguide is warped around the circular guide. The power is being extracted using an azimuthal resonant coupling between the two guides. Different approaches based on longitudinal resonant couplings are also possible.

6 ACKNOWLEDGEMENT

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