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HIGH-POWER HYBRID ATTENUATOR&PHASE-SHIFTER SYSTEMS

S. Ohsawa, I. Abe, M. Yokota, Y. Ogawa,
S. Anami, I. Sato and A. Asami
National Laboratory for High Energy Physics
Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan

Abstract

Two kinds of waveguide systems which can change the attenuation and phase independently have been newly designed utilizing 3-dB hybrids, and manufactured for the prebuncher and buncher of the 2.5-GeV Photon Factory Injector Linac. Measured data show the expected characteristics. The principles, structures and characteristics are described.

Introduction

In an electron linac, beam bunches are produced by a prebuncher and a buncher. Since the shape of the bunches greatly affects the beam characteristic, it is very important to optimize the microwave powers and phases in these devices. For the optimizing process, a system comprising an attenuator and a phase shifter is necessary for each of these devices. However, the former high-power variable attenuators have a problem in that a phase shift is introduced as the attenuation is varied. This feature made it complicated to search for the optimum parameters of the prebuncher and buncher. Accordingly, new systems were designed in order to solve this problem.

The old system for the buncher was pressurized with SF_6, so that it required windows which separate the gas from the vacuum. Bored holes with small cracks were found on the vacuum sides of the windows in the Spring of last year. Fortunately, the holes still did not reach to the other side. In order to avoid this kind of problem, the new systems were designed to be used under vacuum.

Principle of new systems

Although the new systems have the same functions, they look quite different at first glance. It might therefore be better to explain them separately.

System for the prebuncher

We firstly discuss the attenuator & phase-shifter system for the prebuncher. The microwave power required in the prebuncher is usually less than 10 kW. Within this power range a dielectric substance is usually used for varying the power or phase. Therefore the microwave phase is inevitably shifted as the attenuator is changed.

On the other hand, the new system has the configuration illustrated schematically in Fig. 1. It comprises a 20-dB directional coupler as a power divider, a 3-dB directional coupler with two short plungers which move independently and a dummy load for termination. The power for the prebuncher is provided from the main line for the buncher by the 20-dB power divider. Then, the power is divided again by a 3-dB directional coupler into two parts, each of which is reflected by a short plunger at a different position; the two fields are then mixed by the same 3-dB coupler.

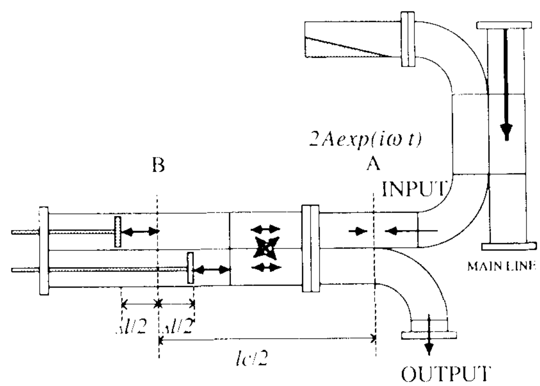

Fig. 1. Attenuator & phase-shifter for the prebuncher

We now consider the output power and the phase of the system. For simplicity, power losses and reflections due to imperfections of the devices are neglected in the discussions below. When the input microwave field is $Aexp(i\omega t)$ at plane A in Fig.1, the output field E_o is given by[1)]

$$E_o = A\cos\phi \sin(\omega t+\theta), \qquad (1)$$

where

$$\theta = lc / \lambda_g,$$

and

$$\phi = \Delta l / \lambda_g. \qquad (2)$$

Here, λ_g is the wavelength in the waveguide.

It can be seen from Eq. (2) that both θ and ϕ depend only on lc and Δl, respectively. This means that the output power or phase can be adjusted independently by moving the plungers in the opposite or same direction by equal amounts, respectively. The output power is changed without a phase shift over the full range from zero to the input power according to ϕ; on the other hand, the output phase, θ, is given by the average phase of the two fields before being added. Thus, the new system has functions both of an attenuator and a phase shifter, as mentioned before.

The backward power returned to the input port is mainly absorbed by a dummy load connected at a port of the 20-dB directional coupler. The part of the power turns back to the source through the 20-dB directional coupler. This is, however, less than - 40 dB of the main line power, because the returning power to the source passes through the 20-dB coupler two times. Hence, this becomes negligibly small in practical use.

Although the plunger control becomes complex, because it is necessary to shift two plungers independently and simultaneously, the new system is both simpler and more compact .

System for the buncher

We next consider the attenuator & phase-shifter system for the buncher. Though the system for the prebuncher mentioned above has a simple configuration, it is not suitable for the buncher. This is because in the buncher system it might usually be impossible to use a very weakly coupled power divider as the 20-dB coupler in the prebuncher system. Without a weak coupler, high power might turn back to the source and destroy it. Even if a circulator is inserted in the circuit, the transient parts of a pulse might be turned back to the source.

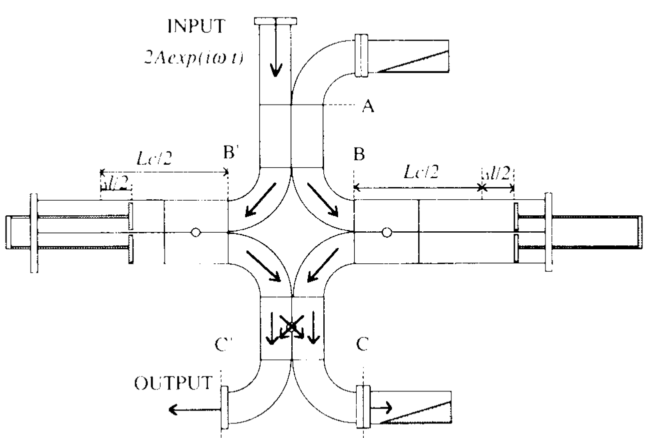

Fig. 2. Attenuator & phase-shifter for the buncher

Accordingly, another type of attenuator & phase-shifter system was newly designed for high power, so that any excessive power is perfectly absorbed by a dummy load and does not turn back to the source.[1)] The new system is illustrated schematically in Fig. 2. It consists of four 3-dB directional couplers combined in a body, two sets of jointed short plungers, and two dummy loads. Each of the joined plungers can be moved independently. The system, comprising a 3-dB coupler and joined short plungers, is a well-known type phase shifter.

We now look at how the new system works. Let the input field be *Aexp(iwt)* at the plane A in Fig. 2, same as in the previous case. The input power is divided at the first 3-dB coupler into two parts. After passing through the corresponding phase shifter, the fields are mixed by the next 3-dB directional coupler. Then, the final field, E_o , in the output port is given at plane C' as

$$E_o = A\sin\phi \sin(\omega t+\theta), \qquad (3)$$

where

$$\theta = lc / \lambda_g + \delta + \delta',$$

and $\phi = \Delta l / \lambda_g$. (4)

The phases, δ and δ', correspond to the electrical lengths between planes A and B and planes B and C (or B' and C'), respectively.

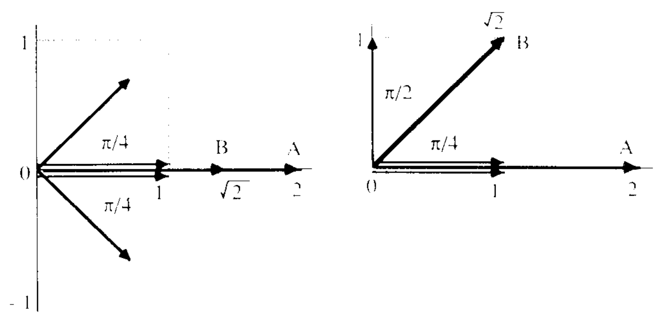

Fig. 3. Field addition in the new and old systems

We now compare the characteristics of the new system with those of the old one. Figure 3a clearly shows the features of the new system when the power is reduced to half. The added fields before and after being attenuated are shown by arrows A and B, respectively. The resultant amplitude is changed from 2 to $\sqrt{2}$ without any phase shift. On the other hand, in the old system, not only the resultant amplitude is changed from 2 to $\sqrt{2}$, but the phase also shifts by as much as $\pi/4$.

Characteristics of manufactured systems

Finally, we describe the characteristics of attenuator & phase-shifter systems which were manufactured according to the principles mentioned above. Figure 4 shows the microwave characteristics for the buncher system. It exhibits phase shifts over a frequency range when attenuations are changed: the phase shifts are shown in the upper part, and attenuations in lower part. Figure 4 shows that the phase shifts are small over a power range of 0 ~ -20 dB. At a frequency of 2856 MHz, the phase shifts are less than ± 2°, as shown in Fig. 5.

The output of this system should obey Eq. (3). Figure 6 shows this relation between ϕ and

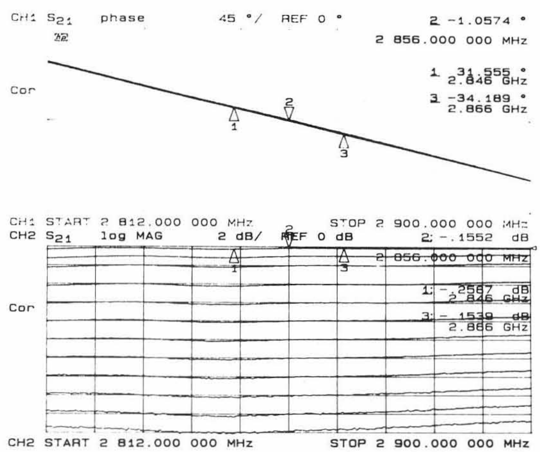

Fig. 4. Characteristics used as an attenuator

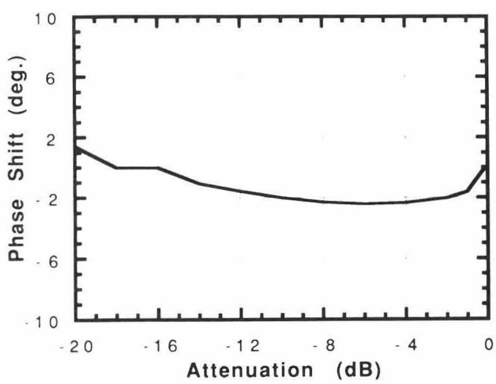

Fig. 5. Phase shift vs. attenuation at 2856 MHz

attenuation: A solid line indicating measured data and a dotted line given by Eq. (3) agree with each other, except in the range of larger attenuation. This disagreement comes from device imperfections: The power divide ratio of 3-dB directional couplers were carefully adjusted by tuning buttons; as the result, the directivity was degraded to about - 25 dB. Accordingly, the output field contains elements which have nothing to do with the plunger positions, although they are very small. Fortunately, it is possible to make the elements cancel each other by means of choosing the input port (Fig. 2) ; the performance of the system is not very impaired. Although there will be no problems in practical use, since the buncher is never used with a power level decreased as low as -20 dB, the characteristics of the system are expected to be much improved by slightly changing the size of the 3-dB directional couplers in order to raise directivity. We did not, however, do it because of a lack of time.

Figure 7 shows the characteristics of this system when it is used as a phase shifter. It indicates that the power change is as small as - 0.2 dB when the phase is changed by 2π. The data were obtained under small attenuation.

The system for the prebuncher has similar characteristics. A micro computer controls the short plungers by using pulse motors, and measures their positions accurately with linear scales. The system for the buncher has had no problems under high-power testing.

Summary

Two waveguide systems which can change the attenuation and phase independently were newly designed and manufactured. The measured data indicate that they have the expected characteristics. The entire systems are scheduled to be used from this September. Both of the two systems have the distinctive feature that they do not introduce an rf phase shift as the attenuation is varied. Hence, it is expected that the process of converging on the optimum phase and power settings for the prebuncher and buncher will be greatly speeded up by the new systems.

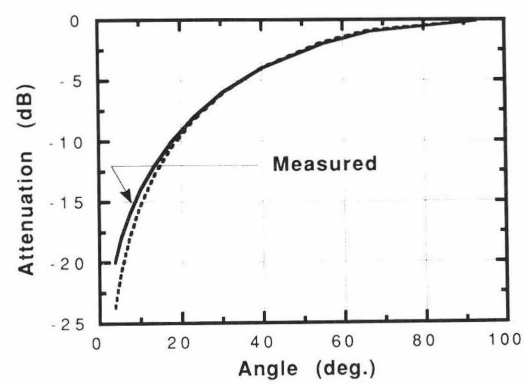

Fig. 6. Attenuation vs. ϕ of the system for buncher

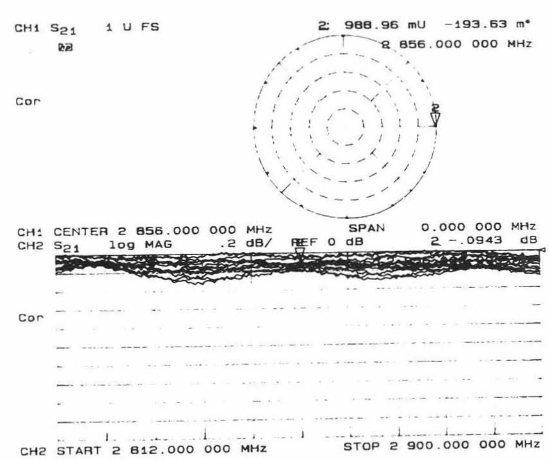

Fig. 7. Characteristics used as a phase shifter

References

1. S. Ohsawa et al. " New High Power Variable-Attenuator/Phase-Shifter Systems," 7th Symp. on Accelerator Science and Tech., Dec. (1989)