QUASI-OPTICAL RF POWER DISTRIBUTION SYSTEMS OF FUTURE LINEAR ACCELERATORS

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Introduction

In the physics of elementary particles, the progress is strongly related to upgrades of high-energy accelerators. A problem of electron/positron acceleration up to 10 TeV energies for linear colliders requires extremely high-power microwave sources. These sources are planned to be placed consequently along ~20 km long accelerator and have to produce $\sim 10^9$ W of microwave power during 100-300 ns.

In order to reach the mentioned parameters it is expedient to sum up powers of a few grouped relatively low power sources which are assumed to be coherent ones. It allows to enhance total power proportionally to a number of summing sources.

Next goal is associated traditionally with an attempt to reduce a total number of necessary sources and, thus, to make all project cheaper. This is based on an idea that the combined sources would to produce long ~1 μs microwave pulses which are to be divided in few (3-4) parts. Each the part can be delivered independently to his own section of a main linac. So, the combined sources serve jointly few acceleration sections simultaneously. A practical combination of the described ideas is realized at so-called Delay Line Distribution System (DLDS) [1].

However, the mentioned DLDS can not be operated with the required high power at shorter (millimeter) waves because of breakdown problems caused by one-mode -3 dB directional coupler. Quasi-optical components only have to be applied in this case. In particular, all components would be assembled of oversized uniform rectangular waveguides which are simple for manufacturing.

Launching of Paraxial Wavebeam into Multimode Rectangular Waveguide

Let us consider briefly phenomena associated with a 2D problem of non-symmetrical launching of an wavebeam in rectangular waveguide. In general case, a paraxial wavebeam excites in the waveguide with a width some combination of eigenmodes. Their propagation coinstants can be represented in a form:

$$h_j \approx k(1-\frac{1}{2}(\frac{\pi n_j}{ka})^2). \quad (1)$$

Therefore, mutual phases between any two modes with indices i and j respectively are given by:

$$\Delta\varphi_{i,j} = (h_j - h_i)\cdot z = \frac{k}{2}\cdot(\frac{\pi}{ka})^2\cdot(n_i^2 - n_j^2)\cdot z. \quad (2)$$

It is important that at distances, which are proportional to a^2/λ, all mutual phases are proportional to squared indices of the modes only and do not depend on the waveguide's size as well as an operating frequency. For example, if $z = 8a^2/\lambda$ all mutual phases are actually multiples of 2π. It means that at this

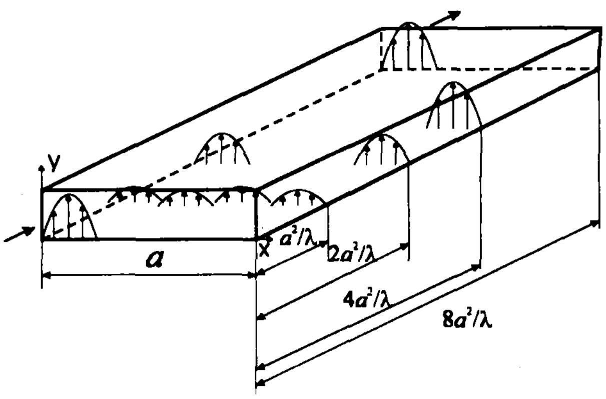

Fig. 1. Wavebeam multiplication phenomena under non-symmetrical excitation of oversized rectangular waveguide by paraxial 2D wavebeam.

distance the incident wavebeam is repeated completely (Fig. 1) [2].

At distance $z = 4a^2/\lambda$ odd modes change its phases on π, and even modes have the phases proportional to 2π. Therefore, the incident wavebeam is repeated but at the opposite side of the rectangular waveguide in comparison with the incident wavebeam (Fig. 1) [2-4].

Let us to be interested further by two phenomena only [6]: 1) dividing of an wavebeam at $z = 2a^2/\lambda$ into two wavebeams with identical amplitudes but different phases and 2) dividing of an wavebeam at $z = a^2/\lambda$ into four parts with different phases too.

Quasi-Optical -3 dB Directional Coupler

Using the first mentioned phenomena and properties of Maxwell's equations to allow an inversion on time, one can combine two wavebeams in order to reach a single wavebeam of two times higher intensity.

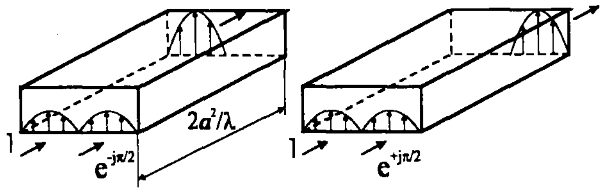

Fig. 2. Quasi-optical -3 dB directional coupler

Moreover, the resulting wavebeam appears on the left or on the right side of the rectangular waveguide, depending on the mutual phases of the incident wavebeams (Fig. 2).

Let us characterize a purity of the resulting wavebeam by means of so-called mutual convolution between the obtained distribution and desired one (sinusoidal distribution of the TE_{10} mode).

The performed calculations show that efficiency η=0.98-0.99 are reachable, if ka exceeds 35. Because the analyzed phenomena exists due to paraxial modes only, the wider the main waveguide the more efficiency. Note that the suggested -3 dB coupler has weak sensibility to the frequency change.

Quasi-Optical Four-Channel Coupler

As it was mentioned, the gain of the DLDS equals to a number of the combined amplifiers. One -3 dB hybrid provides gain of factor 2 only. That is why, JLC collider's project includes combining of four pairs of (2×65 MW per each pair) klystrons [1]. This is

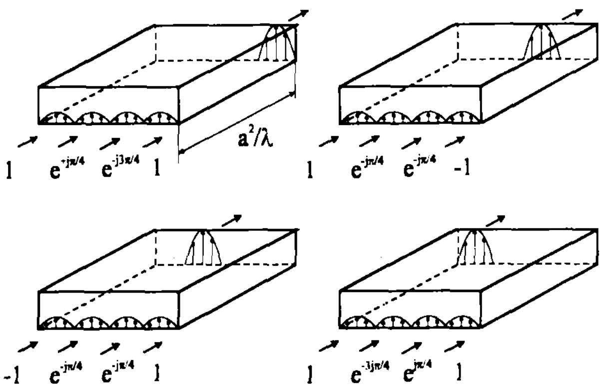

Fig. 3. Quasi-optical four-channel coupler

achieved by means of cascading of four -3 dB hybrids which allow to multiply power by factor 2 step by step

The most important that four-channel coupler

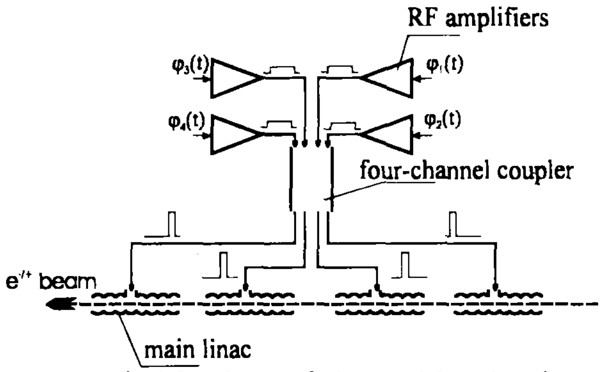

Fig. 4. Principle scheme of 4/4 DLDS based on four channel coupler.

allows to use in DLDS instead of the cascades of -3 dB couplers one device only (Fig.3). In Fig.4 principal scheme of the DLDS, based on such the quasi-optical four-channel coupler, is shown.

Possible upgrades of quasi-optical DLDS concept toward X-band seem also possible. First of all, such attempts have to be associated obviously with ideas how to reduce a total length of the delay lines in order to economize the metal and to reduce the cost.

One of possible way is to use so-called 4/3 DLDS (powers of four sources are combined and distributed to three sections) (Fig.5). The first part of the represented

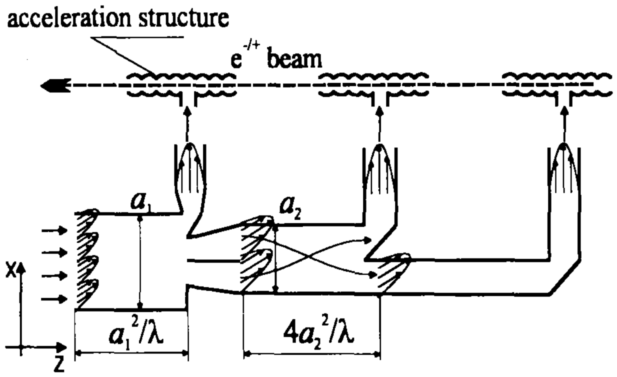

Fig. 5. 4/3 DLDS based on four-channel coupler.

DLDS consists of the four-channel coupler which produce one of three possible wavebeams at the output. In the first regime the wavebeam appears in the far left position of the four-channel output, and it is delivered to the first acceleration section. In the second regime the wavebeam is near the left position, and it must go to the third section due to the repetition phenomena. In the third regime the wavebeam would be placed at near right position, and it is directed into the second section.

Let us introduce an example concerned f=11.4 GHz projects of linear colliders. If a_1=420 mm, it leads to the length of the four-channel coupler closed to 6.5 m. The distances between the extractors are ~20 m using waveguide of a_2=360 mm size behind the coupler. Note that the necessary waveguide has extremely large cross-section. This fact allows to use instead of conventional vacuum pumping the pressurized Le-gas in order to avoid microwave breakdown inside the system.

DLDSes Based on Waveguides with Impedance Corrugation

Upgrades of DLDS concept to frequencies essentially higher than 30 GHz assume to apply delay lines based on extremely oversized waveguides. Such the waveguides are certainly necessary in order to reduce RF fields of transmitting high power microwaves. Besides, it can help to provide a low attenuation level.

One of the way to reach both these goals is to construct delay lanes of rectangular oversized waveguides with impedance corrugation, which have to be operated on low-loss hybrid modes like HE_{11} [5-6].

Conclusion

The presented quasi-optical DLDS concept is efficient and simple. Basing on oversized waveguides, it allows to operate with gigawatt power level of microwaves.

The proposed ideas seem most attractive for frequencies around 30 GHz. Nevertheless, upgrades toward X-band as well as toward shorter millimeter wavelengths are possible.

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