SYMMETRICAL DOUBLE INPUT COUPLER DEVELOPMENT*

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Abstract

RF power is usually transmitted into an accelerator section from a rectangular waveguide through a single coupling iris. This arrangement introduces phase and amplitude asymmetries into the coupler fields with which the beam interacts. Field distortion can be reduced by machining an offset into the cavity wall opposite the iris. However, the compensation is imperfect. In this paper we describe the development and testing of a double input coupler which is completely symmetric about a vertical plane through the beam axis. Two identical irises are used on opposite sides of the coupler cavity. These are fed in-phase by signals from a Magic Tee power divider. Each iris transmits one half of the total power flow. Coupler dimensions for an X-Band model have been optimized using MAFIA and conventional low-power matching techniques. The coupler has been built into a 30-cavity test accelerator section and operated up to 85 MV/m with no evidence of breakdown.

Introduction

The most commonly used method of feeding RF power from a rectangular waveguide into a cylindrical disk-loaded accelerator structure is to couple into the first (coupler) cavity of the structure through a single iris in its outer wall. The geometry of this coupling design is obviously asymmetric with respect to the beam axis of the accelerator structure, and it is no surprise that it gives rise to serious phase and amplitude asymmetries in the coupler cavity fields. The amplitude asymmetry, which causes beam bunch-spreading, can be reduced by a factor of 100 or more by offsetting the coupler cavity with respect to the beam axis [1]. However, such an offset does not reduce the phase asymmetry, which causes a net deflection of the beam.

It would appear that a good solution to the problems is to symmetrize the transverse geometry by feeding equal RF power through two identical irises on opposite sides of the coupler cavity, as shown in Fig. 1(a). The drive from the klystron is split into two signals of equal amplitude and phase, using a well-balanced and matched Magic Tee. These signals propagate around two 180° H-plane waveguide bends having the same length and attenuation, and then enter the coupler cavity through two matched irises, as shown in Fig. 1(b).

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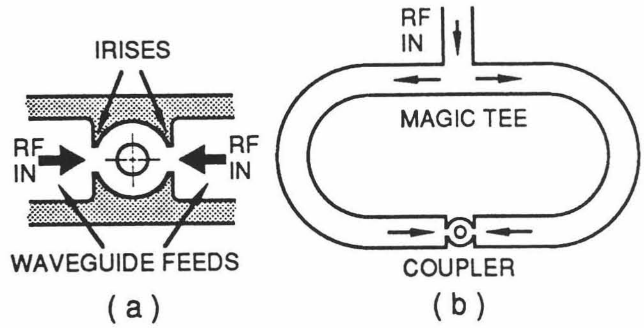

Fig. 1 Schematics of RF power input to coupler.

Coupler fabrication and test

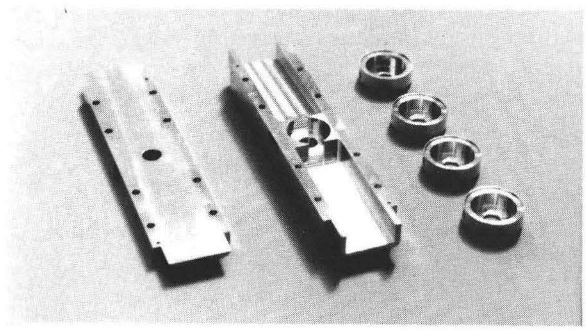

Fig. 2 Coupler components.

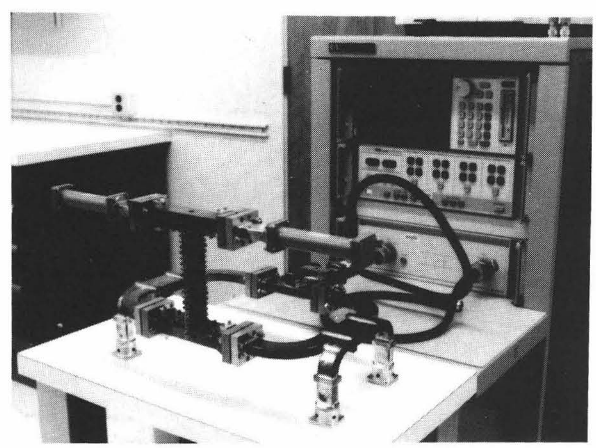

Fig. 3 Cold-test assembly.

Coupler components are shown in Fig. 2. The coupler cavity, coupling irises and rectangular waveguide tapers are machined into one block of copper. An end-plate with a beam aperture is brazed onto one side, and cups forming the accelerator structure are brazed onto the other side. Fig. 3 shows a complete cold-test assembly being measured on a network analyzer. The accelerator cups are stacked unbrazed, and tuning screws are used to set the correct phase advance per cavity. The couplers are matched by iteratively modifying the coupling iris width and the coupling cavity diameter, following the procedure described by Westbrook [2].

The coupler design has been incorporated into a 30-cavity constant impedance X-Band accelerator section. To date, this has been run up to an input power of 73 MW, corresponding to a gradient of 85 MV/m in the input coupler, with no evidence of RF breakdown [3].

The MAFIA simulation model

The MAFIA code [4] is used to model the double input coupler. A 7-cavity accelerator section is considered which includes the input and output coupler cavities. Such a geometry is necessary in order to simulate traveling wave propagation. Two symmetry planes through the beam axis are used at which the magnetic boundary conditions are imposed. As a result only modes in the lowest passband (m=0) can propagate. The dimensions of the standard cavity yield 11.42 GHz at the $2\pi/3$ phase advance. The couplers are loaded by WR90 waveguides through irises. The waveguide endplanes are treated as ports through which power can flow in and out of the structure. The MAFIA geometry is shown in Fig. 4.

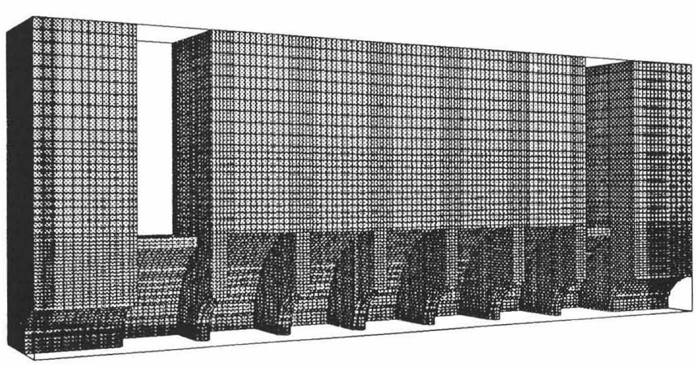

Fig. 4 **MAFIA** geometry for a 7-cavity traveling wave section.

MAFIA determination of S parameters

In order to evaluate the reflection and transmission properties of the structure, MAFIA simulates the problem in the time domain. Power is fed continuously at the input port in the TE_{10} mode with a given frequency, starting with a smooth initial rise and reaching 1 watt at flat-top. The simulation extends over several filling times of the structure until steady-state is reached. The reflection and transmission due to the structure are handled by special boundary conditions at the waveguide ports which correspond essentially to matched loads. At the input (output) port, the complex amplitude of the reflected (transmitted) dominant TE_{10} mode is followed in time. Figs. 5a and 5b show their respective time histories. These results are for the case when the couplers are well matched. It is seen that the transmission (normalized to the input power) is close to unity. The reflected wave shows an initial transient which is caused by the finite rise time in the driving pulse. At long times, the reflection reduces to a negligible amount. The time averages of the amplitudes yield the S parameters. In this well-matched case, $S11$ is found to be only 0.0025 at a frequency of 11.426 GHz, corresponding to a VSWR of 1.005.

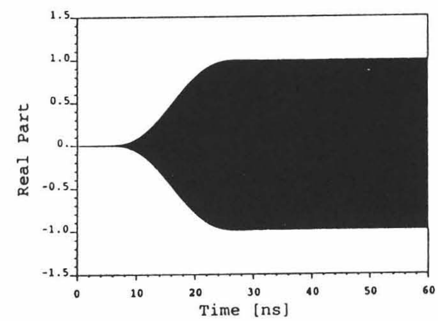

Fig. 5a Amplitude of transmitted wave versus time.

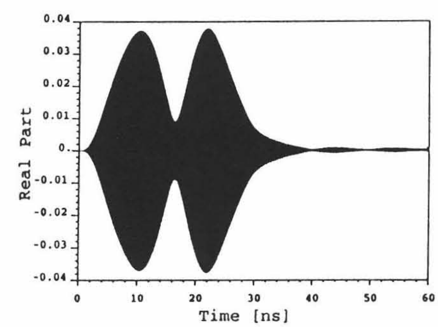

Fig. 5b Amplitude of reflected wave versus time.

Optimization of coupler dimensions

The crucial dimensions of the coupler cavity to be determined for good match to the waveguide feed are those of the coupling iris and the cavity diameter. The optimization of these dimensions is achieved iteratively by carrying out MAFIA simulations in parallel with low-power matching experiments. For a set of coupler dimensions, MAFIA is used to explore the effect on matching as each of the important dimensions is varied, a change that is much easier to implement on the computer than on hardware models. In a way, the simulation serves as a guide towards finding the optimal geometry once a good initial guess is taken. When such an optimum is found, the actual coupler is machined to those dimensions and cold-tests are performed. Since there is always an error in the numerical geometry because of finite mesh effect, further tuning adjustments may be necessary to obtain the best match. Figs. 6a and 6b show the comparison between MAFIA results and cold-test data for the best matched case. In both cases, the VSWRs display a minimum at around the structure frequency of 11.424 GHz.

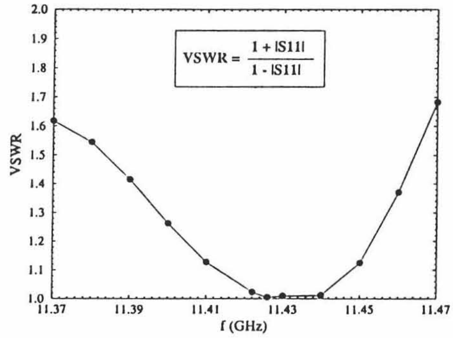

Fig. 6a MAFIA results of VSWR versus frequency.

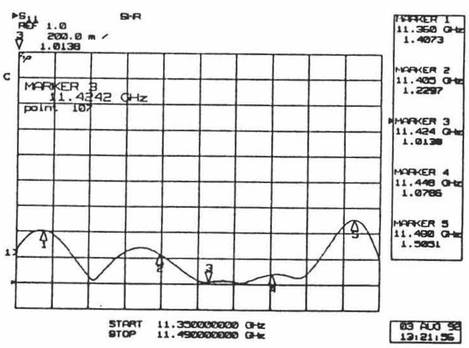

Fig. 6b Cold-test data of VSWR versus frequency.

Amplitude and phase asymmetries in coupler fields

To find the amplitude and phase asymmetries in the coupler fields, MAFIA records the field time histories on opposite sides of the input coupler beam aperture (radius r_a) in the plane of the beam axis and the waveguide feed. The computed asymmetries in this plane for a single input coupler with imperfect offset correction are shown in Fig. 7. The asymmetries in the same plane for the double input coupler are zero.

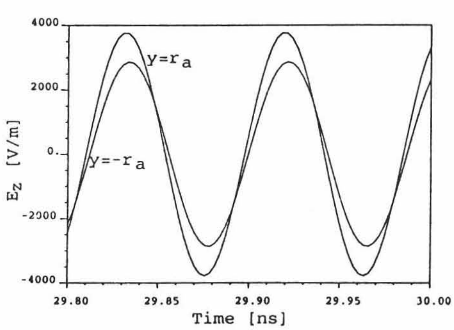

Fig. 7 Amplitude and phase asymmetries in a single input coupler cavity.

When the coupler is matched, close to all of the power is transmitted, setting up a traveling wave in the structure. Since MAFIA integrates the fields in time, the propagation of the traveling wave can be followed. Fig. 8 shows a sequence of snapshots of the electric field taken over a wave period at steady-state. The input waveguide is to the left and it can be seen that the wave travels from left to right and exits through the output waveguide port. The mode pattern characteristic of the $2\pi/3$ phase advance can be recognized in the linac section.

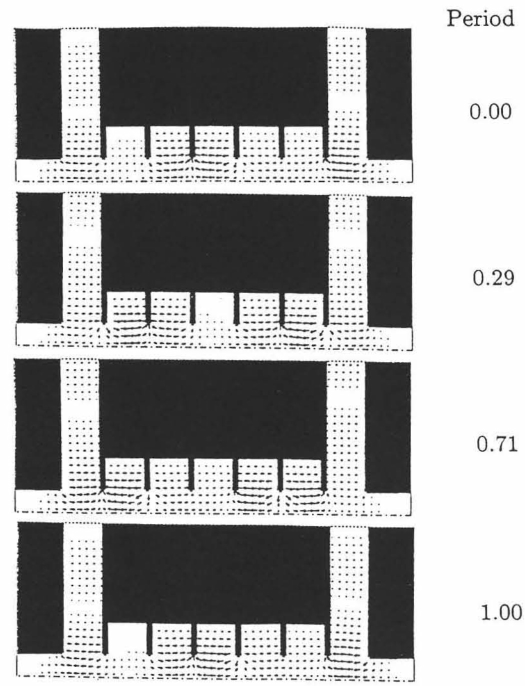

Fig. 8 Propagation of a traveling wave through the couplers and the accelerator structure.

Conclusion

The feasibility of a symmetrical double coupler to transfer power between a rectangular waveguide and a disk-loaded waveguide accelerator has been demonstrated by MAFIA simulation and analysis, by low-power RF testing and optimization, and by very high-power testing in a short X-Band accelerator section. The advantages of the design are seen to be the provision of very good field symmetry, which is important for reducing transverse field mode excitation in linear collider machines, and the halving of power flow through each iris, which increases the coupler power-handling capacity.

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