WAVEGUIDE DIRECTIONAL COUPLERS FOR HIGH VACUUM APPLICATIONS

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Abstract

Directional couplers have always been critical elements in the RF feed systems for accelerator structures. Until now, however, such devices have been confined to areas outside of the high vacuum cavity feeds. The level control of the RF signal required at the cavity inputs is continually increasing and it has become apparent that a directional coupler design for the high vacuum side of the system is necessary. The following paper highlights a novel coupler design to allow high vacuum directional couplers to be realized. Results are presented for both electrical and mechanical characteristics for an L-band device.

INTRODUCTION

Waveguide directional couplers have been utilized routinely in the construction of Accelerator structures to feed amplitude and phase information of the applied RF signals to the control systems managing the RF feed points. As the beam energy required for the accelerator experiments continues to rise in order to achieve greater levels of understanding, the control of the RF input signals is becoming more and more critical. An additional factor, which is necessary to achieve the greater beam powers, is that the vacuum levels necessary within the accelerator structures are continually becoming more refined. It has become apparent that in order to further optimize the control of the RF signals, it is necessary to position directional couplers as close to the accelerator inputs as possible. This optimum position places these devices within the Ultra High Vacuum area of the accelerator structure. The directional coupler under development meets the stringent vacuum requirements demanded by the Accelerator system. The coupling/directivity performance characteristics measured suggest that RF control will be enhanced. The steps taken to arrive at the current design are described and discussed. The new coupler design utilizes a vestigial loop technology housed within a waveguide section which supports an evanescent mode.

VESTIGIAL LOOP COUPLER DESIGN

Vestigial loop couplers have been utilized for decades due to their versatility in being able to optimize RF coupling and directivity performance. The operational characteristics of such devices are well understood to utilize the E and H fields of a mode launched from the waveguide housing into a short circular waveguide section, well below cutoff. [1,2] This *evanescent* mode decays rapidly as it travels within the circular waveguide portion. The coupling section, as depicted in figure 1, is, for all intents and purposes, a matched section of microstrip suspended within the confines of the circular waveguide section.

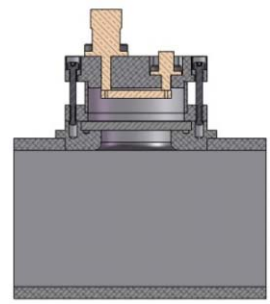

Figure 1: Cross Section of a Typical Vestigial Loop Coupler.

The mechanical parameters of the coupling loop play a major role in the electrical coupling and directivity performance of the device due to the nature in which the E and H fields actually interact with the loop geometry to induce the necessary coupled signal.

VACUUM COUPLER DESIGN

It is readily recognized that a waveguide section may be constructed to handle the UHV conditions which this coupler design will encounter. There is currently a flange design, which has been developed for use with such a waveguide section and that same flange has been incorporated into the current UHV coupler design. The challenge has been to develop a coupling port which can be adequately sealed and still provide the coupling accuracy and high directivity necessary for successful system operation. One of the issues to be resolved revolves around the coaxial connector used for the coupling port. Numerous sealing methods have been considered for this area, including the use of hermetically sealed connectors and vacuum feed-through style connectors. However, for UHV applications requiring a working vacuum level of 10^{-9} Torr, the necessary leak rate of 10^{-12} Torr is envisaged to be very challenging for a connector to survive since numerous cables will be attached and re-attached to the connector where any movement could potentially cause a vacuum leak to occur.

After exploring numerous possibilities, it was decided to incorporate a vacuum window into the evanescent mode section of circular waveguide. The UHV requirement necessitates the use of a Sapphire window. The base design is such that the coupling structure will be built around this window, which will be attached to an opening in the center of the waveguide broad wall where the evanescent mode is launched into the circular waveguide portion of the coupling structure. The design is set up in such a way that the window may be attached to the waveguide and vacuum integrity of the device checked prior to attaching the remainder of the coupling device. In this way, the vacuum seal and the coupling mechanism may be completely separated from a construction standpoint, thus allowing for a more reliable and streamlined assembly process. During the design process it was necessary to prove out the concept of integrating the Vacuum window and the new coupler design to ensure that the final design parameters could be met.

Figure 2: Aluminum Prototype

An aluminum prototype, Figure 2, was constructed utilizing material thicknesses which replicate those used in the final component design. The Vacuum window, as shown here in figure 3, is affixed to the waveguide

Figure 3: Vacuum Window seal creating Circular waveguide launch port.

section to form part of the Circular waveguide into which the evanescent coupling mode is launched.

PROTOTYPE ELECTRICAL PERFORMANCE

The electrical performance of the prototype Aluminum body device shows that the coupler design is good. The completed prototype device was measured using an Agilent 8753D vector network analyzer. The dynamic range of the measurement system allowed accurate coupling and directivity measurements to be obtained. The coupling, as shown here in Figure 4, has been set to 67 dB at center frequency. It demonstrates the characteristic 6 dB per octave coupling slope associated with this style of coupler.

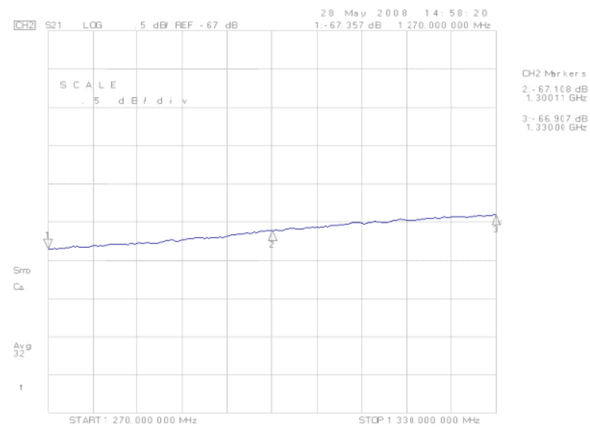

Figure 4: Prototype Coupling Level

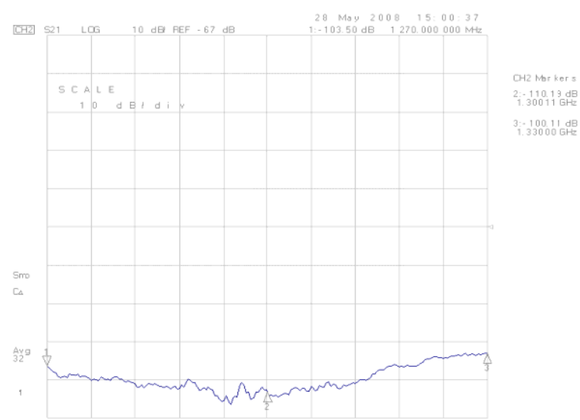

Figure 5 : Prototype Directivity Measurement.

The directivity of the coupler, as depicted here in Figure 5 was measured as greater than 40 dB which is considerably better than the 33 dB initially expected. This is due in part to the coupling loop design which provided a coupled port VSWR match of better than 1.05 : 1.

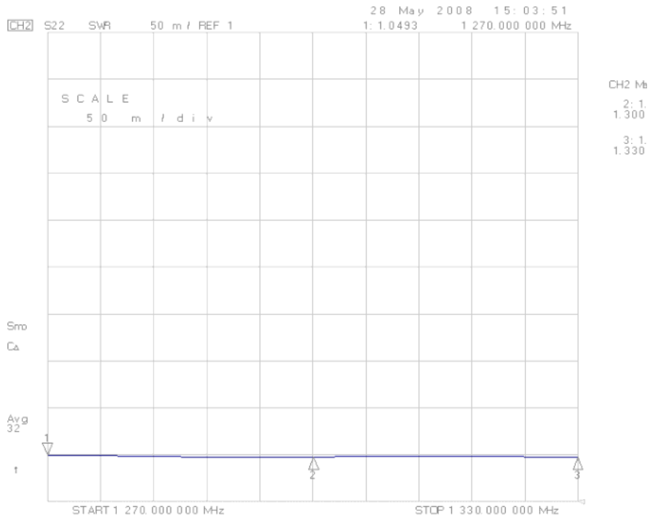

Figure 6 : Prototype Coupling Port VSWR.

The data obtained from the prototype unit readily demonstrates that the electrical parameters sought at the outset of the project may be readily achieved.

VACUUM DESIGN REALIZATION

The operational vacuum level for the final device is of the order of 10^{-9} Torr such that the leak rate requirement is ~10^{-12} Torr. Achieving vacuum levels of this magnitude involves a much more sophisticated manufacturing operation than has typically been used for waveguide components. All surfaces exposed to the vacuum conditions have to be free from any contaminants. The initial device being fabricated, shown here in figure 7, is made from high conductivity copper and incorporates

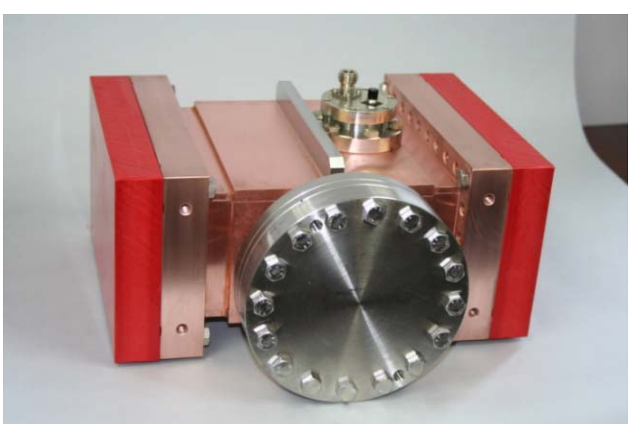

Figure 7: UHV Coupler.

a vacuum pump out port as part of the system design. All vacuum testing is performed using a "time rate pressure increase method". The system, as shown in Figure 8, consists of a roughing pump followed by a standard turbo pump. When the vacuum level reaches 2 x 10^{-8} Torr, a sequence of gate valves is adjusted and an ion pump along with a cryo-pump are utilized to pump the system down to the lowest achievable level where it stabilizes.

Figure 8 : Vacuum Test System.

At that point all of the gate valves are closed and the system pressure is monitored over time, such that an accurate leak rate may be determined. Having calculated the total volume of the device under test and knowing both the volume and the leak rate of the vacuum test system, the calculation is relatively straight forward. The vacuum levels attained for the test system at this point are of the order of 4.0X 10^{-10} Torr with an associated leak rate of 3.8X 10^{-9} Torr-liters/sec. It is expected to lower these levels as system bake out progresses

CONCLUSION

Integrating an RF coupling structure into a waveguide section operating under UHV conditions necessitates the use of unique design approaches. The design approach utilizes a combination of proven vacuum sealing techniques using metal seals for UHV applications and a Vestigial Loop coupling mechanism. It has been demonstrated that such a structure may be formed and the resulting electrical parameters have been presented. The vacuum testing is ongoing and is expected to be successful based upon the sapphire vacuum window manufacturer's specifications. The success of this development will allow more accurate control of the signals at the input of the RF Cavities of the accelerator structure, thus allowing another degree of freedom with respect to beam control.

REFERENCES

[1] P.P. Lombardini, R.F. Schwarz, P.J. Kelly, "Criteria for the Design of Loop-Type Directional Couplers for the L-Band" IRE Trans, MTT, October 1956, pp234-239.

[2] B. Maher,"An L-Band Loop Type Coupler", IRE Trans. MTT, July 1961, pp 362-363.