ANL-HEP-CP-85-41

1985 Particle Accelerator Conference, Vancouver, BC, Canada, May 13-16, 1985

MICROWAVE RIDGED WAVEGUIDE BEAM PICKUPS

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Abstract

Sensitive broad-band beam pickups are a prerequisite for improved stochastic beam cooling. The 2-4 GHz and the 4-8 GHz bands have been of particular interest for stochastic cooling applications. This report summarizes the striking results of an investigation of ridged waveguide pickups at Argonne. An upper-to-lower frequency ratio of 2.4:1 is readily obtained with a ridged waveguide as compared to 1.5:1 with a standard waveguide. Wire measurements and tests at the Argonne beam test facility[1] indicate an approximate 20% increase in gain per unit over a stripline with comparable longitudinal spacing. Another advantage of waveguide pickups is construction simplicity. The output is easily coupled to a transmission line.

Descriptions of the design, construction, and results are included in this report.

Introduction

Ridged waveguide has been used for many years, particularly in radar wideband applications. It has also been used for coupling to the electron beam of a klystron. The author is not aware of previous particle accelerator use of waveguide as a beam pickup.

Design Considerations

Figure 1 is a photograph of a test array of waveguides with which one can visualize how the beam couples to the pickups.

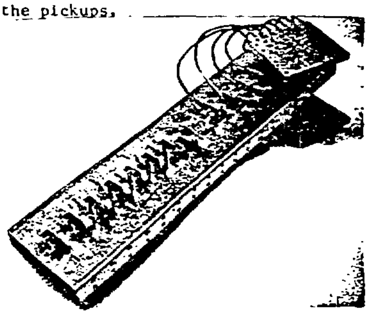

Fig. 1 An array of 7 pair of single ridge 4-8 GHz waveguide pickups are on the left. Output coupling is not shown. An array of 8 pair of capped, double ridged, 4-8 GHz pickups is to the right. The output cables and the 8-way combiners are shown. The stainless steel chamber is 3 cm × 15 cm x 48 cm.

Waveguides tried thus far have been λ/2 at mid-band frequency in length. An exhaustive study has not been made correlating efficiency with length. The beam electromagnetically couples to the waveguide and the energy propagates by the $TE_{1,0}$ mode. Ridges in the waveguide cavity broaden the frequency band by lowering the low frequency cutoff while raising the cutoff of the next higher frequency mode. Basically, the lower and higher frequencies use different areas of the waveguide but the impedance is primarily determined by the ridge gap. The frequency and phase response of the waveguide are within 2 db and 20°, respectively, for an octave bandwidth. Deviations from these response values usually result from mismatches at beam coupling and at output coupling. There is some perturbation also due to cross-coupling between pickups.

Table I shows the dimensions of standardized ridged waveguides and Figs. 2 and 3 relate the dimensions to actual models.

Table 1. Specifications for Standard Ridged Waveguide

Designation	Frequency Range GHz	Fig. No.	Dimensions (in.) (Nominal) A	B	C	D
WRS200D24	2.0 - 4.8	2	2.456	1.105	0.461	0.381
WRS350D24	3.5 - 8.2	2	1.404	0.632	0.264	0.218
WRD200D24	2.0 - 4.8	3	2.590	1.205	0.512	0.648
WRD350D24	3.5 - 8.2	3	1.480	0.688	0.292	0.370
WRD475D24	4.75 - 11.0	3	1.090	0.506	0.215	0.272

ANL-HEP-CP--85-41

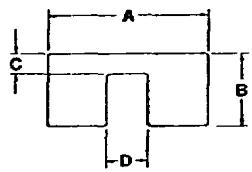

Fig. 2 Single Ridge Wave Guide Cross Section

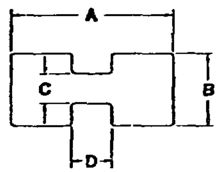

Fig. 3 Double Ridge Wave Guide Cross Section

The dimensions in Table I were used as a guide in the fabrication of test pickups. Components using double-ridged waveguide are commercially available but have rather long lead times. Single-ridged components are a rare breed since it seems that for long lengths (many wavelengths), dimensional tolerances are easier to hold for double ridged. The characteristic impedance for various dimensions can be determined from published curves.[2]

Construction

Components are commercially available in aluminum alloy, brass, copper and silver alloy. Stainless steel seems to work well also. With the short lengths and low power involved with pickups, attenuation due to the material is of little consequence.

Figure 4 shows three typical pickups that have been tested. The first pickups tested, such as the one on the right in Fig. 4, coupled the signal to a 50 Ω coaxial cable by connections to the ridge gap ends. Loss from the open end is reduced and the impedance match is improved by using a λ/4 stub and capping the end (left pickup in Fig. 4). Figure 5 shows a diagram of the capped version and also shows some tuning screws which reduce the VSWR (Voltage Standing Wave Ratio) by improving the impedance match between waveguide and the coaxial cable. Improvement of the VSWR from about 2:1 down to 1.2:1 has been achieved with the tuning screws. This is a standard waveguide matching technique.

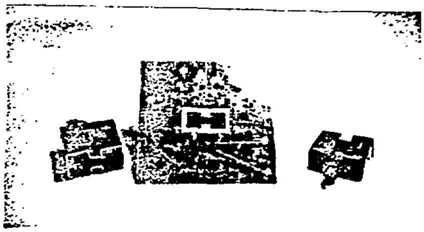

Fig. 4 The capped version of the left and the ridge connected unit on the right are 2-4 GHZ units. The Unit in the center is fabricated of commercial WRD350D24 (4-8 GHz) waveguide.

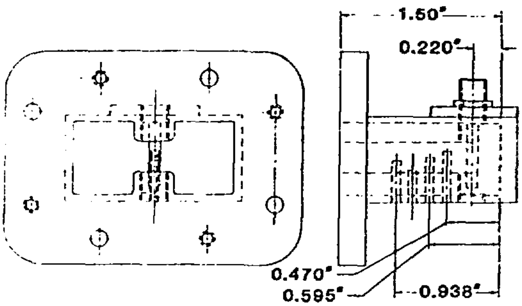

Fig. 5 Cross sections of a 4-8 GHz waveguide-to-coax adapter showing the λ/4 coupling stub and tuning screws for impedance matching.

Evaluation

Preliminary testing of a device is made by direct coupling two units end-to-end and measuring the S_{11} parameter of each unit and the S_{21} transfer parameter for the combination. These measurements are greatly facilitated by a network analyzer such as the HP-8410. At this point, the tuning screw adjustments can be made.

Next, the pickup is tested using a 200 Ω wire transmission line as a signal source. The wire transmission line is not an ideal current source, as is a particle beam, but the network analyzer has a gain normalization feature so that meaningful tests can be made. Wire tests of multiple pickups must take into account the power lost to the upstream units away from the downstream units. This is difficult to normalize, so the results are not precise.

Figures 6 and 7 are the results of 22 MeV electron tests at the Argonne beam test facility. One expects that the voltage gain and the coupling impedance (a figure of merit; $Z_c = v_{pu}/i_{beam}$) increase proportionally to $\sqrt{N}$, where N is the number of pickups. Tests of arrays of pickups with the beam indicate there are problems in the combination which result in good peak and average coupling but erratic frequency and phase response.

More work needs to be done on the impedance match between waveguide and beam and on cross-coupling between units. Preliminary tests of the 2-4 GHz pickups indicate that the cross-coupling is frequency dependent. Cross-coupling can be measured by driving one pickup and observing the coupled signal on the other. This is an extreme worst case condition since, in reality, the only signal cross-coupled is that reflected from a mismatched pickup.

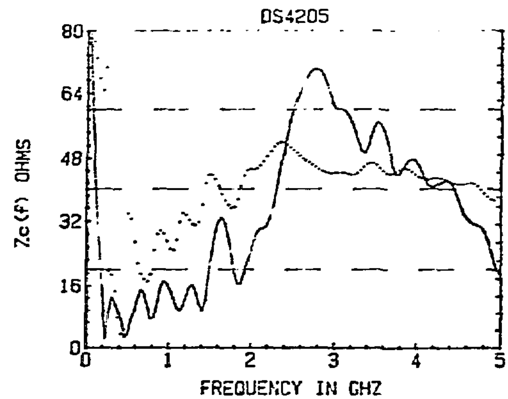

Fig. 6 Amplitude and phase vs. frequency for the sum of . pair of 2-4 GHz pickups like those on the left in Fig. 4. Amplitude is traced by the solid line and phase (10° per right tic mark) by the dotted line.

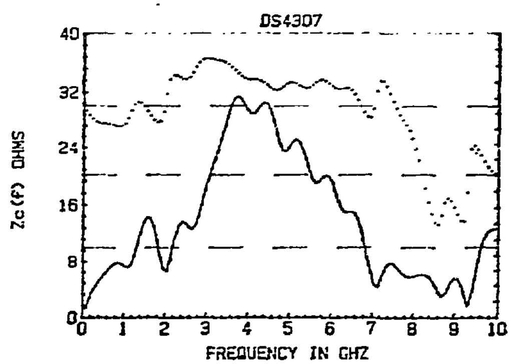

Fig. 7 Frequency and phase response for a pair of 4-8 GHz pickups like those on the right in Fig. 1. WRD475D24 waveguide was used in fabricating these units.

Acknowledgements

The author acknowledges assistance from R. Konecny in fabricating the test units and help from R. Konecny, S. Kramer, and J. Simpson in evaluation.

References

1. J. Simpson, R. Konecny, S.L. Kramer, D. Suddeth, "Test Facility for Relativistic Beam Pickups," in IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1981.
2. S. Hopfer, "The Design of Ridged Waveguides," in IRE Transactions, Vol. MTT-3, pp. 20-29, October 1955.
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