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PURE MODE SWEPT FREQUENCY TE_{02} MEASUREMENTS IN 6.35 cm CIRCULAR WAVEGUIDE*

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Abstract

A mode transducer was developed which generates high purity (> 99%) TE_{02} mode in small diameter (1.64 cm) circular waveguide. The device works from 52-62 GHz which allows relatively wideband, accurate swept frequency measureinents of insertion and return loss in this mode. TE_{01} to TE_{02} insertion loss for the device is approximately 0.2 dB and the TE_{01} mode rejection from the TE_{02} port is 15 dB. A 2- degree linear taper is used to connect to 6.35 cm diameter waveguide. Mode purity of the TE_{02} mode after this taper is > 98%. Some typical measurements of waveguide components as well as a description of the device will be presented.

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Waveguide development work is currently underway at ORNL for the Advanced Toroidal Facility (ATF) ECH System. The initial capabilities of the system will be 200 kW CW at 53.2 GHz. ATF is capable of running steady-state at 1T and less than 5-sec at 2T, however, plans call for initial operation of less than 5 sec pulses with a central magnetic field of 1T. In this mode, heating will be from NBI and the ECH system will be used for plasma startup only.

The proposed waveguide system is actually quite simple as shown in Fig. 1. The entire waveguide length will have a diameter of 6.35 cm and will be under vacuum. The waveguide will propagate the TE_{02} mode generated by the gyrotron. Two bends are required for top launch on the ATF device. These bends will be optimized miter bends which are currently under development. Mode conversion into a Gaussian beam will occur at the launcher which will be a Vlasov type with a polarization rotating reflector.

To facilitate testing and optimize the performance of components under development, a mode transducer to generate pure TE_{02} mode was developed. This transducer converts an input TE_{01} mode (generated by commercially available TE_{10} to TE_{01} transducers) into a high purity TE_{02} mode (> 99%) over a frequency range of 52-62 GHz. The wide bandwidth and small size of this transducer make it quite useful for testing in swept frequency laboratory setups. It will also be useful for testing and alignment of the installed waveguide system on ATF.

The mode transducer consists of a step in waveguide diameter to a larger diameter guide. This diameter step with an incident TE_{01} mode excites a composite TE_{01} - TE_{02} waveguide (plus some evanescent modes) as described in Marcatili.[1] This composite wave is converted entirely into TE_{02} mode by a coaxial waveguide section which has phase shifting inserts.

Adjustment of the transducer is performed using the radiation pattern technique. A computer program was written for calculating patterns for composite modes which provides insight into mode content for a particular positioning of the coaxial converter section. The presence of non-circular mode impurities such as TE_{11} and TE_{12} indicate a tilting or offset of the converter. The presence of TE_{01} circular mode is best determined by the relative height of the inner and outer peak as shown in Fig. 2. The exact pattern for small apertures ($ka \leq 1\text{-}2$) is not accurately given by simple far-field integration of the aperture fields.[2] A more accurate determination of mode purity can be made by using waveguide spacers of several lengths after the transducer and checking for consistency in the measured pattern. This is shown in Fig. 2 where at least one beat wavelength of the TE_{01} and TE_{02} mode is scanned through. The change in height of the inner peak is $\approx <$ .5dB which, based on computer code predictions, indicates a mode purity of 99%. This process can of course be repeated at any frequency of interest to determine the bandwidth of the device.

A back-to-back swept frequency insertion loss measurement of two transducers is shown in Fig. 3. There the normalized reference line corresponds to the TE_{01} transducers (and mode absorber) alone. In the frequency range that applies ($\approx$ 52-62 GHz) the two transducer insertion loss is 7 dB or less, of which $\approx$ .2 dB could be accounted for by reflections from device ($\simeq$ −15 dB return loss each).

There are several components that can be tested in TE_{02} mode for insertion loss. Using these transducers, components such as miter bends, mode absorbers, other mode converters, and directional couplers can be easily tested. This testing can be done in 6.35 cm waveguide by tapering carefully from the transducer output (1.64 cm). A pair of 2° linear tapers was constructed for this purpose. It was determined (using the pattern method) that these tapers produced $\approx$ 5% TE_{01} mode plus some TE_{03} mode.

Since the transducers are not matched perfectly for TE_{01} mode and TE_{03} is cutoff in the taper, there is the possibility of trapped mode resonances which will cause spikes in swept frequency measurements. To reduce this problem and increase accuracy, good wideband tapers are required and any component to be tested should be low in mode conversion. The spikes can be averaged out somewhat by matching the electrical length of the component with a section of plain waveguide for the reference and using the normalizing features of a scalar network analyzer to subtract out the spikes. Presumably, the remaining signal is close to the true value in the region of the spike. In some cases the level of spikes can be reduced further by adding a high frequency FM component to the sweep oscillator signal. This FM tends to average out the high Q trapped mode resonances when multiple sweeps are averaged. An example of an insertion loss measurement is shown in Fig. 3. Here, a Titanium Dioxide lined waveguide mode absorber (12" long) is measured for insertion loss. As desired, the insertion loss is low - approximately .1 dB. This same measurement setup has been quite useful in studying optimized miter bends for use on ATF.

Swept frequency return loss measurements can be made through the TE_{02} transducer using a directional coupler in the rectangular waveguide source line. Unfortunately, without some reflection cancellation technique, this setup is limited to - 15 dB return loss or worse due to reflections off the mode transducer itself. Nevertheless, the resonant frequency of a single disc window was verified using this technique. Further improvements in this technique could come from tuning of the TE_{02} transducer and improvement of the tapers.

An equally useful application for the mode transducer is in testing of launchers designed for the TE_{02} mode. In this case measurements are made at a single frequency anywhere in the transducer passband. The entire launcher for ATF when completed will be tested using this transducer.

By increasing the transducer converter section and the diameter step ratio, it is possible to build a TE_{01} to TE_{03} transducer that will probably have similar performance characteristics to this device. This principle could be extended to higher order circular electric modes, however, the complexity of adjustment will probably make TE_{04} or higher impractical.

REFERENCES

[1] Marcatili, E. A., "A Circular Electric Hybrid Junction and Some Channel Dropping Filters," Bell System Tech. J, January 1961, pp. 185-196.

[2] Collin, R. E. and Zucker, F. J., "Antenna Theory Part 1," McGraw Hill, New York, p. 631.

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MICROWAVE HEATING SYSTEM FOR THE ADVANCED TOROIDAL FACILITY (ATF)

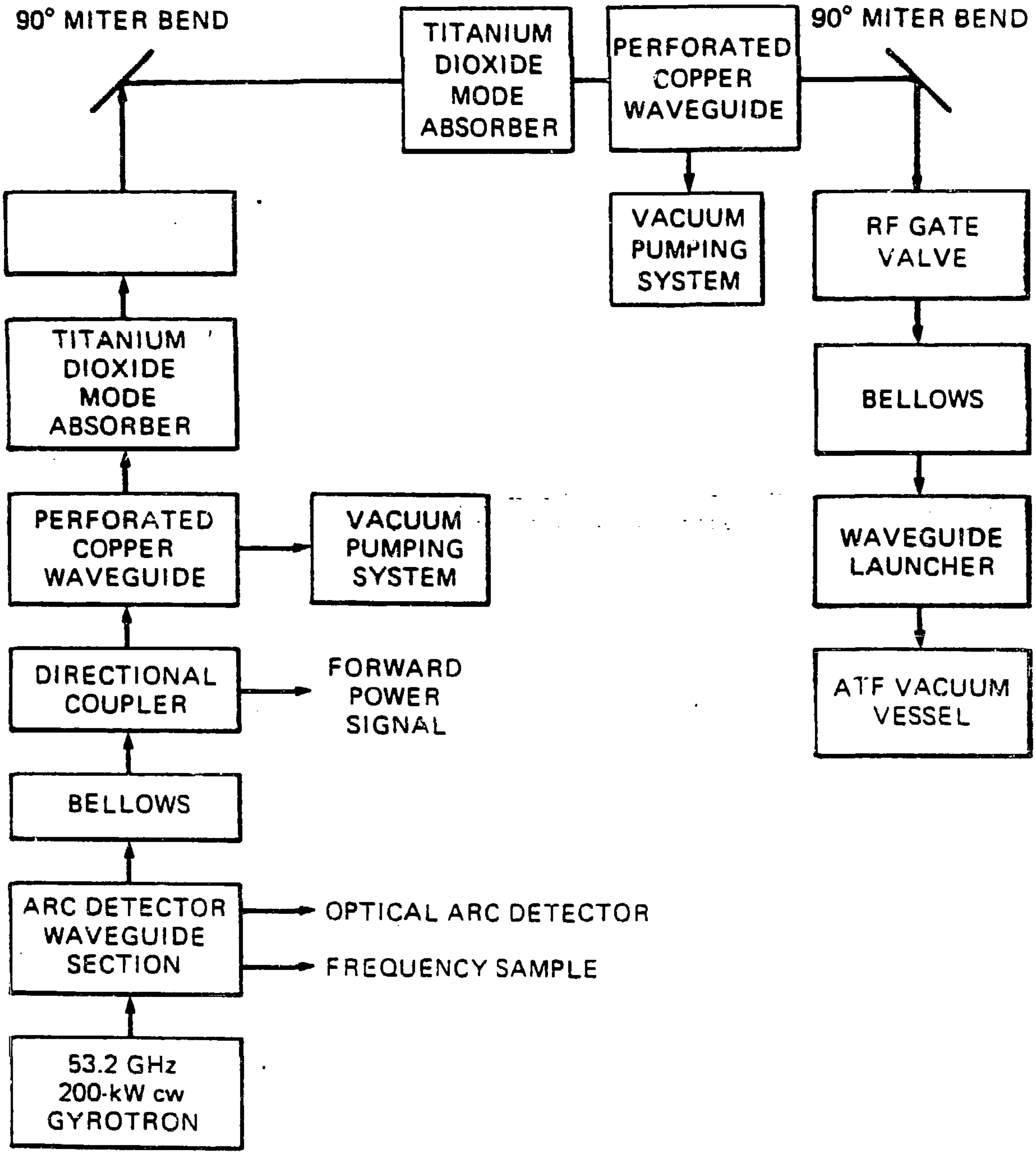

FIG. 1

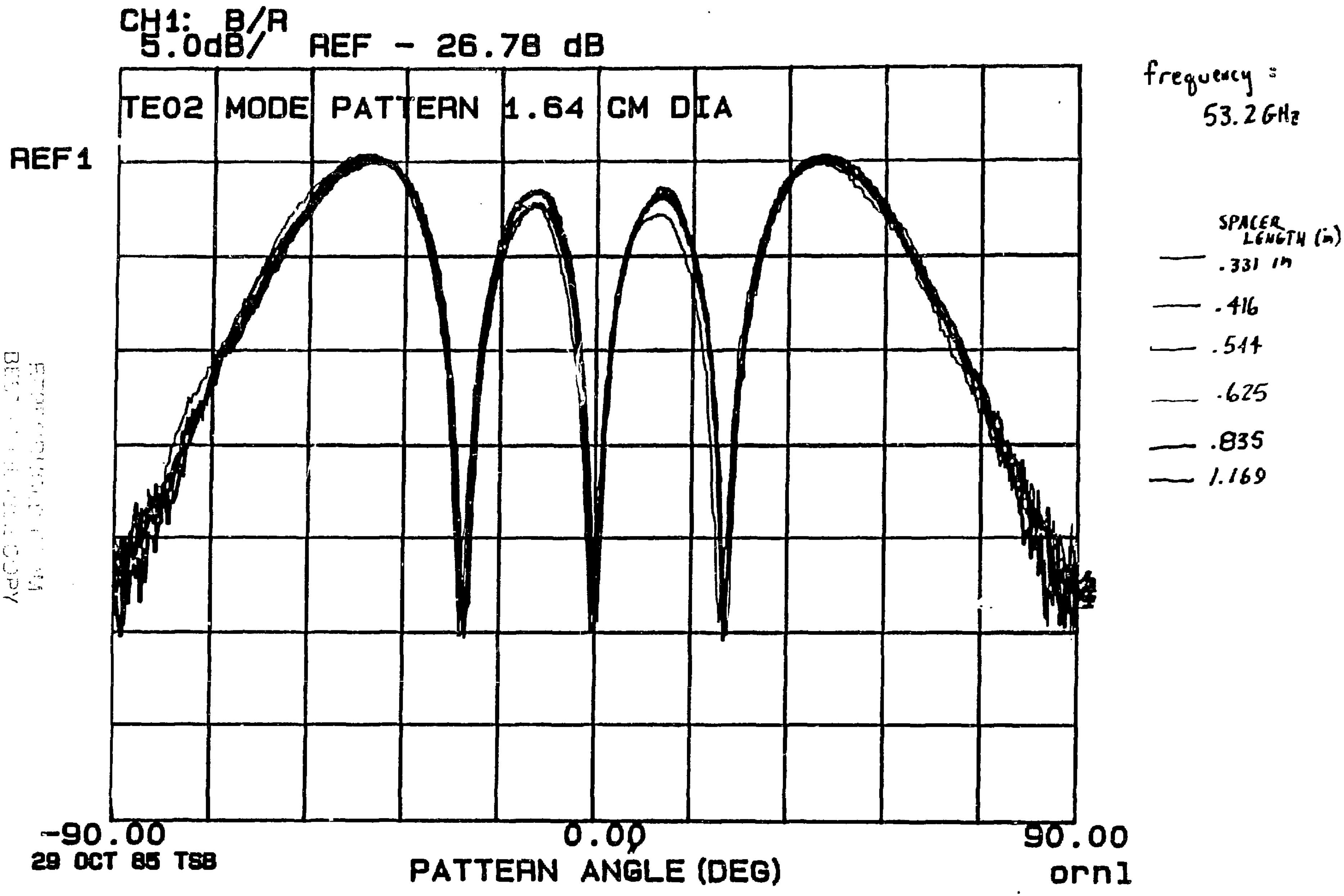

FIG. 2 Transducer Antenna Pattern with Several Spacer Lengths

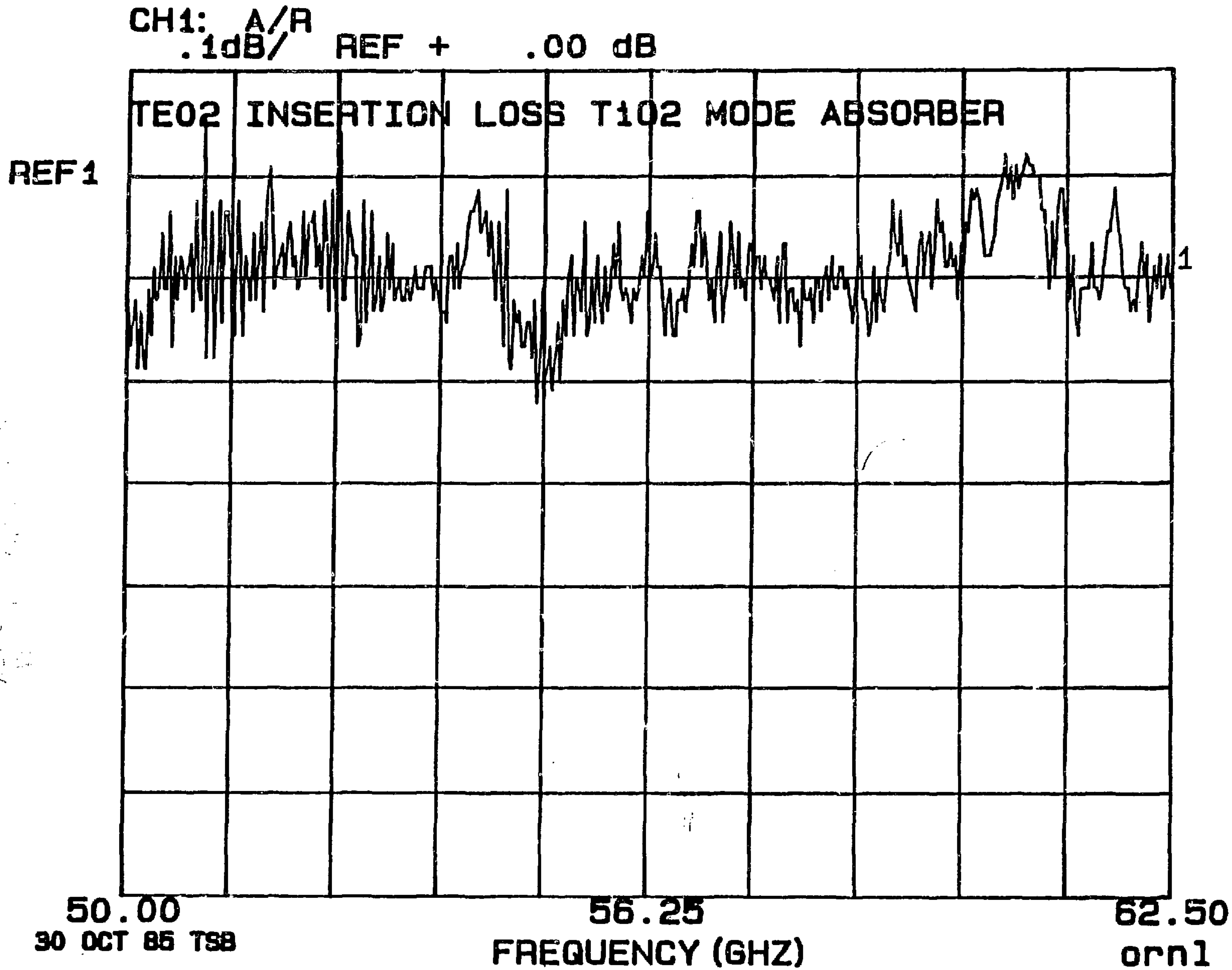

Fig. 3 Swept Frequency Insertion Loss of 12 inch Ti_{02} Mode Absorber