# A NEW COMPUTER-CONTROLLED KLINGER CAVITY MODE CONVERSION TEST SET

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Abstract

In the mm waveguide system, components are needed to transform the $TE_{10}^{\square}$ mode into the $TE_{01}^{\circ}$ mode. A new computer controlled Klinger Cavity Test Set (Fig. 1) has been developed for measuring the modal purity of mm waveguide components.

## Introduction

To meet the increasing communication needs, Bell Telephone Laboratories is engaged in developing a millimeter waveguide transmission system. This circular waveguide uses the $TE_{01}^{\circ}$ mode, is 60 mm in diameter, and operates from 40 to 110 GHz. It will have a capacity of approximately 1/4 million voice circuits.

In developing the waveguide system, measurement components are needed to transform the $TE_{10}^{\square}$ mode into the $TE_{01}^{\circ}$ mode in 60 mm diameter waveguide. A combination of a transducer, mode filter and helix taper is used to make the necessary transition from the millimeter wave source to the waveguide module being characterized. The $TE_{01}^{\circ}$ mode launching components are used in determining the $TE_{01}^{\circ}$ mode transmission characteristics of the waveguide modules. $TE_{11}^{\circ}$ and $TE_{12}^{\circ}$ mode launchers have been designed for determining the unwanted mode attentuation of waveguide modules. The modal purity of all transducers and tapers must be known before they can be reliably used in test sets. The Klinger Cavity Method[1] is a powerful method for determining modal purity.

## The Klinger Method[1]

A simplified diagram which illustrates the Klinger Method of measuring mode conversion is shown in Fig. 2. The letters a and b refer to the incident and reflected modal amplitudes, respectively. The subscripts 0, 1 and 2 refer, respectively, to the input mode, the output main mode, and the unwanted mode. Certain assumptions about the theory must be understood before the Klinger technique can be accurately used. It is assumed that one pure mode ($a_o$) is incident on the junction from a nonreflecting source. The incident mode is not reflected at the junction and is coupled strongly to the output main mode in the forward direction. If the transducer is imperfect, unwanted modes are generated at the junction which are small in comparison to the level of the main mode. All interaction between the incident, main and unwanted modes takes place within the junction. The reflected unwanted mode ($a_2$) sees a very low return loss at the junction and the energy coupled to this mode is trapped in the cavity. The reflected main mode $a_1$ is not reflected strongly at the junction and couples to $b_o$. From these assumptions the analysis can be accomplished using a 3-port representation as shown in Fig. 2. Each unwanted mode is analyzed individually with respect to the main mode.

As the piston, which serves as a short circuit, is moved in the cavity there are certain positions such that the length ($\ell$) of the cavity is an integral multiple of half-guide wavelengths for an unwanted mode. The half-guide wavelength is determined by the cavity diameter, the measurement frequency and the unwanted mode (Fig. 3). At these positions the unwanted mode is resonant causing its field magnitude to increase. The energy driving the unwanted mode is coupled from the incident mode at the junction. Therefore, the reflecting incident mode amplitude ($b_o$) must dip as the piston passes through the resonating position (Fig. 3). The amount of coupling into the unwanted mode is identified by the spacing between its resonances which is one-half its guide wavelength.

A new computer-controlled technique for making Klinger resonance cavity measurements is described in this paper. This new set is more accurate, has greater sensitivity, and has greatly reduced measurement time as compared to manual methods using an x-y recorder and oscilloscope.

## The New Klinger Cavity Test Set

The new Klinger cavity test set (Fig. 1) incorporates many new devices and design improvements which overcome many of the basic limitations of previous methods. The new test set operates under the control of an interactive computer program. The system features automated data acquisition and operator-computer interaction for data analysis. Sequential data pairs representing relative reflected power versus piston displacement are collected at increments of 1.27 microns or 2.54 microns and stored on the computer's mass storage peripheral. A linear incremental encoder, connected to the piston drive, provides the spcing information. After the data is stored in the computer, it is analyzed using the Klinger Analysis Language (KAL). KAL is an interactive computer program used for data acquisition and data analysis. Through the use of the stored computer program, the operator manipulates the data from his teletypewriter. The program displays the requested data on the display peripheral (storage scope). The operator can selectively measure the unwanted mode levels in a manner conceptually similar to the conventional method.

The operating sequence of the new test set is as follows. The BWO is operated at a single frequency. The piston is driven by the drive unit and pulses are obtained from the linear incremental encoder (1.27 microns of 2.54 microns). These pulses and the analog reflected voltage are the inputs to the control box, which is the interface between the Klinger test set and the computer. With each pulse from the encoder, the analog reflected voltage is digitized in the control box by a 12 bit analog to digital (A-D) converter. This digital information is passed to the computer where it is stored on the magnetic tape unit. A magnetic tape is used because of its fast sequential writing speed as compared to the relatively long latency time of a disc storage peripheral. At the conclusion of the data run the information is transferred from the magnetic tape to the disc where it is manipulated and analyzed by the use of KAL. Each piece of data contains both distance and relative reflected power information. Errors due to frequency and amplitude drift are minimized since the data is acquired and stored in about five minutes.

Using KAL, mode identification is accomplished by absolute measurements of unwanted mode half-guide wavelengths (Fig. 4). In 60 mm waveguide, guide wavelengths are 2 to 5 mm from 40 to 110 GHz but wavelength differences between modes of only a few microns are not uncommon. For example, at 110 GHz in 60 mm waveguide the wavelength for the $TE^{o}_{01}$ mode and the $TE^{o}_{11}$ mode are 2920 and 2916 microns, respectively. Since mode identification is accomplished by measuring the half-guide wavelengths, the high resolution linear incremental encoder provides the needed precise distance information.

Using the new test set, enough data is collected to cover at least one-half beat wavelength for the modes of interest. For the previous example the half beat wavelength for $TE^{o}_{01}$ - $TE^{o}_{11}$ is 0.75 meters. The new test set acquires data for up to 1.25 meters of piston travel which is equivalent to about one million data points.

With the new test set, KAL is used to measure, absolutely, the central resonance reflection coefficient ($\Gamma_o$) and the central resonance full width at half power (L) (Fig. 4). The width is easily determined, when the data is collected by a linear incremental encoder, by counting the distance between the half power points. After these measurements are completed KAL calculates the unwanted mode level ($\gamma_{02}$) from the following equation[1]

$$|\gamma_{02}(\text{dB})| = 10 \log_{10} \frac{\beta L}{4} (1-\gamma_o)$$

where $\beta$ = waveguide propagation constant of the unwanted mode in the circular cavity.

## Measurement Results

As a prove-in that the new Klinger test set and KAL were working properly, test measurements were made on a WR-15 $TE^{\square}_{10}$ - $TE^{o}_{01}$ transducer. The output diameter is 9.52 mm. Therefore, a 9.52 mm diameter cavity and piston were connected to the transducer output utilizing the area for another test set-up as shown in Fig. 1. This particular transducer was previously characterized using the manual method. The results from the two measurements are shown in Fig. 5.

The data show that the new test set is more sensitive than the conventional method. For example, the $TE^{o}_{31}$ level at 62.0 GHz was too low to measure using the conventional method but a level of -35.9 dB was measured using the new test set at the same frequency. The additional sensitivity estimated at approximately -40 dB for the small diameter mode conversion measurements is due to careful shielding to reduce crosstalk noise, an improved calibration technique for the diode detector, and the ability of the KAL program to increase the horizontal and vertical scale sensitivities thus allowing more accurate measurements of small resonances.

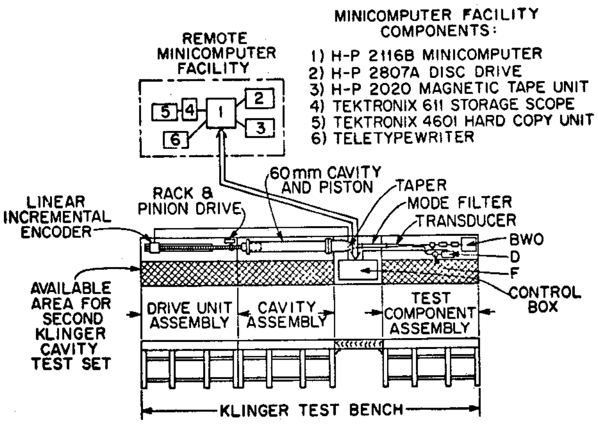
At higher mode conversion levels, where one would expect noise not to interfere, the results differ by about 2 dB. At first this seems to be a large variation but an investigation using the new test set resolved the discrepancy. The approximations Klinger makes in his paper[1] assume the data is an ideal symmetrical beat pattern (Fig. 3). Therefore, to assure minimum error one must measure the central resonance in the beat pattern that best approximates the ideal type. The data using the new set extended over many beat wavelengths. This allows the experimenter to make the mode conversion measurements on resonances which closely approximate the ideal pattern. Since all measurements using the new test set were made on resonances with beat patterns closely resembling the ideal pattern, the resulting unwanted mode levels from the new test set are the more accurate.

## Conclusion

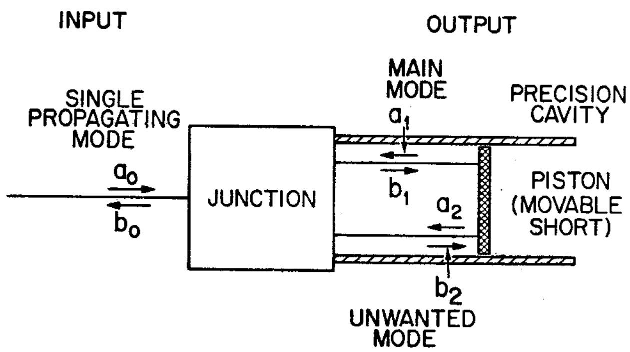
An automated test set to accurately determine mode conversion levels of various circular waveguide millimeter wavelength components has been designed and constructed. This test set allows a greater dynamic range of mode conversion amplitudes to be measured and makes it possible for accurate measurements to be performed in a minimal amount of time.

## References

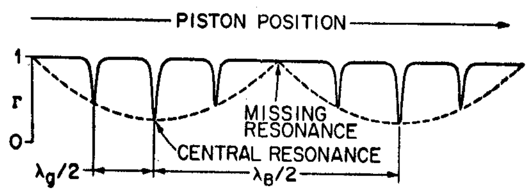
1. Klinger, Y., "The Measurement of Spurious Modes on Over-Moded Waveguide," Proc. of I.E.E. Convention on Long Distance Transmission by Waveguide, Vol. 106, Part B, Supplement B, January, 1959.




THE NEW KLINGER CAVITY TEST SET
FIG. 1




THREE-PORT REPRESENTATION OF A MODE CONVERTING JUNCTION
FIG. 2




$\frac{1}{\lambda_g^2} = \frac{1}{\lambda_0^2} - \frac{1}{\lambda_c^2}$

$\lambda_B = \left|\frac{\lambda_m \lambda_g}{\lambda_m - \lambda_g}\right|$

$\frac{c}{f} = \lambda_0$ = FREE SPACE WAVELENGTH

$\lambda_g$ = UNWANTED MODE GUIDE WAVELENGTH

$\frac{\pi D}{x_i} = \lambda_c$ = UNWANTED MODE CUTOFF WAVELENGTH

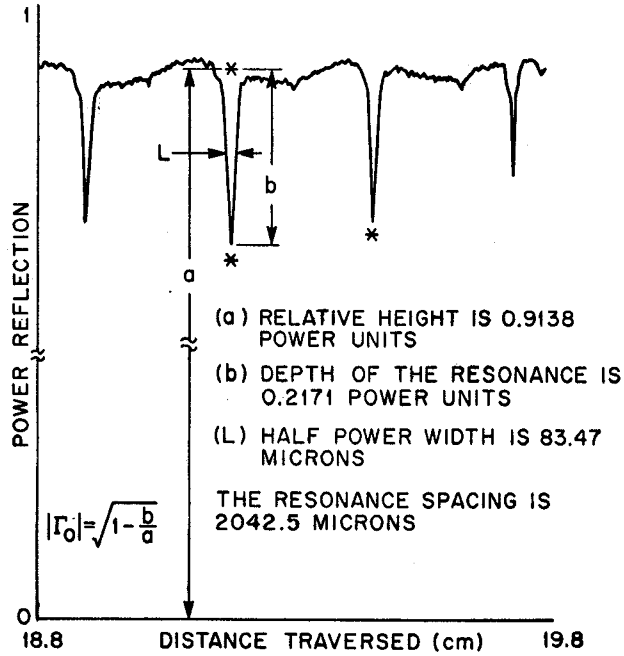
$\lambda_m$ = MAIN MODE GUIDE WAVELENGTH

$\lambda_g$ = UNWANTED MODE GUIDE WAVELENGTH

C = SPEED OF LIGHT  D = DIAMETER OF CAVITY

f = FREQUENCY OF MEASUREMENT  $x_i$ = EIGENVALUE OF MODE

IDEAL KLINGER DATA
FIG. 3




WR-10 TRANSDUCER KLINGER DATA
FIG. 4

| | X-Y RECORDER TEST SET RESULTS | | NEW KLINGER TEST SET RESULTS | |
|---|---|---|---|---|
| FREQUENCY (GHz) | $TE^{\circ}_{11}$ | $TE^{\circ}_{31}$ | $TE^{\circ}_{11}$ | $TE^{\circ}_{31}$ |
| 60.0 | -22.5 | -32.2 | -22.7 | -30.2 |
| 62.0 | -23.7 | * | -21.9 | -35.9 |
| 64.0 | -23.1 | * | -21.5 | - |
| 66.0 | -21.9 | * | -20.3 | - |
| 68.0 | -22.5 | -33.0 | -21.0 | -30.7 |
| 75.0 | -23.9 | * | -24.4 | -36.0 |

* DETECTED (TOO LOW TO MEASURE)
- DETECTED (NOT MEASURED)

MODE CONVERSION RESULTS FOR WR 15 $TE^{\square}_{10} - TE^{\circ}_{01}$ TRANSDUCER

FIG. 5