MICROWAVE TESTING WITH MILLIMICROSECOND PULSES

A. C. Beck
Bell Telephone Laboratories, Inc.
Holmdel, N. J.

Introduction

Pulse testing techniques have been used for many purposes for a long time. In studies of waveguides as radio and radar components, and for possible communications systems use, we have employed various types of pulse testing. The need for greater resolution through the use of very short pulses has always been apparent. For this reason, equipment has recently been built to generate and display 9,000 megacycle pulses having a length of about 6 millimicroseconds. In a pulse of this length there are less than 100 cycles of radio frequency energy, and the pulse occupies less than 10 feet of path length in the transmission medium. The r-f bandwidth required is about 500 megacycles.

Equipment

Pulse Generator

A simplified block diagram of the pulse generator is shown in Figure 1. The heart of this system is in the heavy line loop in the center of the figure. The amplifier represented by the box marked "TW TUBE" uses a special traveling-wave tube with a bandwidth of about 1,000 megacycles operating in the 9,000 megacycle range and having a gain of about 30 db. These tubes were designed and built in the Laboratories' Electronics Department under the direction of J. R. Pierce. The amplifier circuits and structures were designed and built by W. W. Mumford and G. D. Mandeville.

The feedback loop consists of a delay line, a crystal expander and an attenuator. The delay line is made of dominant mode rectangular waveguide and has its length, which is in the order of 60 feet, adjusted so that the total delay time around the loop is 78-1/8 millimicroseconds. The crystal expander is included in the feedback loop so that pulses will be obtained instead of c-w oscillations. This is a suggestion of C. C. Cutler of Bell Laboratories. For a strong signal, the loss of this crystal expander is less than for a weak signal. The attenuation in the loop is adjusted until the circuit is just in the oscillating condition for a strong signal. Since the loss for a weak signal is higher due to the expander, it will not oscillate except for the strongest signal in the loop. Under these conditions a pulse is produced which circulates around the loop, having a repetition rate which is determined by the time of transit through the loop. Each time the pulse goes around the loop it tends to shorten, due to the expander action, thus using the entire bandwidth available. Actually a 500 megacycle filter is used in the loop to determine the length of the final pulse.

In order to avoid jitter and to make the pulse steady on an oscilloscope, a synchronizing system must be used. A 100 kilocycle precision crystal oscillator is the basis of this system. One output through the cathode followers is used to synchronize the pulse generating loop. This is accomplished by doubling the frequency seven times so that a 12.8 megacycle synchronizing signal is obtained from the multiplier, which is applied to the crystal expander. This sets the pulse repetition rate very accurately at 12.8 megacycles which corresponds to the delay time of 78-1/8 millimicroseconds around the feedback loop. Another cathode follower output is used as a synchronizing signal on the receiving oscilloscope. Since the repetition rate of the pulses obtained by this generator is too high to use for most testing purposes, it is necessary to reduce this rate by means of the gated TW tube shown on this figure. This tube is kept in a cut-off condition for 127 pulses and then gated to give normal amplification for the 128th pulse. By this method the output of the pulse generator consists of 6 millimicrosecond pulses at a 100 kilocycle repetition rate.

Receiver and Indicator

The receiving equipment is shown in Figure 2. This consists of three traveling-wave tube amplifiers in cascade. A wideband detector and a video amplifier then connect the signal to the vertical deflecting plates of a 5XP type oscilloscope tube. The video amplifier is actually the band limiting part of the system in use. It consists of two or three Hewlett-Packard wideband distributed amplifiers having a baseband width of about 175 megacycles. The last one of these is of the high output type. The sweep circuits for this oscilloscope have been built especially for this use and produce a sweep speed in the order of 6 feet per microsecond. An intensity pulser is used to eliminate the return trace. These parts of the system are controlled by the 100 kilocycle synchronizing input from the pulse generator standard frequency oscillator. A precision phase shifter is used at the receiver for the same purpose that a range unit is employed in radar systems. This has a dial calibrated in millimicroseconds which moves the position of a pulse appearing on the scope and makes accurate measurement of pulse delay time possible. A photograph of the outgoing pulse is shown on this figure as an indication of how it appears. The ripples following the pulse on the base line come from the video amplifier which is not completely smooth, mainly because the input pulse has more bandwidth than the amplifier can pass. This equipment has a measuring range of about 70 db before the input signal is lost in the noise.

Applications

Resolution

Figure 3 shows a piece of equipment which was placed between the pulse generator and receiver to show the resolution which can be obtained using this equipment. A hybrid junction has its arm marked 1 connected to the pulse generator, and the arm numbered 3 connected to the receiver. If the two side branches, marked 2 and 4, were terminated, no energy would be transmitted from the pulser straight through to the receiver. However, a short circuit placed on either side branch will send energy through the system to the receiver. Two short circuits were so placed that the one on branch 4 was 4 feet further away from the hybrid junction than the one on branch 2. The pulse on the left hand side of the illustration is produced by a signal travelling from the pulser to the short circuit on branch 2 and then through to the receiver, as shown by the path drawn with short dashes. The second pulse is produced by a signal which travels from the pulser through branch 4 to the short circuit and then to the receiver as shown by the long dashed line. This pulse has travelled 8 feet further in waveguide than the first pulse, and it is seen to be well resolved on a time basis. This would be equivalent to seeing two radar echoes from targets 4 feet apart.

Dominant Mode Waveguide Tests

Figure 4 shows another use of this equipment to test 3-inch round waveguides such as those used from radio relay equipment to an antenna. This particular 150-foot long line had very good soldered joints and was thought to be electrically very smooth. The signal is sent in at the end through a transducer to produce the dominant TE_{11} mode. The receiver is connected through a directional coupler on the sending end to monitor for any reflections from imperfections in the line. The overload signal at the left of the photograph of the oscilloscope trace is produced by directional coupler unbalance, and is about thirty db down from the input signal. The overloaded signal on the other end of this trace is produced by the reflection from the short circuit at the far end of the waveguide. The signal between these two, which is about 45 db down from the input signal, is produced by an imperfect joint in the waveguide. The polarization was oriented so that a maximum reflection was found in the case of the lower trace. In the other trace, the polarization was changed by 90 °. It is seen that this particular joint produces a stronger reflection for one polarization than for the other. By use of the precision phase shifter the exact location of this defect was found and the particular joint that was at fault was sawed out. Figure 5 is a photograph of this joint after the pipe had been cut in half through the middle. The guide is quite smooth on the inside in spite of the discoloration of some solder that is shown here, but on the left hand side of the photograph the open crack is seen where the solder did not run in properly. This causes the reflection that shows on the trace. The fact that this crack is less than a semi-circumference in length causes the echo to be stronger for one polarization than for the other.

Figure 6 shows the same kind of a test for a 3" diameter aluminum waveguide 250 feet long. This line was mounted horizontally in the test building with compression couplings used at the joints. The line expanded on warm days but the friction of the mounting supports was so great that it pulled open at some of the joints when the temperature returned to normal. These open joints produced reflections from 40 to 50 db down, which are shown here. They come at intervals equal to the length of one section of pipe, about 12 feet. Some of these show polarization changes in response where the crack was more open on one side than on the other, but others are almost independent of polarization. These two photographs of the trace were taken with the polarization changed 90°.

Figure 7 shows the same kind of a test for a 3-inch diameter galvanized iron waveguide. This line had shown fairly high loss to c-w measurements. The existence of a great many echoes from random distances indicates a very bad interior finish in the waveguide. Upon inspection this was found to be true. Figure 8 is a photograph showing the kind of imperfections in the zinc coating used for galvanizing which caused these reflections.

Testing Antenna Installations

Figure 9 illustrates the use of this equipment in testing waveguide and antenna installations for microwave radio repeater systems. This particular work was done in cooperation with A. B. Crawford's antenna research group at Holmdel, who designed the antenna system. A directional coupler was used to observe energy reflections from the system under test. In this case a 3-inch diameter round guide carrying TE_{11} mode was used to feed the antenna. Two different waveguide joints are shown here. In addition, a study was being made of the return loss of the transition piece at the throat of the antenna which connected the 3-inch waveguide to the square section of the horn. The waveguide sections are about 10 feet long. The overloaded pulse at the left is due to directional coupler unbalance. The other echoes are associated with the parts of the system from which they came by the dashed lines and arrows on the figure. A clamped joint in the line gave the reflection shown next following the initial overloaded pulse. A well made threaded coupling in which the ends of the pipe butted squarely is seen to have a very much lower reflection, scarcely observable on this trace. Since there is always reflection from the mouth and upper reflector parts of this kind of an antenna, it is not possible to measure a throat transition piece alone by conventional c-w methods, as the total reflected power from the system is measured. Here, use of the resolution of a short pulse completely separated the reflection from the transition piece from all other reflections and made a measurement of its performance possible. In this particular case, the reflection from the transition is more than 50 db down from the incident signal which represents very good design. As can be seen, the reflection from the parabolic reflector and mouth is also quite low, and this characterizes a good antenna installation.

Figure 10 shows the same installation with the addition of a fiberglass weatherproof cover over the open mouth of the horn. This cover by itself would produce a troublesome reflection. However, in this antenna, it is a continuation of one of the side walls of the horn. Consequently, outgoing signals strike it at an oblique angle. Therefore, reflections that come from it are not returned directly and focused by the parabolic section back at the waveguide, so the overall reflected power in the waveguide was found to be rather low. However, measuring it with this equipment, we found that a reflection appeared to come from a point 16 feet out in front of the mouth of the horn. We believe that this is accounted for by the fact that energy reflected obliquely from this cover bounces back and forth inside the horn before getting back into the waveguide, thus travelling the extra distance that makes the measurement seem to show that it comes from 16 feet out in front.

Multimode Waveguide Tests

Mode Separation. This pulse equipment has also been used in the study of various multimode effects in round waveguides. Mode conversion caused by certain components, and by guide imperfections, has been measured. This is done by providing enough length of waveguide following the point of conversion so that the converted mode is separated from the desired mode on a time basis because of its different group velocity.

Separation of modes on a time basis is shown on Figure 11. Here a probe coupling to a round waveguide about 250 feet long was used. The sending end of the round guide was terminated to avoid reflections at this point. The far end was closed with a piston. This type of coupling excites 11 of the 12 modes that can be supported at this frequency in a guide of this diameter. Energy travels at different group velocities in each mode to the piston at the end, then back to the probe. A directional coupler is used at the probe so that returning energy can be coupled to the receiver and indicator. The photograph of the trace shows the returning energy only, and the outgoing pulse is some distance off the trace to the left. The time at which each of these pulses appears corresponds to the round trip time of travel for each mode designated on this figure.

On Figure 12 a plot of normalized group velocity versus frequency is shown for these modes. Group velocity is zero at cut-off, and approaches the velocity obtained in an unbounded medium at very high frequencies. The oscilloscope trace shown in the previous figure is repeated on this one. It will be noticed that the spacing of the pulses from left to right corresponds to the spacing of the curves from top to bottom in the pulse bandwidth shown by the shaded area.

Delay Distortion. Another characteristic of waveguides made evident by the broadband of the pulse that is used with this equipment can be observed on this figure. It will be noticed that the pulses that have travelled for a longer time in the guide, those modes closer to cut-off, the ones on the right-hand side of the photograph, are broadened and distorted compared with the ones on the left-hand side. This effect is due to delay distortion in the round waveguide. The modes at the top of the figure, or left of the trace, can be seen to have a more nearly constant group velocity, over the bandwidth of the pulse, than the modes at the bottom of the figure whose curves have a large slope across this band. When the group velocity is different for one edge of the band than it is for the other, the signal is distorted by the different delay across the band. This is something that we will always have to contend with in the use of waveguides as transmission elements for very broad bands. One way of reducing its effect is to use frequency division multiplex so that each signal uses a smaller bandwidth, and consequently has a smaller delay distortion. Another way, of course, is to invert the band in the waveguide between one pair of repeaters compared with that between an adjacent pair of repeaters, so that the slope is in effect placed in the opposite direction and the delay distortion effects tend to cancel out.

Conclusion

This paper has presented a brief description of equipment which produces and displays very short microwave pulses. Some examples of its use have been shown. We have found it very useful for these, and numerous other purposes. The equipment is still rather complex, but we feel that with improvements in the microwave art, such measuring techniques will be used more and more for research, design and testing purposes.

Acknowledgments

Many people have taken part in the design, construction, and use of this equipment. In addition to those previously mentioned, special credit should be given to S. E. Miller, who initiated and encouraged this project; to N. J. Pierce, who designed and built part of the equipment, and to R. W. Dawson and J. W. Bell, who assisted in the construction. G. D. Mandeville has assisted throughout in the construction and operation of the equipment.

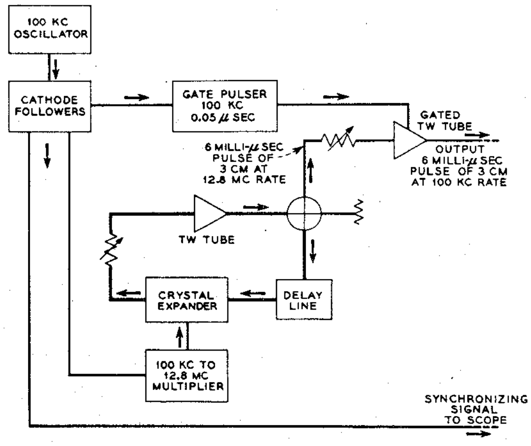

Fig. 1 - Simplified block diagram of the pulse generator.

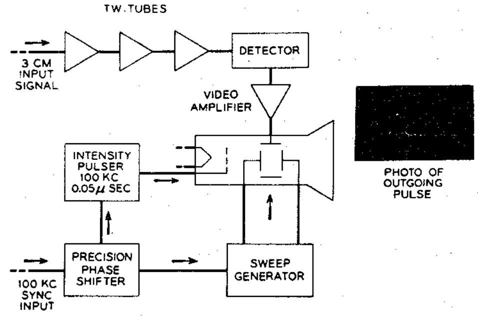

Fig. 2 - Simplified block diagram of the receiver and indicator with a photograph of the millimicrosecond pulse.

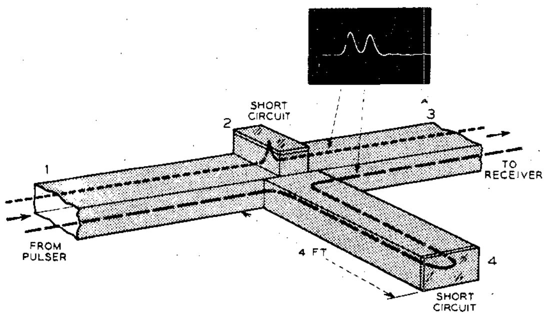

Fig. 3 - A hybrid circuit used to show that a signal delayed by 8 feet of a waveguide is resolved as a separate pulse.

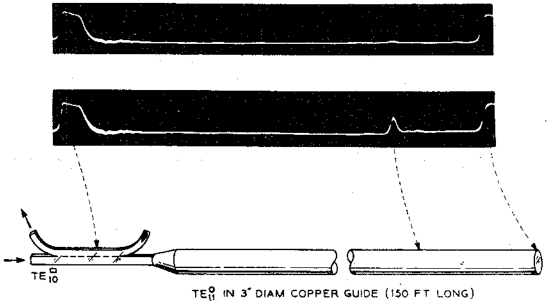

Fig. 4 - Arrangement for using millimicrosecond pulses to show reflection from a defective joint in a waveguide. The two photos are for polarizations differing by 90 degrees.

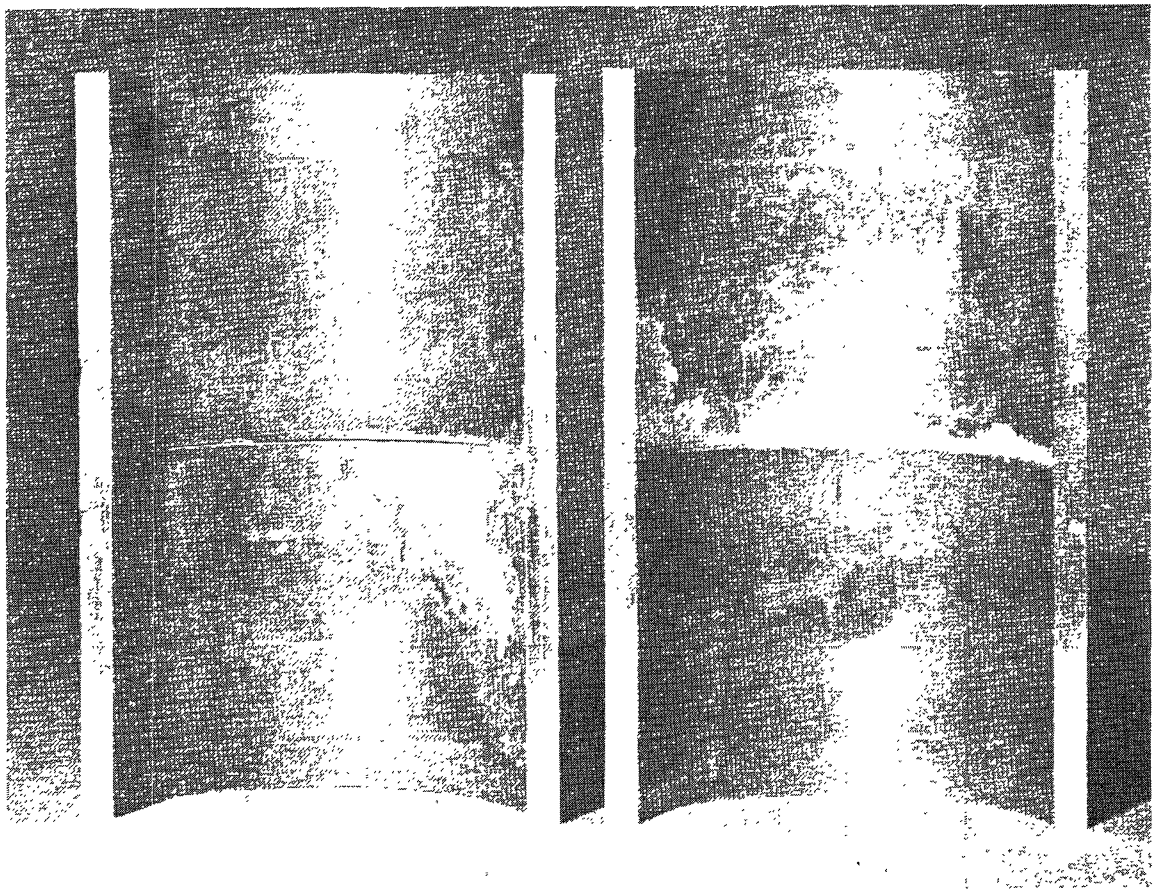

Fig. 5 - The open crack on the left side of this defective joint caused the reflection shown in Fig. 4. The discoloration is smooth solder.

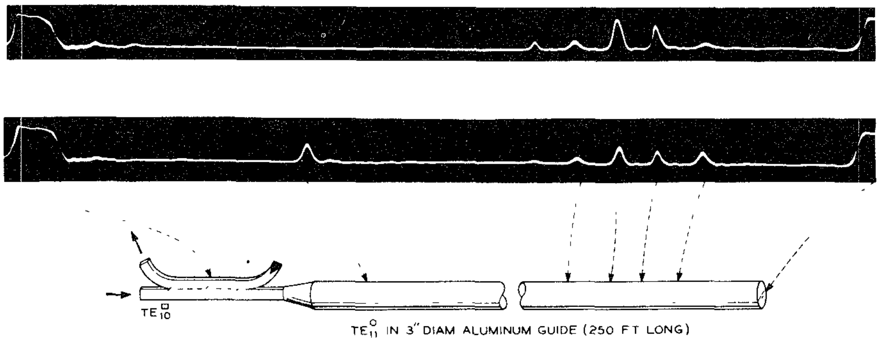

Fig. 6 - Reflections from several defective joints in a waveguide. The two photos are for polarizations differing by 90 degrees.

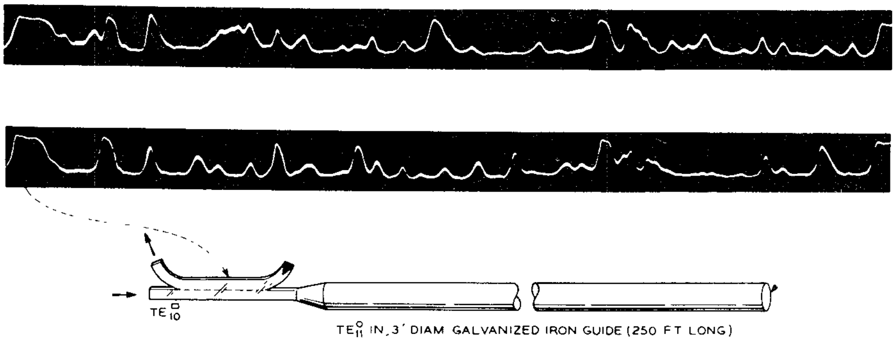

Fig. 7 - Multiple reflections from a waveguide with a rough inside surface. The two photos are for polarizations differing by 90 degrees.

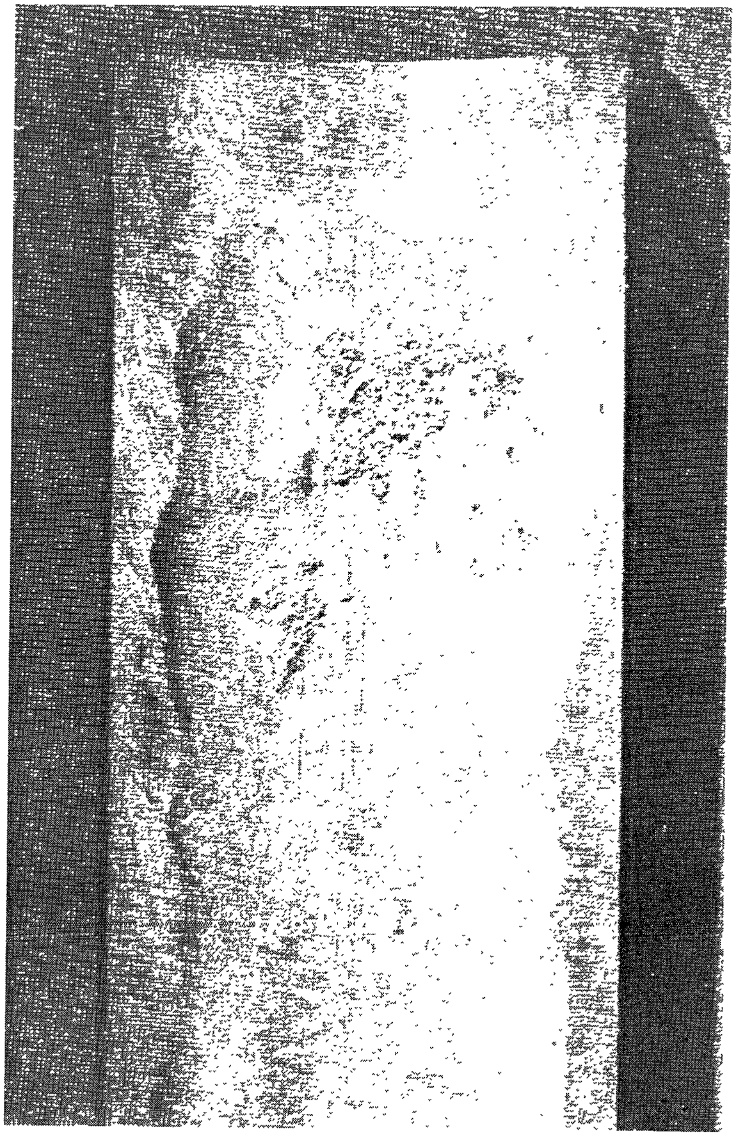

Fig. 8 - Rough inside waveguide surface producing the reflections shown in Fig. 7.

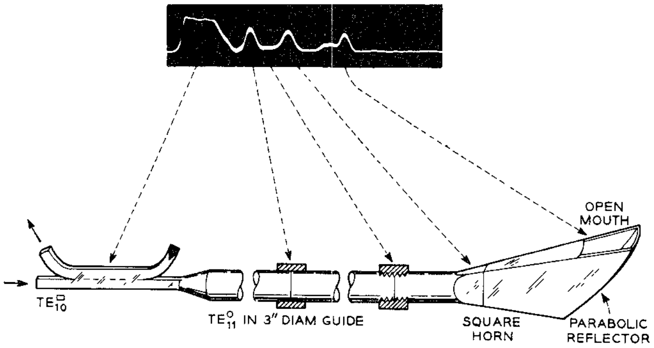

Fig. 9

Arrangement for using millimicrosecond pulses to show reflections from a waveguide and antenna installation. The photo shows the separate pulses from different sources of reflections.

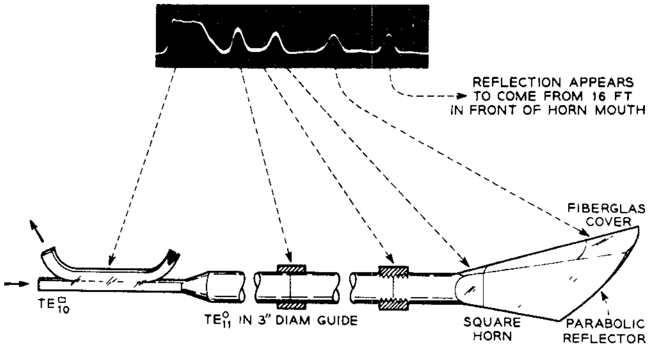

Fig. 10

Same as Fig. 9 except for the addition of a fiberglas cover. The photo shows the additional reflections caused by the cover.

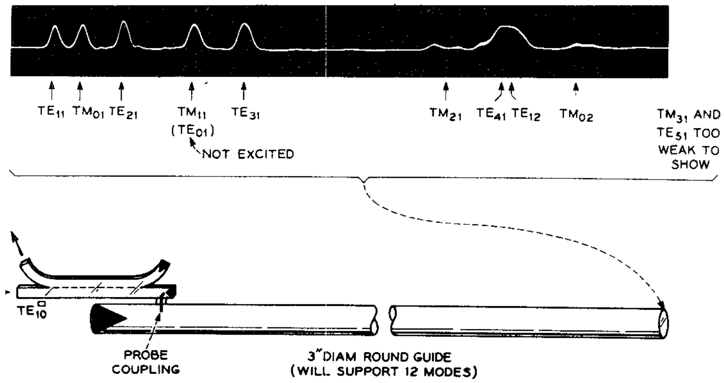

Fig. 11

Arrangement for showing the separation of modes on a time basis. The pulses in the photo are all due to reflection from the piston. The outgoing pulse due to directional coupler unbalance is not shown.

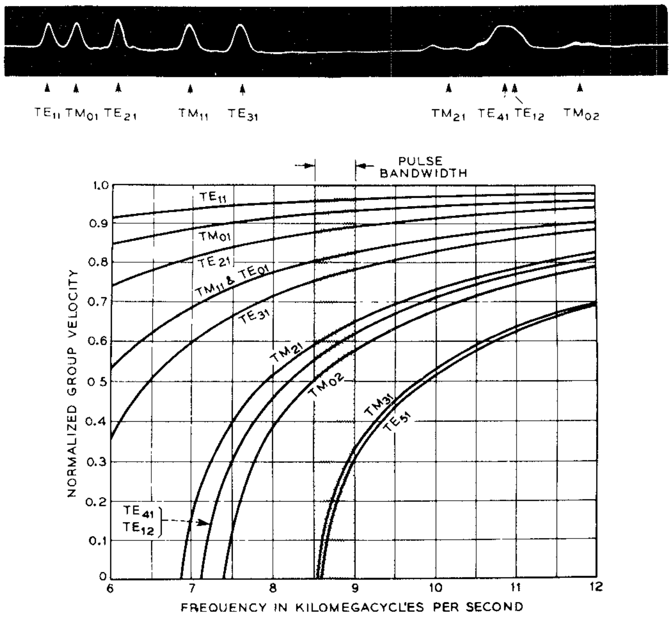

Fig. 12

Group velocity plotted against frequency for the first 12 modes in a 3-inch diameter waveguide. The photo is the same as the one shown in Fig. 11.