The Measurements Column

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Alignment Fixture for Millimeter Waveguide

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[Our measurements column this month describes an alignment fixture for handling the precise waveguide connection procedures required in performing gain measurements of millimeter-wave antennas. The device was designed and implemented by the two coauthors of this article: Douglas Kremer and Allen Newell, from the US National Institute of Standards and Technology, in Boulder, Colorado.]

Introduction

Millimeter-wave measurements require care in the connection and handling of the waveguide flanges and their contact surfaces. When properly connected, these flanges can provide many years of reliable and repeatable measurements. Improper use will limit the flange use to just a few connections, and result in large measurement errors. These errors are especially acute in situations requiring repeated connection and disconnection of these flanges, such as in antenna or insertion-loss measurements. Several factors contribute to these errors, but the largest are improperly installed waveguide flanges, misalignment in flange connections, and excess strain on the waveguide or the flange.

We have addressed these problems by developing a mechanical alignment fixture for millimeter-band waveguides. Two fixtures were developed: one for small devices, such as standard gain horns, which can be supported by the fixture, and another for larger devices. These systems, along with a properly-installed flange, can reduce the measurement uncertainty associated with the connection from greater than 1 decibel to a few hundredths of a decibel.

Insertion loss measurements

Before the use of the alignment fixture, our largest source of error in determining antenna gain at millimeter-wave frequencies was the insertion-loss measurement. This was true for both the extrapolation [1] and planar near-field ranges [2]. Both of these measurements require that the transmitting and receiving antennas are removed, and the generator and load ports are connected as shown in Figure 1. The generator is defined as the terminal connected to the transmitting antenna's input port, and the load is defined as the terminal connected to the receiving antenna's input port. This generator-to-load connection is done several times during the measurements, to check for insertion loss repeatability and system gain drift, and to reduce the effect of random errors. In some extrapolation measurements, the generator and load ports can be connected and disconnected as many as 500 times, and the antennas can be connected and disconnected as many as 250 times.

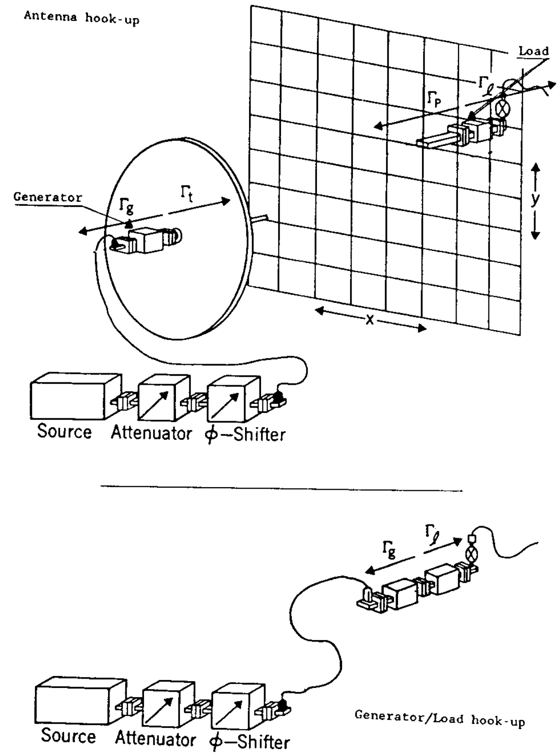

Fig. 1. Measurement of planar near-field insertion loss.

At frequencies below 30 GHz, insertion loss variation is at most a few hundredths of a decibel, which is the typical goal of such measurements. At higher frequencies, where the waveguide and flanges are small, variations on the order of 1 decibel have been observed. These variations are due to several problems:

- The flanges were not installed on the waveguide within the required tolerances
- The flanges were not connected with adequate repeatability
- The antennas were supported by their flanges

The solution for these problems required development of the alignment fixture, and strict specifications on the waveguide flange.

Improper use of the flanges during connection causes the flanges to wear or deform quickly, and replacement of the flanges requires recalibration of the device. If flanges are connected at an angle, overtightened on one side as shown in Figure 2, or stressed by other means, physical defects, such as

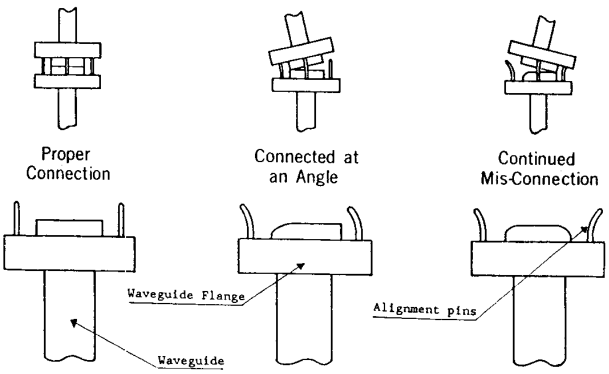

Fig. 2. Waveguide flange contact area rounding caused by continued improper connection of the two flanges.

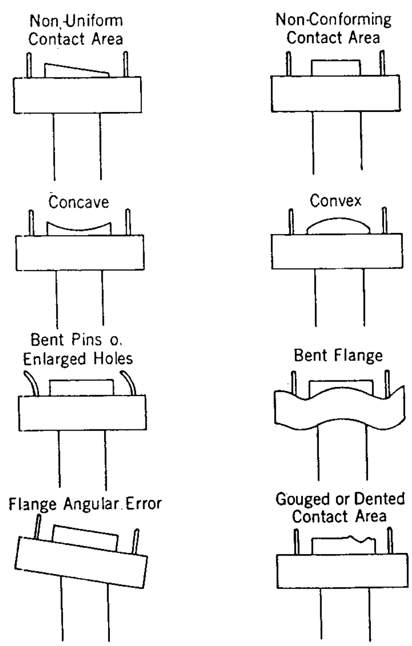

Fig. 3. Examples of millimeter flanges that are out of specification.

shown in Figure 3, result.

Millimeter waveguide flanges are designed with alignment pins and holes which require connections to be made straight on, brought together uniformly to the contact area, and the screws to be tightened evenly with a torque wrench. These requirements can be met by the alignment jig described below. Bringing the flanges together properly does not guarantee a repeatable connection if the flanges are not faced off correctly. Based on our research at 45 GHz, the waveguide flange's raised connection area should be flat to within 0.001 cm (0.0005 in), and perpendicular to the waveguide axis to within 0.5 degree (Figure 4). If the flange does not meet this specification then it should be refurbished.

Supporting an antenna or probe, even a small one, by its flanges causes a large instability in the alignment, when it is removed and then replaced on the generator or load flange. In addition, solder joints at the waveguide flange on the antenna, generator, and load ports can be broken, due to the weight of the antenna, and due to the rocking motion used to make or break a connection. This problem requires that, in addition to making a correct connection, the alignment jig must support the weight of the unit under test during installation and during subsequent tests.

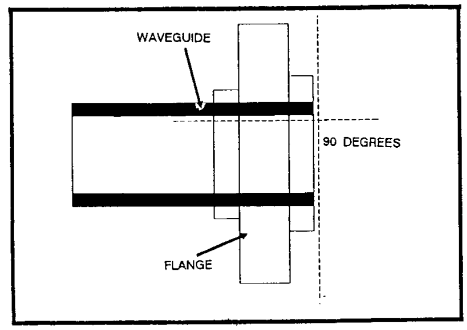

Fig. 4. Correctly installed millimeter waveguide flange.

The final design had to be versatile to accommodate different antennas. Waveguide sizes depend on the frequency band. Due to the varying circumstances, two alignment fixture systems were developed. The generator or load fixture is useful for either alignment fixture system, and is discussed along with this first alignment fixture system.

The first system was designed for small horns and open-end waveguide probes, which are usually evaluated on the NIST extrapolation range. These antennas can be easily removed and replaced, and their mounts can be designed as part of the alignment system. The generator or load alignment jig and a standard gain horn mount are shown in Figure 5. The generator or load jig consists of four hardened, stainless steel rods, moveable inside two sets of four linear bearings. Attached to the end of these rods is an alignment ring that provides the mechanical connection for the antenna mount. A precision section of waveguide is clamped in a holder that is mounted, centered, and made parallel to these rods. This holder has been made to accommodate WR-15 and WR-22 waveguide sizes, and can be made for other millimeter waveguide sizes.

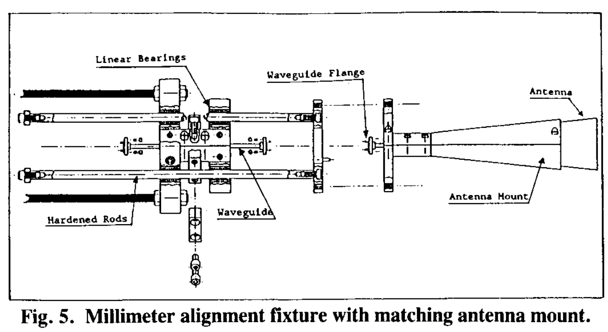

Fig. 5. Millimeter alignment fixture with matching antenna mount.

The antenna is mounted inside a matching alignment fixture, that supports it along the side walls, and allows the mechanism to rotate in the fixture, so that the flange alignment pins can be matched to the connecting generator or load flange. The antenna is connected to the generator or load alignment flange, and moved to the generator or load port along the axis of the linear rods. As the alignment pins meet, the flanges are connected at the proper angle and brought together uniformly. A visual inspection will reveal if the antenna flange is perpendicular to its waveguide or if it requires machining. The waveguide screws can then be tightened with a torque wrench. Note that the waveguide screws should never be used to pull the two flanges together. In our tests, we found that an electric screw driver with an adjustable torque collar worked quite well.

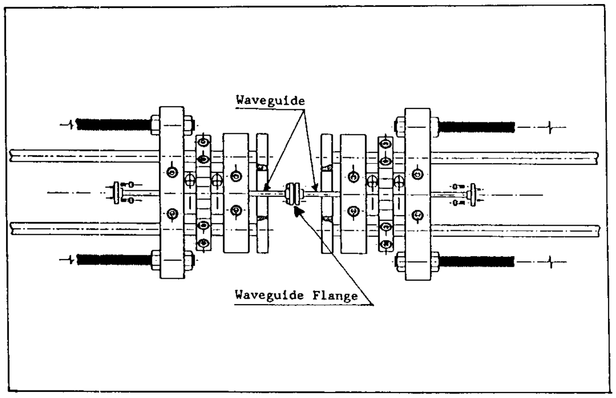

Fig. 6. Generator to load connection with two millimeter alignment fixtures.

Generator-to-load connections can be made by removing the antennas and bringing the two ports together (Figure 6). A typical alignment fixture system is shown in Figure 7. The second system was built for larger antennas that cannot easily be dismounted and replaced. This system is designed to remove the generator or load port from the antenna input port and place it to the side, beyond its aperture, where it can be connected to the near-field scanner probe, generator, or load. Access ports for these larger antennas can be located anywhere on the antenna. Cassegrain antennas usually have their input ports located behind the dish's vertex, and large horns have input ports centered at the rear of the horn. Since a large number of our measurements involve these two types of antennas, the system was designed for them, and for use on the planar near-field range. This system is shown in Figure 8.

The antenna is mounted on a Z-axis linear transport system. Built into the mount is a tilt plate that allows the antenna to be rotated in azimuth. The Z-axis linear transport system moves the antenna in the Z-direction, which is used for the preliminary multipath tests [2], done on each antenna to determine its final Z test position. The generator is mounted on top of these rails, and is capable of moving independently

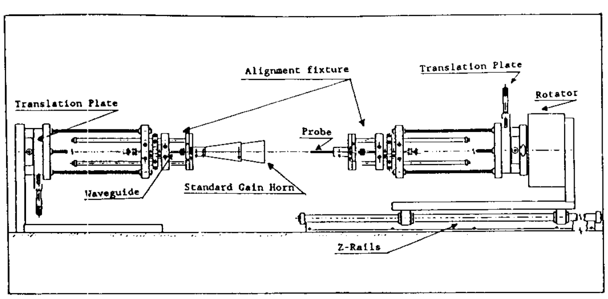

Fig. 7. Extrapolation measurement system using a millimeter alignment fixture.

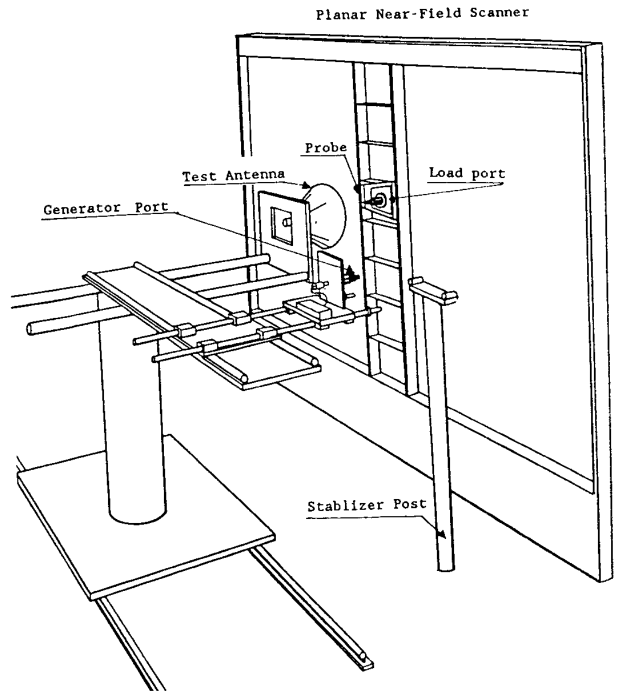

Fig. 8. Planar near-field measurements using a millimeter alignment fixture.

in X and Z from the antenna's Z-axis. There is a removable connection rod between the two Z-axis stages, for cases when the antenna needs to be moved with its generator connected to it. The generator's Z-axis stage rods are capable of spanning across from the input port of the antenna to the alignment fixture on the near-field scanner. A stabilizer post has been fixed to the side of the scanner to support the rods across this span.

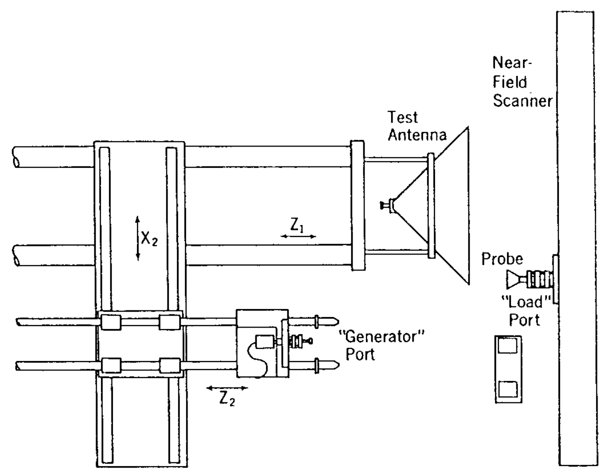

Fig. 9. Schematic of a generator-to-load measurement on the planar near-field range.

The antenna's input port is connected to the generator. Figure 9 shows a typical generator configuration. The waveguide system is mounted on a rotatable gimbal plate, and has its own Y-axis translation stage. With this system, translation in three dimensions and rotation in azimuth are possible. These degrees of freedom are required for the dual connections made by this generator to the antenna and to the load. Normally the probe's Z-axis is aligned to be level, then the generator is aligned to the load, and then the antenna is aligned to the generator.

It was also necessary to tighten the waveguide screws using a device that supplied constant torque; manual tightening would not yield repeatable connections. The straightness and flatness criteria were addressed by ensuring that the waveguide flanges were flat to within 0.001 cm (0.0005 in), and perpendicular to the waveguide axis within about 0.5 degree. The jig described above was used to determine whether the flanges met these specifications. This can be done by bringing the flanges together with the alignment jig, and inspecting the connection for a correct fit between the two surfaces of the flanges. If required, the flanges can be refurbished on a lathe. In order to make accurate and repeatable insertion loss measurements, the generator-load, the antenna-generator, and the probe-load connections must be repeated. To ensure a proper waveguide connection, we must properly align and partially torque alternate screws, while observing that the flanges remain flush during the tightening process until the final torque is applied. These procedures are necessary even when the device is installed in an alignment fixture.

Conclusions

Two types of alignment fixtures have been used for several different antenna gain measurements, done on both the extrapolation and the planar near-field antenna measurement facilities, in the WR-22 and WR-15 waveguide bands. Measurement uncertainties, due to non-reproducibility of flange connections for both of these facilities, have been reduced from 0.30 dB to 0.05 dB (RSS). As a result, the overall gain error for millimeter frequency antenna measurements has decreased from 0.31 dB to 0.10 dB.

References

[1] Newell, A.C., Baird, R.C., Wacker, P.F., "Accurate Measurement of Antenna Gain and Polarization at Reduced Distances by an Extrapolation Technique," *IEEE Trans. Ant. Prop.*, vol. AP-21, pp 418-431, July 1973.

[2] Newell, A.C., and Crawford, M.L., "Planar Near-Field Measurements on High Performance Array Antennas," Nat. Bur. Stand. Int. Rep. NBSIR 74-380, July 1974.

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Mr. Douglas Kremer is a Supervisory Technician with the Antenna Metrology Group at the National Institute of Standards and Technology in Boulder, Colorado.

Mr. Allen Newell is the Group Leader of the Antenna Metrology Group at Boulder. He has recently been awarded the W.R.G. Baker prior for his paper on error analysis of planar near-field measurements.

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Reviews and Abstracts

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Book Reviews

Introduction to Antennas, by Martin S. Smith, New York, Springer-Verlag, Inc., 1988, 128 pp. [Reprinted from *IEEE Communications Magazine*, vol. 27, no. 5, p. 69, May 1989.]

This slim volume of 128 pages is reputed to be an introduction to antennas, and suitable, according to the preface, "...for recently qualified engineers working in industry."

Actually, the book is a collection of topics on antennas that require the reader to have had a good grounding elsewhere. The inclusion of a "case study" at the end of each chapter is supposed to be a special feature. In fact, short outlines of the important points of antenna designs are presented, and not the detailed analysis understood in North America to be a "case study." The descriptions are interesting, and apply the work covered in Chapters 2 through 6.

The first chapter gets to Maxwell's equations and vector analysis after two pages of text, and this tone is held, more or less, throughout the book. The elementary and basic properties of an antenna, which a newcomer to the field would find interesting and useful, are not discussed in the detail necessary for an "Introduction." There are a few typographical errors, and some statements which lack clarity for the uninitiated.

The book has six chapters, and three appendices. The chapters are as follows:

"Basic Antenna Concepts:" 16 pages covering frequency range, Maxwell's equations for plane waves, basic antenna properties, and reciprocity;

"Wire Antennas:" 16 pages discussing the Hertzian dipole, dipoles and monopoles, parasitic elements, loops and slots, printed antennas, an introduction to moment methods, and note on antennas on aircraft;

"Aperture Theory:" 24 pages incorporating sections on diffraction by apertures, aperture theory in two dimensions, applications to two and three dimensions, gain, and an explanation of airport radar antennas;

"Linear Arrays:" 18 pages including sections on radiation patterns, nulls, pattern multiplication, beam steering, Woodward's synthesis of antenna patterns, and a description of an ILS array system;