NWC TM 5717

Free-Space Anisotropy Experiment

by

D. R. Gagnon
Physics Division
Research Department

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NAVAL WEAPONS CENTER
China Lake, CA 93555-6001

FOREWORD

This report documents a design study for the proposed free-space anisotropy experiment. The study was carried out during fiscal year 1985 and was supported by 6.1 Independent Research Funds.

The report was prepared for the purpose of technical review and is released at the working level.

JERRY J. SMITH
Head, Physics Division
Research Department
21 January 1986

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INTRODUCTION

The free-space anisotropy experiment is designed to test the second postulate of the special theory of relativity, which states that the speed of light is constant for an observer in any inertial reference frame. This assumption has been examined within the framework of a semiclassical theory in which the special theory of relativity is found to be a special case incorporating the Einstein synchronization convention. It is found that the second postulate is not a necessary condition for the observed invariance of the round-trip speed of light (Reference 1). We shall consider an alternative viewpoint which postulates the existence of a preferred or absolute frame of reference in which light propagates isotropically at a fixed speed. In all other reference frames, the one-way speed of light depends on the state of motion of an observer with respect to the preferred reference frame. The mathematical description of this alternative theory shall here be referred to as the generalized Galilean transformation (GGT). The theory is in predictive agreement with special relativity to a high degree of precision of nearly every type of measurable effect.

When the Einstein convention of synchronization by light signals is imposed upon the GGT, the usual Lorentz transformations of special relativity are obtained (Reference 2) and possible measurement of variation of the speed of light is automatically precluded. In order to experimentally distinguish between these two theoretical alternatives, it is therefore necessary to measure the one-way speed of light, without recourse to the Einstein synchronization. Nor can the measurement depend on the length of a "standard" rod or the transport of clocks because the effects of length contraction and time dilation produce the same result as the Einstein synchronization. The Naval Weapons Center (NWC) free-space anisotropy experiment meets the special requirements for a true one-way measurement since it measures interference between unidirectional continuous waves that are excited by a single radio frequency "clock."

The experiment is motivated, in part, by measured anisotropy in the cosmic microwave background radiation. Smoot and others have interpreted their measurements of a dipole anisotropy as being attributable to Doppler shift produced by motion of the solar system with respect to the primordial matter which emitted the radiation

(Reference 3). If this interpretation is correct, it implies the existence of a reference frame in which the background radiation is isotropic. This makes a reasonable case for the existence, in some sense, of an absolute reference frame.

In this paper, some important features of the semiclassical theory employing GGT are described and an experimental hypothesis is derived. An experimental principle is developed to test the stated hypothesis, and the present design of the free-space anisotropy experiment is described in detail.

THEORY AND HYPOTHESIS

For the simple case of motion along the x-direction, the GGT is given by the following expressions:

$$x = \gamma (x_o - vt_o) \quad ; \quad t = \gamma^{-1} t_o$$

$$y = y_o \tag{1}$$

$$z = z_o$$

where the zero-subscripted coordinates are the coordinates of space and time in the so-called absolute reference frame. The unsubscripted coordinates are the coordinates in a reference frame which is moving with velocity v with respect to the absolute frame. The quantity γ is the usual length-contraction, time-dilation factor which appears in special relativity, i.e.,

$$\gamma = (1 - v^2/c^2)^{-1/2} \tag{2}$$

Here c is the constant of the velocity of light in the absolute reference frame. The inverse transformations of the GGT are also represented here, being obtained by ordinary algebraic inversion of these equations. This is a result of the fact that length contraction and time dilation are taken to be real physical effects rather than the result of measurements which are made according to the conventions of special relativity.

The GGT has many of the properties of the Lorentz transformation. For instance, the four-dimensional line element,

$$dS^2 = (dr_o)^2 - c^2(dt_o)^2 \tag{3}$$

is invariant with respect to the generalized Galilean transformation. Unlike the Lorentz transformation, however, the GGT allows the possibility of absolute simultaneity, at least in an ideal sense. Notice that events which are simultaneous in the absolute frame are simultaneous when viewed from any reference frame.

$$\Delta t = \gamma^{-1} \Delta t_o \tag{4}$$

If $\Delta t_o = 0$, then $\Delta t = 0$. This implies the existence of spatially separated clocks which read the same coordinate time. In order to circumvent the problems involved with instantaneous synchronization (i.e., faster-than-light signaling), we shall avoid considering any experiment which requires the synchronization of timekeeping clocks. While this is a rather restrictive condition, it does apply to many important experiments such as Michelson-Morley. The remaining problem is to find an experimental arrangement which is not a round-trip measurement like the Michelson-Morley experiment. Toward this end we shall examine the way that Maxwell's equations transform under the GGT.

Chang has employed the four-dimensional tensor form of the generalized Galilean transformation to obtain the formulation of Maxwell's equations in vacuum in a reference frame moving with absolute velocity, v (Reference 4). The vacuum wave equation which is obtained from Chang's formulation of Maxwell's equations is given by

$$\nabla^2 E + 2\left(\frac{v}{c} \cdot \nabla\right) \frac{1}{c} \frac{\partial E}{\partial t} - \left(1 - \frac{v^2}{c^2}\right) \frac{1}{c^2} \frac{\partial^2 E}{\partial t^2} = 0 \tag{5}$$

By substituting the usual solution for a plane wave moving in the z-direction [i.e., $E - E \exp(ikz - iwt)$] and solving for k, we find that the wave number corresponds to a wave with phase velocity $c + v$. Thus, the classical velocity addition is obtained for electromagnetic waves in a moving reference frame.

For the development of the experimental hypothesis, we require an expression for the wave number of a transverse electric (TE) or transverse magnetic (TM) wave in a waveguide. The field on the waveguide is required to have the following form:

$$E(x,y,z) = E(x,y,z) \exp(ikz - i\omega t) \tag{6}$$

Next, by employing the boundary conditions appropriate for a rectangular waveguide (Reference 5), the following expression is obtained for the guide wave number in the reference frame of the laboratory:

$$K = \frac{\omega}{c}\frac{v}{c}\cos\theta - \frac{1}{c}\left[\omega^2 - \omega_c^2 - \frac{v^2}{c^2}\left(\omega^2 \sin^2\theta - \omega_c^2\right)\right]^{1/2} \tag{7}$$

Here ω_c is the cutoff frequency of the fundamental mode of the waveguide and θ is the angle between the axis of the waveguide and the absolute velocity vector. Notice that for $v = 0$, the usual results for waveguide propagation are obtained. Also, if ω_c is allowed to approach zero, the result reduces to the transverse electromagnetic (TEM) case; as ω approaches ω_c from above, the wave number approaches zero. This last case requires that, in the limit as cutoff frequency is approached, the guide wavelength becomes infinite and there is no longitudinal position dependence for the electrical phase of the wave along the waveguide. This familiar result is, of course, highly idealized and cannot be applied to the case of a real waveguide. It does, however, suggest some interesting possibilities for at least a conceptual experiment. For instance, if the phase of the wave on an ideal waveguide at cutoff is compared with the phase of an unbounded plane wave, it is found that the phase difference is linearly dependent on the absolute velocity of the experimental reference frame.

While infinite guide wavelength is not physically realizable, phase velocities which are much greater than the speed of light can certainly be achieved. With this fact in mind, let us now consider the actual case of two waveguides of the same length with widely different cutoff frequencies and which are driven together at the same frequency. Let waveguide number 1, with cutoff frequency ω_1, be operated close to its cutoff frequency so that the common driving frequency is $\omega_1 + \delta$. If it is further assumed that the cutoff frequency of waveguide number 2 is much lower than the cutoff frequency of waveguide number 1, then the following approximation can be made for the phase difference between the two parallel waveguides:

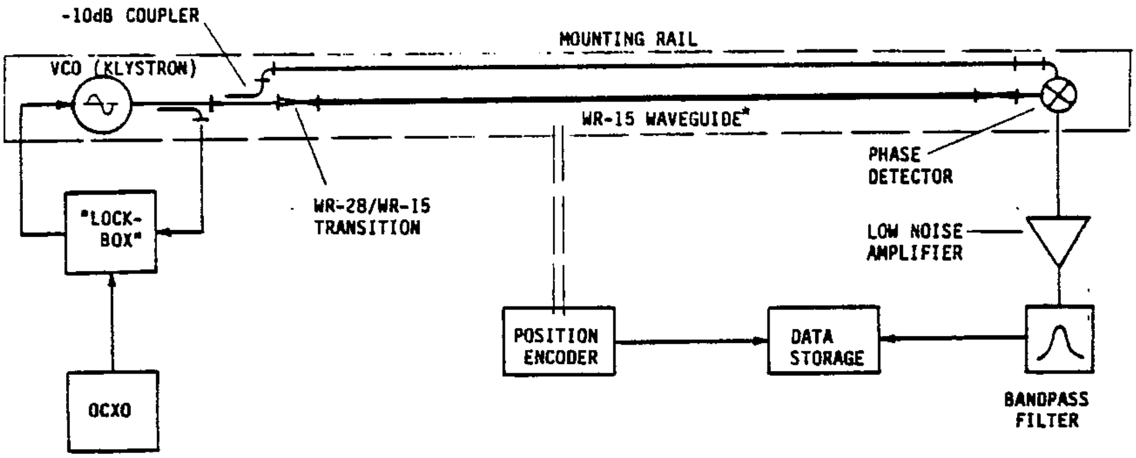
$$\Delta\phi = \phi_o + \frac{\omega_1 L}{2c}\sqrt{\frac{\omega_1}{2\delta}}\,\frac{v^2}{c^2}\sin^2\theta \qquad \left(\frac{\delta}{\omega_1} \gg \frac{v^2}{c^2}\right) \tag{8}$$

Here, ϕ_o is a constant phase difference for a given inertial reference frame and θ is the angle between the absolute velocity vector and the waveguide. We see from this expression that for a nonzero separation of the driving frequency from the cutoff frequency, a second-order effect is obtained which depends on the pointing angle of the waveguide.

An estimate for the absolute velocity of an earth-based laboratory is provided by measured anisotropy of the cosmic microwave background radiation. According to Smoot and others, their data can be interpreted to give a value of 390 km/sec for the absolute velocity of the solar system (Reference 3). As a test case, this value shall be used for the absolute velocity of the experimental reference frame in Equation 8. Having arrived at a well-defined hypothesis, we must consider the additional constraints which are imposed on the experimental parameters by nonideal waveguides and by instrumentation. It is well known, for instance, that as the cutoff frequency is approached, attenuation in the waveguide increases sharply, placing a limit on the length of the experiment baseline. Also, since the cutoff frequency of a waveguide is determined by its cross-sectional size, the dimensional tolerance from the manufacture of the waveguide imposes a limit on the proximity of the driving frequency to the cutoff frequency. Within these limitations, a simple and practical experiment has been designed which should yield a small but easily measurable effect, according to the hypothesis presented here.

EXPERIMENT DESIGN

In this section, the present design of the free-space anisotropy experiment is described in sufficient detail to estimate the magnitude of measured effects predicted by the hypothesis. A basic block diagram of the apparatus is shown in Figure 1. Two waveguides are attached to a rigid mounting rail which is suspended by cables and which is free to rotate about its center in the manner of a torsion pendulum. The rail is allowed to swing at the natural frequency, affording the required steering of the apparatus without the use of noise-producing motors. This arrangement also provides a sinusoidal signature to aid in signal detection.



*Increased-height waveguide

FIGURE 1. Block Diagram of the Experiment Apparatus.

The two waveguides are WR-28 and WR-15 types with nominal cutoff frequencies of 21.1 and 39.9 gigahertz, respectively. At a driving frequency just above cutoff for the fundamental mode of the WR-15 waveguide, the WR-28 waveguide will be just below cutoff for the next higher mode, with a guide wavelength within 15% of the free-space wavelength. The choice of operating frequency near 40 gigahertz offers a good compromise between experimental sensitivity and ease of fabrication. While the experimental sensitivity is scaled to the operating frequency, the required precision of the waveguide dimensions becomes much more critical at higher frequency.

The waveguides are driven by a klystron oscillator which is capable of delivering radio-frequency (RF) power at a level of about 1 watt. The klystron is phase-locked to a 5-megahertz, oven-controlled crystal oscillator (OCXO) with short-term frequency stability of 5 parts in 10^{12}. The "lock box," shown in Figure 1, is a commercially available microwave frequency stabilizer that generates harmonics of the reference signal near the frequency of the microwave signal and supplies a frequency control voltage in series with the reflector voltage to phase-lock the klystron to the stable reference. It has been experimentally determined that with a frequency stabilizer of this type, the fractional stability of the microwave oscillator is equal to the fractional stability of the reference oscillator for averaging times greater than 1 millisecond (Reference 6). This arrangement should, therefore, provide an effective signal bandwidth on the order of a few tenths of 1 hertz at 40 gigahertz in the appropriate postdetection integration period.

The phase detector consists of a waveguide balanced mixer with a direct-current coupled intermediate frequency (IF) output. The local oscillator power to the mixer is provided at the output end of the WR-28 waveguide path at a level of about 100 milliwatts. The highly attenuated power at the output of the WR-15 waveguide is applied to the RF input of the mixer. The output signal from the mixer is amplified and filtered in a passband centered on the rotation frequency of the apparatus. In order to estimate the magnitude of this signal, it is necessary to specify the length of the waveguide measurement path, the precise operating frequency in relation to cutoff frequency of the WR-15 waveguide, and attenuation in the waveguide. It is also necessary to estimate contributions to the signal by noise sources such as amplitude-modulation (AM) and frequency-modulation (FM) noise components of the driving oscillator and receiver low-frequency noise.

The most fundamental limitation to the sensitivity of the free-space anisotropy experiment is imposed by the requirement for uniformity of the waveguide cross-sectional dimensions over a long length of the waveguide. For the case at hand, a gradual variation of 50 microinches in the broadwall dimension of WR-15 waveguide with a 40-gigahertz cutoff frequency results in a 13.5-megahertz variation of the cutoff frequency from one section to another. Since 50 microinches probably represents a limiting value on the available precision for waveguide produced by conventional manufacturing techniques, it will be stipulated that the waveguide be driven at a frequency no closer than 15 megahertz to the nominal cutoff frequency so that no section of significant length will be below cutoff. Waveguide components with 50-microinch tolerance are manufactured by precision machining or by electroforming. The 50-microinch dimensional precision desired for the WR-15 waveguide does not truly represent a manufacturing tolerance since the driving frequency can be tuned according to the actual cutoff frequency which is finally obtained. The dimensional precision of the waveguide is, however, a critical issue that will be addressed further in another section of this report.

The attenuation caused by ohmic loss in the waveguide walls is generally calculated as a perturbation of the ideal waveguide with perfectly conducting walls. The usual formulas for attenuation in waveguide are obtained under the assumption that the change in the propagation constant is small compared with the propagation constant. These formulas are therefore invalid at frequencies adjacent to the cutoff frequency where the propagation constant changes rapidly with frequency and tends toward zero. This shortcoming can be remedied, up to a point, by including higher order perturbation terms. For frequencies near cutoff in rectangular waveguide, the attenuation constant from the first-order perturbation is approximately given by

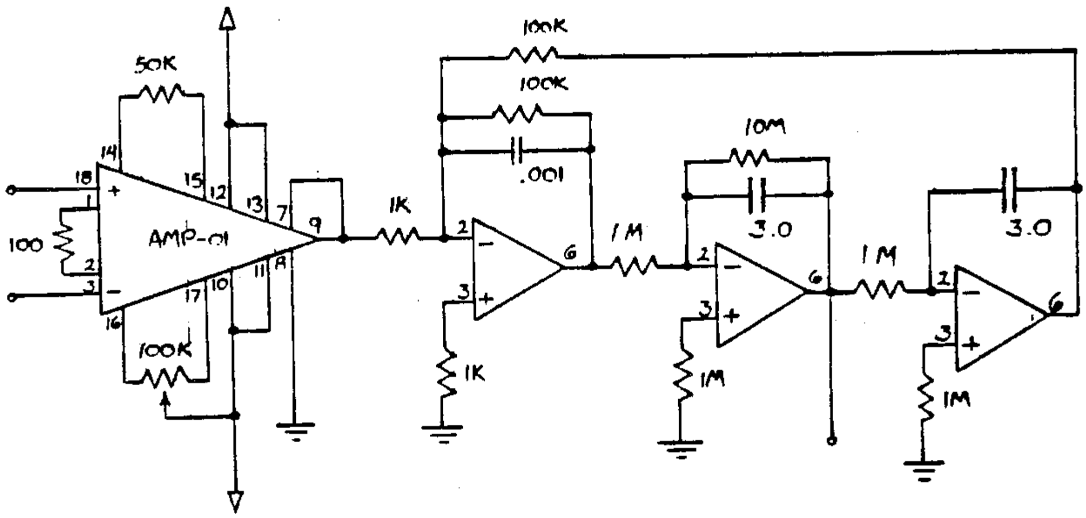
$$\alpha\left(\frac{\mathrm{dB}}{\mathrm{length}}\right) = 20\ \log(e)\left[\frac{d}{cb}\ \frac{\omega_c^{\ 2}}{(\omega^2 - \omega_c^{\ 2})^{1/2}}\right] \tag{9}$$

where d is the skin depth of the metal at frequency ω and b is the height of the waveguide. For the particular case of WR-15 copper waveguide which is driven at a frequency 15 megahertz above the cutoff frequency, Equation 9 gives a value of 0.50 dB/cm. This result is in good agreement with the more general formula (Reference 7). In order to improve the accuracy of the calculated attenuation constant, the second-order perturbation has been calculated for rectangular waveguide near the cutoff frequency. Incorporating the second-order perturbation term, the attenuation constant for rectangular waveguide near cutoff is given by the following relation:

$$\alpha\left(\frac{\mathrm{dB}}{\mathrm{length}}\right) = 20\ \log(e)\left[\frac{d}{cb}\ \frac{\omega_c^{\ 2}}{(\omega^2 - \omega_c^{\ 2})^{1/2}} + \frac{d^2}{cb^2}\ \frac{\omega_c^{\ 2}}{(\omega^2 - \omega_c^{\ 2})^{3/2}}\right] \tag{10}$$

This calculation is in good agreement with the results of measurements made near cutoff in WR-112 waveguide. The formula gives a value of 0.63 dB/cm for the WR-15 waveguide at 15 megahertz above cutoff frequency. In this case, the third-order perturbation term is also significant, but it is small enough that it shall be ignored here. At the present time, the attenuation constant of WR-15 waveguide has not been measured because of the lack of necessary equipment in the WR-15 waveguide band.

The maximum length of the waveguide path will be determined by the minimum RF power that is required to produce a measurable signal from the phase detector. In the absence of other sources of noise, this threshold is determined by the conversion loss of the phase detector and the input noise level of the amplifier that follows the detector. To determine the input noise level of a particular amplifier for a particular measurement frequency and bandwidth, a prototype circuit has been built and tested. For the present design, a period of 20 seconds has been chosen for the rotation of the experiment mounting rail. With a Q of 10 for the output bandpass filter, a workable tolerance of about ±1 second is allowed for the rotation period of the rail. The circuit, shown schematically in Figure 2, is built around the AMP-01 low-noise instrumentation amplifier manufactured by Precision Monolithics, Incorporated, Santa Clara, Calif. This amplifier was chosen for its very low input noise specifications and its low 1/f noise corner frequency. The amplifier is operated at its maximum rated voltage gain of 10,000. The filter section is a state-variable-type bandpass filter



All capacitances in microfarads

FIGURE 2. Schematic Diagram of the Amplifier/Filter Test Circuit.

with a center frequency of 0.05 hertz and a Q of 10 with additional voltage gain of 100, giving an overall voltage gain of 1 million. With 50-ohm terminations on the input terminals, the output voltage fluctuation was found to be about 50 millivolts peak to peak, giving an equivalent input noise voltage of about 50 nanovolts. Larger spurious fluctuations were observed that were probably caused by poor shielding and the presence of transient noise from the environment.

A 50-nanovolt noise voltage across a 50-ohm resistor represents a noise power level of -163 decibels with respect to 1 watt. If the conversion loss of the mixer is estimated to be 10 decibels when used as a phase detector, then the minimum RF power for the signal to exceed the noise is -150 decibels with respect to 1 watt. For small phase changes, the output voltage of the mixer is roughly proportional to the relative phase change between the waveguides if the waveguides are near phase quadrature. For a phase change of 1/100 wavelength, the output signal is reduced by about 15 decibels from the case of whole wavelength variations. With the waveguide driven at a power level of 1 watt, it shall be required that the attenuation in the waveguide does not exceed 135 decibels.

The maximum length of the waveguide at a given frequency can be determined using the figure of 135 decibels for the total attenuation. Using this criterion, Table 1 was generated to give the attenuation constant, the length, and the volume of the relative phase change for a number of different frequencies above the cutoff. The table is useful for examining how the measurable effect depends on the choice of frequency. Notice that the measurable phase change does not vary rapidly with change of operating frequency, although the maximum length does.

TABLE 1. Predicted Effects With Standard WR-15 and WR-28 Waveguides.

Frequency separation δ, MHz	Attenuation constant in WR-15 α, dB/cm	Baseline length L, cm	Relative phase change $\Delta\phi$, deg
15	0.63	215	3.18
20	0.52	262	3.34
25	0.45	302	3.45
30	0.40	338	3.53
35	0.36	372	3.59
40	0.34	402	3.63
50	0.30	457	3.70
60	0.27	507	3.74
80	0.23	594	3.80
100	0.20	671	3.83

With increased separation from the cutoff frequency, the power level to the mixer can be increased by whole orders of magnitude with only a small reduction of the measurable phase change for a fixed length. For instance, if the baseline is held fixed at 215 centimeters while the frequency is increased from 15 to 20 megahertz above cutoff frequency, the attenuation is reduced by 23 decibels with a reduction of only 0.4 degree in the relative phase change.

Also, the signal can be increased greatly by replacing the standard WR-15 waveguide with an "increased height" waveguide. The inside height of the waveguide can be nearly doubled without introducing mode degeneracy. Referring back to Equation 10, it is found that by doubling the inside height of the waveguide, the signal power can be increased by 73 decibels for the case of 15-megahertz separation from cutoff on a 215-centimeter baseline. While this affords the opportunity to increase the length of the baseline, there is little to be gained by this approach since the relative phase change is only proportional to the length. Also, the measurement baseline must be held to a reasonable length for the apparatus to be easily steered.

For a final estimate of the magnitude of the measurable effects that have been hypothesized, consider the case of a 250-centimeter measurement baseline employing increased-height WR-15 waveguide driven at a frequency 15 megahertz above cutoff frequency. Assume that the power level available to drive the waveguides is 1 watt. The overall attenuation in the waveguide would be about 70 decibels, and the maximum value of the relative phase change would be 3.7 degrees. For a phase detector with 10 decibels of conversion loss and a 50-ohm equivalent load resistance, the output signal would have an amplitude of about 120 microvolts as the apparatus is rotated in a plane containing the presumed absolute velocity vector of the laboratory. This is an easily measurable signal if, in fact, system noise is sufficiently low.

One important source of noise — which has not yet been discussed — is the phase-locked klystron oscillator which drives the waveguides. With a worst-case estimate of 1 hertz for the averaged frequency variation, the relative phase change between the two waveguides is unaffected by the FM noise component. With an ideally balanced mixer for the phase detector, the AM noise also would have no effect on the output signal. However, since any real balanced mixer is far from this ideal case, the AM noise can indeed produce a significant contribution to the output signal from the phase detector. The issue of AM noise effects is addressed further in the following section.

CRITICAL ISSUES

PRECISION WAVEGUIDE

For the present design of the free-space anisotropy experiment, the stated requirements for the precision waveguide are that the broadwall dimension of the waveguide shall vary by no more than 50 microinches over a length of more than 8 feet. This requirement could be relaxed somewhat by increasing the separation of the driving frequency from the cutoff frequency without severely limiting the sensitivity of the experiment. However, since the experiment critically depends on a well-defined cutoff frequency and because the requirement does appear feasible at this point, it remains the goal for the precision waveguide.

Although 50 microinches is only 1/3000 of the dimension of WR-15 waveguide, the walls of typical quality waveguide are relatively smooth at this scale. The impact of surface roughness is to slightly increase the attenuation in the waveguide. For precision-drawn waveguide, this increase is less than 2% typically (Reference 8). Features that are small in extent compared to a wavelength can be treated as lumped elements. What is important is the overall parallelism of the walls from one end of the waveguide to the other. Perhaps the most difficult problem is how to make the necessary measurements to qualify a long length of waveguide at this level of precision.

A number of different approaches have been examined for the fabrication of the precision waveguide. For instance, the A. J. Tuck Company, Brookfield, Conn., proposed to manufacture waveguide in 10-inch lengths, with control of the dimensions to 50 microinches, by a two-step electroforming process on a precision machined, expendable aluminum mandrel. The experiment waveguide would have to be assembled from several of these parts, and repeatability for the fabrication of the parts is questionable. A basic problem with this approach is that each length of the waveguide is formed on a separate mandrel that is chemically dissolved away.

Precision-drawn copper waveguide, supplied by Space Machine and Engineering Corporation, St. Petersburg, Fla., is claimed to have a limit of 50 microinches on the dimensional variations. The waveguide is first extruded, then after allowing the extruded stock time to stabilize, three separate passes are made on the inside of the waveguide with a "wiping die." An important advantage to this approach is that the waveguide can be produced in lengths of up to 12 feet. For the purpose of test and evaluation, a few lengths of this high-precision waveguide were manufactured for the free-space anisotropy project in the standard WR-15 configuration with 0.040-inch wall thickness.

In an attempt to measure the degree of variation in the broad-wall dimension of the waveguide, a 10-foot length was cut into 4-inch sections and electrical measurements were made to determine variation of the cutoff frequency section by section. Type UG-385 flanges were slip-fit onto each section. An RF sweeper and a crystal detector were connected at either end of the waveguide to determine the "cutoff mark frequency" at which the power transmitted through the waveguide fell below a certain arbitrary level. The cutoff mark frequency was measured with a resolution of 1 megahertz and was found to be insensitive to mismatch at the flanged connections. Figure 3 is the plotted variation of the cutoff mark frequency of the serially numbered sections with respect to Section 1.

To determine the amount of distortion caused by cutting the waveguide into sections, precise measurements of the waveguide outside dimensions were made before and after sectioning. Measurement targets were placed every 2 inches on the broad wall and the narrow wall and

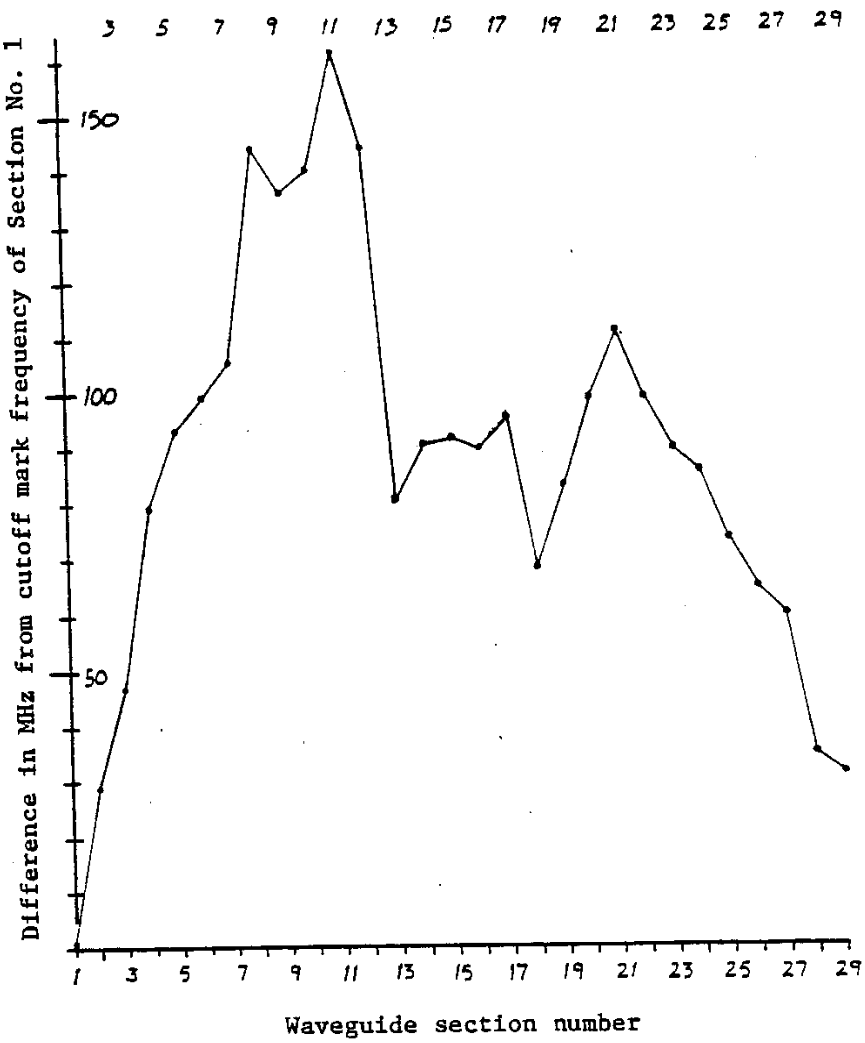


FIGURE 3. "Cutoff Mark Frequencies" of Sections From Precision WR-15 Waveguide Measured With Respect to Section Number 1.

were numbered in the same order as the 4-inch sections. The measurements were made using dial indicators, with readouts of 0.000 05 inch per division, on either side of the waveguide. Figure 4 is a plot of the change in the outside dimensions at the measurement targets on the narrow wall.

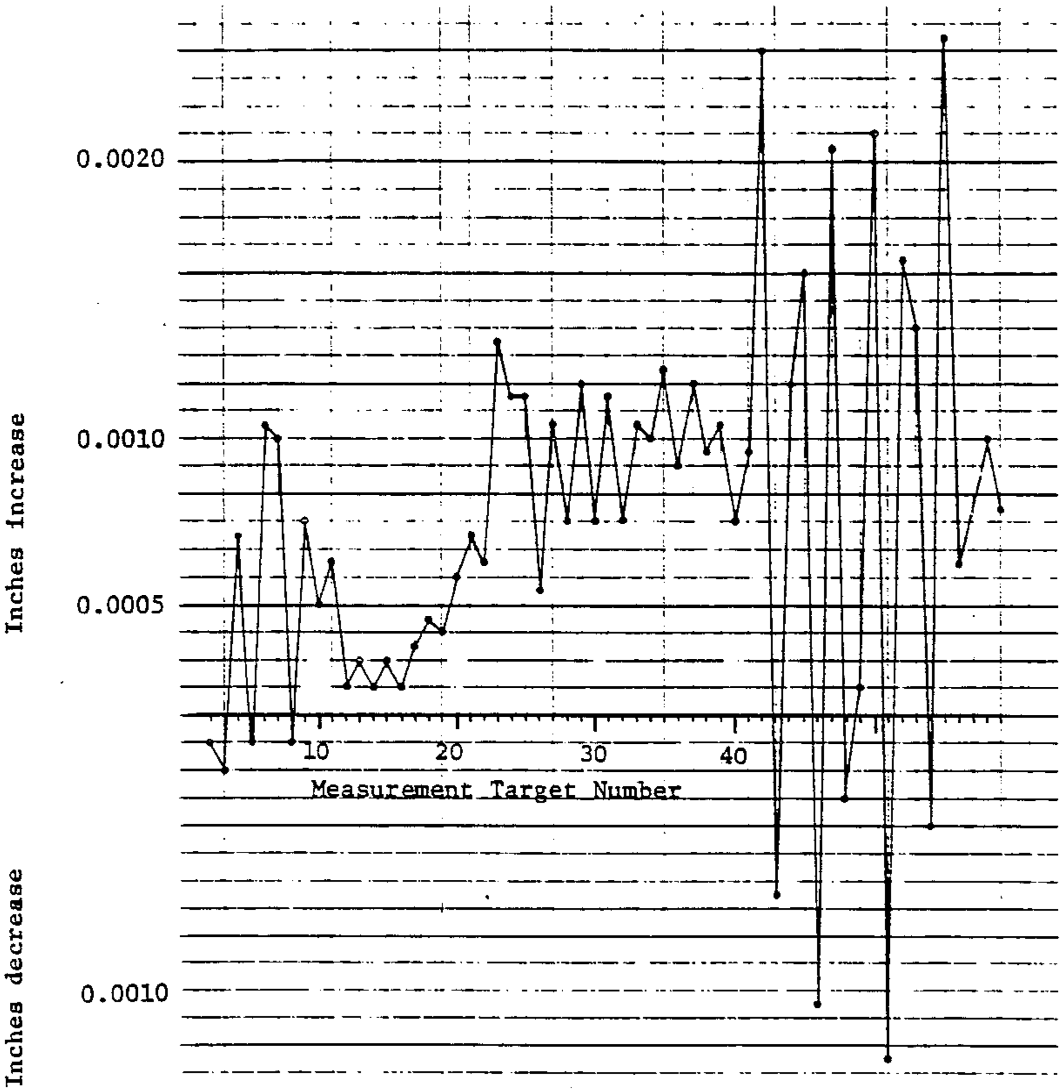


FIGURE 4. Measured Changes in the Broad-Wall Dimension of Precision WR-15 Waveguide Caused by Sectioning the Waveguide.

Figure 3 shows a maximum variation of about 160 megahertz for the cutoff mark frequency of the sectioned waveguide, which is about 10 times greater than the desired maximum variation of the actual cutoff frequency. The data of Figure 4 are apparently uncorrelated with the data of Figure 3, although it is expected that variation in the cutoff frequency should be inversely proportional to variation of the broad-wall dimension. From these results, it appears that a 2-inch separation between the measurement points is too wide to adequately characterize the dimensional changes on the waveguide. Interestingly, the variations of the cutoff mark frequency are smaller than would be expected from the measured dimensional changes, assuming that the waveguide was perfectly uniform before cutting. This suggests that most or all of the variation of the cutoff mark frequency could be the result of distortion caused by cutting the waveguide.

For the next trials, an increased-height, precision WR-15 waveguide shall be obtained. According to the supplier, the waveguide could be made available with greatly increased wall thickness. Heavy-wall fabrication would certainly give the waveguide better dimensional stability and might make practical the "cut-and-measure" approach to qualification testing of the waveguide.

Another important consideration is the efficiency of the coupling into a waveguide operated so close to cutoff. A 2-inch, WR-28/WR-15, tapered transition was used to feed a 1-foot length of the precision WR-15 waveguide. Power reflected from the transition was measured in the WR-28 waveguide and the mismatch loss was determined. At a frequency 20 megahertz above the estimated cutoff frequency of the WR-15 waveguide, the measured coupling loss was 3.3 decibels. Coupling losses could be reduced even further with a more carefully designed transition (Reference 9).

AM NOISE

The AM noise output from a phase-locked klystron in the post-detection measurement bandwidth was measured using a crystal detector and the filter section of the circuit in Figure 2. The output of the klystron, operating at 35 gigahertz, was attenuated to give the best square-law response from the detector. In the 0.01-hertz bandwidth of the filter, the AM noise was measured to be 30 decibels below the carrier power from the klystron. For 100 milliwatts of output power, this gives an effective fluctuation of 0.1 milliwatt in the local oscillator (LO) power delivered to the mixer.

To determine the amplitude of the noise signal that would appear at the output of the mixer caused by the fluctuations of the LO power, measurements were made of the output offset voltage as a function of LO power for a particular mixer. We chose a Honeywell Spacekom Model CKa-1 balanced mixer. Figure 5 is a plot of the offset characteristic curve which was measured. By measuring the slope of the curve at 20 decibels with respect to 1 milliwatt of LO power, it is found that a 0.1-milliwatt change in LO power would produce a 10-microvolt change in the output offset voltage. Notice that at a LO drive level somewhere between 15 and 16 decibels with respect to 1 milliwatt, the slope of the curve is zero. Therefore, by judicious choice of the LO power level, the effects of AM noise can be greatly reduced. Also, the offset characteristic curve can be made flatter by carefully matching the diode pair at a particular frequency.

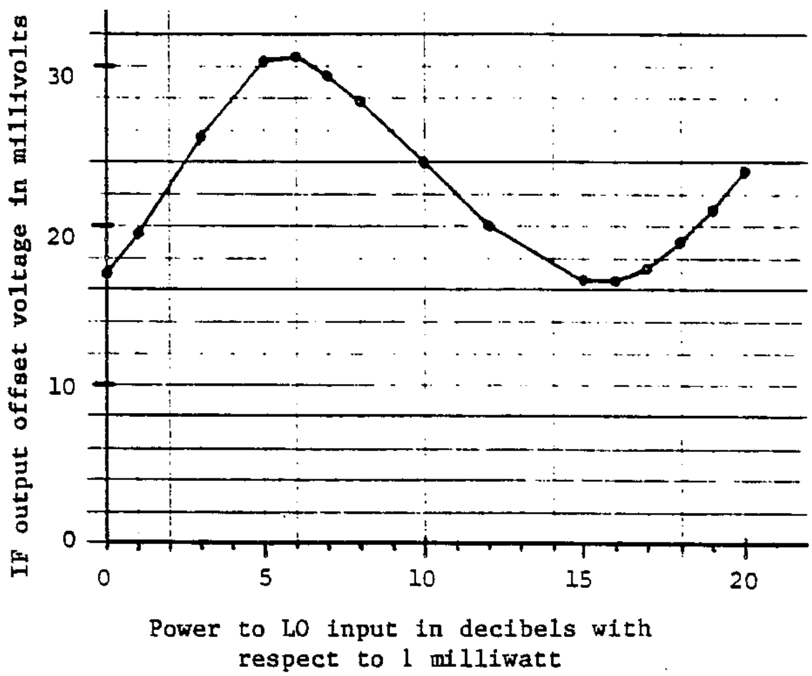


FIGURE 5. Offset Voltage Characteristics of the Waveguide Balanced Mixer at 39.9 Gigahertz.

CONCLUSIONS AND RECOMMENDATIONS

The Naval Weapons Center's free-space anisotropy experiment is unique in approach and may be the only experiment to date which offers the possibility of measuring the true one-way speed of light. The present design of the experiment would be sensitive enough to detect velocity of an earth-based laboratory as small as 10 km/s with respect to the hypothetical absolute frame of reference. The technology base for the experiment is well developed at this laboratory, with much of the required equipment already on hand. This experiment affords the opportunity to test a set of principles that are very fundamental to modern science without requiring large expenditures.

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