A Method for Measuring Group Time Delay Through a Feed Horn

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A technique is described for measurement of time delay through a feed horn. The technique consists of measuring the time delay between the input and output ports of two identical horns separated by a known airpath distance. Ground multipath signals, which normally produce errors in this type of measurement, were identified and eliminated by using a time domain technique. Experimental results at 2113 MHz showed good agreement with calculated values.

I. Introduction

Ground station delays for 64-m antenna Deep Space Stations (DSS) are currently being calibrated by the Translator Method. As described in References 1 and 2, the major portion of the ground station delay is measured during pre- and post-track calibrations by this method. The remaining (smaller) portion of station delay is calculated and assumed to be time and frequency invariant. One of the more difficult components for which delays are calculated is a complex feed horn assembly. The current feed horn assembly used in the S-Band Polarization Diversity (SPD) Cone used on 64-m antennas consists of orthomode transducers, quarter wave plates, mode generator, and a corrugated horn. Calculated delay values for these components have been reported in Reference 3. The monopulse feed horn assembly used in DSN 26-m antenna systems is even more complex and no simple method is currently known to the authors for calculating delays of monopulse feeds. The current use of dish-mounted zero delay devices (Ref. 1) for ranging has made it unnecessary to determine the delay of the monopulse feed. However, it may become important to determine 26-m antenna monopulse feed horn delays in the near future for such projects as the VLBI Time Sync Experiment and VLBI Validation Project.

This article presents a method which can be used to experimentally determine the delay through a feed horn assembly. The technique was used on simple standard gain horns, but can be extended to complex feeds.

II. Test Setup

The method to be described is very similar to the antenna gain measurement method discussed by Silver (Ref. 4) and Beatty (Ref. 5). The method consists of using an antenna range where two horns (or antennas) are separated by a known physical distance R as shown in Fig. 1. Figure 2 shows the actual test setup on the antenna range located on the South End of the JPL Mesa Facility. The standard gain horns are mounted on two antenna towers, one of which is rotatable and can be moved axially on a rail in the direction of the main beam. The second tower is stationary but permits a mounted horn to be adjusted in a vertical direction. Both horns were mounted at a height of 5.55-m above the ground and 1-m above the top of the roof of Mesa Building 212. The horns being tested are Scientific Atlanta Model (12-1.7) pyramidal horns. The horns were separated at distances varying from 152.4 cm (5 ft) to 1676.4 cm (55 ft) in 152.4 cm (5 ft) increments. The smallest and largest separation distances correspond to $1.6D^2/\lambda$ and $17.5D^2/\lambda$, respectively, where D is the widest opening of the horn equal to 36.88 cm (14.52 inch) and λ is the free space wavelength of the test frequency of 2113 MHz.

The basic instrument used to measure delay was a Scientific Atlanta Fault Locator Model 1691 shown in Fig. 3. This instrument was developed to be portable for field use and is normally used as a high resolution time domain reflectometer to locate discontinuities (faults) in microwave antenna transmission lines. For the results of this article, this instrument was temporarily modified to measure transmission time delay. The absolute accuracy of the modified instrument is estimated to be better than ±2 ns and the resolution is about ±0.2 ns. The main advantage of this instrument is in its time domain logic whereby the time delay of the primary (desired) signal can be isolated and measured separately from the effects of other undesired signals such as from ground multipath.

Figure 4 shows typical X-Y recording of this instrument for horn separation distances of 152.4 cm (5 ft) and 304.8 cm (10 ft).* The recordings show only primary signals because multipath signals were at least 35 dB down from the main signal amplitude in the particular test setup used. The basic measurement technique is described as follows. As indicated by the block diagram of the test set-up shown in Fig. 1, measurement of the time delay is made of the total system which includes the delays of the two horns, airpath, cables, amplifier and the Fault Locator instrument. Then a reference measurement is taken by disconnecting the cables at the input and output of the coax-to-waveguide transitions and then connecting the cables together with a coaxial adapter or pad inserted between them. Subtraction of this reference measurement from the test measurement values results in the delays of only the two horns plus waveguide transitions plus airpath. After further subtraction of (1) the airpath delays, (2) the delays of the waveguide-to-coax transitions, and (3) making a small correction for coaxial adapters used, then one arrives at the delays of the two horns only. If the two horns are identical, the delay of a single horn is obtained by dividing the result by 2.

*The use of the Fault Locator in a transmission mode rather than the reflectometer mode required that the indicated instrument readings be multiplied by 2 as shown in the table in Fig. 4.

The airpath delays are easily calculable from precise measurements of the physical separation distance R between the horn apertures using a plumb bob and a steel tape measure. The delays of the two waveguide transitions are determined by measuring them separately at the same test frequency by use of a network analyzer.

III. Test Results

Table 1 shows test results of measurements made at 2113 MHz. It can be seen that the horn delay measured at the largest separation $17.5D^2/\lambda$ does not differ from the measured value at the smallest separation $1.6D^2/\lambda$ by more than 0.41 ns. At very close distances, multiple reflections between horns cannot be isolated by the Fault Locator. Figure 5 shows the theoretical calculated delay for a single horn at 2113 MHz. This calculated delay of 1.39 ns is based on the theoretical group velocities in the constant and tapered section of the horn at 2113 MHz. It can be seen that the calculated and measured delays in Table 1 are in agreement to within ±0.3 ns.

The entire set of measurements was again repeated with absorbers placed on the ground midway between the horns at each separation distance. A slight (but non-significant) improvement in agreement was obtained between theoretical and measured values. It was concluded that absorbers would not generally be needed for most test setups.

Although the Fault Locator instrument is not intended to be used for accurate gain measurements, relative amplitude data accurate to ±0.5 dB is simultaneously available and can be used to provide a good cross check on the experimental setup. Amplitude data obtained from recordings such as the one shown in Fig. 4, were used to calculate horn gain. For the various separation distances shown in Table 1, the measured horn gains agreed to within 1 dB of the theoretical value of 15.95 dB at 2113 MHz.

IV. Conclusions and Future Application

A technique has been presented for the measurement of time delays of a feed horn. The technique presented in this article involves the measurement of the time delay of a pyramidal standard gain horn. This technique can be extended to make measurements of corrugated standard gain horns, spacecraft antennas, and most non-dispersive types of complex feed assemblies used in the DSN. Two identical feeds are not required if the delay of a simpler horn of the same polarization has already been determined.

The measurement technique is not necessarily restricted to the use of a Fault Locator (such as described in this article) provided that it is already known that the antenna range is free from multipath errors. In such a case, a network analyzer can be used and possibly give more accurate time delay measurements over frequency intervals (spanned bandwidths) of about 20 to 40 MHz. However in most cases, the sources of ground multipath and multiple reflection are generally not known and special time consuming techniques must be employed to minimize or identify their effects. The Fault Locator time domain instrument provides a simple method for quickly identifying and making a direct measurement of the time delay of only the desired primary signal to accuracies of about ±1 ns.

Acknowledgement

The modification of the Fault Locator was suggested and accomplished by A. Ray Howland, JPL consultant and President of the Howland Company at Atlanta, Georgia.

References

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Table 1. Scientific-Atlanta Model 12-1.7 Standard Gain Horn Delay measurement results at 2.113 GHz

Horn separation			①	②	③	④	⑤
R, ft	R, cm	$\frac{R\lambda}{D^2}$	Airpath delay t_R, ns	Net measured delay,[a] ns	Waveguide transition pair delay, ns	Two horn delay,[b] ns	Single horn delay, ns
55	1676.4	17.5	55.92	60.39	1.44	3.03	1.52
50	1524.0	15.9	50.84	55.11	1.44	2.83	1.42
45	1371.6	14.3	45.75	50.02	1.44	2.83	1.42
40	1219.2	12.8	40.67	44.73	1.44	2.62	1.31
35	1066.8	11.2	35.58	39.45	1.44	2.43	1.22
30	914.4	9.6	30.50	34.97	1.44	3.03	1.52
25	762.0	8.0	25.42	29.48	1.44	2.62	1.31
20	609.6	6.4	20.33	24.40	1.44	2.63	1.32
15	457.2	4.8	15.25	19.11	1.44	2.42	1.21
10	304.8	3.2	10.17	14.03	1.44	2.42	1.21
5	152.4	1.6	5.08	8.74	1.44	2.22	1.11

[a]Net delay results from subtracting Fault Locator reference reading from test reading in units of feet and converting the result into transmission delay in units of nanoseconds.

[b]Delay of two horns = column ② data – (column ① + column ③ data).

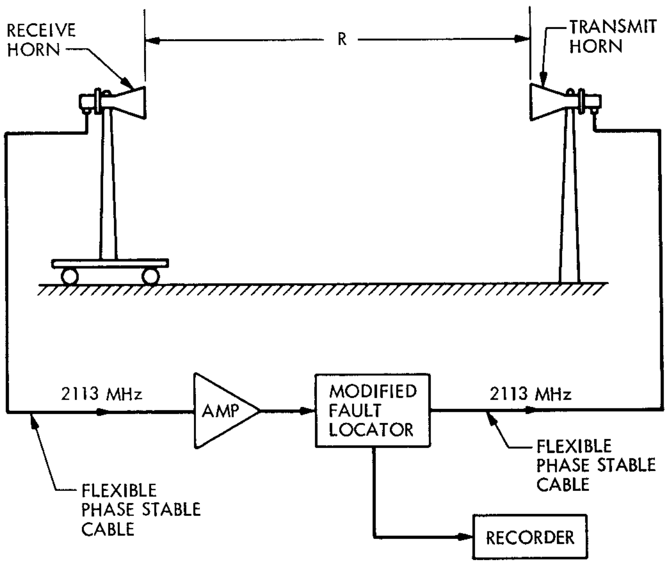


Fig. 1. Block diagram of test setup for antenna time delay measurements using a Fault Locator

Fig. 2. Test Setup at JPL Antenna Range Facility. Horns are 152.4 cm (5 ft) apart

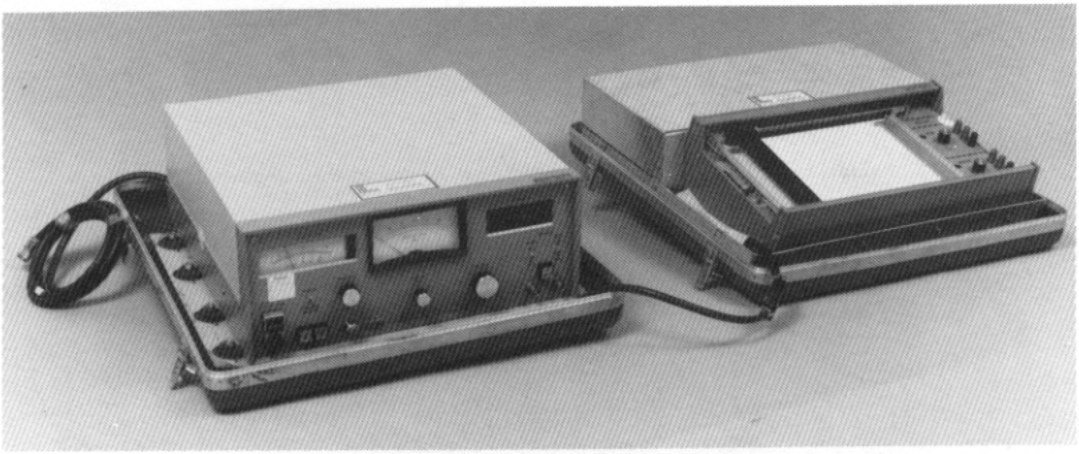
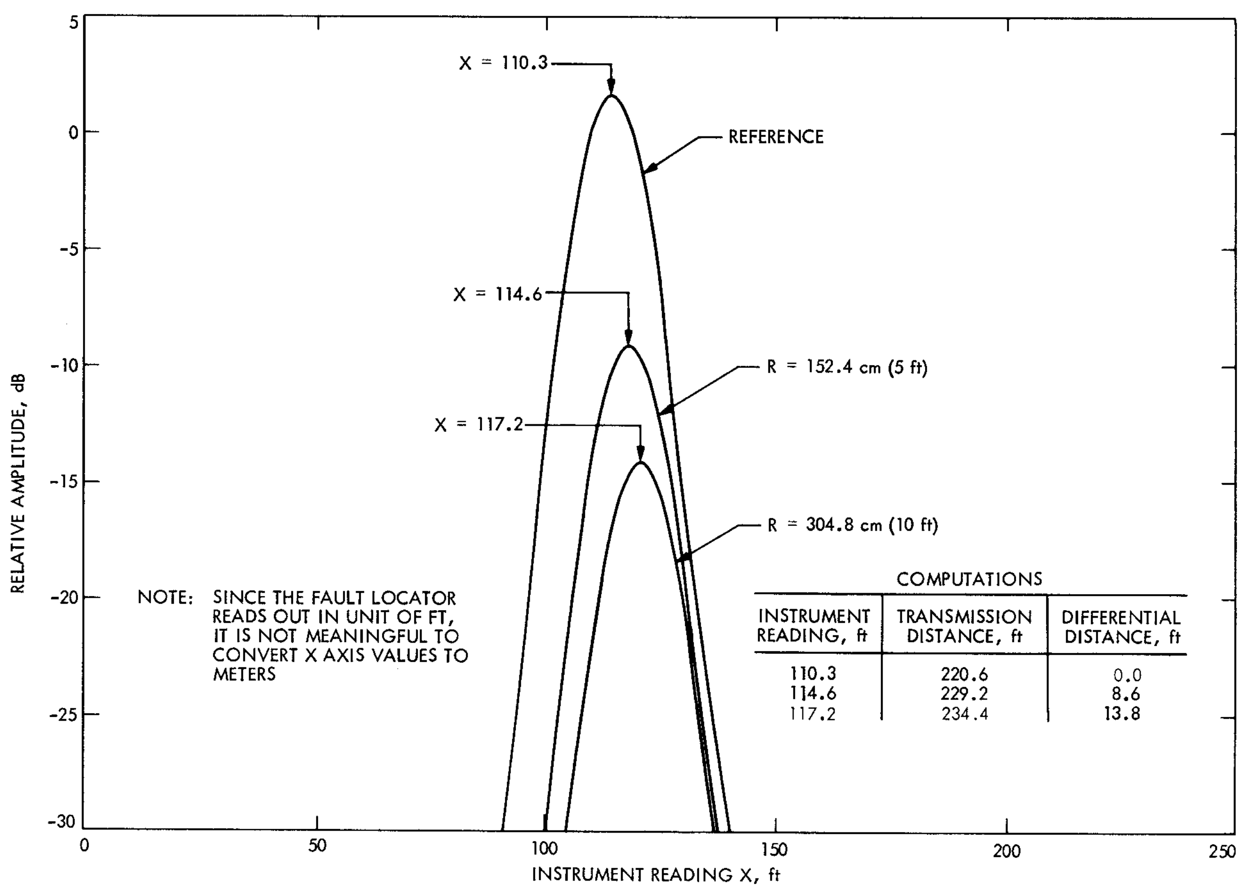
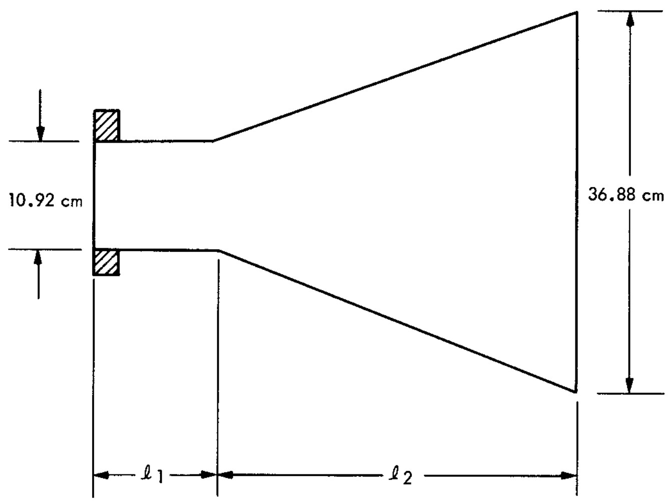


Fig. 3. Scientific Atlanta Fault Locator Model 1691 and Recorder



INSTRUMENT READING, ft	TRANSMISSION DISTANCE, ft	DIFFERENTIAL DISTANCE, ft
110.3	220.6	0.0
114.6	229.2	8.6
117.2	234.4	13.8

Fig. 4. Sample recording of transmission distance measurement using Fault Locator



$$t_{gi} = \frac{1}{c} \int_0^{\ell_i} \frac{\lambda_0 \, dx}{\sqrt{\left[\lambda_c(x)\right]^2 - \lambda_0^2}}$$

WAVEGUIDE SECTION	λ_c, cm	ℓ_i, cm	t_{gi}, ns
CONSTANT WR430 SECTION	21.84	10.08	0.44
TAPERED HORN SECTION	21.84 → 73.76	26.49	0.95
		TOTAL	1.39

Fig. 5. Calculated time delay of standard gain pyramidal horn (Scientific Atlanta Model 12-1.7) at 2113 MHz