IMPROVEMENTS IN POLARIZATION MEASUREMENTS OF CIRCULARLY POLARIZED ANTENNAS

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ABSTRACT

A new measurement technique that is used to measure the polarization properties of dual port, circularly polarized antennas is described . A three antenna technique is used, and high accuracy results are obtained for all three antennas without assuming ideal or identical properties. This technique eliminates the need for a rotating linear antenna, reduces the setup time when gain measurements are also performed, and reduces errors for antennas with low axial ratios.

Key Words: Circular Polarization, Measurements, Antenna, Axial Ratio.

INTRODUCTION

A generalized three-antenna measurement technique has been used for some time to measure both gain and polarization properties of nominally linearly polarized antennas[1,2]. When two or more of the antennas were circularly polarized, the polarization parameters could not be obtained, and in most cases circularly polarized (CP) antennas were measured using a rotating linear technique. The axial ratio and tilt angle were obtained with the rotating linear antenna, and then in a separate measurement, gain was obtained in a three-antenna measurement. The rotating linear antenna technique is conceptually simple, but for antennas with axial ratios < 0.2 dB, receiver resolution, rotary joint errors, and other errors make the measurement very difficult.

A new technique that overcomes many of these problems for dual polarized CP antennas has recently been developed . The gain and polarization are obtained from the same three-antenna measurement, thereby saving alignment and measurement time. Accuracy is improved by averaging a large number of measurements and by eliminating some sources of error. The technique has been used on two sets of CP horns with very good results.

THEORETICAL DEVELOPMENT

Two of the horns involved in the measurement are shown schematically in figure 1. The horns are equipped with orthomode transducers and polarizers so that one port is nominally right circularly polarized, and the other is nominally left circularly polarized. The plane-wave transmitting spectra for the R-port of the transmitting antenna is denoted as $\underline{s}_{10}(\underline{K})$, and the similar quantity for the L-port is denoted by $\underline{t}_{10}(\underline{K})$. The receiving antenna is also described in terms of its <u>transmitting</u> spectra , and reciprocity is assumed. The spectra for the R and L-ports are respectively denoted $\underline{u}_{10}(\underline{K})$ and $\underline{v}_{10}(\underline{K})$. The coordinate systems of both antennas are defined with their z-axes outward as shown in figure 1. Since the transmitting properties are used throughout the following discussion, the subscripts 10 can be deleted. Also since far-field conditions are assumed, only the spectrum for $\underline{K} = 0$ contributes to the coupling, and the explicit reference to $\underline{K}$ can be deleted. Using this concise notation, the coupling equation for the R-R case (transmitting from the R-port and receiving from the R-port) is then [1]

$$
\begin{aligned}
b_{su} &= \frac{C\, a_s}{(1-\Gamma_\ell \Gamma_u)} \left[s_x u_x - s_y u_y \right], \\
&= \frac{C\, b_g}{(1-\Gamma_\ell \Gamma_u)\,(1-\Gamma_g \Gamma_s)} \left[s_x u_x - s_y u_y \right], \\
&= \frac{C\, b_g}{M_{su}} \left[s_x u_x - s_y u_y \right]. \qquad (1)
\end{aligned}
$$

In Eq. (1), C is a constant involving parameters such as the separation distance and the receiver gain. a_s is the input to the R-port of the transmitting antenna; b_g is the generator output; and b_{su} is the output from the R-port of the receiving antenna. Γ_g, Γ_ℓ, Γ_s, and Γ_u are the reflection coefficients for the generator, load, transmitting antenna R-port, and receiving antenna L-port respectively. M_{su} denotes the mismatch factor for the R-R case. Similar notation will be used to denote the reflection coefficients and mismatch factors for the other cases. The relations between linear and circular components are,

$$s_x = (s_R + s_L)/\sqrt{2}, \quad (2)$$

$$s_y = i(s_R - s_L)/\sqrt{2}, \quad (3)$$

and the coupling equation becomes

$$b_{su} = \frac{C\, b_g}{M_{su}} \left[u_R s_R + u_L s_L \right]. \quad (4)$$

We define a complex polarization ratio for the R-port of the transmitting horn,

$$p_s = \frac{s_L}{s_R}, \quad (5)$$

The axial ratio and tilt angle are then

$$\text{Axial Ratio} = A_s = \frac{|s_R| + |s_L|}{|s_R| - |s_L|}, \quad (6)$$

$$\text{Tilt angle} = \tau_s = \frac{\arg(p_s)}{2}. \quad (7)$$

The measurement involves a rotation of one antenna about the z-axis, and the effect of this rotation must be included in the coupling equation. If the transmitting antenna is rotated about its z-axis by the angle ϕ in the direction $y \rightarrow x$, the magnitude of the right and left circular components in a fixed coordinate system will not change, but the tilt angle will decrease by the angle ϕ. The rotated components are

$$s_L(\phi) = |s_L| e^{-i(\tau_s + \phi)} = s_L e^{-i\phi}, \quad (8)$$

$$s_R(\phi) = |s_R| e^{+i(\tau_s + \phi)} = s_R e^{+i\phi}. \quad (9)$$

The coupling equation as a function of ϕ rotation is then

$$b_{su}(\phi) = \frac{C\, b_g}{M_{su}} \left[u_R s_R e^{i\phi} + u_L s_L e^{-i\phi} \right]$$

$$\approx \frac{C\, b_g}{M_{su}} \left[u_R s_R e^{i\phi} \right]. \quad (10)$$

The latter approximation is very good since $u_L s_L \ll u_R s_R$.

The R-R case is used as a reference condition, and the receiver is set to zero dB amplitude and zero degrees phase at $\phi = 0$. Data are not recorded as a function of ϕ for this case since rotation produces only a linearly varying phase. After changing to the L-port of the receiving antenna, the transmitting antenna is rotated about the z-axis while amplitude and phase are recorded as a function of ϕ as shown in Fig. 2. The coupling equation for this case, normalized to the R-R case at $\phi = 0$ is

$$b'_{sv}(\phi) = \frac{b_{sv}(\phi)}{b_{su}(0)}$$

$$= \frac{M_{su}}{M_{sv}\, s_R u_R} \left[v_R s_R e^{i\phi} + v_L s_L e^{-i\phi} \right]. \quad (11)$$

A second independent equation, required for determining the polarization ratios, is obtained from measurements at $\phi + \pi/2$:

$$b'_{sv}(\phi + \pi/2) =$$

$$= \frac{M_{su}}{M_{sv}\, s_R u_R} \left[v_R s_R e^{i(\phi+\pi/2)} + v_L s_L e^{-i(\phi+\pi/2)} \right]$$

$$= \frac{i\, M_{su}}{M_{sv}\, s_R u_R} \left[v_R s_R e^{i\phi} - v_L s_L e^{-i\phi} \right]. \quad (12)$$

Combining Eq.(11) and (12), we define $\Sigma_{sv}(\phi)$ as

$$\Sigma_{sv}(\phi) \equiv \frac{b'_{sv}(\phi) + i\, b'_{sv}(\phi + \pi/2)}{2}$$

$$= \frac{M_{su}}{M_{sv}} \left(\frac{s_L\, v_L}{s_R\, u_R} \right) e^{-i\phi}. \quad (13)$$

Referring to Eq. (5), s_L/s_R in Eq. (13) is one of the desired polarization ratios. The other ratio in the brackets of Eq. (13) is called the port-to-port ratio for the receiving antenna,

$$\wp_{uv} \equiv \frac{v_L}{u_R}. \quad (14)$$

The port-to-port ratio is the ratio of main components for the two ports of an antenna. Its magnitude is usually near 1, and its phase is due to the difference in electrical path lengths between the two ports. It must be determined in a separate measurement that will be described later.

The desired polarization ratio is obtained from Eq. (13) and given by

$$p_s(\phi) \equiv \frac{s_L}{s_R} = \frac{M_{sv}\; \Sigma_{sv}(\phi)\; e^{i\phi}}{M_{su}\; \wp_{uv}}. \quad (15)$$

A sample of measured data, $b'_{sv}(\phi)$, is shown in Fig. 3. The polarization ratio in Eq. (15) can be calculated for each pair of measurements 90 deg. apart. In this case measurements were made at one degree intervals, resulting in 360 determinations of the axial ratio and tilt angle. The results as a function of phi are shown in Fig. 4, and show a deviation of less than 0.01 dB in axial ratio and 2 deg. in tilt angle. All 360 results are averaged to obtain the final value. The polarization parameters for the L-port of the receive antenna are obtained by defining the quantity $\Delta_{sv}(\phi)$,

$$\Delta_{sv}(\phi) \equiv \frac{b'_{sv}(\phi) - i\, b'_{sv}(\phi + \pi/2)}{2}$$

$$= \frac{M_{su}}{M_{sv}} \left(\frac{s_R\, v_R}{s_R\, u_R}\, \frac{v_L}{v_L} \right) e^{+i\phi}$$

$$= \frac{M_{su}}{M_{sv}} \left(\frac{v_R}{v_L}\, \frac{v_L}{u_R} \right) e^{+i\phi}. \quad (16)$$

From the definition of the polarization ratio for the L-port of the receiving antenna,

$$p_v = \frac{v_L}{v_R}, \tag{17}$$

$$p_v(\phi) = \frac{M_{su} \, \mathcal{P}_{uv} \, e^{i\phi}}{M_{sv} \, \Delta_{sv}(\phi)}. \tag{18}$$

The polarization ratios for the other two ports are obtained from a second measurement similar to the one described above. The reference condition for this measurement is the L-L case. The receiver is then changed to the R-port of the receiving antenna and measurements are taken as a function of ϕ resulting in data denoted as

$$b'_{tu}(\phi) \equiv b_{tu}(\phi)/b_{tv}(0). \tag{19}$$

Sigma and Delta functions are again defined as

$$\Sigma_{tu}(\phi) \equiv \frac{b'_{tu}(\phi) + i\, b'_{tu}(\phi + \pi/2)}{2}, \tag{20}$$

and

$$\Delta_{tu}(\phi) \equiv \frac{b'_{tu}(\phi) - i\, b'_{tu}(\phi + \pi/2)}{2}. \tag{21}$$

The four equations for the complex polarization ratios of the four ports are summarized below.

For the R-port of the transmitting antenna,

$$p_s(\phi) = \frac{M_{sv} \, \Sigma_{sv}(\phi) \, e^{i\phi}}{M_{su} \, \mathcal{P}_{uv}}. \tag{22}$$

For the L-port of the receiving antenna,

$$p_v(\phi) = \frac{M_{su} \, \mathcal{P}_{uv} \, e^{i\phi}}{M_{sv} \, \Delta_{sv}(\phi)}. \tag{23}$$

For the L-port of the transmitting antenna,

$$p_t(\phi) = \frac{M_{tu} \, e^{i\phi}}{M_{tv} \, \mathcal{P}_{uv} \, \Delta_{tu}(\phi)}. \tag{24}$$

For the R-port of the receiving antenna,

$$p_u(\phi) = \frac{M_{tv} \, \mathcal{P}_{uv} \, \Sigma_{tu}(\phi) \, e^{i\phi}}{M_{tu}}. \tag{25}$$

Similar equations can be obtained for measurements where the port change is made on the transmitting antenna, and/or the receiving antenna is rotated. The combination used is primarily a matter of convenience.

SAMPLE RESULTS

In one measurement, four horns were used, and results for one of these was obtained from four different measurements. The results of these tests shown in Fig. 5 illustrate the repeatability and accuracy of the measurements. Further evidence is demonstrated in Fig. 6 showing the standard deviation of repeated measurements for each of the four horns. Measurements were repeated after realignment, for different orientations within the anechoic chamber, at different separation distances, and for different antenna combinations. One of the main causes of changes in results was due to coupling between the ports along with changes in the termination on the opposite port. Horns that had isolators on both ports showed the best consistency.

MEASUREMENT OF PORT-TO-PORT RATIOS

There are two methods for measuring the port-to-port ratios, $\mathcal{P}$, required for the solution of Eq. (22-25). In the first method, a linearly polarized antenna is used as a transmitter or receiver and the other antenna is a dual port CP antenna. Measuring the amplitude and phase change caused by switching between the two ports provides the data for determining $\mathcal{P}$ for that antenna.

The second method uses data obtained for pairs of CP horns during the polarization measurement. With the ϕ rotation at zero, the R-R configuration is used and the receiver initialized to zero amplitude and phase. The transmission lines are then changed to the L-L condition, and the change in signal measured. The resulting equation, using the previous notation is

$$\frac{b_{tv}(0)}{b_{su}(0)} = \frac{M_{su}}{M_{tv}} \mathcal{P}_{st} \, \mathcal{P}_{uv}. \tag{26}$$

Two similar equations are obtained for the other two antenna pairs, and these can be solved for the three port-to-port ratios. Since a square root is involved in this solution, there remains a sign ambiguity. This must be resolved by an additional measurement such as a coarse measurement with a linearly polarized antenna, or by some additional information. The additional information can be about the tilt angles of the horns, since $\mathcal{P}$ *affects these results.*

CONCLUSIONS

This new approach to polarization measurements for dual port CP antennas has significant advantages over the rotating linear approach. It saves time, reduces errors, and gives results for all three antennas involved in the measurement. Estimates of the uncertainty in axial ratio are approximately 0.02 dB.

REFERENCES

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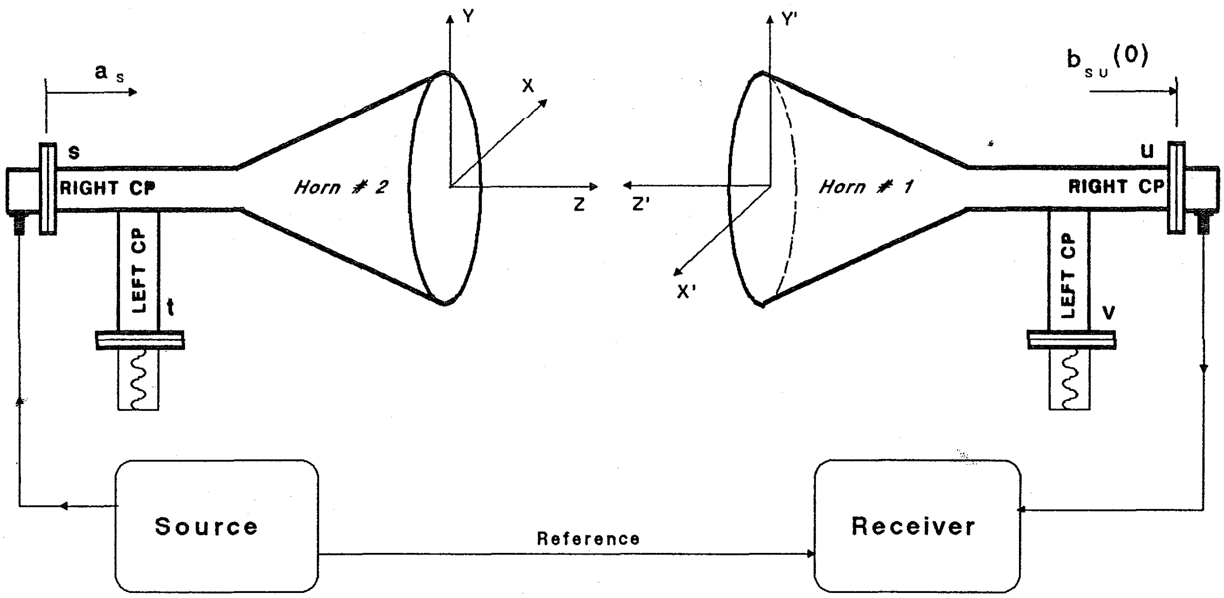

Figure 1. Schematic of dual polarized horns with the initial connection to the R-ports and no rotation.

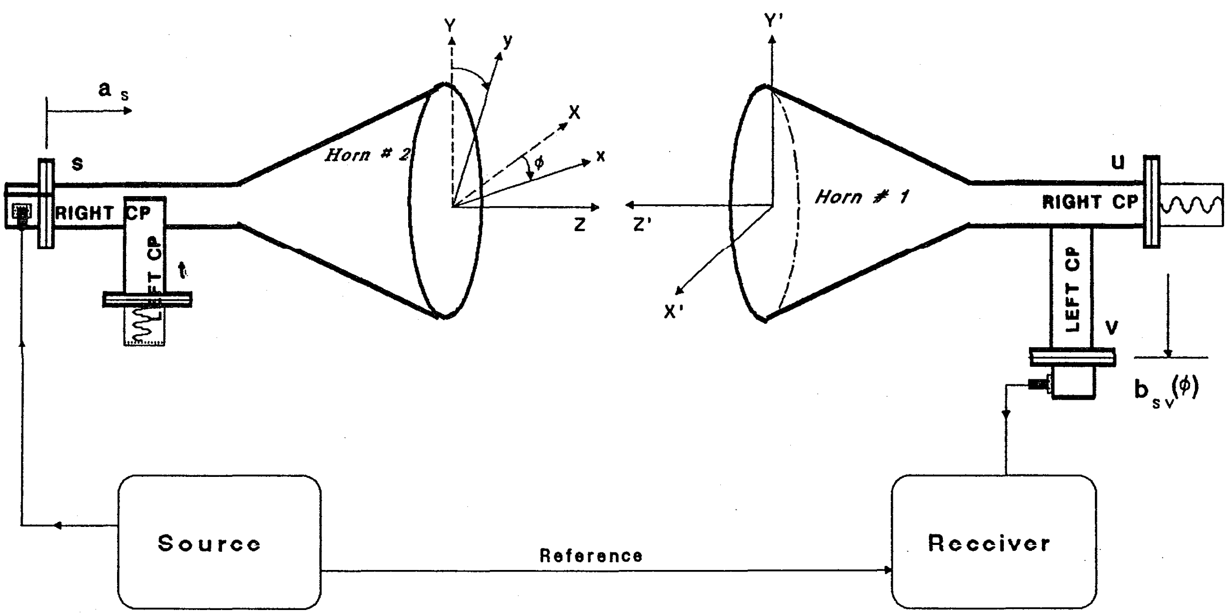

Figure 2. Schematic of dual polarized horn. Transmitting from the R-port and receiving from the L-port with the transmitting horn rotated about its axis by the angle ϕ.

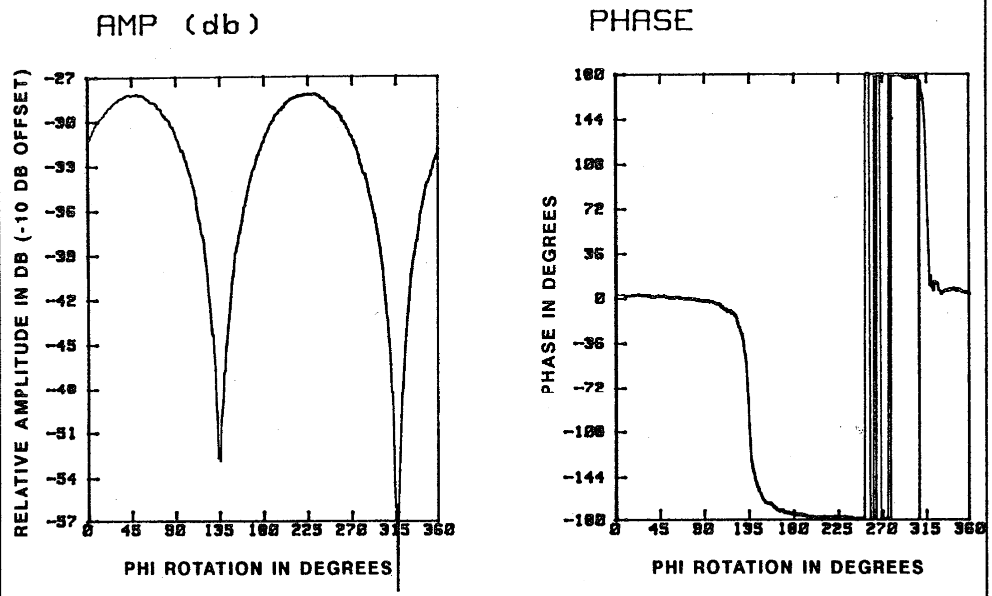

Figure 3. Sample of measured data for circular polarization measurement. Transmitting from L-port and receiving on the R-port. Both antennas have axial ratios of approximately 0.1 dB.

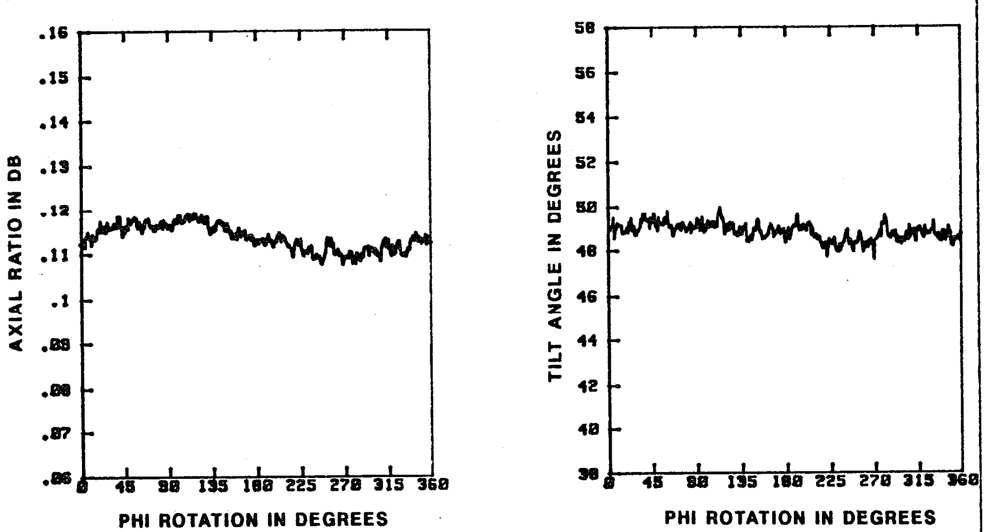

Figure 4. Sample of axial ratio and tilt angle for transmitting antenna from data in figure 3.

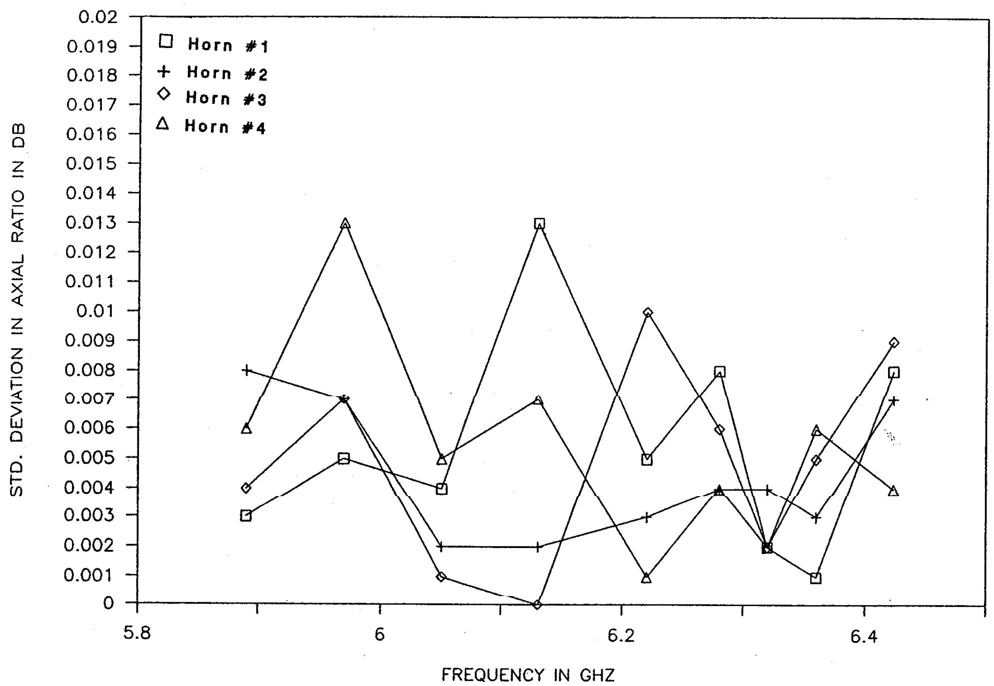

Figure 5. Results of four separate measurements on one circularly polarized horn using two dual port CP horns.

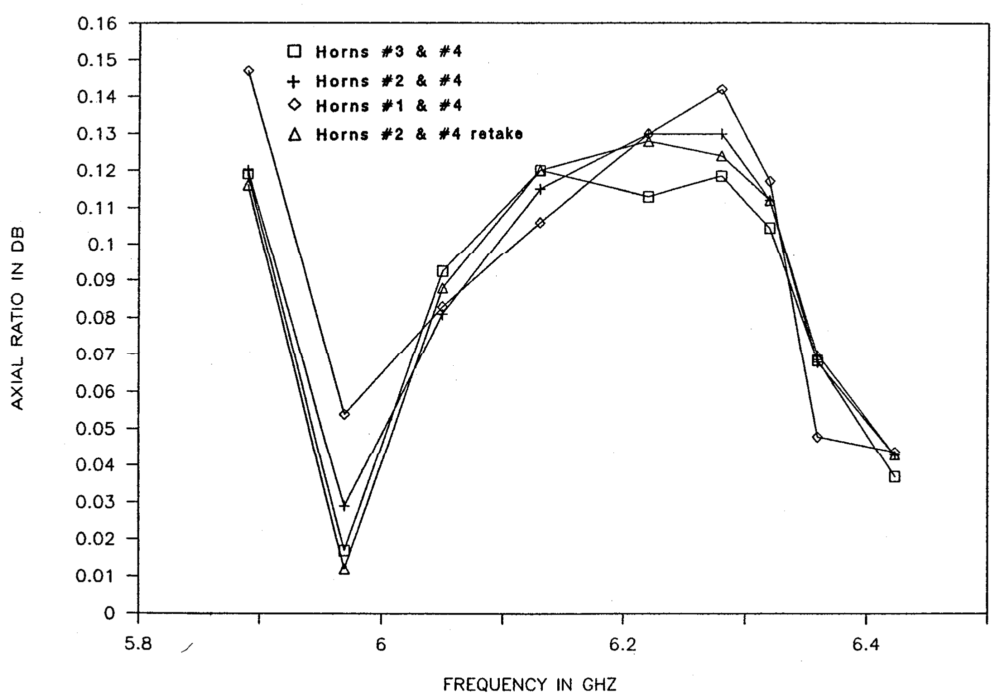

Figure 6. Standard deviation for repeat measurements on four different horns.