

A METHOD FOR MAKING FAST HIGH ACCURACY  
POLARIZATION MEASUREMENTS

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ABSTRACT

A method is presented for making fast multi-frequency high accuracy polarization measurements using a digital computer. This paper will provide a brief review of the IEEE standard polarization definitions, their applicability to the three antenna method, and finally a fast two antenna method.[1]

The fast two antenna method uses a dual polarized orthomode sampling antenna along with a standard antenna whose polarization is known. The dual polarized sampling antenna is calibrated before the test data is acquired using the polarization standard in two different orientations 90 degrees apart. Once the calibration data is acquired the dual polarized orthomode antenna is used as a sampling antenna for the AUT.

Since the sampling antenna is dual polarized the AUT polarization data can be obtained rapidly for many frequencies since neither antenna is required to rotate. This method has been used to acquire polarization data for over 500 frequencies in less than 20 seconds.

INTRODUCTION

This paper will present a technique for making fast multi-frequency polarization measurements on microwave antennas. A brief description of the IEEE standard definitions will be presented. The standard three antenna method will be used to determine the polarization of a standard gain horn. A standard gain horn will be utilized to determine an overall system calibration constant as well as the polarizations of each of the two ports of the dual polarized antenna. Finally the polarization of the AUT will be determined using the dual polarized sampling antenna.

One of the limitations of most current polarization measurement techniques is the requirement that one of the antennas must be rotated in order to acquire the data. The use of a dual polarized sampling antenna allows for fast multifrequency data acquisition since neither the sampling antenna or the AUT has to be rotated.

DEFINITIONS

The polarization of an antenna is defined according to the IEEE standards [2] as the polarization of the wave which is radiated or transmitted by the antenna. The polarization of the wave incident upon the AUT is the polarization of the transmit antenna (i.e. the dual polarized antenna).

The receiving polarization of the AUT is defined as the polarization of the wave to which the antenna is polarization matched.

By IEEE standards, the polarization of an antenna is defined in a right-hand coordinate system, as shown on the left side of Figure 1, with the unit vector  $\vec{u}_{pt}$  in the direction of propagation. The tilt angle reference is  $\vec{u}_{1A}$ , and the tilt angle is  $\tau_A$ .

The incident wave is defined in a separate right hand coordinate system, such as that on the right side of Figure 1, with the unit vector  $\vec{u}_{pB}$  in the direction of propagation of the incident wave. The tilt angle  $\tau_B$  is referenced to  $\vec{u}_{1B}$ . The tilt-angle reference  $\vec{u}_{1B}$  may or may not be aligned with  $\vec{u}_{1A}$ .

To permit calculation of the coupling between a wave whose polarization is known in its transmitting coordinate system and a reciprocal receiving antenna whose polarization is known in its transmitting coordinate system, the coordinate systems of the two antennas must be properly related.

Specifically, the tilt angles must be defined with respect to the same reference direction and in the same coordinate system, or the differences in the tilt-angle reference directions and the orientations of the coordinate systems must be accounted for.

The coupling coefficient or coupling between a wave and an antenna takes into account these two coordinate systems and is defined as

$$\hat{V} = \cos \gamma_A \cos \gamma_{rB} + \sin \gamma_A \sin \gamma_{rB} e^{j(\delta_{cA} - \delta_{crB})}$$

(1)

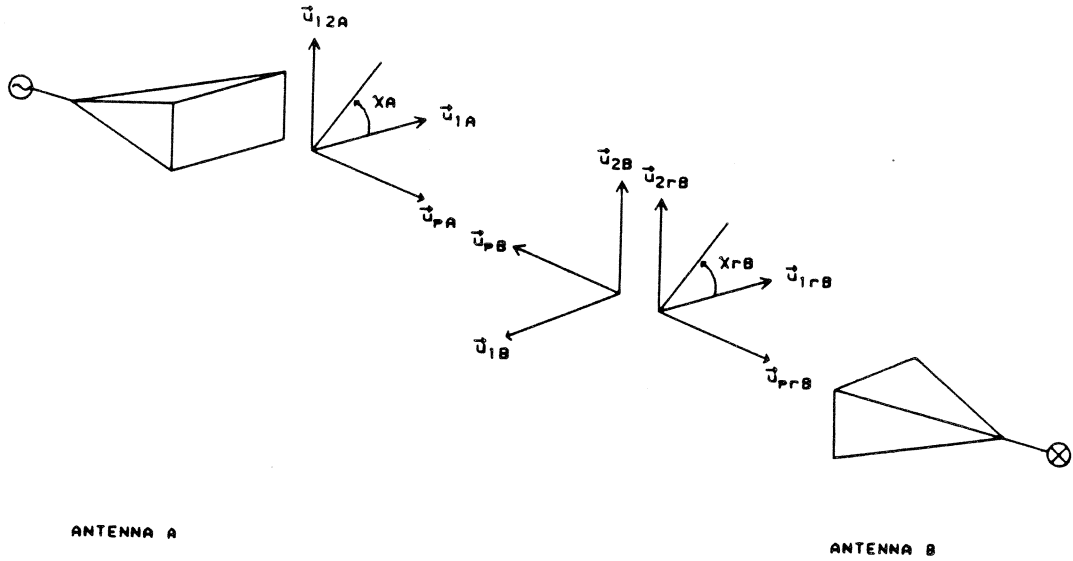


Figure 1.

where

$$\gamma_A = \tan^{-1}(\rho_{cA}) \quad (2)$$

$$\gamma_{rB} = \tan^{-1}(\rho_{crB}) \quad (3)$$

and

$$\delta_{cA} = 2\tau_A \quad (4)$$

$$\delta_{crB} = 2\tau_{rB} \quad (5)$$

$\rho_{cA}$  is the magnitude of the circular polarization ratio for the wave or transmitting antenna (dual ported probe) and  $\tau_A$  is the tilt of the transmitted wave.

$\rho_{crB}$  is the magnitude of the circular polarization ratio for the receive antenna (AUT) and  $\tau_{rB}$  is its associated tilt angle.

Rotation of either or both antennas has the following effect on the coupling coefficient,

$$\begin{aligned} \hat{V}(\chi_A, \chi_{rB}) = & \cos \gamma_{rB} \cos \gamma_A e^{j(\chi_{rB} - \chi_A)} + \\ & + \sin \gamma_{rB} \sin \gamma_A e^{j(\delta_{cA} - \delta_{crB} - \chi_{rB} + \chi_A)} \end{aligned} \quad (6)$$

The angle  $\chi_A$  represents a rotation from  $\vec{u}_{1A}$  toward  $\vec{u}_{2A}$  in the transmitting coordinate system

of the source antenna (Figure 1). The angle  $\chi_{rB}$  represents a rotation from  $\vec{u}_{1rB}$  toward  $\vec{u}_{2rB}$  in the receiving coordinate system of the AUT.

Therefore, depending on which antenna is rotated determines the form of the coupling coefficient between them.

### THREE ANTENNA METHOD

In the standard three antenna polarization measurement technique the coupling between two antennas is determined by taking the antennas, two at a time (Figure 2). This particular measurement configuration was selected to minimize the number of times each antenna has to be mounted and aligned. It also requires that only one of the three antennas be a reciprocal antenna. The measurement requires that one of the antennas (usually the receive antenna) be rotated through  $90^\circ$ . Thus, assuming  $\chi_A = 0$  and  $\chi_{rB} = 0$  is one position, and  $\chi_A = 0$  and  $\chi_{rB} = 90$  is another position resulting in  $90^\circ$  rotation, then the ratio of the two measurements can be written

$$\frac{\hat{V}(\chi_{rB} = 90)}{\hat{V}(\chi_{rB} = 0)} = j \frac{1 - \hat{\rho}_{cB} \hat{\rho}_{cA}}{1 + \hat{\rho}_{cB} \hat{\rho}_{cA}} \quad (7)$$

where  $\hat{\rho}_{cA}$  and  $\hat{\rho}_{cB}$  are the transmit polarizations of the transmit and receive antennas, respectively.

$$\hat{\rho}_{cB} = \hat{\rho}_{crB}^* = \frac{\sin \gamma_{rB}}{\cos \gamma_{rB}} e^{-j\delta_{crB}} \quad (8)$$

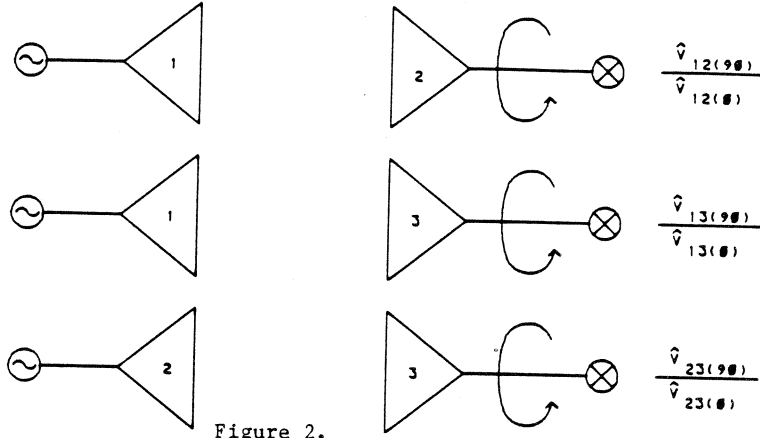


Figure 2.

and

$$\hat{\rho}_{cA} = \frac{\sin \gamma_A}{\cos \gamma_A} e^{j\delta_{cA}} \quad (9)$$

where the asterisk (\*) denotes a complex conjugate.

Making the  $\chi_{rB} = 0$  and  $\chi_{rB} = 90$  measurements for all three antenna pairs and substituting into equation (7) yields the standard three antenna equations

$$\hat{Q}_1 = \frac{\hat{V}_{12}(90)}{\hat{V}_{12}(0)} = j \frac{(1 - \hat{\rho}_{c1} \hat{\rho}_{c2}^*)}{1 + \hat{\rho}_{c1} \hat{\rho}_{c2}} \quad (10)$$

$$\hat{Q}_2 = \frac{\hat{V}_{13}(90)}{\hat{V}_{13}(0)} = j \frac{(1 - \hat{\rho}_{c1} \hat{\rho}_{c3}^*)}{1 + \hat{\rho}_{c1} \hat{\rho}_{c3}} \quad (11)$$

$$\hat{Q}_3 = \frac{\hat{V}_{23}(90)}{\hat{V}_{23}(0)} = j \frac{(1 - \hat{\rho}_{c2} \hat{\rho}_{c3}^*)}{(1 + \hat{\rho}_{c2} \hat{\rho}_{c3})} \quad (12)$$

Solving equations (10), (11) and (12) for  $\hat{\rho}_{c1}$ ,  $\hat{\rho}_{c2}$ , and  $\hat{\rho}_{c3}$  gives

$$\hat{\rho}_{c1} = \left[ \frac{\hat{k}_1 \hat{k}_2}{\hat{k}_3} \right]^{1/2} \quad (13)$$

$$\hat{\rho}_{c2} = \left[ \frac{\hat{k}_1 \hat{k}_3}{\hat{k}_2} \right]^{1/2} \quad (14)$$

$$\hat{\rho}_{c3} = \left[ \frac{\hat{k}_2 \hat{k}_3}{\hat{k}_1} \right]^{1/2} \quad (15)$$

where

$$\hat{k}_n = \frac{1 + j\hat{Q}_n}{1 - j\hat{Q}_n} \quad (16)$$

#### CALIBRATION

The system is calibrated similar to the previous three antenna measurement procedure described by mounting a standard horn of known or previously measured polarization at the AUT (antenna under test) location of the range and measuring the wave to antenna coupling from both ports of the dual polarized transmit antenna:  $\hat{V}_{Am}(\chi_{rB} = 0)$  and  $\hat{V}_{Bm}(\chi = 0)$ . The standard gain horn is then rotated  $90^\circ$  and another measurement is made:  $\hat{V}_{Am}(\chi_{rB} = 90)$  and  $\hat{V}_{Bm}(\chi_{rB} = 90)$ . From these measurements the complex circular polarization ratio for each port is determined at each required frequency ( $\hat{\rho}_{cB}$  for the vertical polarized port and  $\hat{\rho}_{cA}$  for the horizontally polarized port) using equation (10) rearranged to solve for  $\hat{\rho}_{cA}$ . The circular polarization ratio for the standard gain horn  $\hat{\rho}_{cSTD}$  has been substituted for the receive antenna ( $\hat{\rho}_{c2}$ ). This yields

$$\hat{\rho}_{cA} = \frac{(1 + j\hat{Q})}{\hat{\rho}_{cSTD}(1 - j\hat{Q})} \quad (17)$$

where

$$\hat{Q} = \frac{\hat{V}(90)}{\hat{V}(0)} \quad (18)$$

and  $\hat{\rho}_{cA}$  has been substituted for  $\hat{\rho}_{c1}$ .

Once the polarization ratios for the two ports of the dual polarized antenna are determined a system calibration factor  $\hat{k}$  can be determined.  $\hat{k}$  is a complex multiplier which will be used to balance

the relative gain and phase in-balance between the two independent signal channels of the measurement system.

The calibration factor  $\hat{k}$  is determined from the ratio of the previous measured data  $\hat{V}_{Am}(\chi_{rB} = 0)$  and  $\hat{V}_{Bm}(\chi_{rB} = 0)$  at each required frequency.

$$\hat{V}_0 = \frac{\hat{V}_{Bm}}{\hat{V}_{Am}} = \hat{k} \frac{\hat{V}_B}{\hat{V}_A} \quad (19)$$

$$= \hat{k} \frac{\cos \gamma_{rB} \cos \gamma_{STD} + \sin \gamma_{rB} \sin \gamma_{STD} e^{j(\delta_{cSTD} - \delta_{crB})}}{\cos \gamma_{rA} \cos \gamma_{STD} + \sin \gamma_{rA} \sin \gamma_{STD} e^{j(\delta_{cSTD} - \delta_{crA})}} \quad (20)$$

where  $\hat{V}_{Bm}$  and  $\hat{V}_{Am}$  are the measured receiver response for ports A and B respectively. Solving equation (16) for  $\hat{k}$  gives

$$\hat{k} = \hat{V}_0 \frac{\cos \gamma_{rA} \cos \gamma_{STD} + \sin \gamma_{rA} \sin \gamma_{STD} e^{j(\delta_{cSTD} - \delta_{crA})}}{\cos \gamma_{rB} \cos \gamma_{STD} + \sin \gamma_{rB} \sin \gamma_{STD} e^{j(\delta_{cSTD} - \delta_{crB})}} \quad (21)$$

Since the complex polarization ratios for the standard  $\hat{\rho}_s$ ,  $\hat{\rho}_{cA}$  and  $\hat{\rho}_{cB}$  are known, and  $\hat{V}_0$  has been measured, then the calibration constant can be determined by substitution into equation (21) for each frequency. Once the calibration constant and the complex polarization ratios for the two ports of the transmit antenna have been characterized, fast multi-frequency polarization measurements can be obtained.

#### FAST MEASUREMENT TECHNIQUE

This technique is based on the fact that the AUT is not required to rotate during the data acquisition, resulting in a significant speed improvement (see Figure 3). The standard gain horn used to acquire the calibration factor is replaced with the AUT. The receiver response of the AUT for ports A and B transmitting time shared is measured and the ratio

$$\hat{V}_m = \frac{\hat{V}_{Bm}}{\hat{V}_{Am}} \quad (22)$$

is determined.

Substitution of the complex circular polarization ration ( $\hat{\rho}_{cAUT}$ ) into equation (20) for the standard gain horn ( $\hat{\rho}_{cSTD}$ ) and rearranging to solve for ( $\hat{\rho}_{cAUT}$ ) yields

$$\hat{\rho}_{cAUT} = \frac{\hat{k} \cos \gamma_{rB} - \hat{V}_m \cos \gamma_{rA}}{\hat{V}_m \sin \gamma_{rA} e^{-j\delta_{crA}} - \hat{k} \sin \gamma_{rB} e^{-j\delta_{crB}}} \quad (23)$$

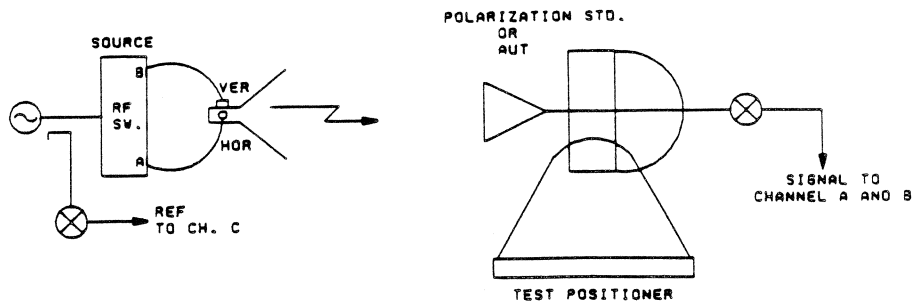


Figure 3.

Substitution of  $\hat{V}_m$ ,  $\hat{k}$ ,  $\hat{\rho}_{cA}$ , and  $\hat{\rho}_{cB}$  into equation (23) for each required frequency determines the circular polarization ratio of the AUT.

$$\hat{\rho}_{cAUT} = \rho_{cAUT} e^{j\delta_{cAUT}} \quad (24)$$

where the axial ratio ( $r$ ) and tilt angle ( $\tau$ ) are determined by

$$r = \frac{\rho_{cAUT} + 1}{\rho_{cAUT} - 1} \quad (25)$$

and

$$\tau_{AUT} = \delta_{cAUT}/2. \quad (26)$$

## RESULTS

Frequency in MHz	AUT Measured by the Three Antenna Method		AUT Measured by the Fast Polarization Method	
	Axial Ratio in dB	Tilt Angle in Degrees	Axial Ratio in dB	Tilt Angle in Degrees
14000	23.16	.92	23.12	.86
14200	23.58	.14	23.52	.40
14400	23.78	.76	23.98	.90
14600	23.61	.15	23.46	.49
14800	23.55	.42	23.50	.58
15000	24.48	.45	24.50	.68
15200	23.08	.24	23.50	.65
15400	24.63	.10	24.34	.54
15600	24.69	.59	24.92	.69
15800	24.00	-.13	23.81	.14
16000	25.82	.35	25.37	.69

## CONCLUSIONS

A technique for making fast multi-frequency polarization measurements has been presented. The technique allows the capability of making polarization measurements at any particular orientation of the AUT since it is not necessary that it rotate about the range axis or line of sight between the two antennas. This is made possible due to the use of a dual polarized transmit antenna which can be electrically switched very rapidly. The calibration procedure is performed once for the range. This data can be used many times as long as the basic measurement configuration is maintained. This technique has been used to acquire polarization data at a rate of over 25 frequencies per second. The AUT can be moved in a raster scan fashion and the polarization coefficient can be obtained over the complete pattern at many frequencies.

The accuracy of this technique results from calibrating each port of the system together. Once the polarization of a standard is obtained, the sampling antenna and the range are calibrated together.

## REFERENCES

1. Unpublished notes by J. Searcy Hollis and Raymon A. Heaton, Scientific-Atlanta, Inc., Instrumentation Division
2. IEEE Standard Test Procedures for Antennas, ANSI/IEEE Std 149-1979

