# A New Real-Time Six-Port A N A Method

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ABSTRACT

A method for real-time six-port automatic network analyzer (ANA) measurements based on the use of a pre-calculated six-port chart is developed. It is shown that a swept frequency generator can be used to read the module and/or phase of the reflection coefficient (Γ) on a computer screen at sweep rates of up to 75 Hz. The test band is determined by the six-port design, typically 9:1, the accuracy of measurement is dependent on the swept frequency interval and on the six-port circuit design.

## INTRODUCTION

Six-port automatic network analyzers [1,2,3] measure the reflection coefficient, Γ, using four power detectors, that give:

$$P_3 = |aA + bB|^2 \quad (1)$$
$$P_4 = |aC + bD|^2 \quad (2)$$
$$P_5 = |aE + bF|^2 \quad (3)$$
$$P_6 = |aG + bH|^2 \quad (4)$$

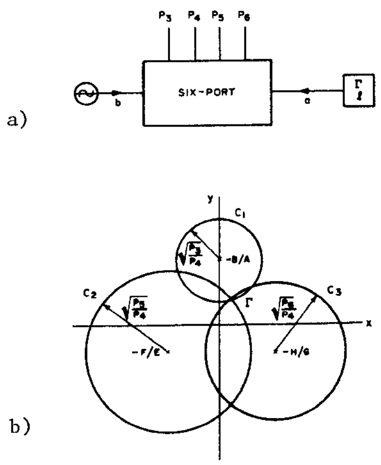
where a, b are the reflected and incident wave (Γ = a/b), and A,B...H are complex constants of the six-port design.

For an ideal six-port, C=0, and the ratios -B/A, -F/E and -H/G all have the same module (.5 to 1.5), and a phase difference of 120°. The reflection coefficient, Γ, is then calculated as the intersection of three circles with centers in the Γ plane, given by -B/A,-F/E and -H/G (Fig. 1a&b).

In practice, a six-port is more easily realized with standard components, such that |B/A| = √2, |F/E| = |H/G| = 2, with a phase difference of 135°-135° and 90° [4].

Moreover, experimental measurements have shown that the six-port constants, A,B...H, diverge from design objectives and vary with frequency. Thus, precise evaluation of Γ requires a careful calibration procedure at a given set of frequency points. For this reason, six-port measurements are normally done at discrete frequency points and this excludes continuous swept frequency measurements. Swept frequency measurements are very useful in experimental development work, where it is often necessary to visualize the phase and amplitude of Γ in real-time over a given bandwidth, say $f_1$ to $f_2$.

Engen has already referred to the possibility of using analog signals, corresponding to the power readings, in order to display on an oscilloscope screen the module and phase of Γ, as a function of frequency [4]. However, the method requires the transmission of weak analog signals, specific and predetermined values of A,B...H, and a constant incident power level; these conditions tend to reduce the accuracy and reliability of the measurements.




1.a) A six-port network analyzer gives four output power readings as a function of both module and phase of Γ. where Γ = x + j y .
1.b) The reflection coefficient, Γ, is calculated as the intersection of three circles in the Γ plane.



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In this paper, we derive a six-port amplitude chart (SPAC) to measure the module of $\Gamma$, and a six-port phase chart (SPPC) to measure the phase of $\Gamma$. Both charts may be separetely displayed or superimposed on a computer screen along with the measured phase and amplitude response of $\Gamma$, over a given bandwidth, $f_1$ to $f_2$. The power readings are digitized at the six-port and transmitted to the computer via a IEEE 488 bus.

Both six-port charts (SPAC and SPPC) are derived from calibration measurements taken at a number of frequencies within the bandwidth of the six-port: this information is stored in the computer data bank for later use. In a given frequency band, the SPAC and the SPPC are generated on the computer screen from the stored calibration data for the chosen swept frequency interval ($f_1$ to $f_2$). At first, a single frequency sweep may be obtained across the full test band at reduced accuracy using an average SPAC and SPPC across the band. Then the swept frequency interval $f_1$-$f_2$ is reduced to a predetermined value and the base band frequency $f_1$ is manually scanned across the full test band for increased accuracy of measurement.

## THEORY

For six-port network analyzers, the power ratios $P_3/P_4$, $P_5/P_4$ and $P_6/P_4$ are respectively given by:

$$\frac{P_3}{P_4} = \left|\frac{A\Gamma + B}{C\Gamma + D}\right|^2 \qquad (5)$$

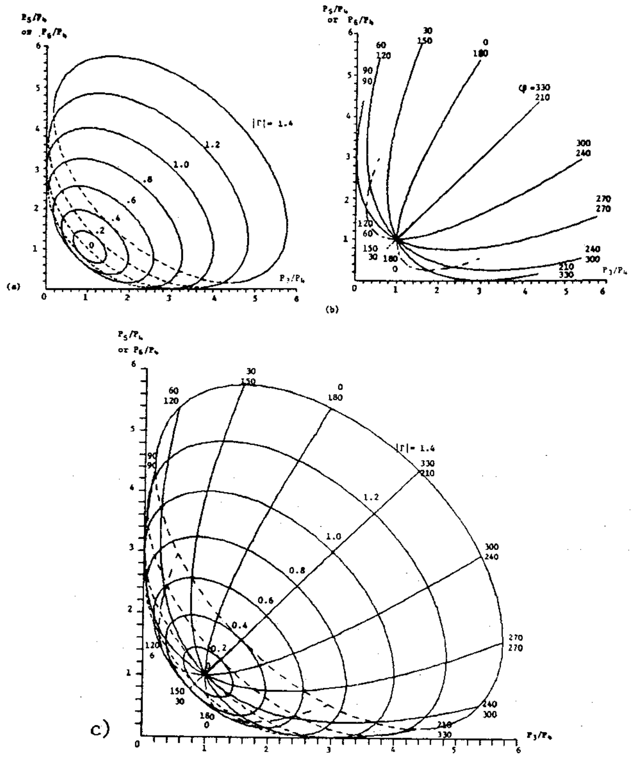
$$\frac{P_5}{P_4} = \left|\frac{E\Gamma + F}{C\Gamma + D}\right|^2 \qquad (6)$$

$$\frac{P_6}{P_4} = \left|\frac{G\Gamma + H}{C\Gamma + D}\right|^2 \qquad (7)$$

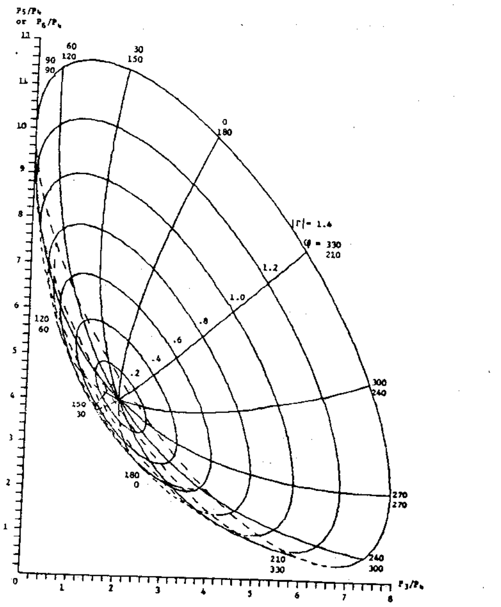
It's possible, using equations (5), (6) and (7), with calibrated values of A,B...H, to calculate loci of constant module and phase of $\Gamma$, as a function of the power ratios $P_3/P_4$, $P_5/P_4$ and $P_6/P_4$.

Figures 2a&b show this chart for an ideal 120° distribution where
$C = 0$, $|A|^2 = |D|^2 = |E|^2 = |G|^2$,
$-B/A = 1\angle 90°$, $-F/E = 1\angle 210°$ and $-H/G = 1\angle 330°$.
Superimposed SPAC and SPPC are shown in Fig. 2c for the above case. Similar charts are obtained for 135°-135°-90° distribution where
$-B/A = \sqrt{2}\angle 90°$, $-F/E = 2\angle 225°$ and $-H/G = +2\angle 315°$
as seen in Fig 3.

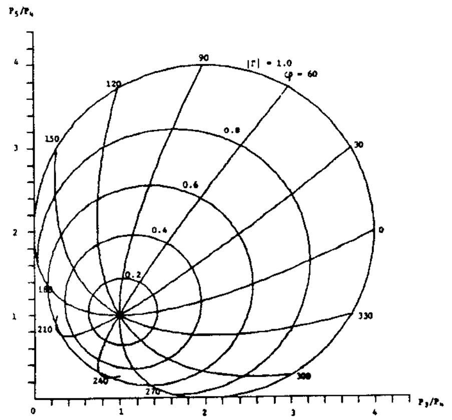
The approach is equally applicable to five-port systems [6,7] as shown in Fig. 4. In this case, it has been assumed,
$C=0$. $-B/A = -1$ and $-F/E = -j$.



2.a) A SPAC showing locus of constant module of $\Gamma$, for a six-port assuming ideal 120° distribution.
2.b) A SPPC showing locus of constant phase (in degrees) of $\Gamma$, for a six-port assuming 120° distribution.
2.c) Superimposed SPAC and SPPC showing locus of constant module and phase (in degrees) of $\Gamma$, for a six-port assuming ideal 120° distribution.



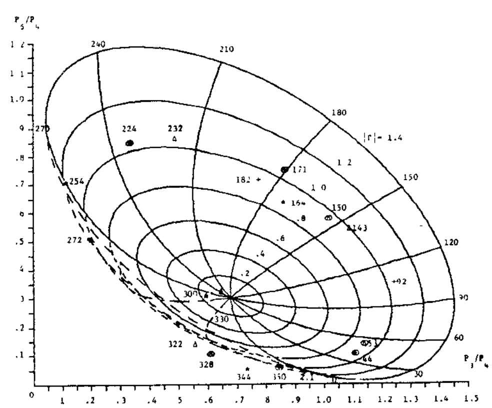
3. Superimposed SPAC and SPPC for a six-port assuming common 135°-135°-90° distribution.



4. A five-port superimposed SPAC and SPPC chart assuming a 90° separation between the two circle centers.

EXPERIMENTAL RESULTS

An ideal 120° six-port designed in our laboratory [3] using microwave integrated technology has been measured in the interval 2-4 GHz. A six-port chart (for $P_3/P_4$ and $P_5/P_4$) at 3 GHz is given in Fig. 5, with $|A/C|^2=8.22$, $|E/C|^2=3.40$, $|G/C|^2= 5.21$ $-D/C = 6.06\angle 3°$, $-B/A = 1.74\angle 3°$, $-F/E = 1.80\angle 265°$, $-H/G = 1.43\angle 90°$.



5. A SPAC and SPPC chart at 3 GHz with actual values of A,B...H as measured from an actual 120° six-port design [3]. Experimental measurements done at 3 GHz (+), 2.9 GHz (*) ($\varphi_{off}$ = 52°) and 3.1 GHz (Δ) ($\varphi_{off}$ = 21°) are shown. Encercled data points near $|\Gamma| = 1$ correspond to fixed short and open circuit, and the non-circled data corresponds to a sliding short. For the test data near $|\Gamma| = 0$ the three experimental points correspond to a matched load condition.

Measurement of $\Gamma$ for some loads (matched load, open short, fixed short, sliding short at four different positions) are also shown. Similar measurements were repeated at f = 2.9 GHz and f = 3.1 GHz . As expected, the error is negligeable at f = 3 GHz. However at 2.9 and 3.1 GHz the data points for short circuit, open circuit, matched load and sliding short conditions are seen in Fig. 5 to produce the following average errors:
$\Delta|\Gamma| = .07$ and $\Delta\varphi = 10°$ ,
where an offset phase $\varphi_{off}$ is taken into account at $f_1$. The repetitive accuracy of amplitude and phase measurements are in this case less than 10% and 5%.

The offset phase $\varphi_{off}$ is known and it can be displayed on the screen in numerical form for any given frequency interval, $f_1 - f_2$.

CONCLUSION

A six-port amplitude chart (SPAC) and a six-port phase chart (SPPC) displayed on a computer screen can be used with good accuracy for swept frequency measurements of the module and phase of the reflection coefficient of a device under test (DUT). It is found that the accuracy of the phase and amplitude measurements depend on the swept frequency interval. The accuracy is sufficiently good to allow experimental optimization of DUT performance using a swept frequency test mode. The same apparatus may then be used at single frequency points to obtain the usual six-port accuracy.

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