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Novel Approach for Wideband VNA by Sixport Principle

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Abstract**—** Paper presents simple sixport principle and its frequency bandwidth. The novel multisixport approach is presented with its possibilities, typical parameters and frequency bandwidth. Practical implementation is shown with its measurement parameters and calibration. The bandwidth circa 1:100 is obtained.

Keywords**—** microwave measurement, sixport, VNA, wideband.

I. Introduction

VECTOR microwave measurement is necessary in a lot of cases. The problem is that the classical vector network analyzer (VNA) is very expensive. In presented work there is showed design of simple six-port, which served as test bed for acquisition system and following computation programs. Next part of the paper describes the modification of the simple system towards wideband operation from the principle to the realization results.

II. Basic principle

In the 1970th there was published the principle of the measurement method by G.F. Engen [1]. Port 1 is connected to the microwave generator (Fig.1.), to the port 2 is connected the unknown impedance. On the ports 3 to 6 there are measured the incidental powers with preferable diode detectors.

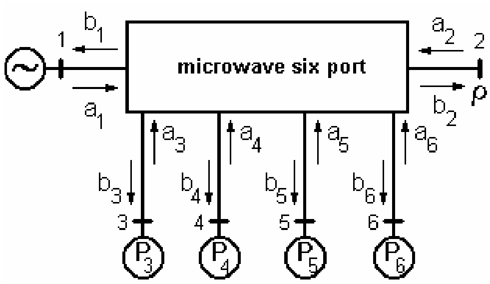

Fig. 1. Basic arrangement of the six-port.

For the practical reasons, the whole measurement has to be done relatively to the power on the port 1. There has to be measured one power from generator only, not reflected power from the unknown terminator. Then it is possible to describe the sixport by the formulas, from [1]. The geometrical interpretation is shown in Fig.2. Position of detectors in the sixport is described by distance of points q from the center of the impedance plane and by angle between the q points. Measured powers at respective ports are represented by the circles with the centers at q points. From the Fig.2 and also from practical experiences of other builders of six-port, the most important condition has to be fulfilled. The centers of circles have to be separated by minimum angle around 15°. The numerical results are not accurate and stable with smaller angle. The distance of q points from the center of impedance plane have to be set carefully too. The optimum distance is frequently used 1.5.

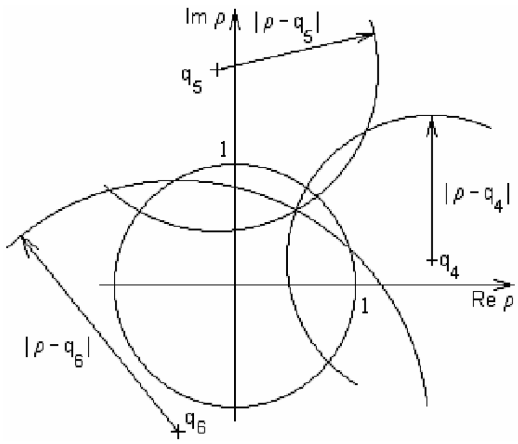

Fig. 2. Geometrical interpretation of the formulas in [1].

The simplest sixport configuration is presented in Fig.3. From the left there is a resistive bridge for obtaining reference port of signal from generator to port 2. Transmission lines between the ports 3, 4 and 5 are producing the desired phase shifts. Attenuator is situated between port 5 and output port. Output port is determined for connecting unknown impedance. The attenuator reduces slightly the influence of connected impedances and also secures the distance from center of impedance plane circa 1.5.

The main parameters are evident. Transmission loss through six-port from generator to measuring port is around 8.5 dB. The biggest influence on this value is from the resistive bridge which has 6 dB losses. At the frequency range

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below 2 GHz the resistive bridge can be replaced with lumped element directional couplers from Mini-Circuits [2] and the overall transmission loss would be then greatly reduced. The frequency band, in which the sixport is working, is determined by the length of the transmission lines and the minimum angle α_{min} which is necessary. It is possible to state:

$$\alpha_{max} = 180 - \alpha_{min} / 2 \quad (1)$$

After that, the frequency band ratio can be obtained:

$$\frac{f_{max}}{f_{min}} = \frac{\alpha_{max}}{\alpha_{min}} = \frac{180 - \alpha_{min} / 2}{\alpha_{min}} = \frac{180}{\alpha_{min}} - \frac{1}{2} \quad (2)$$

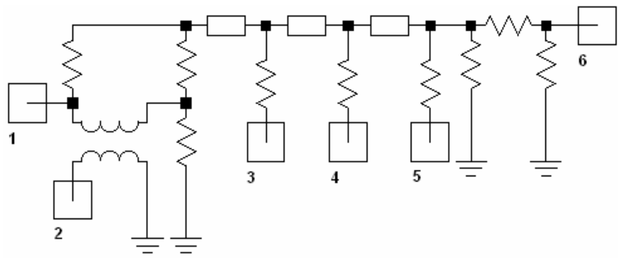

Fig. 3. Design of the simple six-port.

The results of the equation (2) are given in Fig.5. There are two important points in the figure. Firstly, the maximum possible separation angle is 120°. Secondly, the bandwidth ratio is 11.5:1 for 15° of separation angle. Practical measurement bandwidth is between these two extreme points depending on required accuracy and used calibration methods.

III. Wideband possibilities

There were constructed sixport systems with the modified resistive bridges for the wider obtained bandwidth, published in [3]. This designed system provides very wide bandwidth ratio up to three decades. But there are problems with resistive connections which provide transmission losses circa 20dB and more. The design of these systems is also impossible for frequencies above 2 GHz.

IV. Theory of Operation for Proposed System

Sixport for wider frequency area could be designed by using more simple designs from Fig.3 set in cascade. The advantage is that the design contains only one resistive bridge for generator power sensing. There is necessary to measure power at 7 ports with two sixports in cascade, but only 4 of them are valid for one frequency at the same time. The new proposition is, to use such a system, where multisixport configuration occurs. The fifth port can be added to the simple six port configuration from Fig.3. Data from the added detector will be used, when the signals from some pair of detectors will be under α_{min}. Further using of such a system leads to a multisixport measurement setup, with more than one sixport valid in time. That approach can be used for measurement precision improvement. General multisixport contains n detectors sensing for signal from output. Three of them are necessary for one sixport. This leads to several combinations of sixports in multisixport:

$$C_n^3 = \frac{n!}{3!(n-3)!} = \frac{n!}{6(n-3)!} \quad (3)$$

The numbers 4, 10, 20 and 35 are the results for number n equal to 4, 5, 6 and 7 detectors. There are several problems, which appeared during the design of the multisixport, like high number of sixports inside, difficult description of the system with the changing of angles with frequency. For optimization of these problems is very effective to use numerical methods.

V. Simulation Results

Firstly there is necessary to construct the goal function for the sixport system. Main significance in goal function is given to the frequency range where condition for α_{min} is fulfilled. Smaller significance is then given to the number of valid sixports in the frequency range.

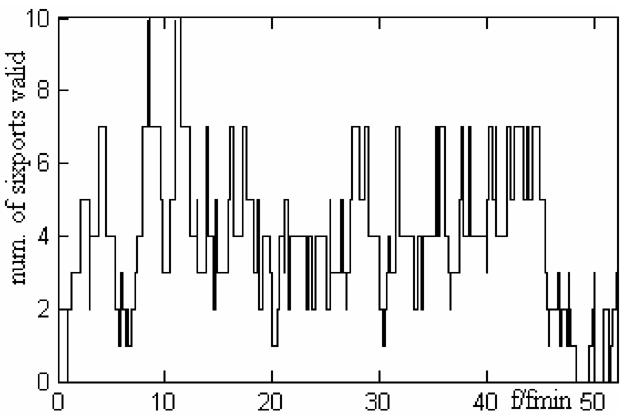

Fig. 4. Example of the multisixport computed for n=5 and α_{min}=45°.

The frequency sweep of the results for the computed multisixport is given in Fig.4. Obtained frequency bandwidth is 1:48.3 for given input parameters. There were tested methods of steepest descent and polytop optimization without success for the optimization. Modified steepest descent optimization for this specific problem showed some possibilities, but only around optimum. Good results were obtained with Genetical Optimization (GO) and best with the Particle Swarm Optimization method (PSO) from [4]. However are the results from GO and PSO comparable, the GO is more time-consuming which means that for the similar result is necessary to compute more generations. There was computed multitude of simulations for given α_{min} and n and the results are given in Fig.5. There are compared cascade of simple sixports with proposed multisixport system in frequency bandwidth for given α_{min}. Fig.4 and 5 show the big potential of the multisixport method in the frequency bandwidth area and precision advancement. This is done by more valid sixports on each frequency.

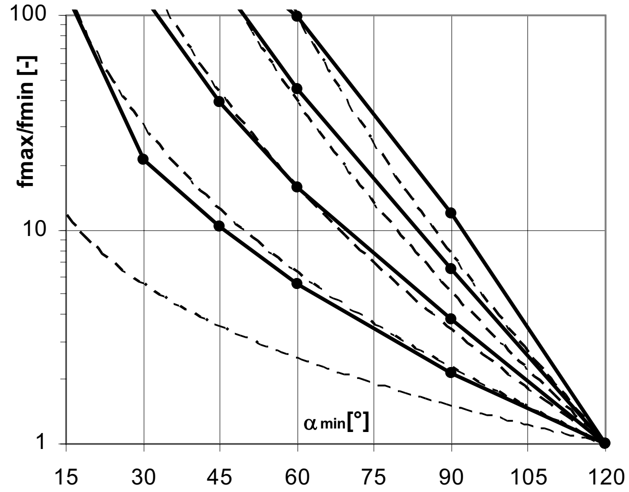

Fig. 5. Frequency bandwidth for simple sixport (lowest) and its cascades (2, 3, 4, 5) - dashed lines; multisixports with 4, 5, 6 and 7 detectors with transmission lines between them - solid lines.

VI. HARDWARE DESIGN CONSIDERATIONS

In the realization of the multisixport hardware technique, there it is necessary to count with material specific problems such as frequency dependent permittivity, dispersion and accuracy of manufacturing. The necessary hardware for evaluation of multisixport method was built for the frequency range from 50MHz to 2000 MHz with the 6 detectors, 35 sixports inside and α_{min}=45°. Acquisition circuits and software are already finished also. Instead of resistive bridge, there was used the lumped element directional coupler from Mini-Circuits [5]. Such a solution greatly reduces losses in the measurement system but it is available for this frequency band only. For higher frequencies it is necessary to use the bridge.

VII. PRACTICAL RESULTS

In order to make the multisixport system working, there it necessary to do a lot of software steps. At first, the detectors need to be calibrated, this is done by generator and its integrated attenuator. Points obtained are then interpolated with 6th order polynomial. Calibration of every sixport is done according to equations:

$$\sum_{i=1}^{4} F_i \cdot P_i - r \cdot \sum_{i=1}^{3} H_i \cdot P_i = r \cdot P_4 \qquad (4)$$

$$\sum_{i=1}^{4} G_i \cdot P_i - x \cdot \sum_{i=1}^{3} H_i \cdot P_i = x \cdot P_4 \; . \qquad (5)$$

So for calibration it is necessary to use 7 known impedances, in our case we used open, short, matched, inductor 12nH, capacitor 4.7pF and two resistors 15Ω and 150Ω. From (4) and (5) we calculated calibration coefficients for every sixport and whole frequency band. Of course not all calibration got us successful results due to the α variations, as described above. Visualization of the testing measurement for 8.2Ω impedance with 36cm semirigid cable can be seen in Fig.6. As can be seen, the results are very wide distributed in amplitude and less in the phase.

To select the actual properly working sixports on respective frequency there are two possibilities, first use the info from calculation of multisixport in the design stage, second possibility is, to use numerical approach

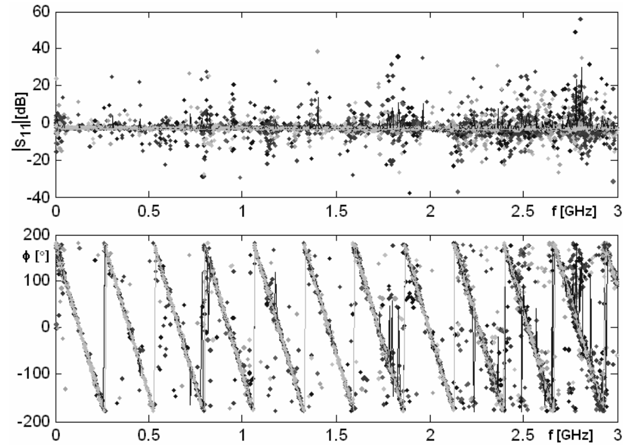

Fig.6. Measurement of 8.2Ω with 36cm cable, results from all of the sixports.

for selection of likely good results. We have used the latter. In the Fig.6 can be seen, that the right results are concentrated and evidently bad results are far from good results. We use function, which repeatedly calculates main value and distance of every point from it. The point with greatest distance is discarded and loop continues to get predefined number of points left.

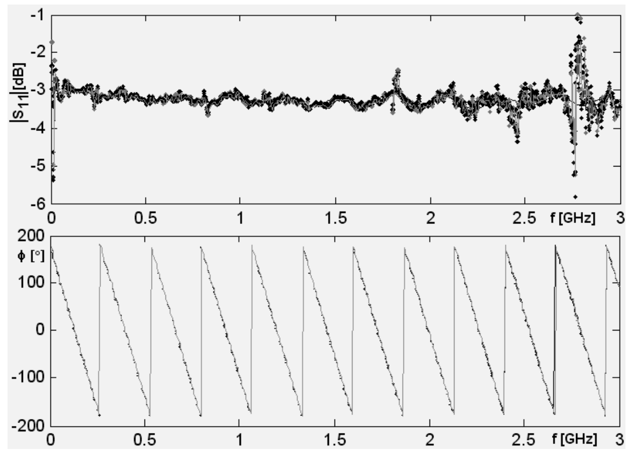

Fig.7. Measurement of 8.2Ω with 36cm cable, results from the selection of the sixports.

As can be seen in the Fig.7, the method is very successful even if actually does not knows anything about the measured impedance itself. Precision of measurement can be seen from Fig.8, where the error from the correct value of amplitude and phase is depicted. Typical values are amplitude error circa ±0.2 dB with some peaks exceeding that value and ±1 degree in phase. Phase error rise with frequency indicates probably problem of proper connection of connectors. In the Fig.9 there is shown the hardware realization of the multisixport on the PCB. To the multisixport it is attached the board of amplifiers to match the signal level from detectors to AD converters.

Program control in the PC is done in the Agilent VEE Pro design environment and the calibrations are calculated in the Matlab.

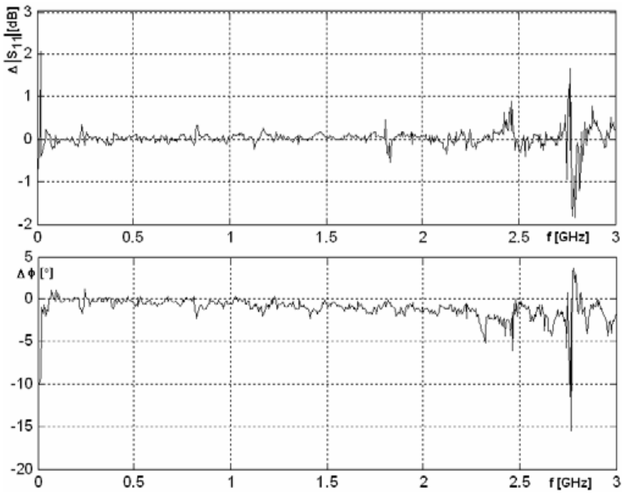

Fig.8. Measurement error in amplitude and phase for 8.2Ω with 36cm cable.

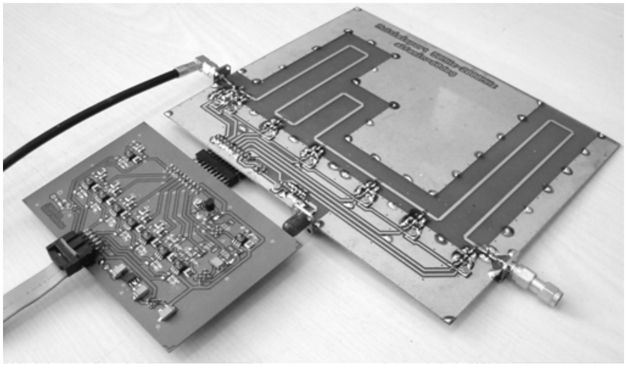

Fig.9. Multisixport measurement PCB with amplifier board attached.

VIII. Conclusion

The principle of simple operation sixport was described in the paper. There was shown a new approach for multisixport theory and its computation. Fig.4 presents advantages of the multisixport against the simple sixport cascade evaluation. Multisixport design offers more flexibility in the desired parameters which leads to wider frequency bandwidth available or more accurate measurement. The multisixport system was designed and realized for the frequency band 50MHz to 2000MHz and the calibration approach was described. At last the test measurement was shown, with the typical erros±1 degree and ±0.2 dB. Next work will be in the dynamic range improvements and building real microwave multisixport reaching above 10GHz.

References

[1] Engen, G. F.: Determination of Microwave Phase and Amplitude from Power Measurements. *IEEE Trans. Instrum. Meas.,* vol. IM-25, PP. 414-418, Dec. 1976.

[2] Directional Couplers for SMT. Mini-Circuits, http://www.minicircuits.com/dg03-186.pdf, 2005

[3] Hesselbarth, J.; Wiedmann, F., Huyart, B.: Two New Six-Port Reflectometers Covering Very Large Bandwidths. *IEEE Transactions on Instrumentation and Measurement*, Vol. 46, No. 4, August 1997

[4] Robinson, J., Rahmat-Samyi, Y.: Particle Swarm Optimisation in Electromagnetics. *IEEE Transactions on Antennas and Propagation,* Vol. 52, No. 2, February 2004

[5] Directional Couplers for SMT. Mini-Circuits, http://www.minicircuits.com/dg03-186.pdf, 2005