# INTRODUCTION

LRR- LINE REFLECT REFLECT is a new self-calibration procedure for the calibration of vector network analyzers (VNA). VNA measure the complex transmission and reflection characteristics of microwave devices. The analyzers have to be calibrated in order to eliminate systematic errors from the measurement results.

The LRR calibration circuits consist of partly unknown standards, where L symbolizes a line element and R represents a symmetrical reflection standard. The calibration circuits are all of equal mechanical length. The obstacle, a symmetrical-reciprocal network is placed at three consecutive positions. The network consists of reflections, which might show a transmission. The calibration structures can be realized very easily as etched structures in microstrip technology.

During the calibration [G], [H], which represents the systematic errors of the VNA is eliminated in order to determine the unknown line and obstacle parameters.

# MICROWAVE DEVICES

Microwave devices are devices operating with a signal frequency range of 1-300GHz. A microwave circuit ordinarily consists of several microwave devices connected in some way to achieve the desired transmission of a microwave signal.

The various microwave solid state devices are,

* ***Tunnel diodes***

These are also known as Esaki diodes. It is a specially made PN junction device which exhibits negative resistance over part of the forward bias characteristic. Both the P and the N regions are heavily doped. The tunneling effect is a majority carrier effect and is very fast. It is useful for oscillation and amplification purposes. Because of the thin junction and shot transit time, it is useful for microwave applications in fast switching circuits.

* ***Transferred electron devices***

These are all two terminal negative resistance solid state devices which has no PN junction. Gunn diode is one of the transferred electron devices and which works with the principle that there will be periodic fluctuations in the current passing through an n-type GaAs substrate when the applied voltage increases a critical value i.e. 2-4Kv/cm.

****Avalanche transit-time devices***

These are used for amplification purposes. And the basic principle is the voltage breakdown at the reverse biased PN junction with the supply of electrons and holes.

These microwave solid state devices are used for generation and amplification of microwave signals by means of velocity-modulation theory. The interconnection of two or more microwave devices is regarded as a microwave junction. From the network theory a two-port device can be described by a number of parameter sets, such as the H, Y, Z and ABCD. All these network parameters relate total voltages and total currents at each of the two ports. If the frequencies are in the microwave range, the two port network representation is as shown in FIG: 1.

The logical variables are traveling waves rather than total voltages and total currents. These are S-parameters, which are expressed as

$b1 = S11a1 + S12a2$

$b2 = S21a1 + S22a2$

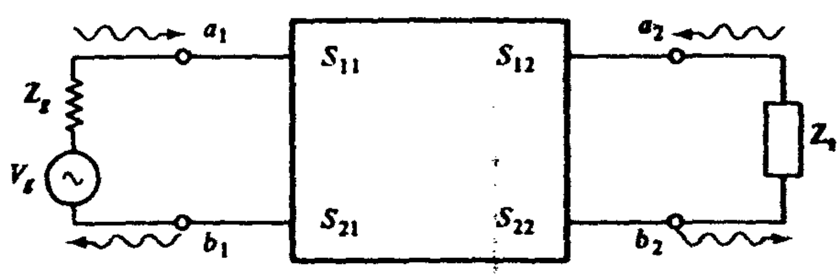



FIG: 1 A two port network.

A typical microwave system usually consists of a transmitter subsystem, including a microwave oscillator, waveguides, and a transmitting antenna, and a receiver subsystem that includes a receiving antenna, transmission line or waveguide, a microwave amplifier, a receiver.

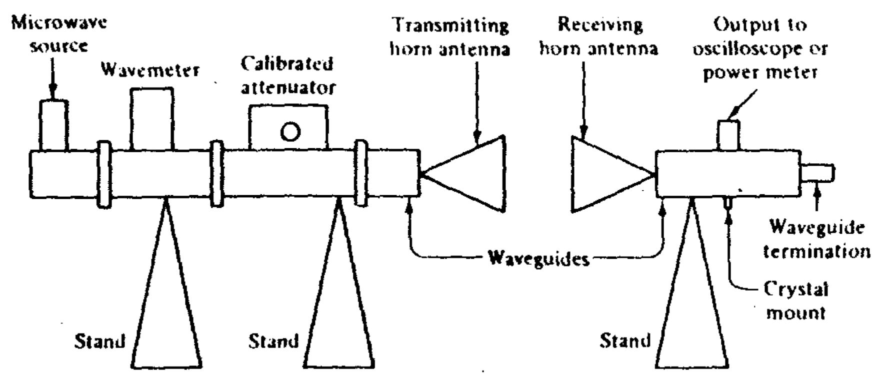



FIG: 2 A microwave system.

# VECTOR NETWORK ANALYZERS

It measures the complex transmission and reflection characteristics of microwave devices. This is achieved by comparing the signal input to the device, with the signal either transmitted through or reflected back from the device. They incorporate very narrow bandwidth receivers tuned to the signal source frequency and give a direct readout of the four coefficients contained in a scattering matrix-the scattering or ‘s’ parameters, each of which has magnitude and phase elements. The network analyzer was controlled by an external personal computer. The raw measurement data have been read out and processed on a computer.

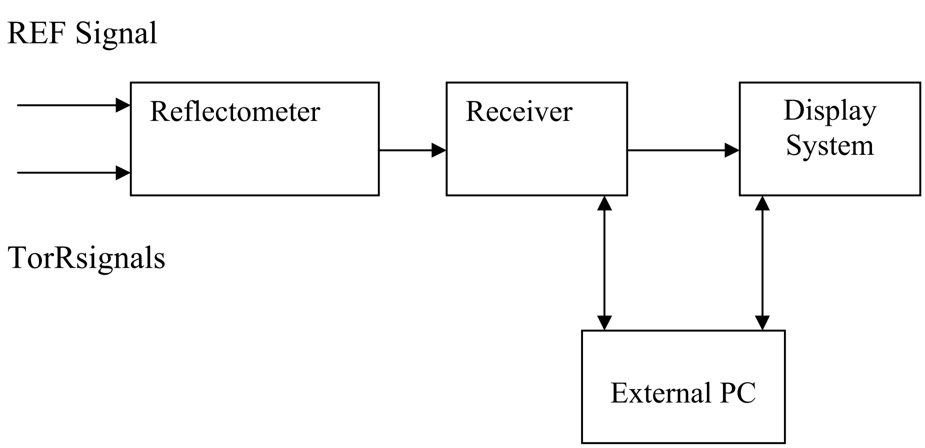
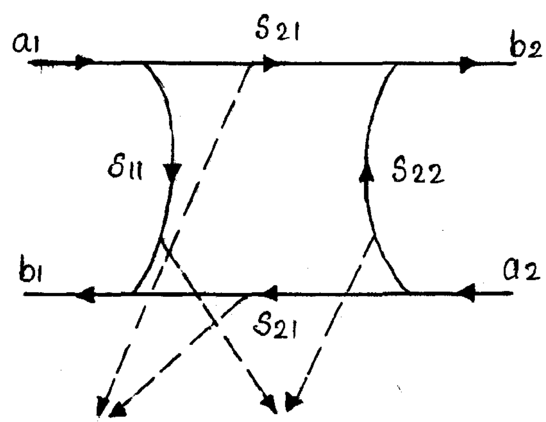



FIG: 3 The VNA system




Transmission Reflection

FIG: 4 S-parameter model for a two port linear network

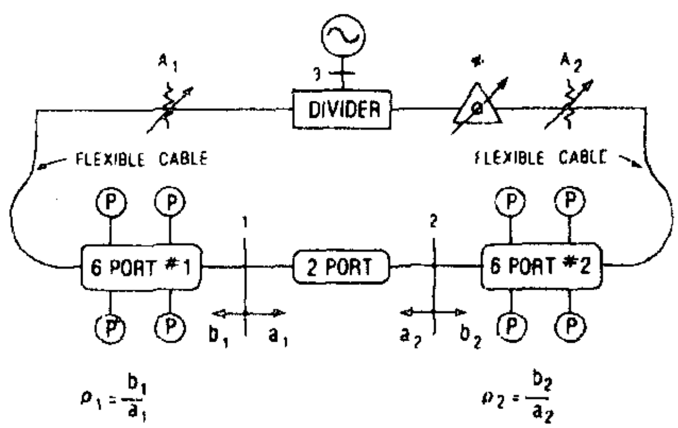



FIG: 5 Block diagram of a dual six-port automatic network analyzer.

P indicates power detector. The network parameters of a two-port device are measured by inserting the two six-port between the two six-port reflectometers.

# DESCRIPTION OF LRR TECHNIQUE

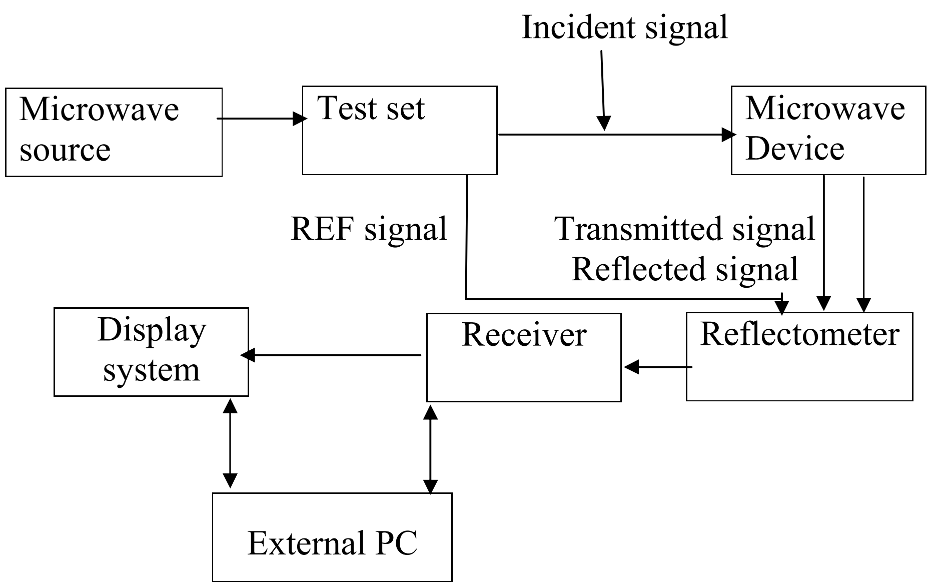



FIG: 6 Overall system block diagram:

The calibration circuits of the LRR method consists of,

- Line elements of mechanical length, l and
- A symmetrical, reciprocal network i.e. an obstacle network placed at three consecutive positions.

Two LRR procedures are,

- LRR method without transmission

- LRR method with a weak transmission

## LRR METHOD WITHOUT TRANSMISSION

The calibration circuits can be described with the help of the line parameter k, a reflection coefficient , and wave parameters(s- parameters) a1,i, …….a4,i and b1,i,…….b4,i, i=1,2,3 , which are set according to the setup shown below.

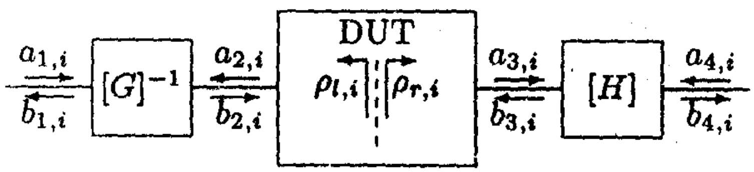



FIG: 7 Simplified block diagram of analyzer setup.

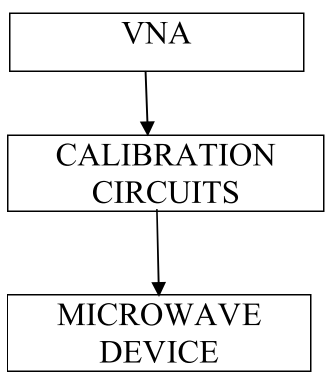



FIG: 8 General representation

Within the self calibration procedure the reflection coefficient ζ, and the line parameter k are determined. Suppose, the error two-port [G]-1 is described by the following equation with, $\left[\bar{G}\right] = [G]^{-1}$

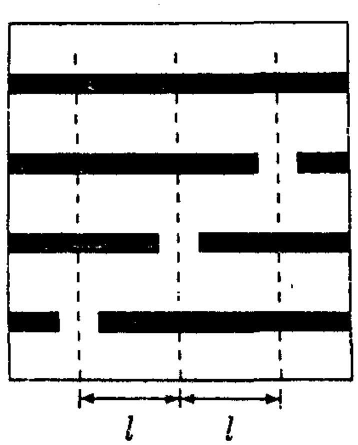
$$\begin{bmatrix} b_{1,i} \\ a_{1,i} \end{bmatrix} = \left[\bar{G}\right] \begin{bmatrix} \zeta_{l,i} \times b_{2,i} \\ b_{2,i} \end{bmatrix}$$

Resulting in a bilinear relation,

$$V_{l,i} = \frac{\bar{G}_{11}\,\zeta_{l,i} + \bar{G}_{12}}{\bar{G}_{21}\,\zeta_{l,i} + \bar{G}_{22}}$$

Concerning the Two-port [H], a similar equation can be found as,

$$\begin{bmatrix} a_{4,i} \\ b_{4,i} \end{bmatrix} = [H]^{-1} \begin{bmatrix} b_{3,i} \\ \zeta_{r,i} \times b_{3,i} \end{bmatrix}$$




$$[M_0] = [G]^{-1}[L][L][H]$$

$$a_{2,1} = k^4 \rho b_{2,1},\ a_{3,1} = \rho b_{3,1}$$

$$a_{2,2} = k^2 \rho b_{2,2},\ a_{3,2} = k^2 \rho b_{3,2}$$

$$a_{2,3} = \rho b_{2,3},\ a_{3,3} = k^4 \rho b_{3,3}$$

FIG: 9 LRR calibration structures in microstrip technology.

Considering the first structure the equation can be rewritten as follows,

$$[M_0]\begin{bmatrix} a_{4,i} \\ b_{4,i} \end{bmatrix} = \begin{bmatrix} \bar{G} \end{bmatrix}\begin{bmatrix} K^2 b_{3,i} \\ \zeta_{r,i} K^{-2} b_{3,i} \end{bmatrix}$$

So that another bilinear relation results

$$V_{r,i} = \frac{\bar{G}_{11}\,\zeta_{r,i} + \bar{G}_{12}}{\bar{G}_{21}\,\zeta_{rl,i} + \bar{G}_{22}}$$

The reflection coefficients of the different structures can be related to the measurement values Vl,i and Vr,i with

$$\zeta_{l,I} = K^4 \zeta \Rightarrow V_{l,1}$$
$$\zeta_{l,2} = K^2 \zeta \Rightarrow V_{l,2}$$
$$\zeta_{l,3} = \zeta \Rightarrow V_{l,3}$$
$$\zeta_{r,1} = K^4 \zeta^{-1} \Rightarrow V_{r,1}$$
$$\zeta_{r,2} = K^2 \zeta^{-1} \Rightarrow V_{r,2}$$
$$\zeta_{r,3} = \zeta^{-1} \Rightarrow V_{r,3}$$

On the basis of the measurement of four reflection coefficients the unknown error two port parameters can be eliminated. This can be performed with the help of the cross ratio,

((y1-y2)*(y3-y4)) / ((y1-y4)*(y3-y2)) =

((x1-x2)*(x3-x4) / (( x1-x4)*(x3-x2)

which generally holds for a bilinear transformation also known as Mobius transformation of two variables xi and yi, with i=1,….4 and the constants C1…C4.

$$X_i = (C_1 \cdot y_i + C_2) / (C_3 \cdot y_i + C_4)$$

In this way, a set of equations can be constructed, which only depends on the unknown reflection coefficient ζ and the unknown line parameters K in dependence of the measurement values $V_{l,i}$ and $V_{r,i}$.

The line parameter and the reflection coefficient are thus calculable. This solution is based on the representation of the obstacle networks show no transmission.

The LRR calibration with an unknown obstacle on a planar microwave substrate is shown below.

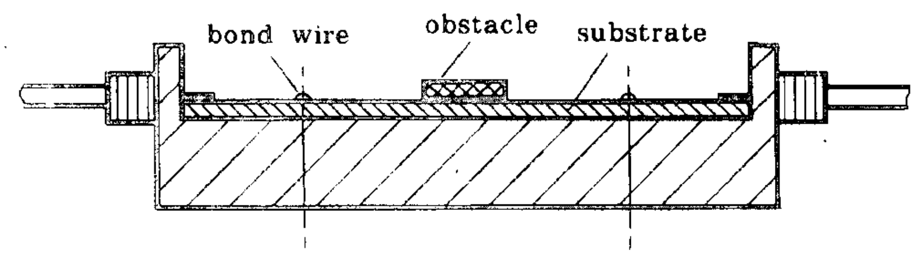



FIG: 10 LRR calibrations on a microwave substrate.

# LRR METHOD WITH A WEAK TRANSMISSION

This algorithm is based on the representation of the obstacle networks with pseudo transmission matrices. As the obstacles might also be realized as pure reflections, the networks cannot be described with transmission matrices, because in this representation a factor Δmi might become zero. The measurement matrix,

$$[M_i] = \begin{bmatrix} b'_{1,i} & b''_{1,i} \\ a'_{1,i} & a''_{1,i} \end{bmatrix} \frac{1}{a'_{4,i}\, b''_{4,i} - a''_{4,i}\, b'_{4,i}} \begin{bmatrix} b''_{4,i} & -a''_{4,i} \\ -b'_{4,i} & a'_{4,i} \end{bmatrix}$$

Where the primes indicate from which side of the setup the generator signal is fed. By multiplying the measurement matrices with the factor Δmi, the pseudo transmission matrices [Qi] result

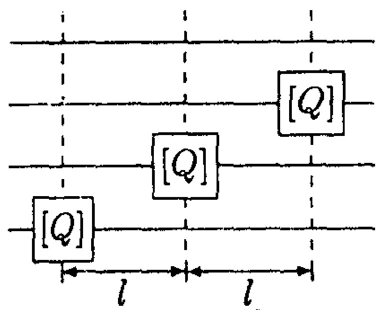
$$\left[\bar{Q}_i\right] = \frac{1}{\mu_{f,i}} \begin{bmatrix} \mu_{f,i}\, \mu_{r,i} - \zeta^2 & \zeta \\ -\zeta & 1 \end{bmatrix}$$

The transmission characteristics in forward and reverse direction are described by μf,i and μr,i. These values are related to the scattering parameters of the obstacle as follows:

μf,i = S21,i /Δmi and

μr,I =S12,i * Δmi, taking into account the reciprocity of the obstacle.

In order to determine the unknown obstacle and line parameters, the obstacle networks are positioned as depicted in FIG: 9 & FIG: 11 respectively. Considering the setup shown below various pseudo transmission matrices can be constructed with measurement matrices.




$$[M_0] = [G]^{-1}[L][L][H]$$
$$[M_1] = [G]^{-1}[L][L][Q][H]$$
$$[M_2] = [G]^{-1}[L][Q][L][H]$$
$$[M_3] = [G]^{-1}[Q][L][L][H]$$

FIG: 11 Calibration structures with a weak transmission.

On the basis of this representation certain trace relations can be evaluated and then can be transformed into a set of nonlinear equations and the unknown parameters can be determined. An approximate knowledge of the circuits' dimensions is necessary in order to choose the correct solutions.

# MICROSTRIP LINES

Prior to 1965 nearly all microwave equipment utilized coaxial, waveguide, or parallel strip-line circuits. In recent years microstrip lines have been used extensively because they provide one free and accessible surface on which solid state devices can be placed. It is an unsymmetrical stripline, that is a parallel plate transmission line having dielectric substrate, one face of which is metalised ground and the other(top) face has a thin conducting strip of certain width 'w' and thickness 't'. Sometimes a coverplate is used for shielding purposes but it is kept much farther away than the ground plane so as not to affect the microstrip field lines. It is also called an open strip line. Modes on microstrip are only quasi transverse electromagnetic (TEM). Thus the theory of Tem- coupled lines applies only approximately.

Microstrip transmission lines consisting of a conductive ribbon attached to a dielectric sheet with conductive backing are widely used in microwave technology. Because such lines are easily fabricated by printed-circuit manufacturing techniques, they have a technical merit. Most microstrip lines are made from boards of copper with a thickness of 1.4 or 2.8 mils. Line width of less than 0.1 is uncommon.

There are various types of microstrip lines,

*Embedded microstrip lines.

*Standard inverted microstrip lines.

*Suspended microstrip lines.

*Slotted transmission lines.

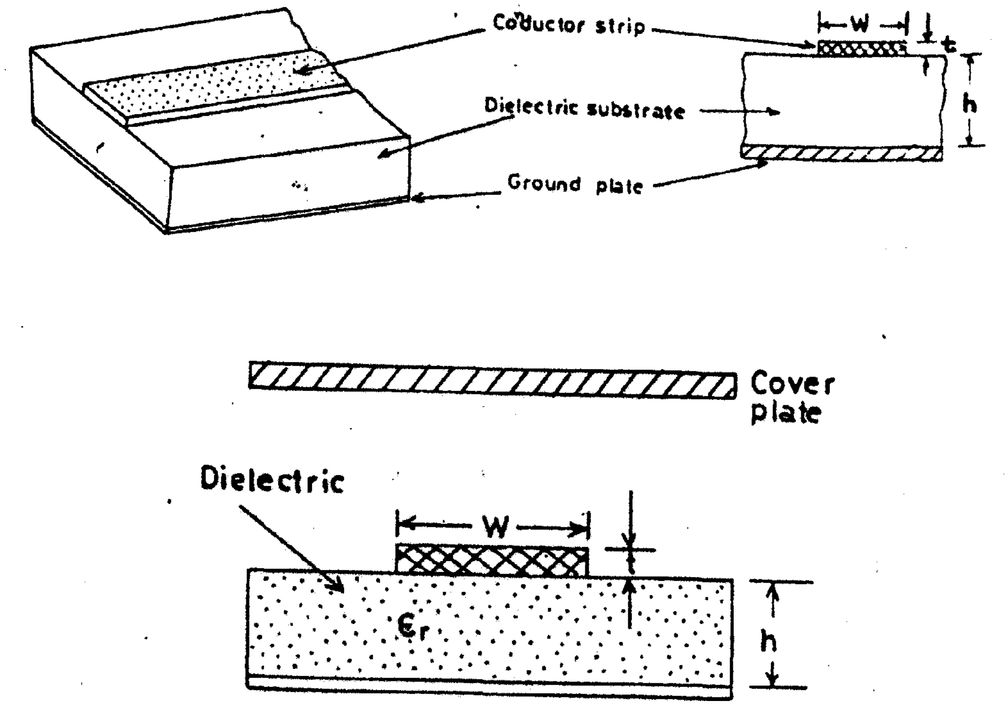



FIG: 12 Microstrip lines.

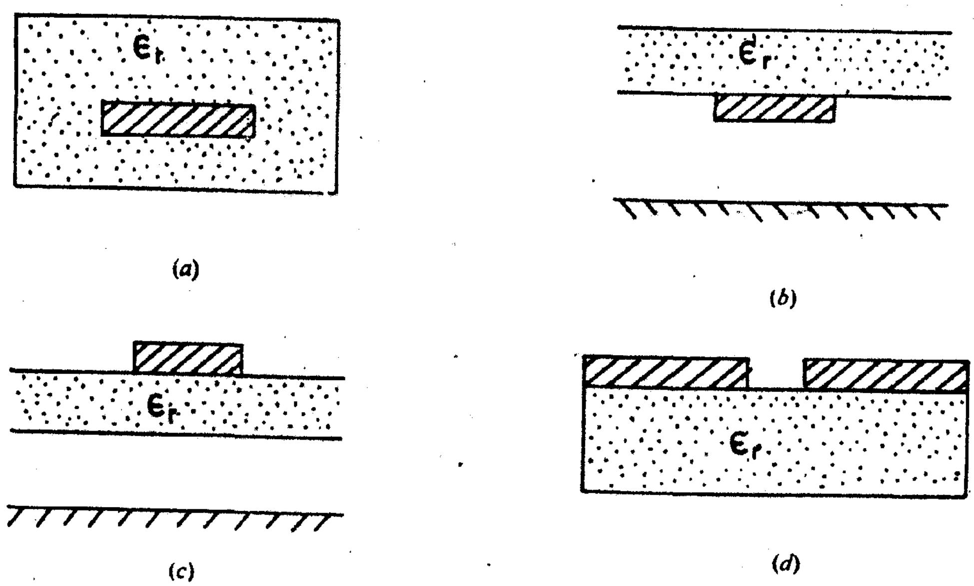



FIG: 13 Various types of microstrip lines.

## ADVANTAGES

- Cost effective.
- Provides uniform signal paths.
- Better interconnection features and easier fabrication.
- Miniaturization.

## DISADVANTAGES

- Numerical analysis of microstrip lines requires large digital computers
- For long transmission lengths, they suffer from excessive attenuation per unit length.
- They have higher radiation losses or interference due to the openness of the microstrip structure.

## MERITS

- The complexity of the test fixture can be reduced.
- The connectors of the VNA do not have to be placed at different distances from each other during calibration.
- Enlargement of the bandwidth.
- Improved accuracy.
- The calibration structures can be realized very easily in microstrip technology.

## DRAWBACKS

- Difficult to obtain an unknown obstacle whose electrical properties must not change when it is moved.
- The frequency coverage of the line standard is approximately 8:1, so more line standards are needed to cover a wide frequency range.
- An approximate knowledge of the circuits' dimensions is necessary in order to choose the correct solutions.

# APPLICATIONS

- In free space systems where the variation of the antenna positions might be critical due to changes of the beam propagation.
- When test fixture needs to be simple.
- When the connectors of the analyzers measurement ports cannot be displaced.

# MEASUREMENT COMPARISON

- Measurements of a planar stripline bandpass filter were performed with a VNA on the basis of the LRR method in comparison to the TRL method.
- The measured scattering parameters show good agreement between the two methods.
- The measurement results are shown next. The plots for both the magnitude and phase of S-parameters are given.

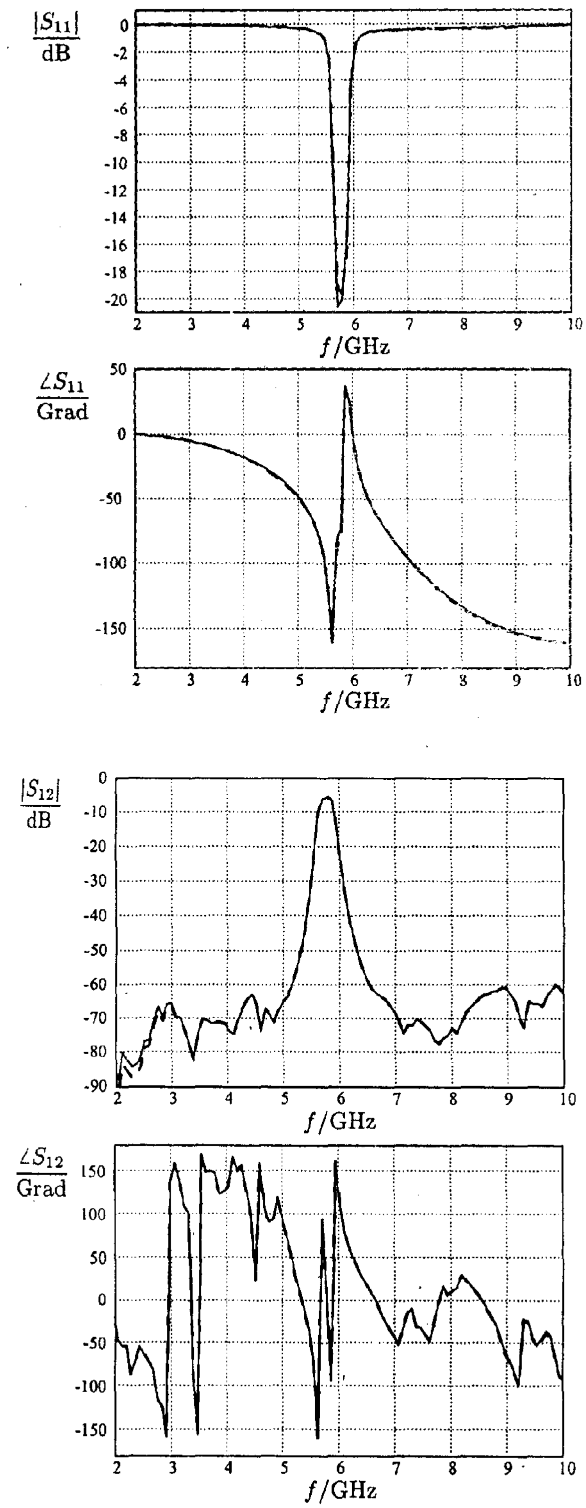



FIG: 14 TRL (- -) and LRR method (— ) applied to a bandpass- filter

# CONCLUSION

LRR technique is a new self-calibration procedure. The calibration circuits are all of equal mechanical length. This is advantageous for the calibration of vector network analyzers, such as, for instance, for applications where the connectors of the analyzers measurement ports cannot be displaced.

The robust functionality is confirmed by measurements, and for that the calibration circuits can be realized in microstrip technology. In the LRR method two solutions are there and depending on the realized calibration structures, the appropriate way should be chosen in order to improve the accuracy.

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## CONTENTS

# ABSTRACT

The *Line-Reflect-Reflect* (LRR) technique is a new self-calibration procedure for the calibration of *vector network analyzers* (VNA), which are used for complex scattering parameter measurements of *microwave devices.*

The calibration circuits of LRR method consist of partly unknown standards, where L symbolizes a *line element* and R represents a symmetrical *reflection standard*. The calibration circuits are all of equal mechanical length. This is advantageous because the complexity of test fixture can be reduced. The LRR method is able to perform a calibration on the basis of reflective networks, which leads to an enlargement of the bandwidth.

The calibration structures of the LRR method can be realized very easily as etched structures in *microstrip technology* or as metal plates for free space applications.

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