

CHARACTERIZATION OF X-BAND MICROWAVE COMPONENTS USING VECTOR NETWORK ANALYZER E5071C

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Abstract:

Microwave and RF testing has gained importance with increased number of microwave applications in diversified fields like defense, domestic and space applications. The characteristics of the microwave devices are found by proper examination of S-parameters, which relates power levels at different ports by using s-parameter values, auxiliary parameters like insertion, isolation, coupling, VSWR, reflection coefficient etc., can be obtained. Network Analyzer is a sophisticated testing device which is used to characterize active and passive components, such as amplifiers, mixers, duplexers, filters, couplers, and attenuators. These components are used in systems as common and low-cost as pagers, or in systems as complex and expensive as communications or radar systems. Components can have one port (input or output) or many ports. The ability to measure the input characteristics of each port, as well as the transfer characteristics from one port to another, gives designers the knowledge to configure a component as part of a larger system.

In this paper we find the different auxiliary parameters for different X-band microwave components like directional coupler, attenuator, isolator and circulator. These components are tested by using vector network analyzer and gives different parameters like magnitude, phase, and group delay over certain frequency range in a single moment. In this work with dynamic frequency range of 300kHz to 14GHz is used to test the microwave X-band devices and the results obtained like VSWR, S-parameters, coupling factor, insertion and the isolation are very accurate.

1. Introduction:

Microwave technology is the back bone of ever increasing array of products for personal, commercial, military and aircraft applications. The essential measurements conducted on microwave communication systems are

- RF Power out of transmitter
- The insertion loss
- Isolation loss
- Return loss
- Noise figure
- Gain
- Receiver sensitivity

X-band microwave components are very important for measurements done in laboratories, research and development side. We have different types of microwave components among them some of the important components mostly used are directional coupler, circulator, isolator, attenuator. These components are mainly used in microwave bench setups.

2. Some of the details of components:

2.1. Isolator

An RF isolator is a two-port ferromagnetic passive device which is used to protect other RF components from excessive signal reflection. Isolators are common place in laboratory applications to separate a device under test

(DUT) from sensitive signal sources. An Isolator provides very small attenuation for transmission from port-1 to port-2, but offers maximum attenuation for transmission from port-2 to port-1.

Table 1:Manufacturer Specifications of XI-621:

Model	Freq. Range (GHz)	Max VSWR (dB)	Min. Insertion loss(dB)	Min. Isolation (dB)
XI-621	8.6-10.0	1.2	0.5	20



Fig 1.Isolator

2.1.1. *Insertion loss:*

Insertion loss is the measure of signal power which has lost when power entered in port-1 and received at port-2.It is calculated from the S_{21} .For an Isolator we desired to have a possible minimum of insertion loss in the desired direction of propagation, which means the Isolator should not provide any loss in that direction. It is the extra loss produced by the introduction of the DUT between the 2 reference planes of the measurement.

$$\text{Insertion loss (IL)} = -20\log|S_{21}| \text{dB} \tag{1}$$

2.1.2. *Isolation:*

Isolation is the measure of signal power which has lost when power entered in port-2 and received at port-1.This is called Isolation because the Isolator has to provide great attenuation to the signal from port-2 to port-1, which means isolating the two ports. For an Isolator we desired to have a possible maximum of isolation.

$$\text{Isolation} = -20\log|S_{12}| \text{dB} \tag{2}$$

Calibration Data:

- Start Frequency : 8GHz
- Stop Frequency : 12.5GHz
- IF Bandwidth : 70 KHz
- Number of frequency Points : 201
- Number of ports used : Full two port
- Power : -5dBm

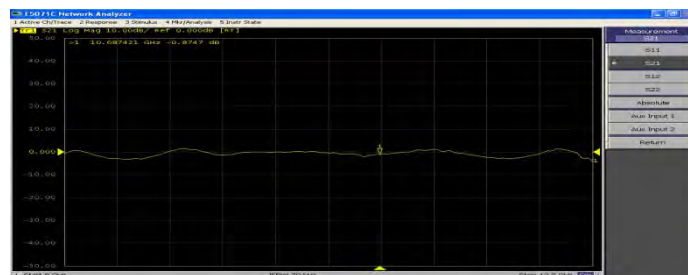


Fig 3:S21 log Magnitude data of Isolator XI-621

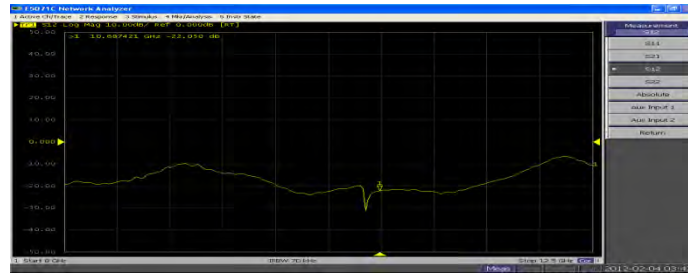


Fig 4:S12 log Magnitude data of Isolator XI-621

Results(As observed on E5071C):

- Max insertion loss : 2.92dB at 8.6525GHz
- Minimum Insertion loss : -0.22dB at 9.6875GHz
- Minimum Isolation : 9.708dB at 9.035GHz
- Maximum Isolation : 23.176dB at 10.GHz

2.2. Circulator

A Microwave Circulator is a passive non reciprocal three or four port ferro magnetic device , in which microwave or radio frequency power entering any port is transmitted to the next port in rotation (only).Circulator is defined as a device with ports arranged such that the energy in a port is coupled to the adjacent port in clockwise direction but not coupled to the other ports.

The circulator shown below is a three port circulator. According to the type of physical shape, they are classified as T-shaped circulators and Y-shaped circulators, but the performance would be the same. Circulators are used in many forms like duplexer and Isolators by using it in different configurations.

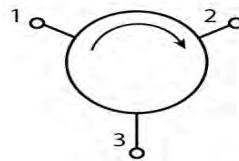


Fig 5:Symbolic representation of Three port Circulator

The Important Parameters of Circulator

2.2.1. Insertion loss:

Insertion loss is the ratio of power detected at the output port to the power supplied by source to the input port, measured with all other ports terminated in a matched load.

$$\text{Insertion loss (dB)} = -20\log|S_{ji}| \tag{3}$$

Where power entered at ith port and received at jth port

2.2.2. Isolation:

Isolation is the ratio of power applied to the output to that measured at the input i.e, in the direction opposite of measuring insertion.

$$\text{Isolation (dB)} = -20\log|S_{ij}| \tag{4}$$

Where power entered at jth port and received at ith port

2.2.3. Input VSWR:

It is the VSWR measured at any particular port with all other ports matched.

$$\text{Reflection Coefficient } |\Gamma| = \text{VSWR}-1/\text{VSWR}+1 = |S_{ii}| \tag{5}$$

Where power entered at ith port and received at ith port

2.2.4 . S-Matrix of 3-port Circulator

Manufacturer Specifications of XC-621:

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$$

Model	Freq. Range (GHz)	Max VSWR (dB)	Min. Insertion loss(dB)	Min.Isolation (dB)
XC-621	8.6-9.6	1.2	0.4	20

Results(as observed on E5071C) :

The values are taken at 9.125GHz for comparison with the values obtained at same frequency on Microwave bench setup.

- Port 2-1 Insertion loss : 1.08dB
- Port 3-2 Insertion loss : 4.459dB
- Port 1-3 Insertion loss : 2.03dB
- Port 1-2 Isolation : 16.04dB
- Port 2-3 Isolation : 18.12dB
- Port 3-1 Isolation : 20.74dB
- Port-1 VSWR : 1.66
- Port-2 VSWR : 1.33
- Port-3 VSWR : 1.33

S-Matrix:

S-Matrix can be calculated by converting the log magnitude of auxiliary parameters into linear format.

$$[S] = \begin{bmatrix} 0.25 & 0.15 & 0.79 \\ 0.88 & 0.14 & 0.12 \\ 0.09 & 0.59 & 0.14 \end{bmatrix}$$



Fig 6.: Measurement setup for testing 3- port Circulator XC-621

2.3. Waveguide attenuators

Attenuators are used to attenuate the microwave power and commonly used for measuring power gain or loss in dBs, for providing isolation between instruments, for providing the signal generators with a means of calibrating their outputs accurately so that precise measurement could be made.

Attenuators may be of the fixed or the variable type

2.3.1. Fixed attenuator :

Fixed Attenuator consists of a dielectric slab consisting of glass slab coated with Aquadog or carbon film which provides attenuation. The waveguide consists of lossy dielectric or vane.



Fig 7:Fixed Attenuator

2.3.2. Variable attenuator :

Variable Attenuators provide attenuation in continuous or stepwise variable attenuation. The variable attenuator tested on E5071C is a movable lossy vane type variable attenuator which is designed to obtain the low VSWR characteristics over entire frequency range band.

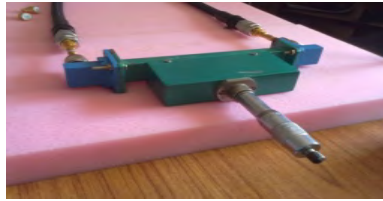


Fig 8: Variable Attenuator



Fig 9: Variable Attenuator(XA-520) connected to E5071C

Calibration Data:

Start Frequency : 8GHz
 Stop Frequency : 12.5GHz
 IF Bandwidth : 70 KHz
 Number of frequency Points : 201
 Number of ports used : Full two port
 Power : -5dBm
 Parameters of Interest : S_{21} , VSWR

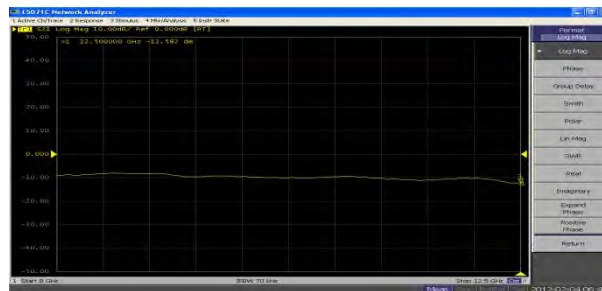


Fig 10: S_{21} Log Magnitude of Fixed Attenuator

Results of Fixed Attenuator (as observed on E5071C):

- Minimum Attenuation : 8.04dB at 8.54GHz
- Maximum Attenuation : 12.54GHz at 12.5GHz
- Max Group Delay : 872ps at 9.035GHz

Results of Fixed Attenuator (continuation):

- Min Group Delay : 218ps at 12.5GHz
- Minimum VSWR from port1-2 : 1.62 at 12.5GHz
- Maximum VSWR from port 1-2 : 2.33 at 8.54GHz

Results of Variable Attenuator (as observed on E5071C):

- Max Attenuation (At position 0) : 33.1dB at 12.5GHz
- Minimum Attenuation (At position 20) : 0.01 dB at 11.7GHz VSWR at position 0: 1.04 at 12.5GHz

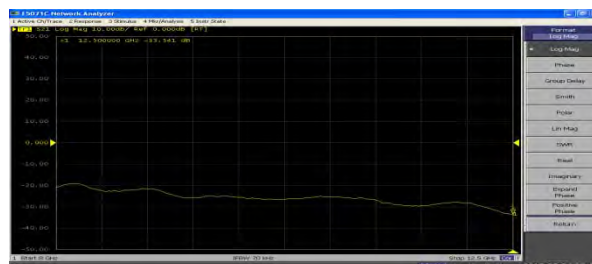
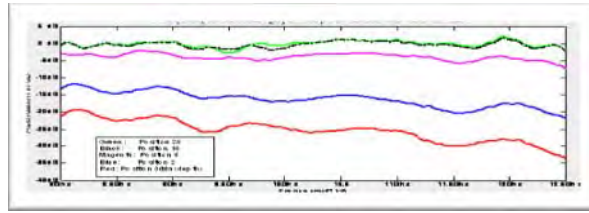


Fig 11: Variation of Attenuation of XA-520 w.r.t depth of Vane



2.4. Directional Couplers

A directional coupler is a four-port microwave junction. The ideal directional coupler has the property that a wave incident in port 1 couples power in to ports 2 and 3 but not in to port 4. Similarly power in port 4 couples in to port 2 and 3 but not in to port 1. Thus port 1 and 4 are uncoupled. For waves incident in port 2 and 3, the power is coupled in to ports 1 and 4 only, so that port 2 and 3 are also uncoupled.

In addition, all four ports are matched. That is, if three ports are terminated in matched loads, the fourth port appears terminated in a matched load, and an incident wave in this port suffers no reflection.



Fig 12: Schematic diagram of Directional coupler XK-610

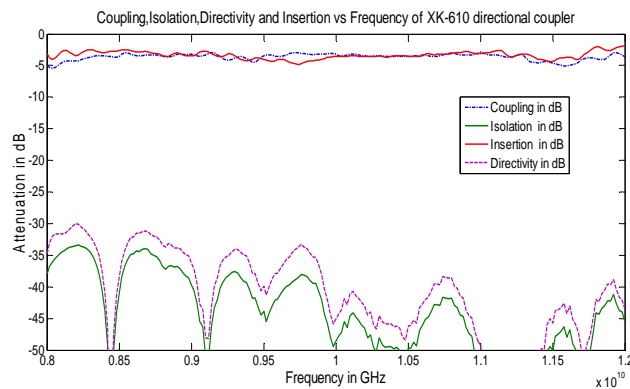
Parameters Evaluated for Directional Coupler

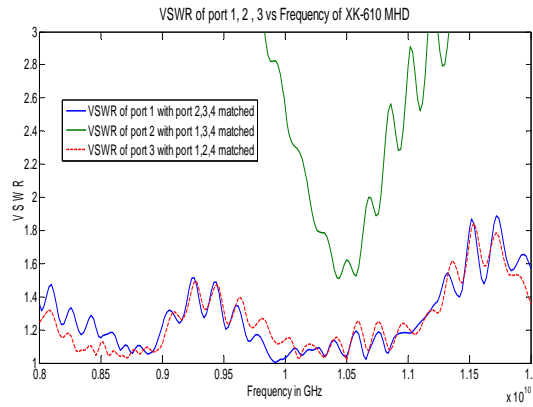
- Coupling (C) = $-20\log|S_{31}|$ dB
- Isolation (I) = $-20\log|S_{32}|$ dB
- Directivity (D) = $-20\log|S_{43}| = I - C$ dB
- Insertion loss = $-20\log|S_{21}|$

Manufacturer Specifications of XK-610:

XK-610 is a Multi Hole directional coupler (MHD) which has 4 ports with port 4 matched.

Model	FREQ.RANGE (GHz)	COUPLING (dB)	DIRECTIVITY (MIN.)	VSWR (MAIN)	VSWR (AUXILIARY LINE)
XK-610	8.2-12.4	10±0.6	35	1.12	1.2





Results at particular frequency of 9.125GHz

- Main Line VSWR of MHD Coupler:1.2
- Auxiliary Line VSWR of MHD Coupler:1.6
- Coupling: 2.85dB
- Insertion:3.08dB
- Isolation :51.0dB
- Directivity: 48.15dB



Fig 13:Measurement Setup for Directional coupler characteristics

3. Conclusion

For fixed attenuator, it is found that attenuation is constant over entire range in between 8 to 12.5 dB. For variable attenuator (XA-520) the attenuation is a function of vane depth and attenuation tends to increase slightly as the frequency increases from 8 to 12.5GHz. Isolator XI-621 gives minimum attenuation of 9.3dB as compared to 20dB of specified minimum isolation. Insertion loss is found to be satisfactory over entire region near to 0.5dB. Circulator, XC-621 gives 16.04dB Isolation as compared to minimum of 20dB isolation and all port VSWRs are slightly greater than specified VSWR of 1.2. Multi Hole Directional Coupler (MHD) XK-610 has given satisfactory results with minimum directivity of 30dB, but coupling is around 5dB against the specified value of 10dB. VSWRs of port 1,3 is found to be good but port-2 is found to matched imperfectly, This may be due to the fact that it is impossible to construct a perfectly matched lossless reciprocal 3-port junction.

4. References:

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