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Quick Experiments Description Manual for Radiowave Absorption Measurements

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Abstract - *In this article we introduce a quick manual for radiowave absorption measurement techniques. Researchers, developers, manufactures and end users of radiowave absorber material need parameters and performance evaluation. This manual is aimed to help research beginners as well as experts to select a suitable performance test method that can be adopted with minimum costs. A set of experiments each suit a form of absorbers used in the field of radiowave absorption. We described experiments in brief. Technical terms definitions, can be found in open literatures and equipment descriptions.*

Key Words: **Microwaves, Antenna, Absorption, FSS, Metamaterial, Measurements**

1. INTRODUCTION

Microwave and antenna measurements are basic organs in the electromagnetic science and technology body. Radiowave absorption material (RAM) also called Radar Absorbing Material are increasingly used in both military and civilian sectors. Research, manufacturing, development of RAM requires performance measurements to assure compliance with applications targeted. In this manual we classified measurement techniques according material forms (sheets – solid blocks – paints – printed patches). RAM types such as dielectric sheets – frequency selective surfaces (FSS) – Metamaterial can be tested using the adequate experiments. Dielectric sheets are made of a polymer loaded with absorbing material as carbon or ferrite additives to increase the losses of radiowaves passing through them. They can be formed as flexible sheets or foam. FSS is a periodic surface with identical 2-D arrays of elements arranged on a dielectric substrate. It is designed to be transparent in some frequency bands while reflective, absorbing or redirecting to others [1]. There is no commonly definition for metamaterial; however, all common descriptions of metamaterial are artificial materials that gain their properties from the structure rather than from the composition which can provide unusual electromagnetic effects that are difficult to be accomplished by natural materials [2]. Metamaterials are designed through different forms of split rings or periodic structures fabricated from highly conductivity materials like gold, silver, or copper. Two parameters define the response of a material; electric permittivity ε, and magnetic permeability μ, so the propagation of the electromagnetic wave inside any material depends on the sign of μ and ε. We can conveniently describe most electromagnetic materials by the quadrant where they lie in the permittivity ε and permeability μ plane. The artificial materials or as defined metamaterials lie in the quadrant where $\mu < 0$ and $\varepsilon < 0$, this region can be called Double Negative Medium (DNM). The electromagnetic wave in this region will obey Left Hand Medium (LHM) where the wave will propagate in the opposite direction of propagation.

We introduce in this paper measurements for dielectric absorbers and metamaterial. There are two types of measurements, waveguide and free space measurements. Therefore, samples to be have prepared for measurements. In case of waveguide tests, it should be possible to insert the sample into the waveguide or the coaxial line sample holder. Sample dimensions should match the waveguide in the operating bands or the coaxial line dimensions. For free space tests, samples of dimensions 25 × 25 cm^2 to 30 × 30 cm^2 may be quite suitable. The ground plane should be at the same sample dimensions [3]. A quick test selection table is listed below in table 1.

These experiments listed in table 1 help for quick selection of a suitable performance test method. In this paper, a quick experiments description manual for radiowave absorption measurements are presented. The paper is constructed in five sections. Introduction is set in Section 1. Section 2 describes the measurements types for dielectric absorbers and FSS. The absorption calculations are presented in Section 3. Section 4 describes various measurements laboratories that can be used in measurements. Finally, a conclusion is set in Section 5.

Table -1: Test selection table

Experiment No.	Test Form
Experiment (1), (2)	Waveguide samples (Special material forms)
Experiment (3), (4), (5)	Free space ungrounded dielectric sheets and FSS for, normal incidence, oblique incidence, transmission measurement, and reflection measurement
Experiment (6), (7), (8)	Free space, grounded dielectric sheets and metamaterial for, normal incidence – single feed, normal incidence – double feeds, and oblique incidence – double feeds

2. ABSORBERS and FSS

In this section the measurements of dielectric absorbers and FSS are described in details. There are two types of measurements, waveguide and free space measurements. These measurement are suitable for transmission and reflection measurements. Also the absorption (loss) can be calculated.

Note, notations: input and output shown in experiments setups are the two ports of the Vector Network Analyzer (VNA).

1.1 Waveguide Measurements

1.1.1 Experiment (1): Ground Free Dielectric Sample

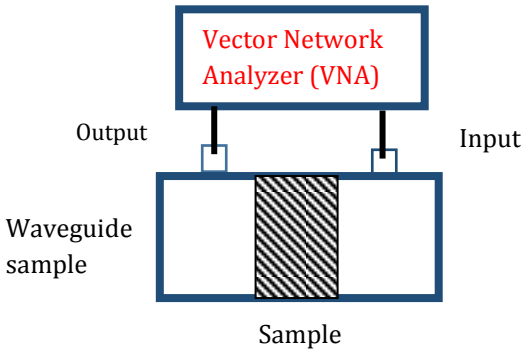

Figure -1: Waveguide sample test (without ground plane)

-- Instruments:
A Vector Network Analyzer (VNA) – waveguide sample holder or a coaxial cable sample holder.
--Sample:
Is formed to fill a portion of the waveguide or a coaxial cable sample holder.
--Procedures:
- Set the arrangement of figure 1.
- Record the reflection coefficient S_{11} and the transmission coefficient (S_{21}) with the sample inserted.
- Normalize the results to the case of removed sample to eliminate the wave guide or the coaxial holder losses.

-- Formulas:
The absorption (L) in sample can be calculated as [4]:

$$L = 1-|S_{11}|^2-|S_{21}|^2 \quad (1)$$

Note: S_{11}, S_{21} and L are normalized ratios of field magnitudes.
Loss in decibels: $L = 10\log(L)$ (2)

1.1.2 Experiment (2): With Ground

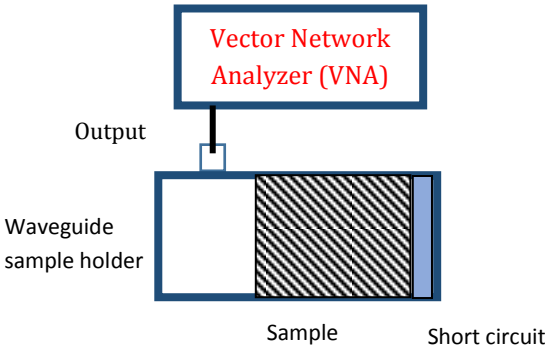

Figure 2. Waveguide sample test (with ground plane)

--Instruments:
A Vector Network Analyzer (VNA) – waveguide sample holder or a coaxial cable sample holder.
--Sample:
Is formed to fill a portion of the waveguide or a coaxial cable sample holder.
--Procedures:
- Set the arrangement of figure 2.
- Record the reflection coefficient (S_{11}) with and without the sample.
- Normalize the results to the case of removed sample to eliminate the wave guide or the coaxial holder losses.

-- Formulas:
The absorption (L) in sample can be calculated as [4]:

$$L = 1-|S_{11}|^2 \quad (3)$$

1.2 Free Space Measurements

1.2.1 Experiment (3): Unground Sheets: Normal Incidence

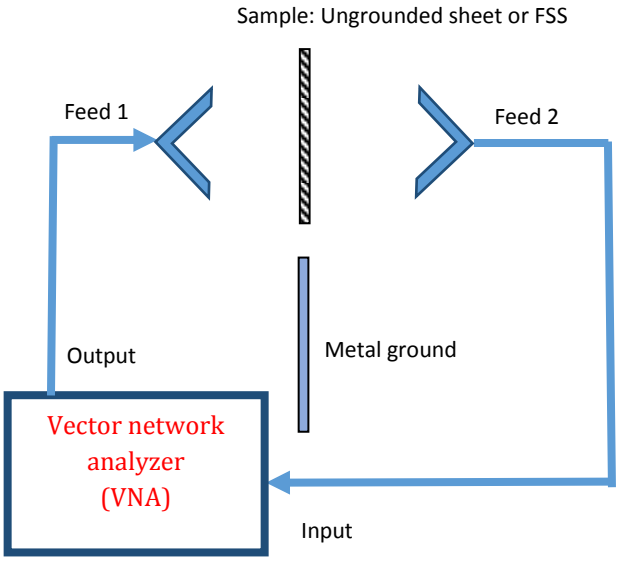

Figure -3: Transmission – Reflection measurement

--Instruments:
A Vector Network Analyzer (VNA) – two feeds.
--Sample:
A sheet of a dielectric material (ungrounded).
--Procedures:
- Set the arrangement of figure 3.
- For transmission coefficient / insertion loss:
- Measure S_{21} with and without sample.
- Normalize S_{21}
- For reflection coefficient:
- Set the arrangement of figure. 3.
- Measure S_{11} with the metal sheet placed between the two feeds.
- Repeat measuring S_{11} with the absorber placed instead of the metal sheet (at the same location).
- Normalize S_{11}
-- Formulas:
The absorption (L) in sample can be calculated as [4]:

$$L = 1-|S_{11}|^2-|S_{21}|^2 \quad (4)$$

- Repeat this measurement for various polarizations.

1.2.2 Experiment (4): Unground Sheets: Oblique Incidence (Transmission Measurements)

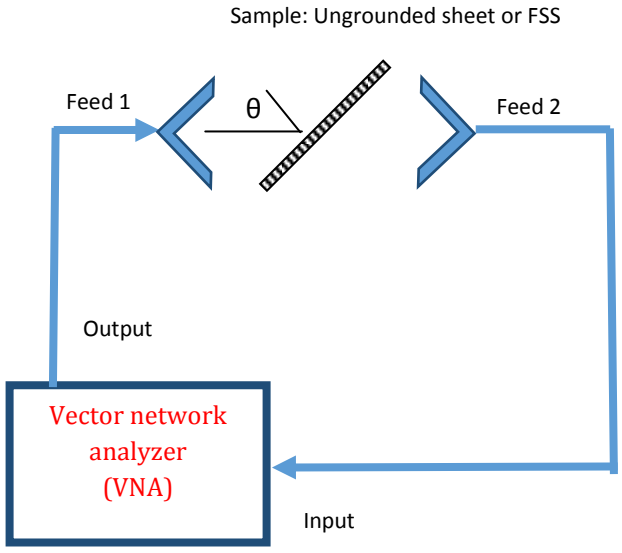

Figure -4: Oblique incidence transmission measurement

--Instruments:
A Vector Network Analyzer (VNA) – two feeds.
--Procedures:
- Set the arrangement of figure 4.
- Measure S_{21} without sheet.
- Measure S_{21} with the sheet (ungrounded).
- Normalize results.
- Repeat at various angles of incident (θ).
- Repeat for TE and TM incidences.
-- Formulas:
The absorption (L) in sample can be calculated as [4]:

$$L = 1-|S_{21}|^2 \quad (5)$$

1.2.3 Experiment (5): Unground Sheets: Oblique Incidence (Reflection Measurements)

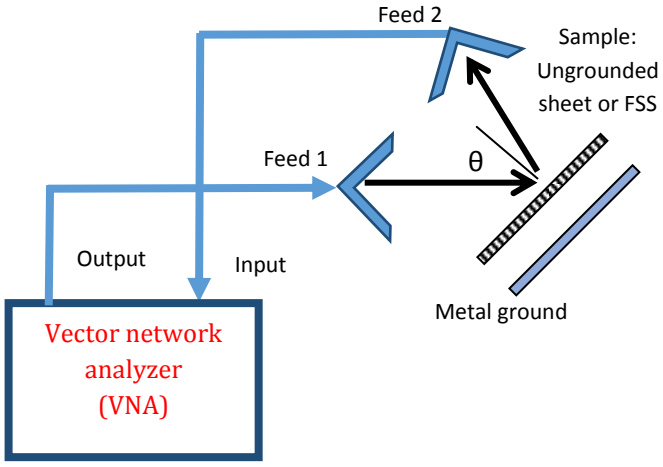

Figure -5: Oblique incidence reflection measurement

--Instruments:
A Vector Network Analyzer (VNA) – two feeds.
--Procedures:
- Set the arrangement of figure. 5.
- Measure S_{21} in case of ground mounted (select S_{21} on VNA).
- Measure S_{21} in case of sheet without ground (select S_{21} on VNA).
- Normalize results.
- Repeat at various angles of incident (θ).
- Repeat for TE and TM incidences.

-- Formulas:
The absorption (L) in sample can be calculated as [4]:

$$L = 1-|S_{21}|^2 \quad (6)$$

1.2.4 Experiment (6): Grounded Sheets: Normal INCIDENCE (Reflection Measurements – Single Feed)

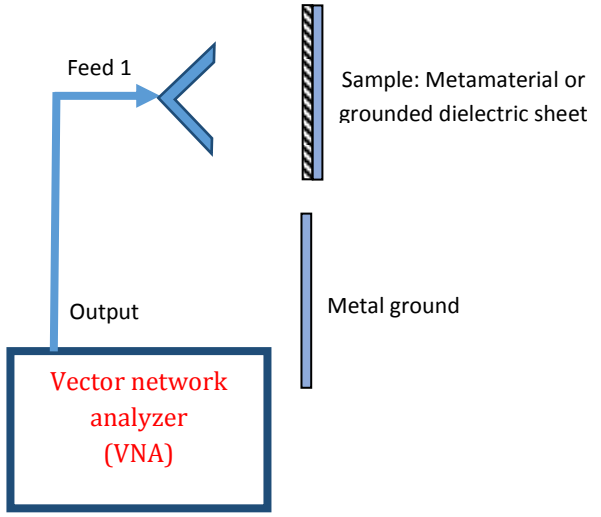

Figure -6: Reflection measurement (single feed)

--Instruments:
A Vector Network Analyzer (VNA) – single feed.
--Procedures:
- Set the arrangement of figure. 6.
- Measure S_{11} for:
- Ground plane only.
- Sample facing the feed at the same ground plane location.
- Normalize results.
- Repeat this measurement for different polarization.

-- Formulas:
The absorption (L) in sample can be calculated as [4]:

$$L = 1-|S_{11}|^2 \quad (7)$$

1.2.5 Experiment (7): Grounded Sheets: Normal INCIDENCE (Reflection Measurements – Two Feeds)

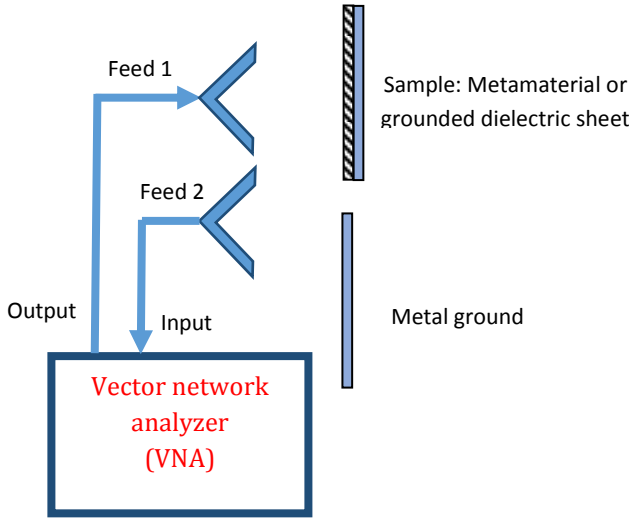

Figure -7: Reflection measurement (two feeds)

--Instruments:
A Vector Network Analyzer (VNA) – two feeds.
--Procedures:
- Set the arrangement of figure 7.
- Measure S_{21} for:
- Ground plane only.
- Sheet facing the feed at the same ground plane location.
- Normalize results.
- Repeat this measurement for different polarization.
- Compare results of experiments (6) and (7)

-- Formulas:
The absorption (L) in sample can be calculated as [4]:

$$L = 1-|S_{21}|^2 \quad (8)$$

1.2.6 Experiment (8): Grounded Sheets: Oblique Incidence (Reflection Measurements – Two Feeds)

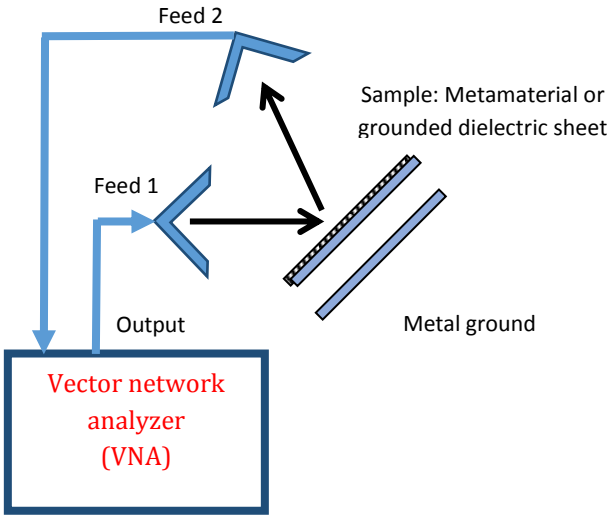

Figure -8: Reflection measurement (two feeds)

--Instruments:

A Vector Network Analyzer (VNA) – two feeds.

--Procedures:

- Set the arrangement of figure 8.
- Measure S_{21} with metal ground without the sheet.
- Measure S_{21} with grounded sheet.
- Normalize results.
- Repeat at various angles of incident (θ).
- Repeat for TE and TM incidences.

-- Formulas:

The absorption (L) in sample can be calculated as [4]:

$$L = 1-|S_{21}|^2 \quad (9)$$

3. ABSORPTION CALCULATIONS

To test metamaterial use experiments of normal / oblique incident used with grounded dielectric sheets for reflection measurements (Experiments 6-7-8).

Figure 9 in appendix defines the S-parameters, reflection coefficient (S_{11}) and the transmission coefficient (S_{21}).

Absorption calculation formulas for measurement cases:

- For transmission and reflection results, the absorption is calculated as:

$$L = 1-|S_{11}|^2-|S_{21}|^2 \quad (10)$$

- For the case of normal / oblique incidence with ungrounded sheets use formula listed in (8).
- For grounded sheets, the absorption is calculated as:

$$L = 1-|S_{11}|^2 \quad (11)$$

- For grounded sheets including metamaterial, for a single feed setup, the absorption is calculated as:

$$L = 1-|S11|2 \quad (12)$$

- For grounded sheets including metamaterial, for a double feed setup, the absorption is calculated as:

$$L = 1-|S_{21}|^2 \quad (13)$$

Note that the absorption (L) can be calculated in decibels using (2).

Frequency Selective Surfaces (FSS) are measured as for the Dielectric Sheets to record S_{11} and S_{21}. Loss is not calculated as they can be considered as lossless structures.

4. MEASUREMENT LABORATORIES

A- Experiments (1) and (2) are classified as microwave measurements to be performed in microwave laboratories. A typical laboratory ha to be equipped with the following major components:

1- An RF signal generator (preferable a swept frequency type).
2- A ratio meter (could be a VSWR meter).
3- Microwave detectors

Microwave accessories (cables-wave guides- couplers – adaptors – attenuators….).

Items 1, 2 and 3 can be replaced by a Vector Network Analyzer (VNA). All devices must operate in the same frequency band.

B- Free Space measurements included in experiments (3) though (8), are classified as Antenna Measurements.

Antenna laboratory for absorption measurements should contain:

1- An RF signal generator (preferable a swept frequency type).
2- A Radio Frequency Receiver.
3- Microwave detectors.
4- An antenna Turn Table (Antenna Positioner).
5- Angular Position Measurements.
6- A set of antennas.

Microwave accessories (cables-wave guides- couplers – adaptors – attenuators….).

A Vector Network Analyzer (VNA) can substitute items1, 2, and 3.

For accurate absorption measurements, the antenna lab has to be accommodated in an anechoic chamber sufficiently large to fulfill free space and far field conditions.

General Recommendations:

All devices must operate in the same frequency band.

The practical setups of the waveguide and free space measurements are shown in figure 10 and figure 11 respectively in the below appendix. Note, measurements are performed and tested for certain frequency bands in our laboratory at the Higher Institute of Engineering El Shorouk City. By using a Vector Network Analyzer (Agilent N9923A) in the band up to 4 GHz, using Nvis microwaves test benches (Nvis 9000) in the X-band, and using antenna trainer ED-3200 in the X-band.

5. CONCLUSIONS

In this quick absorption measurement manual we focused on relative performance evaluation techniques. The developers of absorber material need a quick evaluation process to direct their research works. Waveguide tests experiments (1) and (2) can offer this objective in a simple, a quick and a cheap method. This method does not test the polarization and type of incidence sensitivity of absorber parameters. Free space measurements experiments (3) to (8) can evaluate wave incidence modes on absorber parameters. Incidence modes here means: angle of incidence, polarization, and Transverse Electric (TE), Transverse Magnetic (TM) mode types.

APPENDIX

Figure -9: Measurement cases: (a) ungrounded samples, (b) ground backed samples

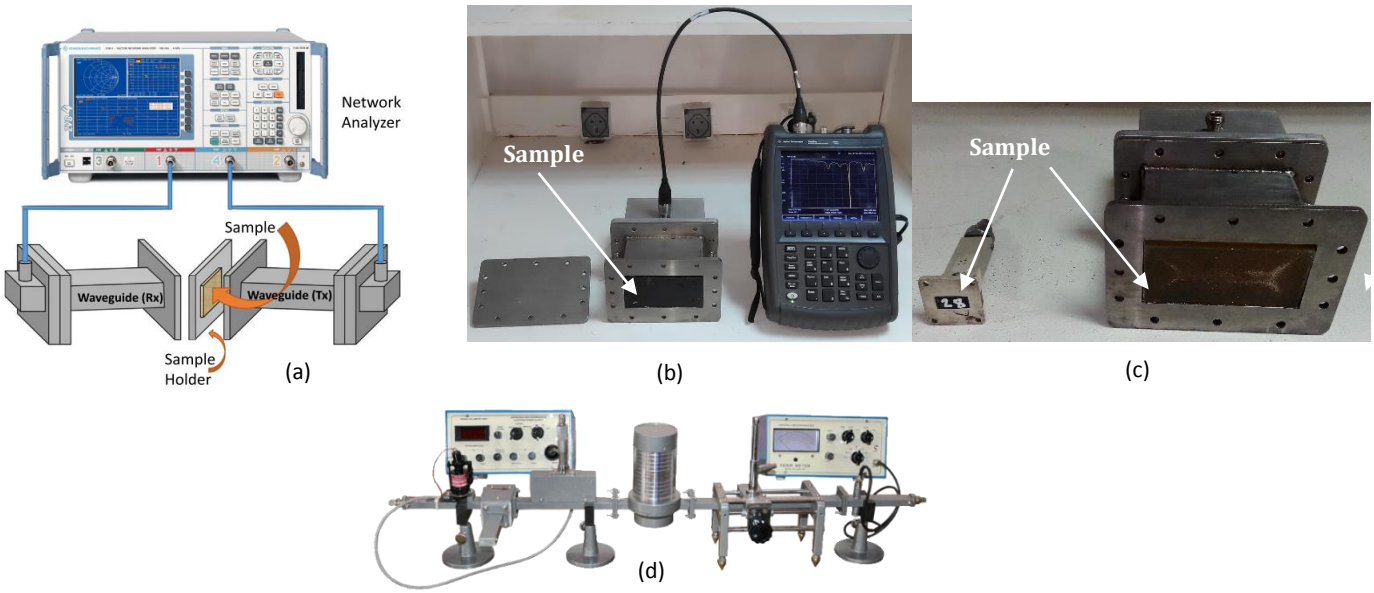

Figure -10: Waveguide measurement setup examples: (a) waveguide test [5], (b) waveguide test using Agilent N9923A, (c) waveguide to coaxial adapters in the bands 1-2 GHz and X-band, (d) waveguide test using Nvis 9000

(a) (b) (c)

Figure -11: Free space measurement setup examples: (a) FSS test [6], (b) free space test using turn table [7], (c) free space test using ED-3200

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