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Preliminary Results on the Use of the Time Domain Option in Vector Network Analyzers to Measure the Impedance Mismatch of Broadband Antennas in any Electromagnetic Environment

Estratto da: *Atti della Fondazione Giorgio Ronchi*
Anno LXXIV, n. 1 - Gennaio-Febbraio 2019

Tip. L'Arcobaleno s.n.c. - Via Delle Pandette, 22 - Firenze
2019

ANNO LXXIV GENNAIO-FEBBRAIO 2019 N. 1

ATTI

DELLA «FONDAZIONE GIORGIO RONCHI»

Pubblicazione bimestrale - Prof. LAURA RONCHI ABBOZZO Direttore Responsabile
La responsabilità per il contenuto degli articoli è unicamente degli Autori

Iscriz. nel Reg. stampa del Trib. di Firenze N. 681 - Decreto del Giudice Delegato in data 2-1-1953

Tip. L'Arcobaleno - Via Delle Pandette, 22 - Firenze - Febbraio 2019

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ELECTROMAGNETISM

Preliminary Results on the Use of the Time Domain Option in Vector Network Analyzers to Measure the Impedance Mismatch of Broadband Antennas in any Electromagnetic Environment

ANGELO GIFUNI (*), MICHELE AMBROSANIO (*), GIUSEPPE GRASSINI (*), ANGELO URCIUOLI (*)

RIASSUNTO – *In questo articolo viene illustrata una procedura per la realizzazione di misure di disadattamento di impedenza per antenne a banda larga applicabile in un qualunque ambiente elettromagnetico. Solo una distanza minima dal più vicino ostacolo deve essere considerata. Al fine di valutare la sola riflessione dell'antenna nel dominio spettrale, le misure di riflessione sono acquisite in frequenza mediante un network analyzer vettoriale, anti-trasformate mediante una trasformata inversa discreta di Fourier, finestrate con un'operazione di gating e nuovamente riportate nel dominio della frequenza. Risultati preliminari, ottenuti da misure di disadattamento di impedenza di un'antenna waveguide double ridge horn effettuate all'interno e all'esterno di una camera anecoica, nonché all'interno di una camera riverberante, confermano e supportano il metodo proposto.*

SUMMARY – *In this paper, a technique for broadband antenna impedance mismatch measurements (AIMM) carried out for a general electromagnetic environment is shown. Only a minimum distance from the nearest obstacle has to be considered. In order to evaluate only the antenna reflection coefficient in the frequency domain (FD), some reflection measurements are acquired in FD by a vector network analyzer (VNA); then, an inverse discrete Fourier transform (IDFT) is applied to move into the time domain (TD). Finally, a gating operation and a discrete Fourier transform (DFT) are applied. Preliminary results from measurements of the antenna impedance mismatch (AIM) on a waveguide double ridge horn antenna performed inside an anechoic chamber (AC), outside the AC, and inside a reverberation chamber (RC) are shown, confirming the validity of the proposed approach.*

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1. Introduction

Antenna impedance mismatch (AIM) is an important characteristic parameter, which coupled with the radiation efficiency, determines the total efficiency of an antenna (1)-(3). Accurate AIM measurements (AIMM) are carried out in an anechoic chamber (AC), which simulates free space, by the reflection coefficient measurement. An alternative to the use of an AC, which is expensive, is to make such measurements in time domain (TD). Under specified conditions, TD measurements can be performed in an electromagnetic environment where obstacles are present. TD measurements use a pulsed radiofrequency (PRF) as an excitation. The width of the PRF, which determines the spread of its spectrum, has to be such that the reflections due to the nearest obstacles from the antenna under test (AUT) can be removed by gating (4)-(8). Actually, any reflecting obstacle should be at least one dived two pi times a wavelength away from the AUT at minimum working frequency, in order to avoid affecting the intrinsic impedance of the AUT itself (9).

When the excitation PRF is synthetized by convenient FD measurements, which is normally made by a vector network analyzer (VNA), an inverse fast Fourier transform (IFFT) can be applied to obtain the corresponding TD measurements (10)-(14); a gating operation and a next fast Fourier transform (FFT) are applied to obtain the only antenna reflection coefficient in FD. Measurement frequency range (FR) and number of samples, i.e., the step frequency (SF), are conveniently chosen so that a sufficient TD resolution, as well as a convenient measurement time range, is obtained. The FR of the reflection coefficient, from which the AIM can be calculated, is in general restricted to the FR of the AUT. However, if the transmission line or the waveguide before the reference plane, by which the antenna is fed, supports the fundamental propagation mode also below the minimum frequency and over the maximum frequency of the operating FR of the antenna, respectively, then measurements could be extended in frequency for both the minimum frequency and the maximum one of the FR. When such an extension is possible, an increase in the response resolution, according to the achieved extension, and especially a reduction of the effects of truncated frequency, windowing, and gating in the FR of the antenna are obtained. This enhances the proposed technique, even though it is not experimentally shown in this paper. For sake of clarity, when frequency extension is considered, the minimum and maximum frequencies of the FR of the antenna are denoted by $f_{\min,FR}$ and $f_{\max,FR}$, respectively, whereas the minimum and maximum frequencies of the measurements are denoted by $f_{\min,meas}$ and $f_{\max,meas}$, respectively. Clearly, $f_{\min,FR} \geq f_{\min,meas}$ and $f_{\max,FR} \leq f_{\max,meas}$.

Preliminary results from AIM measurements on a waveguide double ridge horn antenna carried out inside and outside an anechoic chamber (AC),as well as inside a reverberation chamber (RC), are shown, supporting the proposed methodology.

2. Method

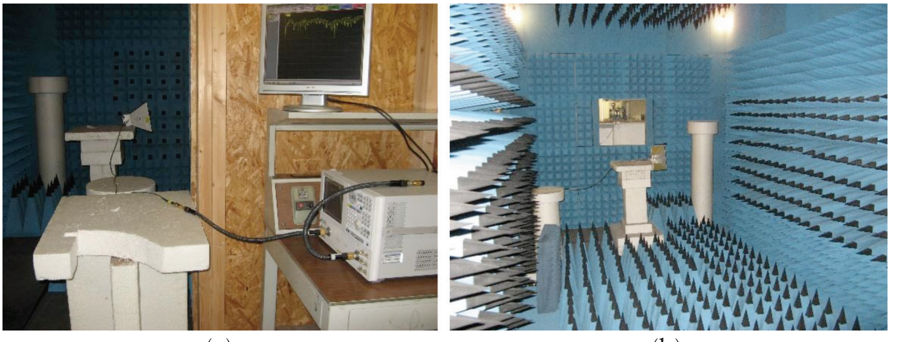
The calculations of the IFFT, as well as the FFT after gating selection, can be performed by the TD option embedded in the VNA (10)-(14). Windowing concerning the IFFT and gating shape concerning the FFT are conveniently selected in the TD option according to the rules deriving from the mathematical processes that govern such calculations (4)-(8). It is specified that any necessary compensation is included in the embedded TD option (10)-(14). It is also specified the algorithms used by Manufacturers of VNA are not made known to the Customers (14). However, the whole data processing can be done off-line without using the embedded option in the VNA after the appropriate measurements in FD are acquired, i.e., common software such as MATLAB and LabVIEW, can normally be used for this aim (15).

Note that the minimum distance (d_{min}) of an obstacle from the antenna, which is known for a given measurement setup, has to be connected with $f_{min,FR}$ and $FR_{AUT} = f_{max,FR} - f_{min,FR}$ or with $f_{min,meas}$ and $FR_{meas} = f_{max,meas} - f_{min,meas}$ when the extension of the measurement frequency range is applied. In fact, if the physical distance of the nearest obstacles from the AUT is denoted by d_{min}, then it has to turn out that $d_{min} \geq (1/2\pi)\lambda_{max,FR}$, in order to avoid affecting the intrinsic impedance of the AUT as above mentioned (9); $\lambda_{max,FR}$ is the wavelength corresponding to $f_{min,FR}$. In principle, to select the only reflection due to the AUT in TD by gating, a response resolution, which is denoted by T_{Res}, less or equal than the time interval corresponding to the minimum real distance of the nearest obstacles is necessary. It is specified that the response resolution (or 50% impulse width) is approximately given by $T_{Res} \sim 2/FR_{AUT(meas)}$ when bandpass mode and normal windowing are selected in TD option embedded in the VNA used for measurements. The symbol $FR_{AUT(meas)}$ means that FR_{meas} has to be considered. Note that each antenna has its specific duration of the reflection response, which depends on the physical structure and on the FR of the antenna itself. As an example, it is seen that horn antennas have generally durations of the reflection responses in TD less than log-periodic antennas. In fact, on the same FR, the latter are usually greater than the former one, both from a physical as well as electrical point of view, and they are fed from the tip. It is important to note that the time interval corresponding to the gate to be selected has to include the whole reflection response of the AUT. Therefore, the application of the method in the general context of broadband antennas, implies that the distance d_{min} has to be increased according to the reflection response of the AUT. However, in most cases, the necessary distance d_{min} is less than 1 m, as shown in the next section as well. Therefore, measurements can be performed in any electromagnetic environment but a distance d_{min} has to be considered.

3. Measurements and preliminary results

Measurements of the S_{11} coefficient of the available AUT are considered. They are acquired in a full AC (16), outside the AC, and in a RC (17)-(20). Result comparisons in order to validate the practical application of the proposed method are shown in the following. Data processing was carried out off-line via LabVIEW. However, this is a preliminary work since a single antenna is used and no windowing and gating shape have been used to improve the results, i.e. the standard rectangular window function was used.

The AC is a rectangular chamber of 72 m^3 volume, whose size is 3 m x 3 m 8 m, as shown in Fig. 1.



(a) (b)

FIG. 1

(a) Measurement setup. (b) Inside view of the AC.

For measurements performed outside the AC, a metallic panel is put in front of the AUT at a distance of about 35 cm, as shown in Fig. 2.

FIG. 2

Measurement setup outside the AC: a metallic panel is located in front of the antenna at a distance of about 35 cm.

The RC is a rectangular chamber of 120 m^3 volume, where the input electromagnetic field can be randomized by means of five metallic stirrers: two of them can work both in step mode and in continuous mode whereas three of them work only in continuous mode. However, it is specified that all stirrers are stopped during the acquisition of measurements. An inside view of the RC is shown in Fig. 3.

FIG. 3

The inside of the RC.

All three measurement setups include a two-port VNA, Agilent model 8363B, one AUT that is a waveguide double ridge horn antenna, whose model is ETS-Lindgren 3115; moreover, a coaxial cable and necessary adapters are used to connect the port of the VNA to the AUT. The FR of the AUT ranges from 1 GHz to 18 GHz. At the extremity of the cable, which corresponds to the reference plane of the AUT, a one-port reflection calibration is made.

Measurements of S_{11} are performed by using the same setting in all three cases: measurements inside the AC, outside of AC, and inside the RC. In particular, 16001 samples are acquired in the FR from 1 GHz to 18 GHz; the SF is 1.0625 MHz.

Figure 4 shows the typical gain of the AUT as a function of the frequency over all its FR (21).

Note that the gain of the AUT versus frequency is useful to understand as it works inside the AC used for tests. In fact, the AC has high performance in terms of reflectivity of its walls starting from some GHz; but the optimization of the performance of the chamber depends also on the gain of the antenna. As an example, it is specified that the optimization of the performance of the AC in terms environment noise in the quiet zone is achieved when an X-band horn standard, which ranges from 8.2 GHz to 12.4 GHz, is used as a transmitting antenna. The considered antenna has a gain of about 16 dB. The AUT works as a transmitting antenna in the measurement campaign.

However, the AUT has a gain such that good performance of the AC is obtained in terms of reflectivity over all FR of the AUT.

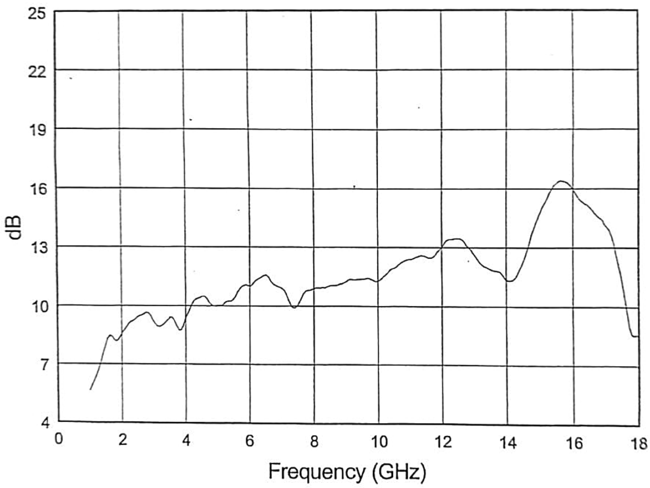


FIG. 4

Typical gain of the AUT
(waveguide double ridge horn antenna, ETS-Lindgren 3115).

Figure 5 shows the mismatch from the AUT measured inside the AC and outside the AC; in the latter case, a metallic panel is put in front of the antenna at a distance of about 35 cm, as shown in Fig. 2. Actually, Fig. 5 shows a third trace, which is achieved from the measurement outside the AC by IFFT, next gating, and FFT to represent results in FD again. The trace concerning measurements inside the AC and that achieved by gating from measurements outside the AC are practically overlapped. In Fig. 6, the comparison is limited to the mismatch measured inside the AC and that obtained from gating operation applied to data acquired outside the AC. It is specified that all results represented in figures are in dB scale.

Figure 7 shows the mismatch from the AUT measured inside the AC and RC. For the latter, the IFFT, gating, and FFT operations are applied. The trace concerning measurements inside the AC and that achieved by gating from measurements inside the RC are practically overlapped.

In Fig. 8, the comparison is limited to the mismatch measured inside the AC and that obtained from gating operation applied to data acquired inside the RC.

It can be noted that results match well; only little differences are noted specially at edge of FR_{AUT}. It is highlighted that no windowing and gating shape was applied for these results. Measurements can be improved; for instance, the same cable should be used for all three measurement setups: that using the AC, outside the AC, and inside the AC, and particular attention should be paid to avoid stress to the cable and connectors during and after calibration is accomplished. Therefore, the improvement of measurements coupled with an optimization for windowing and gating can improve results as well.

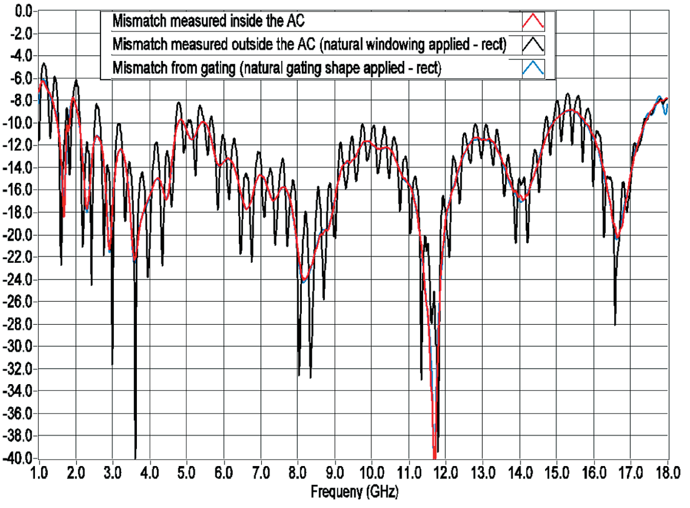


FIG. 5

Amplitude of S_{11} for the AUT. Measurements are acquired inside the AC and outside of it. In the latter case, a metallic panel is in front of the antenna at a distance of about 35 cm; these measurements are also transformed in TD; the concerning trace is transformed in FD again after gate is selected (blue-coloured trace).

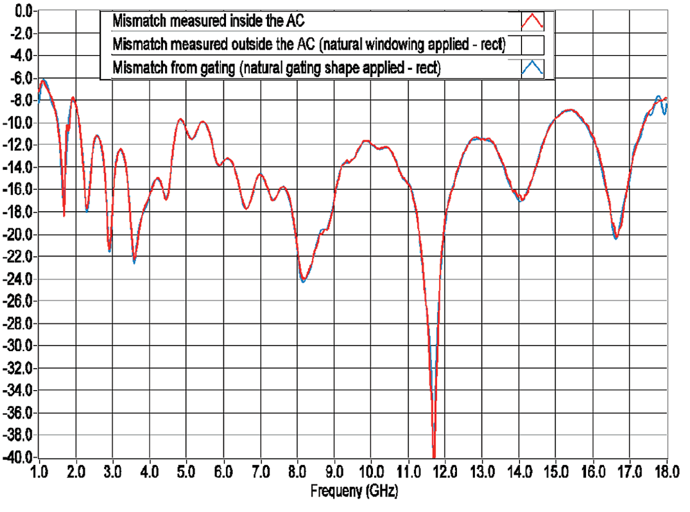


FIG. 6

Amplitude of S_{11} for the AUT. Measurements are acquired inside the AC (red-coloured trace) and outside of it. The latter is transformed in TD; the concerning trace is transformed in FD again after gate is selected (blue-coloured trace).

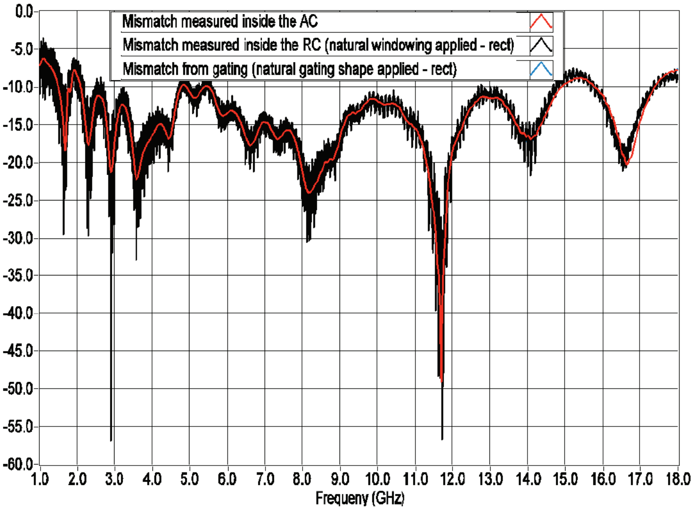


FIG. 7

Amplitude of S_{11} for the AUT. Measurements are acquired inside the AC and RC. The latter is also transformed in TD, the concerning trace is transformed in FD again after that gate is selected (blue-coloured trace).

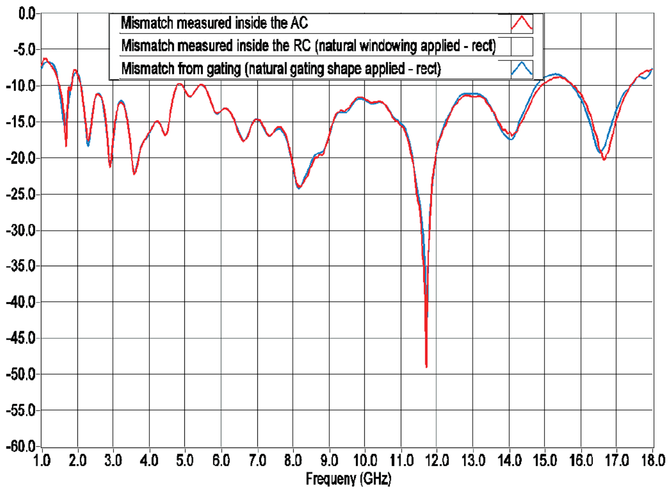


FIG. 8

Amplitude of S_{11} for the AUT. Measurements are acquired inside the AC (red-coloured trace) and RC. The latter is transformed in TD; the concerning trace is transformed in FD again after gate is selected (blue-coloured trace).

4. Discussion and conclusion

It is shown that AIMM of broadband antennas can be made in any electromagnetic environment except for a minimum distance from any reflecting obstacle, in order to avoid affecting the intrinsic impedance of the AUT itself and to achieve a suitable gating. However, in most cases, the necessary distance d_{min} is less than 1 m. Therefore, measurements can be made in any electromagnetic environment but a distance d_{min} has to be considered.

Preliminary results from measurements carried out for a waveguide double ridge horn antenna inside the AC, outside of it, and inside the RC support the practical application of the method proposed in this paper.

The aforementioned minimum distance is properly increased according to the FR_{meas}, and especially according to the duration of the reflection response of the AUT in TD, which depends on the physical structure and on the FR of the antenna itself. Measurements could be optimized by paying attention in the calibration of the whole measurement system. This, together with the optimization for windowing and gating shape, which can be made directly by using the TD option embedded in the VNAs, makes a good application for VNAs also when TD option is not included in them.

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