The well known and widely used “Termination-VSWR” method, used to measure the reflectivity of an absorber wall in an anechoic chamber, has been considerably modernized with the help of new vector network analyzers (VNA) and personal computers (PC), taking advantage of fast sweepers or synthesizers and of the time-domain capability, both automated by the PC. In the past, the measurement, using a slotted line, was made one frequency at a time. It is now possible to cover a complete range of frequencies, with no moving parts, using two different methods: the Advanced VSWR (AVSWR) or the radar cross-section (RCS) method. It is not an exaggeration to say that the progress made in this measurement is as high as the transition between a slotted line measurement and the automated VNA at the end of the 1970s. These new methods allow measuring a complete range of frequencies in the same time it took to measure only one or two frequencies before.

GENERAL CONSIDERATIONS

As a matter of fact, the VNA replaced the slotted line a long time ago to measure RF and microwave components because it was more accurate, it provided phase information and it was possible to measure S-parameters over a full bandwidth in a very short time. The availability of accurate phase measurements, mainly due to the use of synthesizers to produce the RF and microwave signals and to the accurate system calibration, has enabled sophisticated mathematical treatments to be made on the measured signals such as Fourier transform, allowing calculation of echoes in the time domain, filtering and removal of unwanted echoes (time-gating capability), and returning back to the frequency domain with an improved measurement accuracy. The same methodology can now be used also to measure the voltage standing wave ratio (VSWR) of an absorber wall over a full bandwidth, with improved accuracy and in a shorter time. For that purpose, the transmitter/receiver and the stub tuner are now replaced.

G. Cottard
ANTEM
Saint-Maur-des-Fosses, France
Y. Arien
Emerson & Cuming MWP
Westerlo, Belgium
by a VNA with possibly a time-gating capability (time-domain option). This article will first describe the classical Termination-VSWR measurement method, then the new AVSWR and RCS methods.

PREVIOUS VSWR MEASUREMENT METHOD

In the past, to measure the VSWR of a device connected to a line, a conventional slotted section was included in the transmission line feeding the device so that the minimum and maximum levels detected on this line gave the load VSWR, hence its reflection coefficient. The previous Termination-VSWR method was based on this principle to connect a transmitter/receiver to an antenna pointing to the absorber wall under test, and simulate the probe movement in the slotted line by moving linearly the cart carrying the antenna and transmitter/receiver. For better accuracy at low VSWRs, a stub tuner was included before the antenna to reduce the antenna VSWR and enhance the received variations when moving the cart in front of the wall.

Figure 1 shows the basic test set-up used. The measurement procedure is summarized below:

1. The set-up equipment was located on the cart, with the antenna directed towards the wall to be measured.
2. The reference level for 100 percent reflection (short circuit) was obtained by replacing the antenna with a short circuit (without the stub tuner). This level was recorded as level A or Ref. (see Figure 2).
3. The short circuit was removed and the antenna reconnected with a stub tuner in between.
4. The stub tuner was tuned to obtain the minimum signal level possible. When the signal level got too low (that is in the noise floor), then the power level was increased. This increase in decibels was noted on the recorder paper (level L1).
5. The cart was moved either forward or backward along its line-of-sight over a distance relatively small, compared to the distance between the antenna and the absorber wall (generally a few wavelengths, but by a minimum of λ/2 to be sure to have at least a maximum and a minimum). A standing wave pattern was recorded with a minimum level m1 and maximum level M1. Level m1 was caused by the equipment reflected field level (Y) minus the absorber reflected field level (B)

\[ m_1 = 20 \log \frac{Y - B}{A} \]  

(1)

Level M1 was caused by the equipment reflected field level plus the absorber reflected field level (B)

\[ M_1 = 20 \log \frac{Y + B}{A} \]  

(2)

With m1 and M1, one could calculate two reflected field level values

\[ V_1 = \frac{Y}{A} \text{ or } \frac{B}{A} = \frac{1}{2} \left( \frac{-M_1}{10^{20}} + \frac{-m_1}{10^{20}} \right) \]  

(3)

\[ V_2 = \frac{B}{A} \text{ or } \frac{Y}{A} = \frac{1}{2} \left( \frac{-M_1}{10^{20}} - \frac{-m_1}{10^{20}} \right) \]  

(3)

6. In some cases, it was not clear which one was the actual reflected field level value of the absorber or of the equipment. Therefore, a second measurement had to be performed.
7. The stub tuner was set to another level such as level L2.
8. The translation (Step 4) was repeated and another standing wave pattern was recorded. The results were the new minimum level m2 and maximum level M2.
9. In the same way as for the first standing wave pattern, two reflected field level values were obtained

\[ V_3 = \frac{Y}{A} \text{ or } \frac{B}{A} = \frac{1}{2} \left( \frac{-M_2}{10^{20}} + \frac{-m_2}{10^{20}} \right) \]  

(4)

\[ V_4 = \frac{B}{A} \text{ or } \frac{Y}{A} = \frac{1}{2} \left( \frac{-M_2}{10^{20}} - \frac{-m_2}{10^{20}} \right) \]  

(4)
10. Between the first and second measurement the reflected field level of the absorbers (B) did not change. However, by changing the setting of the stub tuner, the reflected field level of the equipment (Y) changed. Therefore, the two identical values out of the four, V1 = V3 or V4, or V2 = V3 or V4 corresponded to the reflectivity (linear) of the absorbers. Examples of the recording and calculations are given in Appendix A.

This method was powerful but rather slow because only one frequency could be measured at a time (receiver limitation), and many cart positions were necessary to find contiguous maximum and minimum levels (slotted line method limitation). Also, with the cart and receiver accuracies, this method was almost never used above 12 GHz.

Now that recent VNAs with time-domain capability and broadband directive antennas exist, it has become possible to modernize the “VSWR method” with two methods:

The “Advanced VSWR method” to measure an absorber wall VSWR. This method works fine between 0.5 and 6 GHz with the help of a broadband horn antenna.

The “RCS method,” for 6 to 18 GHz, which measures the wall reflectivity through its radar cross-section with a quasi-monostatic bench using two broadband horn antennas, located close to each other.

**THE AVSWR MEASUREMENT METHOD**

*Figure 3* shows the equipment necessary to perform this type of measurement. It includes a VNA (covering the requested frequency range), with the time-domain option, a calibration kit for $S_{11}$ (reflection) measurements, that is a short, open and a broadband 50 Ω load, a broadband directive antenna, an antenna pylon or tripod to hold firmly the antenna during the measurements, good quality 50 Ω coaxial cables to connect the antenna to the VNA, microwave absorbers to cover the floor between the antenna front and the wall to reduce unwanted echoes, a yardstick to measure the antenna height and the antenna to wall distance, and optionally (but useful) a computer to record the data and drive the VNA through the right interface (generally GPIB).

The AVSWR procedure can be summarized as follows:

1. The antenna is pointed towards the wall at a close distance (approximately 1 m from the absorber tips).
2. The VNA is calibrated at the end of the cable, for $S_{11}$ with the calibration kit short, open and load. If a sliding load is supplied in the calibration kit, the calibration will, of course, be better with it.
3. The calibration is verified by reconnecting the standards (open, short, broadband load) and check in log-amplitude and Smith charts or polar chart that the points are located correctly. Then, record the calibration in memory. Note: one should see on the polar plots of the short, open and load at the places represented (case of a perfect $S_{11}$ calibration).
4. The broadband antenna is connected to the VNA and the time-domain mode of the VNA is selected, generally in the band pass time-gating mode (refer to the VNA manual for more details). The screen now shows the time-domain response in reflection, including antenna and wall reflection.
5. One validates the time gating and selects the frequency domain. The curve ($S_{11}$ log mag. mode) now shows directly the reflection coefficient of absorber wall in decibels as a function of frequency.

This AVSWR method is much simpler than the Termination-VSWR one. The complete reflectivity curve is obtained without any antenna movement. This is a real improvement in measurement speed and quality. If the time-domain option is not included in the VNA, the time gating can also be made by the associated PC, with the direct fast-Fourier transform, filtering and then reverse fast-Fourier transform.

**THE RCS MEASUREMENT METHOD**

To verify the RCS specifications of an anechoic chamber, or the reflectivity of a specified wall, it is possible to perform RCS measurements of a standard RCS target (called reference target) and to compare it with the RCS of the empty room. A typical set-up used for the RCS measurement is shown in *Figure 4*. The method justifications are shown in Refs. 1 and 2, although it is useful to note that

$$\text{RCS} = \sigma = \pi R^2 \text{Re}$$

is the linear equation relating the RCS of a receive wall covered with absorbers at a distance $R$ to the antennas and Re the linear absorber reflectivity. This equation is also approximately true for the receive wall of a fully anechoic chamber as the other walls have negligible effects.

Expressed in decibels, this equation becomes

$$\text{RCS}_{\text{chamber}} (\text{dBm}^2) = \text{Re} (\text{dB}) + 10 \log (\pi R^2) (\text{dBm}^2 \text{ or } \text{dBsm}, \text{ if } R \text{ in m})$$

This method is convenient and more “natural” for RCS chamber but also to replace or modernize the classical Termination-VSWR method, which in addition gives the reflectivity of an absorber wall under normal incidence.

To perform the measurements, the following equipment is required:

- A VNA (covering the requested frequency range), with good sensitivity and time-domain option.
- Two broadband directive antennas covering the frequency range, or one broadband directive antenna associated with a directional coupler for
a real monostatic measurement. The bandwidth of each antenna must be sufficient to have a time-domain solution able to isolate the antenna(s) from the wall.

- Antenna pylons or tripods to hold firmly the antennas during the measurements.
- At least one metallic reference RCS target to make the reference measurement with its transparent pylon (expanded polystyrene, for example).
- A manual or automated positioner to locate the RCS reference target at the right elevation and azimuth angles in front of the antennas (if a directive flat target), not necessary in the case of a sphere reference target (omni-directional target).
- Good quality 50 Ω coaxial cables to connect the antennas to the VNA.
- Eccosorb absorbers to cover the floor between the antenna front and the wall to reduce unwanted echoes (if necessary), and also to reduce direct coupling between antennas.
- Means to determine the distances between antennas and wall (R) and between antennas and target (D).
- Optionally (and usefully) a computer to record the data and drive the VNA through the right interface (generally GPIB).

...above a positioner at a distance D from the antennas (see Figure 6). The RCS reference target is a known RCS target (conducting flat plate or a metallic sphere or a metallic trihedron, etc.). If the target is a sphere or a well-oriented trihedron, no positioner is needed, since they are almost omni-directional targets.

6. One selects the time-domain mode of the VNA. The screen now shows the time-domain response, including antennas coupling, target and wall reflection. The gating must now start before the target and finish after. One then validates the time gating and selects the frequency domain mode. The curve ($S_{21} \log \text{mag. mode}$) now directly shows the reflection level of the RCS reference target in dB, also called reference level “Ref” (if no other obstacle can exhibit reflection in the same time-gating window).

7. From the linear “Emp” and “Ref” measured data, one computes the RCS of the receive wall, which is also the anechoic chamber RCS. The absorbers reflectivity is obtained from the following formulas:

\[
RCS_{\text{chamber}} = RCS_{\text{ref}}(\text{Emp/Ref})^2(D/R)^4 \text{ (m}^2) 
\]

\[
RCS_{\text{ref}} \text{ being the theoretical reference target RCS, given in dBm}^2 \text{ or dB}_{\text{sqm}}.
\]

\[
RCS_{\text{chamber}}(\text{dBm}^2) = RCS_{\text{ref}}(\text{dBm}^2) + \text{Emp (dB)} - \text{Ref (dB)} - 40 \log(R/D)
\]

**Note:** 40 log(R/D) is the distance correction factor added to Ref RCS as this target is not at the same distance from the antennas as the wall. The wall absorber reflectivity can be then deduced from

\[
RCS_{\text{chamber}} = \pi R^2 \text{Reflectivity}
\]

or, in dB_{sqm}

\[
\text{Reflectivity (dB)} = RCS_{\text{chamber}}(\text{dBm}^2) - 10 \log(\pi R^2)(\text{dBm}^2)
\]

**COMPARISON BETWEEN THE OLD (VSWR) AND NEW (AVSWR AND RCS) METHODS**

The AVSWR was used to test anechoic chamber walls, with a configuration shown in Figure 7, with a wideband horn on a tripod associated with a compact VNA and a laptop.

This technique was originally validated on a dedicated test wall covered with 16 pieces (4 × 4 square) of...
2 × 2 feet VFX-18-NRL absorbers (18 inches high pyramidal absorbers). The curves shown in Figure 8 are the results obtained with two different horns in the same position, for the same wall. These two curves are quite similar in their common part and very close to the VFX-18-NRL performance measured on classical NRL Arch (green line).

Figure 9 shows the RCS experiment conducted on a recent anechoic chamber to measure the absorber wall reflectivity. The old Termination-VSWR method was also used at selected frequencies to validate the RCS method. In Figure 10 the blue line between 6 and 18 GHz is obtained with this RCS method and shows a good agreement with the VSWR method (red dots). Between 0.5 and 6 GHz, the AVSWR method was used and the comparison with the VSWR method also shows a good agreement (green line).

CONCLUSION

The classical Termination-VSWR method was powerful but rather slow because only one frequency could be measured at one time (receiver limitation), and many cart positions were necessary to find contiguous maximum and minimum levels (slotted line method limitation). Also, because of cart and receiver accuracy, this method was almost never used above 12 GHz.

It is now possible to use two new methods:

- The “Advanced VSWR method” to measure an absorber wall VSWR. This method works fine between 0.5 and 6 GHz with the help of a wide-band horn antenna.

- The “RCS method,” for 6 to 18 GHz, which measures the wall reflectivity through its radar cross-section with a quasi monostatic bench using two wideband horns antennas, close together. This RCS method is, of course, more natural for RCS chambers.

The first measurements that were done with these two methods show a good agreement with microwave absorber performance and with the results obtained from the previous VSWR method.

The “Advanced VSWR method” is the natural evolution of the Termination-VSWR method, taking into account the possibilities that are given by the up-to-date equipment, such as vector network analyzers, wideband horn antennas and personal computers.

At this time, this method has been shown to be efficient and valid between 500 MHz and 6 GHz with a standard wideband horn antenna. The frequency range could be extended, depending largely on antenna bandwidth and directivity.

The “RCS method,” which is not as new, but is not widely used in anechoic chamber testing, has been more often used in RCS chamber measurements. Even if more complex than the AVSWR method, it is still a reliable and not too complex method to measure not only the RCS but also the reflectivity of an absorbing wall. It is now used between 6 and 18 GHz with standard double ridge wideband horns, although the frequency range could also be extended.

References

Gil Cottard received his engineering degree in radio communications from Ecole Superieure d’Electricite, Paris, France, in 1981.

Yoeri Arien received his engineering degree in telecommunications from Hogeschool Limburg, Belgium, in 1996.

**APPENDIX A**

**TERMINATION–VSWR METHOD RESULT EXAMPLE**

For a certain setting of the stub tuner, pattern 1 is obtained (see Figure A1).

- Maximum level $M_1 = -18.1$ dB
- Minimum level $m_1 = -22.6$ dB

Converting these values into reflected field level values:

- Maximum level $M_1 = 0.124451461$
- Minimum level $m_1 = 0.074131024$

\[
\text{VSWR} = \frac{M_1 + m_1}{2} = 0.099291243 = -20.1 \text{ dB}
\]

\[
\text{VSWR} = \frac{M_1 - m_1}{2} = 0.025160219 = -32.0 \text{ dB}
\]

A second setting of the stub tuner gives pattern 2:

- Maximum level $M_2 = -14.8$ dB
- Minimum level $m_2 = -17.2$ dB

\[
\text{VSWR} = \frac{M_2 + m_2}{2} = 0.16004256 = -15.9 \text{ dB}
\]

\[
\text{VSWR} = \frac{M_2 - m_2}{2} = 0.021965830 = -33.2 \text{ dB}
\]

Comparing reflected field levels 1 and 2 with reflected field levels 3 and 4 shows that reflected field levels 2 and 4 must be from the absorber and reflected field levels 1 and 3 from the equipment. In theory the absorber values should be exactly the same but in practice they can differ a little. In these cases one takes the average between reflected field level 2 and reflected field level 4. The resulting performance is $-32.6$ dB.

\[\text{Fig. A1: Data sheet for the Termination-VSWR method example.}\]