BASIS OF ELECTROMAGNETIC COMPATIBILITY OF INTEGRATED CIRCUIT

Chapter VII - EMC Measurement Fundamentals

Corrections of exercises

I. EXERCISE NO 1 - Interference

A radio receiver operating at 868 MHz has a receiving sensitivity of -90 dBm. Its radio input is 50 Ω-matched and is terminated by an antenna with an antenna factor of 10 dB/m. The radio receiver is placed 2 metres from some noisy electronic equipment with a CE marking, compliant with standard EN 55022 – class B (refer to Figure 7-8 for the radiated emission limit defined by EN 55022).

The radiated emission test for the noisy equipment is performed in an ALSE. A receiving antenna with a gain of 23 dB/m is placed 3 metres in front of the noisy equipment. The antenna is connected to an EMI receiver by cables and a 30 dB preamplifier. The total cable loss is equal to 2 dB. The maximum level measured by the EMI receiver at 868 MHz is 40 dBµV.

1. What is the maximum electric field radiated by the noisy electronic equipment at a distance of 1 metre?

2. According to the details given about the noisy equipment's radiated emission test, compute the electric field at 868 MHz at a distance of 3 metres. Does the equipment comply with the limit defined by EN 55022?

3. Compute the electric field produced by the noisy equipment illuminating the radio receiver at 868 MHz.

4. Compute the voltage and power induced at the radio receiver input.

5. Draw a conclusion about the interference between the noisy equipment and the radio receiver. Do you think that compliance with EN 55022 is a guarantee against interference?

Corrections:

1. According to Fig. 7-8, the maximum electric field measured at 1 m from the noisy equipment is E_{max} = 57 dBµV/m

2. According to Eq. 7-1, the electric field produced at 3 meters by the noisy equipment is equal to :

$E_{3m} = V_{meas}+AF+L_{cable}-G_{preamp}$ =40+23+2-30 = 35 dBµV/m

If we suppose far-field and free space conditions, the electric field can be extrapolated at 1 meter according to eq. 7.2 :

$E_{1m} = E_{3m}+20.\log10(3/1) =35+9.5 = 44.5$ dBµV/m

The measured electric field is 2.5 dB less than the EN55022 - class B limit, so the equipment is considered as compliant (at least at 868 MHz).

3. According to eq. 7.2 :

$E_{2m} = E_{3m}+20.\log10(3/2) =35+3.5 = 38.5$ dBµV/m

4. According to Eq. 7-1, the voltage induced at the receiver input: $V_{in} = E_{2m} - AF = 38.5 - 10 = 28.5$ dBµV.

The power delivered at the receiver input (50 Ω matched)is:

P_{in} (dBm) = V_{in}(dBµV) – 107 = -78.5 dBm.

5. The power induced by the noisy equipment radiation is 12 dB above the sensitivity floor of the receiver and thus it may desensitize the radio receptor. It may become less sensitive, or reception errors may happen more often in presence of the noisy equipment.

In this situation, the standard EN55022 does not guarantee the lack of interference of nearby radio receiver. It is dependent on the characteristics of the radio receiver and its distance to the noisy equipment.

II. EXERCISE NO 2 - Sensitivity of an emission measurement set-up

A radiated measurement test follows a standard which defines a maximum emission level of 30 dBµV/m over a given frequency range. The antenna used for the test has an antenna factor of 13 dB/m and the overall losses are equal to 2 dB. The measurement receiver has the following settings: RBW = 100 kHz, VBW = 100 kHz, Input attenuation = 10 dB, peak detector. In this configuration, the receiver has a nearly constant noise floor of 15 dBµV.

1. What is the minimum amplitude of the electric field able to be measured?

2. The standard requires that the noise floor of the measurement receiver be at least 6 dB below the emission limit. Does the measurement comply with this condition?

3. Do you think that a preamplifier should be placed between the antenna and the receiver? If so, what should be its gain?

4. Propose alternative solutions for improving the sensitivity of the measurement set-up.

Corrections:

1. The minimum amplitude of the electric field that can be detected by the measurement receiver generates at the receiver input a voltage equal to its noise floor V_{min}, i.e. 15 dBµV. According to Eq. 7.1, the minimum amplitude of the electric field is equal to:

$E_{min} = V_{in} + AF - Lc = 15+13+2+0 = 30$ dBµV/m, where Lc is the cable attenuation.

2. To verify that radiated emission of the device under test is less than 30 dBµV/m, it is necessary that the minimum electric field that can be detected is smaller than 30 dBµV/m. That's why the standard requires that the noise floor of the measurement receiver has to be 6 dB below the voltage generated by an electric field equal to the limit 30 dBµV/m.

To fulfill this condition, the minimum electric field that the receiver can detect should be less or equal to 24 dBµV/m. With the current configuration, the measurement is not enough sensitive.

3. A preamplifier is a low-noise amplifier able to increase the amplitude of the input signal without increasing as much the noise floor. It can improve the sensitivity of the measurement system without changing the receiver.

The measurement system has to detect an electric field equal to 24 dBµV/m. If we neglect the noise introduced by the preamplifier, its minimum gain G_{min} is equal to:

$G_{min} = V_{min} - E_{min} + AF + Lc = 15-24+13+2 = 6$ dB

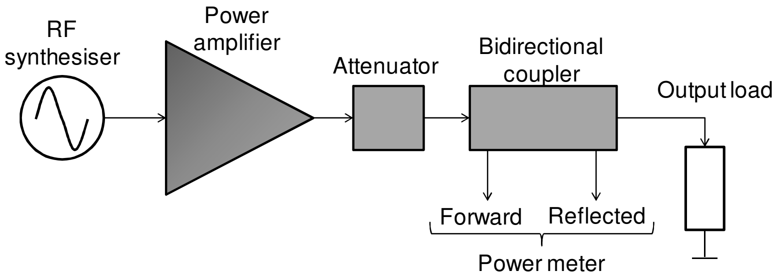
Actually, the minimum gain should be increased by the noise figure of the preamplifier to compensate the increase of the noise floor due to the preamplifier.

4. If no preamplifier are available for this measurement, a more sensitive antenna could be found. If possible, the settings of the receiver could be changed to improve the noise floor of the receiver. For example, reducing the input attenuation to 0 dB will reduce the noise floor by 10 dB, with a risk of saturation of the input stage of the receiver. RBW and VBW could also be reduced, but with a longer sweep time.

III. EXERCISE NO 3 - Power budget for a susceptibility test bench

The following susceptibility test bench has been set up and you want to check that the equipment power capabilities have been selected correctly. The RF harmonic disturbance is produced by an RF signal synthesiser able to deliver a maximum power of 10 dBm to a 50 Ω load. It is followed by an RF power amplifier with a gain of 40 dB. Its output 1 dB compression point is equal to 45 dBm. A 6 dB RF attenuator is placed at the amplifier output. It can dissipate a maximum power of 20 W continuously. The attenuator is followed by a directional coupler, with a coupling factor considered to be constant and equal to -20 dB. The isolation between the forward and reflected signal terminals is equal to 40 dB and the insertion loss introduced by the coupler is equal to 1 dB. The coupler withstands a maximum power of 60 W.

The forward and reflected wave amplitudes are measured by a two-channel power meter, which can withstand a maximum power of 20 dBm. The inputs and outputs of all the equipment are considered to be matched to 50 Ω.



1. A 50 Ω load is connected to the coupler output. The RF generator delivers a power equal to -20 dBm. What is the power dissipated by the load?

2. What are the power values read on each channel of the power meter?

3. Is it possible to damage the coupler?

4. What is the maximum amplitude of the RF generator to prevent the attenuator from overheating? To prevent the power meter channels from overloading? Is it possible to damage the attenuator and the power meter?

5. What should be the power capability of the output load?

Corrections:

1. $P_{load} = P_{in}+G_{PA}-L_{atten}-L_{coupl}$ = -20+40-6-1 = 13 dBm = 20 mW

2. As the output of the coupler is matched by 50 Ω load, the forward power is equal to 13 dBm and the reflected power is null. If we take into account the coupling factor of the coupler, the power read on the channel connected to the "Forward" terminal is equal to 13 – 20 = -7 dBm. Although no backward wave propagates along the coupler, a part of the forward wave is coupled on the "Reflected" terminal because of the finite isolation between "Forward" and "Reflected" terminal. The power read on the channel connected to the "Forward" terminal is equal to -7 – 40 = -47 dBm.

3. The maximum power delivered by the amplifier is equal to 45 dBm, so the power applied to the coupler is limited to 39 dBm, i.e. 8 W. The coupler cannot be damaged.

4. The power meter is able to dissipate a maximum power $P_{atten\ max}$ of 20 W, i.e. 43 dBm. The power dissipated by the attenuator is equal to: $P_{atten} = \frac{P_{out}}{k_c} - \frac{P_{out}}{k_c k_A}$, where P_{out} is the power delivered by the amplifier, k_c is the attenuation coefficient brought by the coupler (1 dB, i.e. 1.26) and k_A the attenuation coefficient brought by the 6 dB attenuator (6 dB, i.e. 4). The maximum output power of the amplifier is equal to:

$$P_{out\ max} = \frac{k_c k_A}{k_A - 1} P_{atten\ max} = \frac{4 \times 1.26}{3} \times 20 = 33.6\ W = 45.3\ dBm$$

The power amplifier delivers this amount of power when the RF generator delivers a power of 5.3 dBm. Normally, the amplifier starts saturating.

The power meter channel input can only withstand an input power of 20 dBm. If the coupling factor is taken into account, this maximum power is reached when the power carried by the forward wave is equal to 40 dBm, i.e when the output amplifier delivers a power of 46 dBm and the RF generator delivers a power of 6 dBm. Normally, the output amplifier starts saturating and cannot deliver 46 dBm.

In both cases, the margins to protect the attenuator and the power meter are not enough (only 1 dB). Either the power delivered by the amplifier should be limited, or an attenuator with a larger power capability and attenuators placed before power meter channels should be introduced.

5. If the power amplifier reaches the saturation, it can deliver 45 dBm. If the losses introduced by the 6 dB attenuator and the coupler are taken into account, the power delivered to the load is equal to:

45-6-1 = 38 dBm, i.e. 6.3 W.

Thus, the load must withstand more than 6.3 W.

IV. EXERCISE NO 4 - Radiated susceptibility test

The RF generator, power amplifier and coupler of the susceptibility test bench described in the previous exercises are reused for radiated susceptibility tests. The tests are performed in an ALSE, with a wideband antenna whose 6 dB gain is considered to be constant. The overall losses due to cables and antenna mismatch are also considered to be constant and equal to 3 dB.

Is the test bench suitable for the following two cases?

1. antenna placed 3 m away, maximum electric field set to 10 V/m
2. antenna placed 1 m away, maximum electric field set to 100 V/m

If not, what should be the maximum power delivered by the power amplifier?

Corrections:

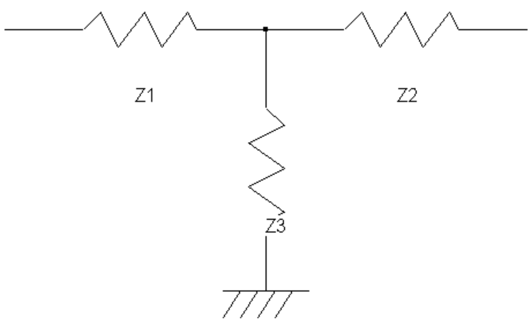
1. Use Eq. 7-3 to make the link between the forward power and the radiated electric field at a given distance to the antenna. In both cases, the maximum forward power is equal to 45 dBm (the 1 dB compression point of the power amplifier), the antenna gain to 6 dB and the overall loss equal to coupler loss plus cable loss, i.e. 4 dB

- ✓ Case 1: at 3 m, the electric field amplitude can reach up: E_{max} = 13 V/m. Normally, a maximum electric field of 10 V/m can be reached with this power amplifier.

- ✓ Case 2: at 1 m, the electric field amplitude can reach up: E_{max} = 39 V/m. A maximum electric field of 100 V/m cannot be reached with this power amplifier. To produce 100 V/m at 1 m, the required power delivered by the amplifier must be at least: $P_{\min}\left|W\right| = \frac{4\pi R^2 \times L}{\eta_0 \times G_{ANT}} E^2 = 209W$, i.e. 53 dBm.

V. EXERCISE NO 5 - Attenuator for susceptibility test

Simple models of attenuators can be found in the literature. The following figure and equations propose a T model of a resistive attenuator.



$$Z_3 = \frac{2L}{1-L^2} Z_C$$

$$Z_1 = Z_2 = \frac{1-L}{1+L} Z_C$$

where L is the voltage attenuation of the device terminated by a resistive load (0<L<1) and Zc is the input and output reference impedance.

1. Propose the circuit diagram of an ideal 6 dB attenuator based on three resistors. The attenuator must be 50 Ω-matched at both input and output.

2. Build the diagram with IC-EMC and place two S parameter ports on each side of the attenuator model. Set up an S parameter simulation between 100 kHz and 1 GHz. Check the properties of your attenuator (attenuation, input and output matching).

3. What is the input impedance of the attenuator when it is terminated by a 50 Ω load? If the attenuator output is opened? If the attenuator output is shorted? In each case, compute the VSWR.

4. Draw conclusions about the effect of the attenuator.

5. Open the file “book\ch7\RFI_atten6dB.sch”. An RFI source modelling a power amplifier is connected to an unmatched load through a coupler and an attenuator. The frequency of the disturbances is set to 100 MHz and the RFI amplitude is set to 30 dBm. Compute the forward and reflected voltage in the following cases:

- with an attenuator
- without an attenuator

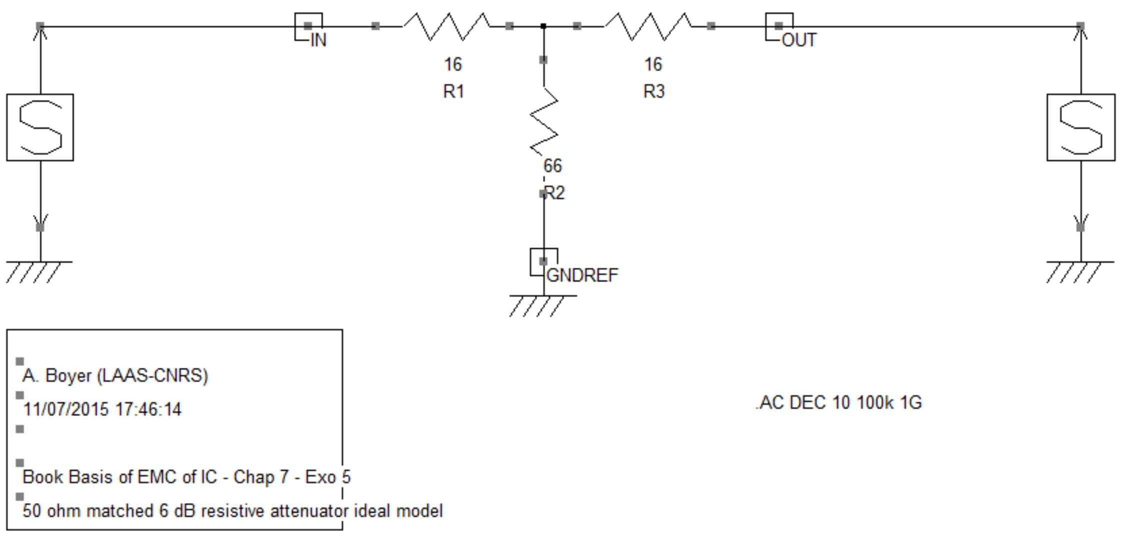
Compare the results. What is the practical interest of the power amplifier?

Corrections:

1. According to the equation for a T model of a resistive attenuator, to build a -6 dB attenuation (L = 0.5), the following resistances must be chosen:

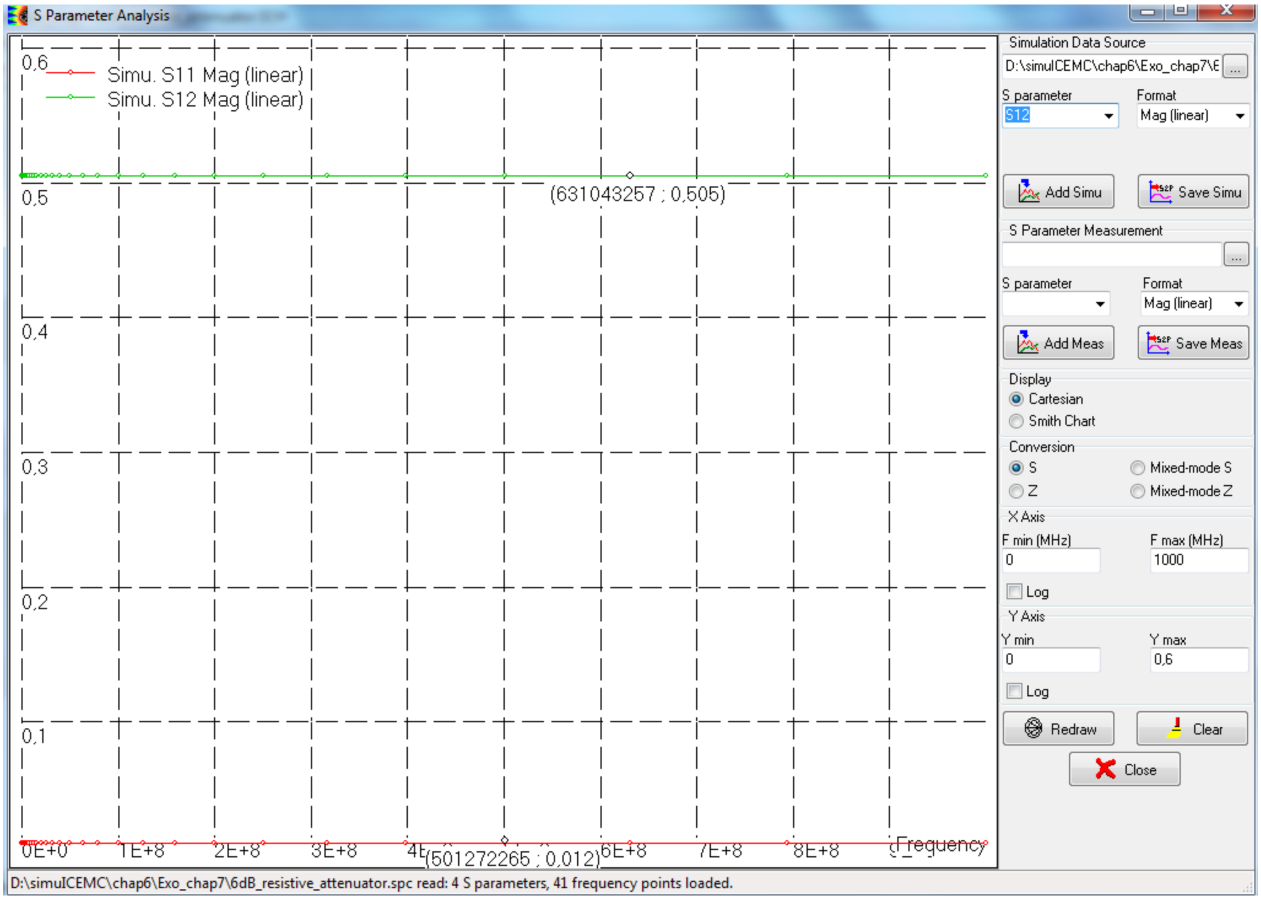
R1 = R2 = 16.7 Ω and R3 = 66.7 Ω

2. Open the schematic 6dB_resistive_attenuator.sch. The schematic diagram is shown below. It includes the three resistances computed in question 1, two S parameter probes and a SPICE command for an .AC simulation (use the command "Insert / Insert Analysis Line" to include a SPICE simulation command). I/O terminals are placed at input (IN), output (OUT) and ground reference (GNDREF) terminals. Port 1 is defined between IN and GNDREF, while port 2 is defined between OUT and GNDREF. Click on to generate the netlist and launch the SPICE simulation.



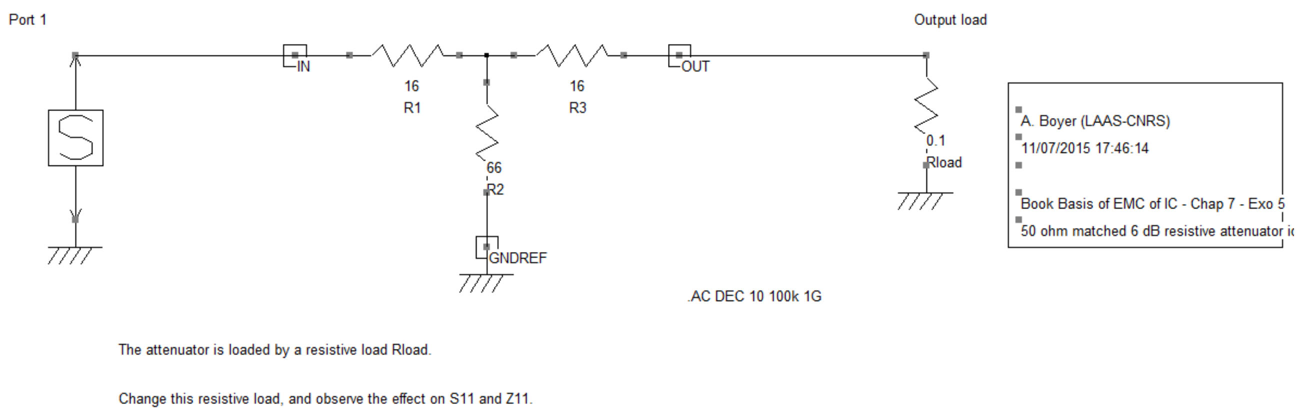
At the end of the simulation, click on to open the S parameter window. In the list "S parameters" in the top right part of the window, select "S11" and click on the button Add Simu to plot the evolution of S11 parameter (reflection coefficient seen from the input terminal when the attenuator's output is loaded by a 50 Ω load). Then Select "S21", click on the button Add Simu to plot the evolution of S21 parameter (transmission coefficient from the input to the output terminals, which is loaded by a 50 Ω load). As the circuit is symmetrical and passive, S11 = S22 and S12 = S21.

The result is shown below.



S11 and S22 are equal to 0 so the attenuator is 50 Ω matched at the input and output. Moreover, S12 or S21 are nearly equal to 0.5 so the attenuation coefficient is equal to 6 dB as expected.

3. Open the schematic Zin_resistive_attenuator.sch. The schematic diagram is shown below. The S parameter probe placed on the terminal OUT was removed and replaced by a termination resistance. We will change its value and simulate its effect on the impedance seen from port 1 (simulated with a S parameter probe).



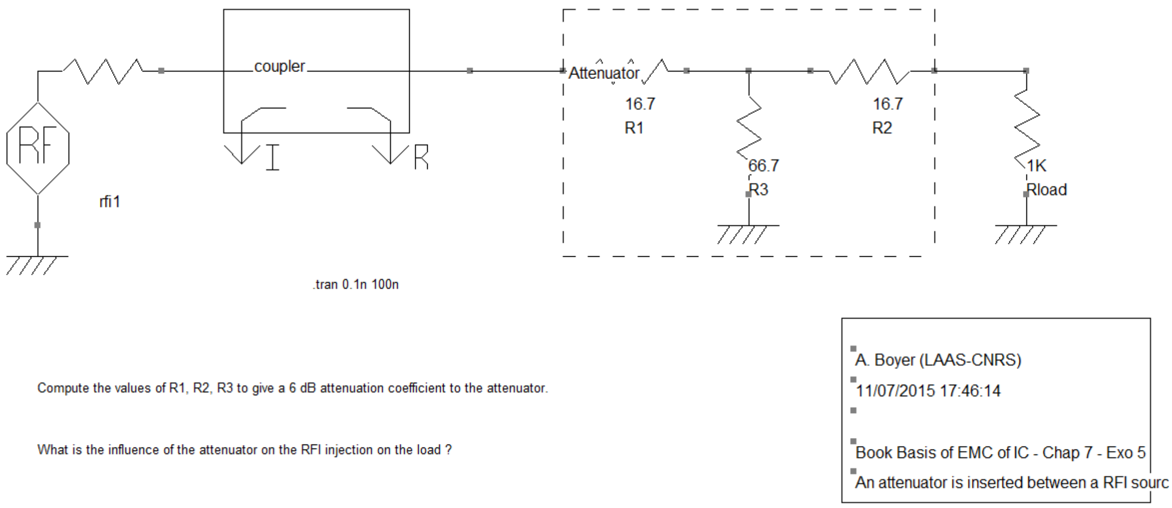
Click on to generate the netlist and launch the SPICE simulation. At the end of the simulation, click on to open the S parameter window. Select "S11" and click on the button Add Simu to plot the evolution of S11 parameter. By default, S parameters are plotted. They can be converted in Z parameters by selecting 'Z' in the list conversion.

The simulation results are:

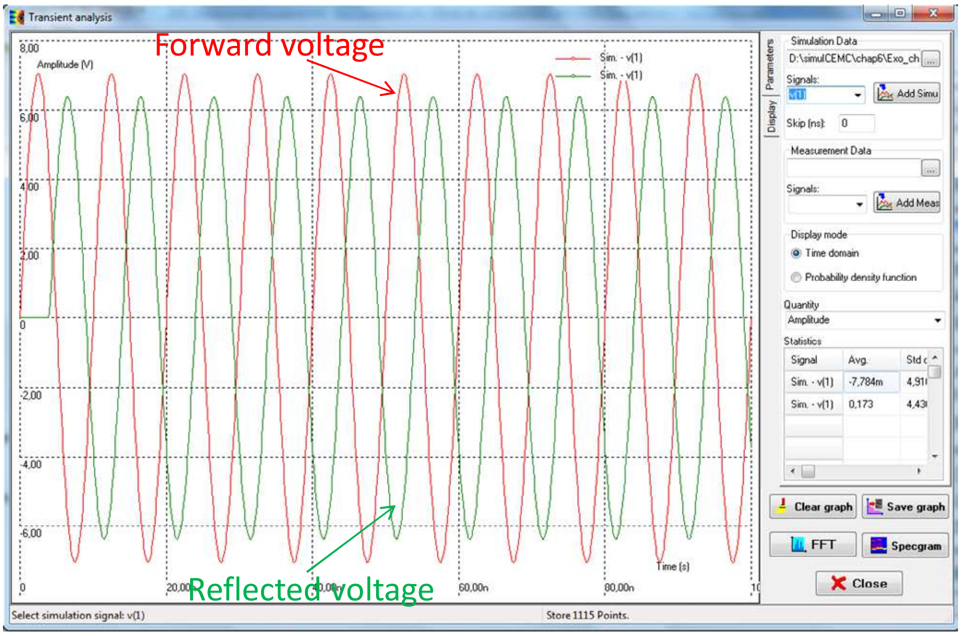
- If the output load is 50 Ω, the input impedance is 50 Ω, the reflection coefficient S11 = 0 and the VSWR = 1.
- If the output is opened (Rload set to 1 M Ω), the input impedance is 82 Ω, the reflection coefficient S11 = 0.242 and the VSWR = 1.63.
- If the output is shorted (Rload set to 0.1 Ω), the input impedance is 29 Ω, the reflection coefficient S11 = 0.267 and the VSWR = 1.73.

4. The attenuator reduces the reflected wave from the terminal to the load, and thus the VSWR. Even if the load is completely unmatched, the input impedance seen from the input of the attenuator gets closer to 50 Ω.

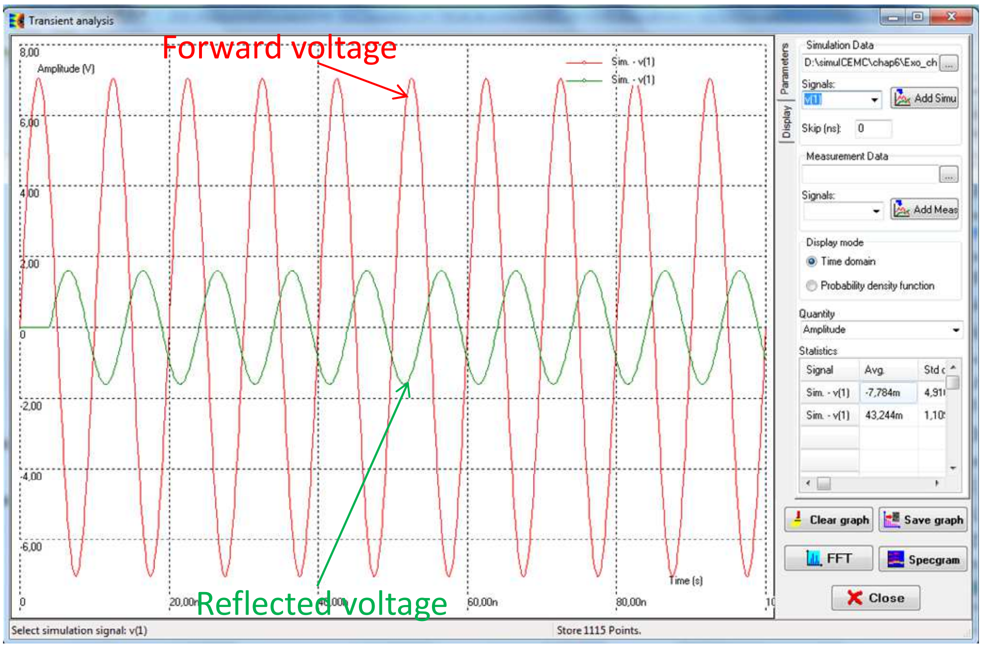
5. The schematic diagram RFI_atten6dB.sch is shown below. It includes a RFI source, a bidirectional coupler to extract the voltage or the power of the forward and reflected wave, the resistive attenuator and the termination load. The amplitude of the RFI generator is set to 7.07 V to induce an average forward power equal to 1 W (30 dBm). The schematic diagram is modified in the file RFI_No_atten.sch. The attenuator is removed in this model. In the following simulation, a 1 kΩ load is inserted.



Without attenuator, the forward voltage is equal to 7.05 V while the reflected voltage is equal to 6.38 V. The reflected wave has nearly the same amplitude than the forward wave, resulting in a high VSWR and a likely degradation of the output of the power amplifier if it cannot withstand such high VSWR.



With attenuator, the forward voltage is equal to 7.05 V while the reflected voltage is equal to 1.6 V. The reflected wave has been seriously reduced, preventing the output amplifier from damages.



An attenuator can have practical applications in EMC to protect the output of power amplifier when they are loaded by unmatched load. Large VSWR may lead to overvoltage conditions on the amplifier's output which may damage it. This protection is made at the price of a reduction of the power delivered to the load.