MEASURING ANTENNÆ INPUT IMPEDANCES

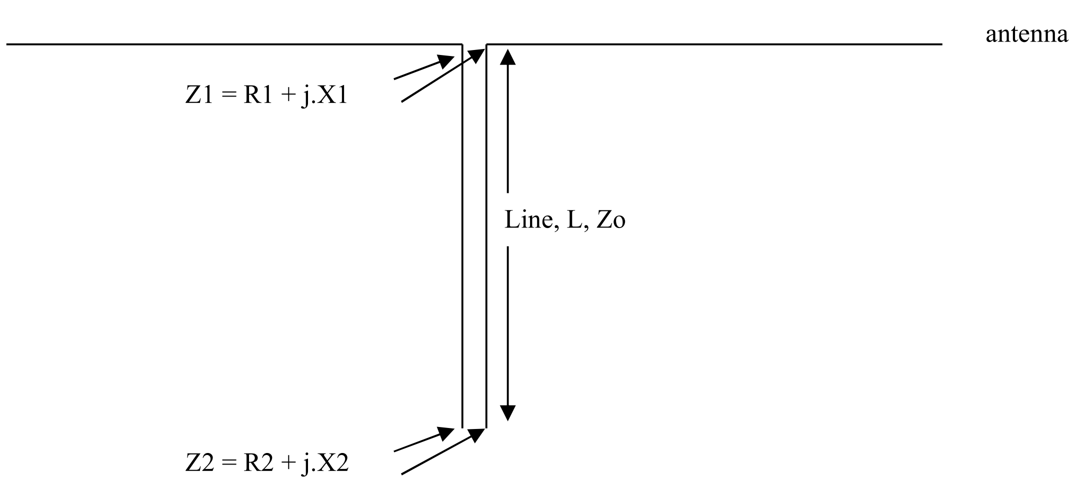
By Luiz Amaral
PY1LL/AC2BR

Using antennæ impedance meters (some well-known by the hamradio community), general impedance meters (as some vector impedance meters, not so well-known) or even homebrew meters, it is relatively simple to measure the impedance at the lower end of the transmission line connected to the antenna. But this doesn't tell much about the input impedance of the antenna itself, as this is shown at the lower end transformed by the line.

To measure locally the antenna input impedance is difficult, as, if we lower the antenna to a more comfortable level, the electrical characteristics change much to render the measured values useless.

To perform the measurements with the antenna at its definitive place presents the physical difficulty of the eventual height, besides the parameters perturbation introduced by the presence of the person body and the meter itself and, depending on the frequency and other parameters, may be fatal.

The best manner to do it is with the line connected, but with its parameters controlled, that is, knowing the line surge impedance, its physical length, its velocity factor and if necessary, its loss at the operation frequency. With this line connected to the antenna, ones measures the impedance reflected to the line lower end and infers the load impedance (the antenna itself at the upper end of the line). See the Figure below.



For practical effects, we may consider the line as ideal (lossless) as we must always work with the minimum loss as possible, but those more purist may perform the tasks considering the losses too.

For an ideal line with surge impedance Zo, with physical length L, loaded by impedance Z1, the reflected impedance Z2 at the other is given by:

$Z2 = Zo \cdot [Z1 + Zo \cdot j \cdot tg(\beta \cdot L)] / [Zo + Z1 \cdot j \cdot tg(\beta \cdot L)]$ [1]

where $\beta = 2 \cdot \pi / \lambda$, with λ the wavelength on the cable, that is, talking into account the velocity factor:

$\lambda = v / f = \gamma \cdot c / f$, with v = velocity of light in the cable, γ = cable velocity factor, f = operation frequency and j = imaginary unity.

So, $\beta = 2 \cdot \pi \cdot f / (\gamma \cdot c)$ [2]

From [1], we can get Z1, that means, which is the load impedance Z1 that corresponds to reflected measured impedance Z2:

$Z1 = Zo \cdot [Z2 - Zo \cdot j \cdot tg(\beta \cdot L)] / [Zo - Z2 \cdot j \cdot tg(\beta \cdot L)]$ [3]

Thus, the measured value Z2 at the lower end of the line put into the expression [3] and using [2], lets us know the impedance presented by the antenna at its upper end.

It is clear that Z1 as much as Z2 can have both resistive and reactive components{1}. If the antenna is a resonant load, its reactive component is zero and, therefore, Z2 is real.

By analyzing [1], we verify that Z2 = Zo if and only if Z1 = Zo{2}, when the standing wave ratio VSWR =1:1.

This process let us adjust an antenna with successive measurements till we get, if possible, the desired condition, that is, Z2 = Zo for any length L, what corresponds to VSWR = 1:1 and when the total loss in the cable is a minimum.

To increase the speed of the process, the expression [3] may be calculated by a computer program (or programmable pocket calculator) using a very simple program, remembering that, indeed, the resistive and reactive components of Z1 are calculated separately.

So, if Z1 and Z2 have components Z1r and Z1i and Z2r and Z2i, where r = real and i = imaginary{3}, we have:

$Z1 = X1 + j \cdot X1$
$Z2 = R2 + j \cdot X2$

{1}The resistive part of impedances is real and the reactive is imaginary. As we are neglecting the losses, here Zo is real.
{2}For finite cable lengths, as it is the case here.
{3}In this notation, both components are real numbers.

We may write [3] as:

$R1 + j \cdot X1 = Zo \cdot [R2 + j \cdot X2 – j \cdot Zo \cdot tg(\beta \cdot L)] / [Zo - j \cdot (R2 + j \cdot X2) \cdot tg(\beta \cdot L)]$

By equaling the real and imaginary parts in both sides, we get:

$R1 = Zo^2 \cdot R2 \cdot [1 + tg^2(\beta \cdot L)] / \{[Zo + X2 \cdot tg(\beta \cdot L)]^2 + R2^2 \cdot tg^2(\beta \cdot L)\}$ [4]

$X1 = Zo \cdot \{(X2^2 + R2^2 - Zo^2) \cdot tg(\beta \cdot L) + Zo \cdot X2 \cdot [1 - tg^2(\beta \cdot L)]\} /$
$/ \{[Zo + X2 \cdot tg(\beta \cdot L)]^2 + R2^2 \cdot tg^2(\beta \cdot L)\}$ [5]

So we measure R2 and X2 with the impedance meter at the lower end of the line and, applying their values in [4] and [5], we get then, R1 and X1.

Let’s see a special case, when the antenna is resonant, that is, X2 = 0 and the cable length is an integer multiple of ½ wavelength, that is, $\beta = 0$ or $tg(\beta \cdot L) = 0$. In this case we have:

$R1 = Zo^2 \cdot R2 / Zo^2$

$X1 = Zo^2 \cdot X2 / Zo^2$

or R1 = R2 e X1 = 0, as we expected.

If, besides, R2 = Zo, that is, VSWR = 1:1, then R1 = Zo, obviously.

The measurement process, although indirect, has the advantage to lead to more reliable results due to there not are spurious factors interference as the modifications introduced by the proximity of conductors, etc.

It is important remember that, before the antenna is put to the place where the measurements will be performed, the transmission line must be measures as its physical length. We cannot forget to have at hand its surge impedance, its velocity factor and the working frequency.

If the measurement doesn’t lead to satisfactory results, modifications to the antenna, as height, length, apex angle (if it is the case), etc, must be done and new measurements executed. The process is repeated till we get the desired results.