TRANSMISSION LINES: ANOTHER APPROACH ANALYSIS

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Introduction

The subject 'Transmission Lines" has had a mist of mystery to the world ham community (and even to some professionals). The reason for this is that the involved concepts are not well presented, permitting some degree of speculation and "in my opinion" type discussions, generating polemics.

In texts on transmission lines, a generator normally it is said 'matched with a line' when its output impedance is equal to **Zo**, the surge impedance of the line. This is not a real match when we remember that, in all well behaved cases[1], a generator is matched with the load when the former transfers the maximum power to the latter, that is, its output impedance is the complex conjugate[2] of the impedance seen at the load. In the line general case, that impedance is not **Zo** and, therefore, we will consider here that a generator is matched to a line when the input impedance of the latter (resulting from the load impedance at the upper end of the line) is matched to the generator output impedance and **Zo** is merely a parameter of the line itself. For us, here, "matched to the line" and "matched to **Zo"** are two completely different things and must be well understood because they will be used from now on in the article.

The "match to the line" is more coherent with the following situation: suppose we have a generator connected to a black box (there may exist a line within the box, but we don't know). We ask someone to adjust the generator output impedance to match the black box input. He cannot adjust it to **Zo** because he was not told about the details of the box. He will adjust things to get the maximum power transfer to the box and this will occur when the generator is matched to the 'seen' input impedance of the black box.

We will not present here any derivation or concept already commonly presented in other texts.

As "return loss" and "line loss" are independent things, we will divide our text into two parts, ideal lines and lossy lines.

[1] Linear and time independent circuits, as normal lines are.
[2] Or simply equal, when no reactances are involved.

Ideal Lines

To simplify things, we will consider for the time being that the line is ideal (lossless) and the load at the upper end of it is pure resistive[3].

Let's have a generator connected to a line (**Zo**) and this to a load **Ri = Zo** as in Figure 1.

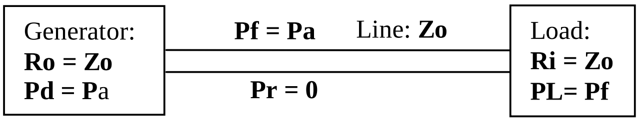

Figure 1

As the input impedance of the load is **Ri = Zo**, the reflected power **Pr** is null and the impedance seen by the generator is **Zo**. This delivers a power **Pd** equal to the maximum available power **Pa** entirely to the line and the forward power **Pf** is equal to **Pa**. Then the power **PL** delivered to the line is **Pa** too. This is the simple case of entire matching.

Now suppose we keep all conditions but the impedance of the load, that is now **Ri = Z ≠ Zo**, as in Figure 2. We have a reflected power **Pr** (not null) that goes towards the generator. Suppose we use an ideal coupler, (if necessary) to match the generator with the line (not with **Zo**), that is, all maximum available power is kept delivered to the line.

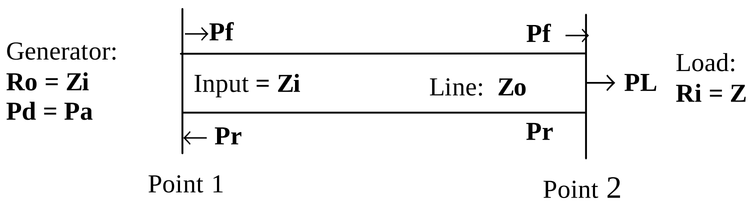

Figure 2

[3] This will not lead to a loss of generality, but only will simplify the discussions.

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Remembering that, in any not dissipative point of a circuit, the arriving power must be equal to the leaving power (by energy conservation law), we may analyze what happens on Points 1 and 2 of the figure (they are respectively the generator and the load ends of the line).

On Point 1, the arriving power is **Pr + Pa** and the leaving power is **Pf**, so **Pf = Pa + Pr (I)**. On point 2, the arriving power is **Pf** and the leaving power is **PL + Pr**, so **Pf = PL + Pr (II)**. By comparing **(I)** and **(II)**, we get **PL + Pr = Pa + Pr**, or **PL = Pa**, independently of the reflection coefficient, as we have not mentioned it. That means, with a matched generator to the line, all the delivered power from the generator is dissipated in the load, no matter how big is the mismatch between the line and the load. As all the involved powers are positive numbers (square of voltages divided by positive impedances or square of currents multiplied by positive resistors), from **(I)** we can see that the forward power **Pf** is greater then de available one, **Pa**.

A question arises immediately: isn't it a power creation from nothing?

The answer is NO, because the forward power is fed not only by the generated power, but also by the reflected one; the excess of power on Point 2 that is not delivered to the load, just **Pr**, will contribute to **Pf** on Point 1, as in Figure 2. We may say that it exists a power equal to **Pa** (the maximum available power) going through the line to the load and dissipating in it, plus a circulating power **Pr**. The forward part of this circulating power sums with **Pa** in the line to form **Pf** and its backward part is the power **Pr** itself (it is a mesh analysis), as in Figure 3.

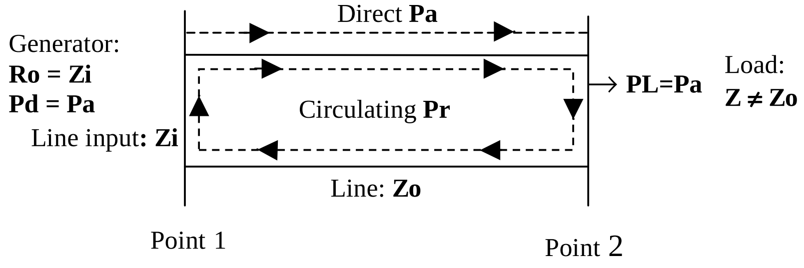

Figure 3

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This shows that **it is not** the reflected power itself that is the reason of the efficiency decrease when there exists a mismatch between a lossless line and the load, as all the available power is delivered to it when we are dealing with lossless lines. This is perfectly in agreement with the fact that, if all power is delivered (nothing given back) by the generator to a system composed by a lossless element (line) and a lossy element (load), this power can be only dissipated in the load (by energy conservation), nothing said about reflections.

When we don't have a "match to the line" condition at the generator end of the line, but, instead, a "match to **Zo**" situation, we have indeed a generator mismatch and **this** is the real reason for the loss, that, despite being called "return loss", it is an internal generator loss.

Lossless lines are only lossless impedance transformers, with the reflected power being used only to adjust and match the involved impedances. **Zo**, although having an impedance dimension, is only a parameter of the transformer.

Lossy Lines

In the real world, however, the presence of a reflected wave increases the voltage/current peaks in certain points of the line (standing waves, with peaks and valleys) and these peaks increase the losses[4]. So it is the **line loss** the responsible for the losses in a mismatched line system and **not** the reflection itself, as commonly thought by many people.

As a simple and well known example, is the case of a 50 Ohm resonant antenna fed with a lossless 300 Ohm ½ wavelength long line. The impedance seen by the 50 Ohm generator is also 50 Ohm because of the line length, but we have a mismatch of 6:1 at the antenna end. Even with a great reflection occurring, no loss will happen. We see that, despite of the difference between generator (50 Ohm) and line (300 Ohm) impedances, the reflected power doesn't mean any loss and no "return loss" occurs. It is just because the generator is really matched to the input impedance of the line and not to its surge impedance (when nothing is told about power transfer).

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[4] **Due the quadratic behavior of the power, the loss increase on the peaks is higher than the loss decrease on the valleys, so the net loss is higher.**

“Matching to Zo”

If the line is lossless and the generator is “matched to the line” (not to **Zo**), we see that, even existing a reflected power, there is no **return loss**. The latter is important, however, when there is a mismatch between the line and the load and we have the condition of the generator “matched to **Zo”**. The reflected power sees the impedance **Zo** of the generator when it arrives to the lower end of the line and, therefore, is totally transferred to the generator that **dissipates** it. The forward power is the same of the fully matched case, but the power transferred to the load is the forward power minus the reflected one. So, we have less power on the load and this difference is dissipated in the generator. Now we have a so called “return loss”. When we have a lossless coupler at the generator output and get a “match to the line” condition, the coupler nullifies that return loss, even with high load mismatch. That’s why the term “return loss” perhaps is not very convenient and it is one of the reasons for the general misunderstanding about transmission lines.

Conclusions

When we have a transmitter with fixed output impedance with no coupler to a lossless line, it is advisable to match the latter with the antenna because of the return loss. With a coupler, or variable transmitter output impedance, the VSWR value is irrelevant for those lines. Indeed, the line adjusts itself to the antenna through the reflection and leaves to the transmitter the task of decreasing the losses.

In the real world, where lines have losses that increase with VSWR, we must keep the latter as low as possible in any situation, but couplers are still useful to cancel the return loss[5].

Another reason for keeping the VSWR in its minimum value is the cable maximum power rating decrease under standing waves[6]

I guess that this focusing of the subject (embracing the fact that the forward power is greater than the maximum available one in the general lossless case) is really a novel one. I have never seen it explicitly in the literature.

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[5] We see clearly here that the expression “return loss” is not very convenient because the coupler, at the generator end of the line, is able to cancel the return loss without affecting the returning (reflected) power in the line that depends only upon the matching conditions at the its antenna end.
This article doesn’t intend to change the use of the expression “return loss” in the literature as it is a well accepted term, but only call the reader’s attention to its correct concept.

[6] The maximum power specified by manufacturers, refers to a VSWR = 1:1 condition; for a VSWR = n:1, the maximum power must be divided by n.

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