# APPENDIX 10 – THE IEEE DEFINITIONS OF DISSIPATIVE AND NON-DISSIPATIVE IMPEDANCE AND RESISTANCE

Are you aware that there is resistance that is non-dissipative? If not, you are not alone, because many otherwise knowledgeable electrical engineers are not only unaware of it, but due to a misunderstanding, some deny it exists. (We are not talking about a physical resis**tor**.) The concept of a non-dissipative resistance is one of the most misunderstood concepts in all electrical engineering. There are at least two reasons for this misunderstanding. First, we learned about dissipative resistance while studying DC circuits, but when moving on to AC theory, many may have failed to notice that *dissipative* resistance is not the *only* kind of resistance. In addition, the concept was seldom, if ever, discussed by the EE professors. Second, the IEEE, in its infinite wisdom, chose to assign the same name, *resistance,* to both types, dissipative and non-dissipative, resulting in the present confusion.

Therefore, to assist in clarifying this unfortunate misunderstanding, I first quote the IEEE definitions, and then examine the real part of impedance, Definition 2 of Resistance.

From the *IEEE Standard Dictionary of Electrical and Electron Terms*, I quote the IEEE Std 100–1972 definitions of Impedance and Resistance:

**Impedance –** (1) **(linear constant-parameter system)**

(B) The ***ratio*** of the phasor equivalent of a steady-state sine-wave voltage or voltage-like quantity (driving force) to the phasor equivalent of a steady-state sine-wave current or current-like quantity (response) The *real* part of impedance is the resistance. The *imaginary* part of impedance is the reactance. (C) A physical device or combination of devices whose impedance as defined in (B) can be determined. *Note:* This sentence illustrates the double use of the word impedance, namely for a physical characteristic of a device or system (definition B) and for a **device** definition (C)). In the latter case the word *impedor* may be used instead of to reduce confusion. Definition (C) is a second use of **impedance** and is *independent* of definition (B). *Editors note:* The **ratio** Z is commonly expressed in terms of its orthogonal components, thus

$$Z = R + jX$$

where Z, R, and X are respectively termed the impedance, resistance, and reactance, all being measured in ohms.

(2) **(electric machine)** Linear operator expressing the relation between voltage (increments) and current (increments) Its inverse is called the *admittance* of an electric machine.

(3) **(two-conductor transmission line)** The *ratio* of the complex **voltage** between the conductors to the complex **current** on one conductor in the same transverse plane.

**Resistance (1) (network analysis)**

(1) That physical property of an element, device, branch, network, or system that is the factor by which the mean-square conduction current musts be multiplied to give the corresponding power

lost by dissipation as **heat,** or as other permanent radiation or loss of electromagnetic energy from the circuit.

(2) The real part of impedance.

*Note:* Definitions (1) and (2) are not equivalent but are supplementary. In any case where confusion may arise, specify definition being used. (End of quote from the IEEE Dictionary)

Summarizing the two resistances:

Definition 1 resistance is the heat-dissipative property of physical resistors.

Definition 2 resistance is the real part of impedance.

Definition 2 represents the general case, and Definition 1 is a special case of Definition 2, and is limited to resistors alone by the definition. In Definition 2 the real part of impedance may be the dissipative resistance of a physical resistor or it may be a non-dissipative resistance representing only the transfer of energy.

We know that resistance is a ratio, the ratio of voltage divided by current. When taking measurements of voltage and current many people imagine they are measuring the dissipative characteristic of resistance when calculating the voltage–current ratio. However, unless it is known that they are dealing with a resistor, they cannot conclude anything about the presence of a Definition 1 resistance. Keep in mind that the impedance of a resistor is exactly equal to its Definition 1 resistance, so the *real* component of a resistor is always a Definition 2 resistance. In other words a resistor will have both a Definition 1 and a Definition 2 resistance that are exactly equal. But, in general, the only resistance we usually measure is the Definition 2 resistance.

When one measures voltage and current at a connection the ratio is always resistance of the Definition 2 kind, i.e. you are measuring impedance. But there is no way to postulate on the mechanisms that are causing the observed relationship strictly from the observed values. Similarly, without more information one cannot know the 'source(s)' of the resistance. Thus it doesn't matter at all whether one is dealing with dissipative or non-dissipative resistances–one cannot tell anything about that from measurements of voltage and current. We know only that the product of voltage and current tells us the power transferred at the connection, and that the ratio of voltage and current tells us the resistance between the terminals (impedance if reactance is involved). And we know that a ratio has no way of dissipating energy into heat, so unless we obtain additional information we can only conclude that the resistance (or impedance) is non-dissipative. A process for measuring Definition 1 resistance requires some form of thermal measurement, but we don't usually do this kind of measurement because we know where the resistors are located if there are resistors involved.

So now you may ask, what resistance is there that is non-dissipative? To answer this question let's first consider a lossless transmission line terminated in its characteristic impedance $Z_0$. In a lossless line $Z_0$ is a pure resistance, R. If we apply a voltage across the input terminals and measure the current flowing into the line, we will find that the current equals the voltage divided by $Z_0$. After manipulating this expression, we find that $Z_0$, or R, equals the ratio of the applied voltage to the resulting current flow into the line. Thus by measuring the voltage and current we can determine the value of R. We also know that the product of the voltage and current equals the power delivered to the line. But what is generally overlooked is that the power delivered to the line is not dissipated there, but is *transferred* along the line to the load where it is then dissipated. Thus the resistance appearing at the input and all along the line up to the load termination is *non*-dissipative. *The dissipation to heat occurs only in the load resis**tor**.*

Continuing, let's also examine the common ham installation consisting of a transceiver, an antenna tuning network, and an antenna. Also let's recall that dissipation in Definition 1 of resistance means dissipation as *heat*, and in Definition 2 resistance is the *real* part of impedance, which is often represented by the term 'Re' to differentiate it from dissipative resistance 'R'. It will be instructive in this discussion to use impedance, with the emphasis on its real part Re, which represents only the *transfer* of energy across terminals connecting one component to another.

As we know, the transceiver delivers power to a transmission line, which *transfers* the power to the antenna-tuning network. The tuning network then *transfers* the power to the transmission line, and the transmission line *transfers* the power to the antenna, where the power is *then radiated* (or dissipated, if you prefer). At each point along the way from the transceiver to the antenna, the power is carried by voltage and current, the product of which is the power. However, at each of these points the *ratio* of the voltage to current is the *impedance* level at which the power is being *transferred*. For example, the usual impedance at which the transceiver delivers power to the transmission line is 50 ohms, where with a power of 100 watts, the voltage is 70.71 volts and the current is 1.414 amps. Verifying, the impedance is 70.71 ÷ 1.414 = 50. (For the purpose of discussing the principles it is customary to consider the components in the system as lossless.) Moving on to the output of the network we measure the voltage and current at the input of the line feeding the antenna, to find 122.47 volts and 0.8165 amps. Multiplying the volts times the amps yields the power transferred, 100 watts, but *dividing* volts by amps yields the impedance level at which the power was transferred to the line, 150 ohms. Different impedance—same power. Observe that the power level remained constant, indicating that there was no dissipation to heat in the system. The impedance at the output of the transceiver is $Z = 50 + j0$ ohms, with 50 ohms the resistance Re. Re is the *real part* of the impedance, which simply means the power was *transferred* at the 50-ohm resistance level, but no power was *dissipated* to heat there. Likewise, the impedance at the input to the antenna line is $Z = 150 + j0$ ohms, where again, the 150 ohms is the real part of the impedance, but no power was dissipated to heat there either. Thus the real part Re of the two impedances just discussed are *non*-dissipative. If the line input impedance had been reactive, as it usually is, such as $Z = 150 - j375$ ohms, the real part of the impedance, Re = 150 ohms as before, and the $-j375$ ohms is simply the capacitive reactance, the reactive part of the impedance, which of course is also non-dissipative.

This concept of non-dissipative resistance also applies to the terminals of networks. The ratio of voltage to current at those terminals also yields the impedance, of which the real part is non-dissipative. The resistance Re simply represents the transfer of power *through* the terminals from one network to the next, with no dissipation *at* the terminals.

John Fakan, KB8MU, Ph.D. in Electrical Engineering wrote the following illuminating discussion on non-dissipative resistance especially for this book, using a mechanical analogy. His mechanical analogy assists in developing a clear understanding of one of electrical engineering most serious misunderstandings concerning non-dissipative impedance, and why a simple mathematical ratio such as voltage divided by current cannot dissipate energy into heat.

"Try this analogy to get your brain focused on the principle. Consider power transfer in a rotating mechanical system. The maximum power available at any connection (for example, at the end of the drive shaft) can be specified as some horsepower level at a given impedance. (I know it is not common practice to use the word impedance here, but it is appropriate and has precisely the same meaning as 'impedance' in electrical power transmission.) Usually the impedance is stated as the ratio of torque and rotational speed - the common variable pair for discussing rotational systems. In other words, the maximum power transfer can only occur at a specific speed and torque. The load connected to the shaft must be able to use all of the torque at that specific speed or it will not receive all of the available power. If the ultimate load has a different impedance (ratio of torque and speed) one must match the two impedances to transfer maximum power. That of course is easily done with gears — which simply change the torque/speed ratio. The product of torque and speed is the power, and the gears (impedance matching device) do not change this.

Losses in the above system are due to friction and friction-like processes. Friction also has characteristics of torque (or drag) as a function of speed– i.e., at a given speed the frictional drag on the rotating shaft will produce a torque load. The losses will be proportional to the product of the speed and frictional torque. These losses will be due to the mechanical energy being changed to thermal energy – i.e.: dissipated as heat. The frictional drag reduces the amount of torque available downstream of the point where the friction occurs. Giving the name 'resistance" to this phenomenon makes a lot of sense. Giving the same name to the other ratio, (the speed/torque ratio at which power is transferred would be a very dumb idea — although the units are the same. **This would certainly cause a great deal of confusion.**

It is also exactly analogous to electrical power transfer. The available power is expressed as the product of some variable pair (we commonly use voltage and current) but this power level is available at a specific ratio of the variables– i.e.: impedance. The common loss process in electrical power transfer is due to electrical 'friction' whereby when current flows through real materials the loss will depend on the amount of voltage 'dropped' while the current passes on through. The voltage loss reduces the amount of voltage available downstream of the point where the loss occurs. This process is named 'resistance', which makes good sense. Unfortunately, the real part Re of the ratio of the voltage and current at which power is being transferred is also named 'resistance' — although it is an entirely different concept. **This *does* cause a great deal of confusion.**

Electrical impedance is nothing more than the ratio of voltage and current with which electrical energy is being transferred. It is just that simple. It is a mathematical ratio — like 12/5. In addition, because it is nothing more than a mathematical ratio (even if it sometimes happens to be a complex mathematical ratio) it cannot dissipate energy nor can it do anything else to the energy transfer process.

The input impedance of a transmission line is simply the ratio between the applied voltage and the current that will be induced because of that voltage. (This is NOT the characteristic impedance of the line.) Again, just a ratio of numbers, and thus nothing to do with dissipation. It may very well be that the transmission line is connected to a dummy load, in which case all of the energy transferred to the transmission line may be dissipated in the dummy load, but nothing at the input of the line can tell us that. If you get focused on the need for impedance (in any kind of energy transfer process) it should all become obvious. It may help to consider 'lossless' systems at first. You still need to describe the ratio of the variables — that doesn't change. So you will still be dealing with electrical 'resistance', **Definition 2),** but will not be dealing with resistance, **Definition 1).**

Also, please note that impedance only deals with what is happening at the connections between components — it has nothing to do with how the values get to be what they are (i.e.: the processes within the components)."

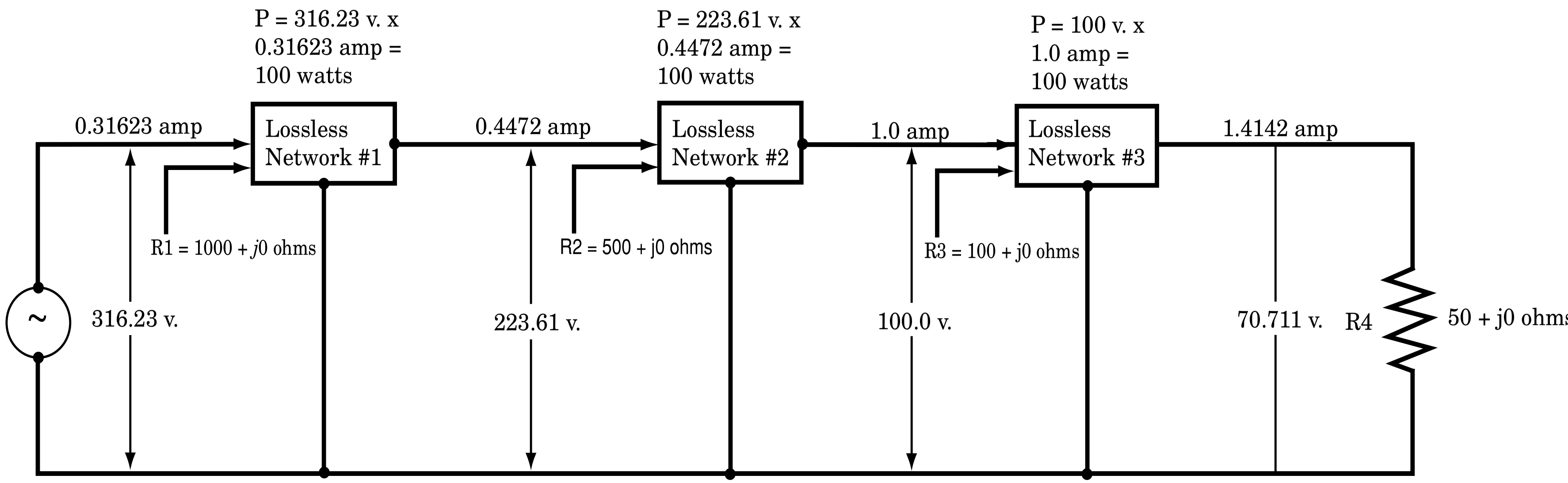
Another example of a non-dissipative resistance occurs between two terminals of a *lossless* network. Here the energy is transferred from one portion of the network to its adjacent component downstream with no energy dissipated as heat. The network components would get hot if there were dissipation. Therefore the voltage *across* the network terminals divided by the current *through* the terminals defines the impedance Z = E/I appearing *at* the terminals, in accordance with IEEE definition (B) of impedance. In this case, where there is no dissipation, the '*R*' term in the IEEE equation $Z = R + jX$ may be replaced by the non-dissipative resistance term 'Re', indicating that it is the 'real part' of the impedance. In a real physical network, all the energy is transferred to the next component downstream, as in the lossless network, except for the loss due to dissipation in the *inherent* resistance in the components of the network.

If the discussion above didn't persuade you that the real part of impedance Re represents non-dissipative resistance in accordance with impedance definition (B), here's still another example, found in electric power transmission systems. Let's assume that at one point in a given distribution system the voltage across the line is 20,000 volts with 50 amperes flowing. With this voltage and current the transmission line is transferring one megawatt of power to its many loads, where the power is then dissipated. The impedance of the line at this point is 20,000 divided by 50, which is 400 ohms. At a point downstream in the system, after going through an impedance-matching device, a step-down transformer, (like the gears in the rotating system) the voltage is 2,000 volts and the current is 500 amperes. The same amount of power is still being transferred, one megawatt, but the impedance has decreased to 4 ohms, 2,000 volts divided by 500 ohms. One megawatt of power was *transferred* at the new value of impedance, but *no dissipation* occurred (except for inherent, but insignificant wire-resistance loss), until reaching the loads down stream. There was *no dissipation* in either the 400- and

4-ohm impedances. If the voltage and current travel in phase, the impedance Z = Re exactly; if the voltage and current travel out of phase, there is a reactance component in the impedance: Z = Re ± *j*X, where *j*X is the reactive component. (Where there are reactive components (usually inductive) in the power being transferred, the power companies use compensating capacitors to maintain the power factor as close to 100% as possible.) However, in either case, no dissipation as heat occurred in the impedances. Thus the resistance components R in the impedances are dissipationless.

Of course, as stated above, there will always be some dissipation as heat in the wires of the transmission line, because they have inherent dissipative resistance according to Definition (1). However, this insignificant dissipation does not detract from the concept of the unrelated *non*-dissipative impedance determined by the ratio of the voltage *across* the line, to the current *through* the line at any point along the line. If the impedance is complex the energy storage in the reactances are unaffected when the resistance is non-dissipative. Thus the voltage/current phase relationships are the same, whether the real part of the impedance is dissipative or non-dissipative.

# Example of Non-Dissipative Resistances




NON-DISSIPATIVE RESISTANCE
R1 =316.23 v./0.31623 amp = 1000 ohms

NON-DISSIPATIVE RESISTANCE
R2 = 223.61 v./0.4472 amp = 500 ohms

NON-DISSIPATIVE RESISTANCE
R3 = 100 v./1.o amp = 100 ohms

DISSIPATIVE TERMINATIVE RESISTANCE
R4 = 70.111 v./1.4142 amp = 50 ohms

R1, R2, and R3 are non-dissipative energy-transfer resistances
R4 is a real resistor, dissipating 100 watts into heat.