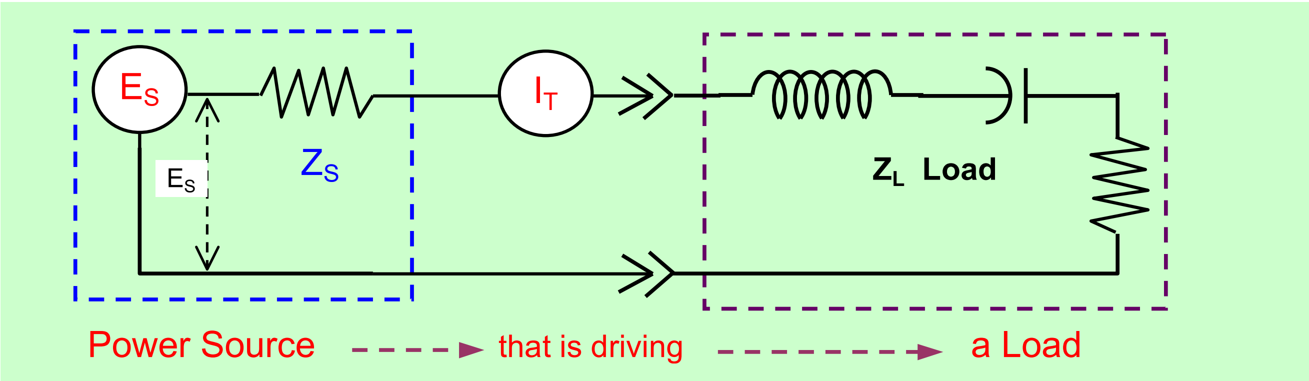
Preface

Load to Source Matching (tool and presentation)

There are many great topics in Amateur Radio and Electronics in general. Matching of a "Load to a Power Source" is one that most Amateur Radio Operators choose to cover. This topic can first be approached on a conceptual level to gain a basic discussion level of understanding.



There are many angles in the study of "Load Matching" that are quantified and qualified through mathematics. However mathematics by itself does not always provide the individual with a firm conceptual grasp.

This Workbook Combines - a Presentation with Spreadsheet Tools

The Tool part of this workbook is in the form of two sets of spreadsheets and plots that are ready for the advanced Radio Amateur or Electronics Hobbyist to plug-in values and review results.

The presentation worksheets along with the table and plot worksheets attempts to provide a conceptual path to a better understanding of how Load to Source matching can be approached in a three step process.

1 - Loads that are Purely Resistive

2- Loads that are both Resistive and Reactive

3 - Loads that receive signals by way of a Transmission Line

This Tool and Presentation was developed using Microsoft ™ Excel 2000. It should be accessible to open by most users of actual Microsoft ™ Excel.   In many cases it can also be opened by other spreadsheet applications, although there can and may be some formatting issues with unsupported features.

Along with the XLS Excel file is a PDF of this entire 14 worksheet, workbook. Although the PDF does not provide for the two Table & Plot worksheets to be usable it still contains them in their default form. If read via the PDF all the default table results and plots can be seen.

Read Me First

This *Spreadsheet Workbook* was developed to assist new folks or a refresher for the experienced, using a three step basic approach in the understanding of *"Matching a Signal Source to a Load"*

This workbook is organized into three sections.

Section 1. is dedicated to Loads that are Purely Resistive (I.e. Non-Reactive)

The worksheets within section 1 are:

- Introduction

- Pure Resistive Circuit (and tool)

- Some Perspective

- Plot Details (optional reading)

Section 2. is dedicated to Loads that are both Resistive and Reactive

The worksheets within section 2 are:

- What is Reactive

- Reactive Loads Explained - 1

- Reactive Loads Explained - 2

- Reactive Load Table & Plots

Section 3. Covers Loads that receive signals by way of a Transmission Line

The worksheets within section 3 are:

What is a Transmission Line -1

What is a Transmission Line -2

Review and Conclusion

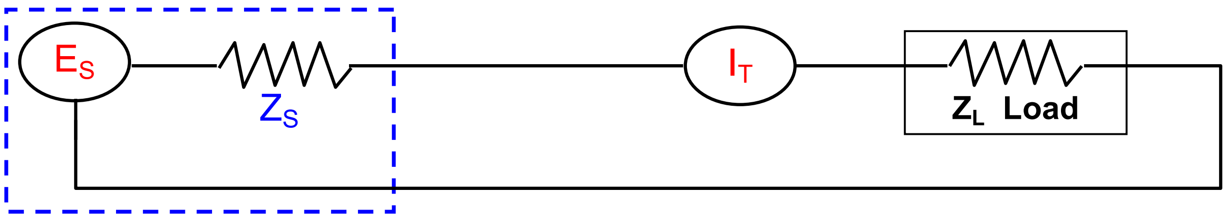
Load_to_Source_Match_Rev 2.0 by L.Ernst WA2GKH (Nov. 20, 2019)

Introduction

Hello and welcome to the "Load to Source Match Tool and Spreadsheet" (Rev 2.0)

Regarding the transmission of electrical power or signals, there is a rule that states *"Maximum Transfer of Power from a Source to a Load occurs when the Load Impedance matches the Source Impedance"* .

There are and can be some complications in understanding this rule. This "Rule" is true under both complex or basic conditions. First, we will explore this rule and its math in action using basic (non-complex) example circuit conditions.



The purpose of this "Load to Source Match" spread sheet is to present to the reader and user of this tool a nice way to see and understand this rule. We start off by just looking at the starting values within the "Pure Resistive Circuit" worksheet (*center horizontal row*). These starting values were selected for a 100 watt signal getting fed to a 50 ohm load from a 50 ohm source. It can be seen that it comes from a total source power of 200 watts and that100 watts makes it's way to the load and that 100 watts are lost. This makes for an over all efficiency of 50%.

There are notes at the bottom of the "Pure Resistive Circuit" worksheet. Also take note to the cells that have an orange triangle in the top right side of cells throughout. Hover (or place) your courser over these cells for the cell notes to appear.

When you are ready to experiment and use the tool you can enter up to three values. The three Orange cells in the middle of the spread sheet allow you to enter your desired values of *Source Voltage* , *Source Impedance* & *Load Impedance* .

The spreadsheet will automatically populate all the necessary cells with your input values. The spreadsheet will adjust your input value of Load Impedance and populate cells above and below with +/- 10% to 100% Load Impedance variance. The results will be computed and populated throughout the spreadsheet. These results are also used to build the four plots within the plot presentation.

All of the worksheets will printout nicely on standard 8.5" X 11" paper. The Table and Plot worksheets print out nicely on Tabloid (11" x 17") paper. Also, if you use the "Print Preview" you will get a nice single screen view.

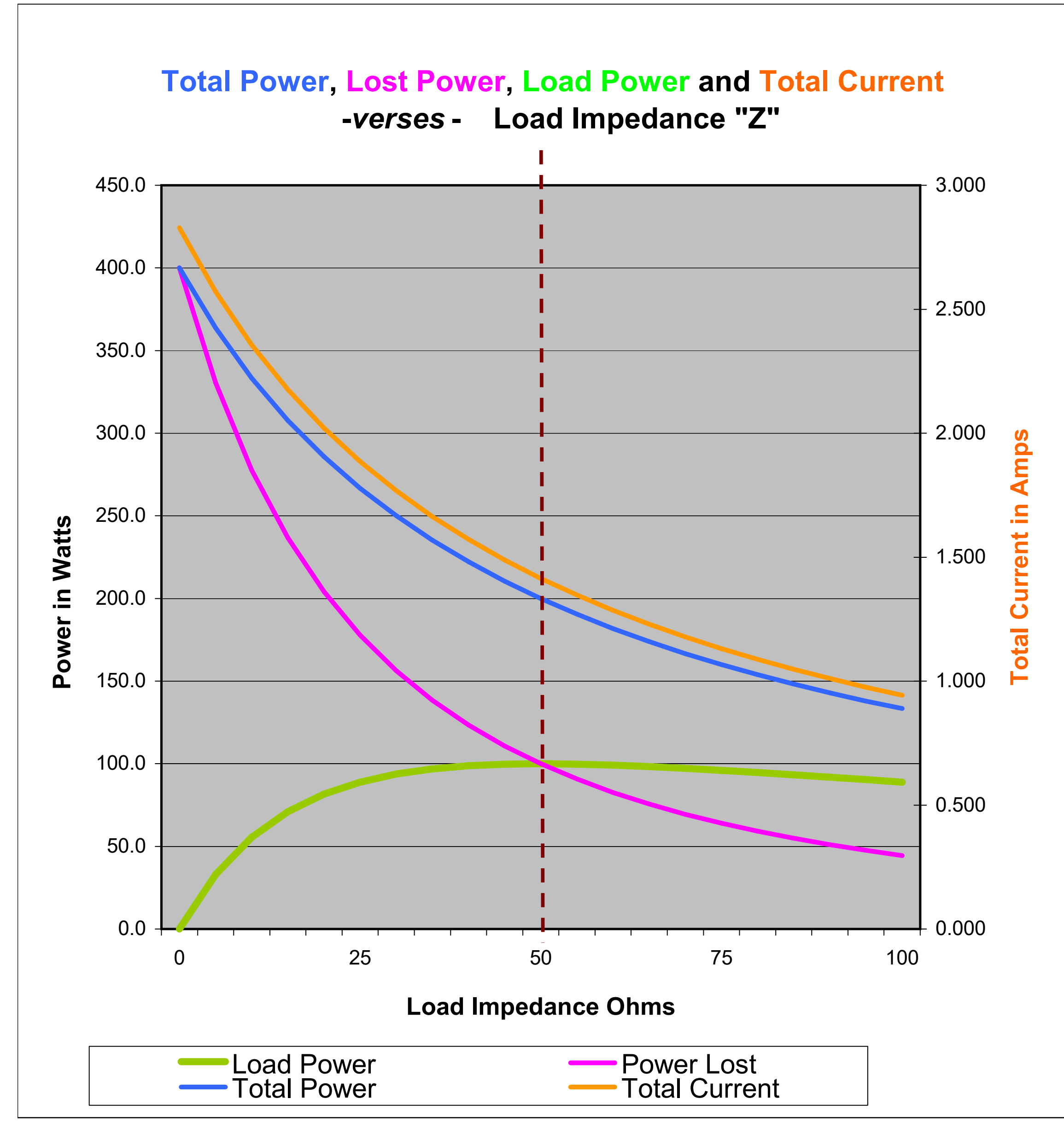
Note: You might want to save a separate original copy of this file, that way you will always have a copy of the unchanged original with the default values.

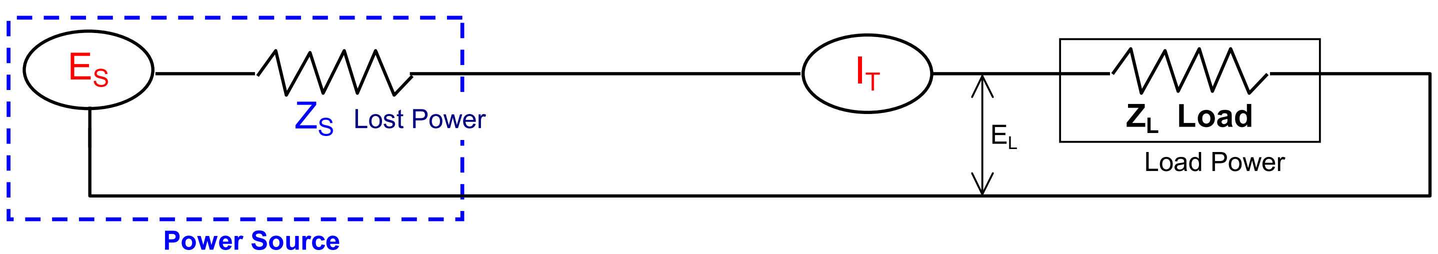
Compute & Plot Total Power, Power Lost & Load Power as a function of Source Voltage, Source Z & Load Z.

Note: This presentation is for Non-Reactive (i.e. resistive) conditions only. (see circuit drawing below)

Insert your selected Source Voltage, Source Z and Load Z values within the three orange cells

E_S Source Voltage	Z_S Source Z	Z_L Load Z +/- 100%	Source to Load Impedance Ratio	I_T Total Current	P_T Total Pwr	P_{lost} Power Lost	P_L Load Pwr	E_L Voltage across the Load	Load Power as a % of Total Power	Load Power % compared to a 100% Match
141.4	50	0	Infinity	2.828	400.0	400.0	0.0	0.0	0.000%	0.000%
141.4	50	5	10.00	2.571	363.6	330.6	33.1	12.9	9.091%	33.058%
141.4	50	10	5.00	2.357	333.3	277.8	55.6	23.6	16.667%	55.556%
141.4	50	15	3.33	2.176	307.7	236.7	71.0	32.6	23.077%	71.006%
141.4	50	20	2.50	2.020	285.7	204.1	81.6	40.4	28.571%	81.633%
141.4	50	25	2.00	1.886	266.7	177.8	88.9	47.1	33.333%	88.889%
141.4	50	30	1.67	1.768	250.0	156.3	93.8	53.0	37.500%	93.750%
141.4	50	35	1.43	1.664	235.3	138.4	96.9	58.2	41.176%	96.886%
141.4	50	40	1.25	1.571	222.2	123.5	98.8	62.9	44.444%	98.765%
141.4	50	45	1.11	1.489	210.5	110.8	99.7	67.0	47.368%	99.723%
141.4	**50**	**50**	**1.00**	**1.414**	**200.0**	**100.0**	**100.0**	**70.7**	**50.000%**	**100.000%**
141.4	50	55	1.10	1.347	190.5	90.7	99.8	74.1	52.381%	99.773%
141.4	50	60	1.20	1.286	181.8	82.6	99.2	77.1	54.545%	99.174%
141.4	50	65	1.30	1.230	173.9	75.6	98.3	79.9	56.522%	98.299%
141.4	50	70	1.40	1.179	166.7	69.4	97.2	82.5	58.333%	97.222%
141.4	50	75	1.50	1.131	160.0	64.0	96.0	84.9	60.000%	96.000%
141.4	50	80	1.60	1.088	153.8	59.2	94.7	87.0	61.538%	94.675%
141.4	50	85	1.70	1.048	148.1	54.9	93.3	89.0	62.963%	93.278%
141.4	50	90	1.80	1.010	142.9	51.0	91.8	90.9	64.286%	91.837%
141.4	50	95	1.90	0.975	137.9	47.6	90.4	92.7	65.517%	90.369%
141.4	50	100	2.00	0.943	133.3	44.4	88.9	94.3	66.667%	88.889%





The selected Source -to- Load Impedance ratio is

1.00

The Blue plot is the total power from the source. NOTE: The Green plot is (Load Power) and the Red plot is (Power Lost) they both ADD up vertically to then equal the Blue plot. This is at any horizontal axis Load Impedance value. The Orange plot just tracks the change in Total circuit Current flow. The BROWN vertical dotted line crosses all of the plots at and for the user selected "Load Z" value

Notes and comments about this presentation.

This presentation is to assist and review (for the new or the advanced) the basics associated with the transfer of electrical energy from a source to a load. This (Section 1) presentation does not include "Reactance" it just covers a circuit that has pure "Resistive" properties only (i.e. no capacitance or inductance). This (Section 1) presentation also does not include "Transmission Lines". In this first basic view of Impedance Matching this example circuit is fundamentally just a "Voltage Divider" with two resistance values (Z_S and Z_L) in series with a voltage source (E_S).

In this basic presentation the only consumption of electrical power is by Z_S and Z_L. Z_S is the Source Impedance and in this case is pure resistance and the power it consumes constitutes "Lost Power" that does not get delivered to the "Load" (i.e. the Load Resistance Z_L). Typically the Source Impedance (Z_S) is internal to the power or signal source.

Since this circuit is pure resistance and the Load is connected right at the power source, the power source can be AC, RF or even DC. There is no SWR (Standing Wave Ratio) to be examined or reported on because the circuit is pure resistance and there is no transmission line. We just examine the values of power lost, power delivered and total power.

Within the next sections (worksheet tabs of this workbook) in a similar style of presentation we will begin to introduce "Load Circuit Reactance" for AC and RF power sources and finely (last section) we will introduce a "Transmission Line" that connects (for various distances) the Source to the Load.

The most important concept here is to see that the (Green Plot) Load Power is at it's maximum level when Load Impedance matches the Source Impedance.

Some Perspective Regarding Maximum Power Transfer.

The previous two worksheets nicely provide details regarding "Load impedance matching to Source impedance". The goal being to transfer maximum power from Source to Load.

This rule is true "that maximum transfer of power from a Source to a Load occurs when the Load Impedance matches the Source Impedance". Generally the source impedance is fixed and we are considering the match conditions for changes in the Load Inpedance.

It is important to know that depending on the type of circuit and its application, that designers don't always want to transfer maximum power. As a general rule in communication circuits where an electrical signal is carrying Information, Voice or Data, then yes, the signal does want to be entirely transferred as best as possible with maximum signal reaching the load / receiver. Such as a receive antenna feeding a receiver. In this case designers want the Load impedance to match the Source impedance.

Now in the case of the transfer of electric power to actually power a load, then we don't generally want the power source to deliver all of its possible power to a load but just to be able to send an amount of power that a load requires. In such case the load has a much higher value of impedance then the source. In this case we transfer energy not information.

The base rule is still true in all of the above, and we generally use it, enforce it and design for it when we transfer communication information. However (and again) we do not generally match the Load to Source when electrical energy is the product that is being delivered from a power source to a load.

For example our electric power companies have a very low output impedance compared to the load community that they feed. If the load community had the same total impedance as the power plant, then the power plant and the transmission lines would all go into overload.

CONCLUSION: Designers do follow the rule when there is a need to recover and deliver every microwatt possible, such as in communications circuits and in the transmission and reception of radiated electromagnetic energy (i.e. radio waves).

Please remember, this first section is for loads connected directly to the Source feeding it. This is the best way to first see and understand the base fundamental rule in action. In the next sections / worksheets of this workbook we will begin the addition and complications of Loads with reactive properties, but still no transmission lines. Then, in the last section we will introduce Transmission Lines with some basic discussion about them.

In a nutshell what you will learn and find out about transmission lines and reactive properties is that designers strive to eliminate, cancel and or mask out the reactive properties so as for the source to mostly see the load's resistive properties. This improves the match condition and helps ensure the delivery of maximum power (at least best as may be practical).

Load matching in complex / reactive circuits requires many skills and techniques to do so. There are entire books dedicated to load matching and impedance conversion in the transmission of AC and RF in reactive circuits that also have transmission lines connecting the Source -to- Complex and Frequency Sensitive Loads.

Plot Details (Optional Reading)

Note: Print out this sheet so it can be read while viewing the "Pure Resistive Circuit" worksheet.

Within the "Pure Resistive Circuit" worksheet plot and using the default values of E_S=141.4 and Z_S=50 and Z_L=50 you can see that the Green and Red plots cross each other at the Brown dotted line. This is the perfect match point (Source to Load impedance ratio = 1.00) and the Green plot is at its maximum value of 100 watts. It can be seen that the Green plot starting from its left most position at "0" zero Load "Z" Impedance is at "0" watts. The Green plot then grows in size as the Load "Z" Impedance (along the Horizontal Axis) gets larger in steps of "5" five. The Green plot reaches it's maximum value (100 Watts) when the Load "Z" Impedance is 50 Ohms. Then, when the Load "Z" Impedance is increased beyond 50 Ohms (again along the Horizontal Axis) to 100 Ohms, the Green plot drops to 88.9 Watts.

This behavior is the Maximum power transfer rule in action.

Let’s take a closer look at why the math works this way.

First we are going to list a few basic Power formulas.

P = Power in Watts I = Current in Amps E = Voltage in Volts R = Resistance in Ohms

$$P=IE \quad \text{or} \quad P=I^2R \quad \text{or} \quad P=E^2/R$$

For our use we will select the $P=I^2R$ formula. Our "R" will be "Z_L" -so- $\mathbf{P_{ZL}= I^2 Z_L}$

Now since Z_S is in series with Z_L it is clear they both feel and pass the same amount of current. That being the case when we look at the bottom left side of the plot along the horizontal axis line where Load Z = Zero, then, at that point the Green Plot is at Zero and the Red Plot is at 400 watts. This is all lost power within the Source Impedance Z_S. This is a huge Mis-match of Infinity.

So in the formula it can be seen that "Z_L's load power" can increase if "I" current in Amps and/or it's "R" resistance in ohms should increase. Ok so it is clear that the Green Plot (the load Z_L's power) to the left side of the Brown dotted line is increasing because it's Impedance (i.e. it's resistance) is increasing as per the values along the horizontal axis.

This will continue until the green plot reaches the center Brown dotted line, where Z_L's power reaches its maximum of 100 watts. Next, we will cover beyond and to the right of the Brown dotted line, the Green Plot will decline and drop off in power, although it is a slow drop-off.

Ok, now that we are at the center Brown dotted line we see (via the Green Plot) the Load Power that is being consumed by Z_L is at its maximum of 100 watts. We also see that Power Lost, the power consumed by Z_S is also 100 watts. Again, this is because their respective Z values match and are equal at 50 Ohms each. The Blue Plot is showing that the total power being put out by the Source Voltage E_S is 200 watts, now down from 400 watts. Also the Yellow plot showing total circuit current is down to 1.414 amps from 2.828 amps.

The main reason the Load Power of Z_L now falls off is because the total power is now down to 200 watts total and continues to get lower as the Z_L value continues to increase, but unlike the left side of the Brown dotted line, the I^2 part of $P_{ZL}= I^2 Z_L$ formula, which is also in decline, rules the outcome for Power Z_L because it's effect in the formula is an Exponential decrease and overrides the increase in Z_L as we move to the right on the Horizontal (Z_L) axis.

What is Reactive and Non-Reactive

Previously within this workbook we have been looking at Load to Source matching where all of the circuit components have been non-reactive. Basically we have been covering power distribution within a voltage divider circuit where all the components are non-reactive (i.e. purely resistive).

Now we are about to switch gears and examine "Load to Source" matching where the load portion of the circuit contains Reactive components. Now in this next section the load is still going to be connected directly to the power source (.i.e. still no transmission line) but now it will be a Reactive Load. The load will have resistance, capacitance and/or inductance.

Before we get started in this section lets first take a look at some of the basic differences between purely resistive (non-reactive) components and reactive components such as Capacitors and Inductors.

Non-Reactive -and- Reactive review.

In a circuit that is purely resistive and current is flowing, if all of the sudden it is switched off from the power source, the whole entire circuit will go dead. That is, no current is flowing anywhere, no current is trying to flow and no voltage is present antwhere, it's just dead.

Also in a purely resistive (non-reactive) circuit when it is turned on, for the most part, current will pretty much instantly go to full current. There are exceptions, such as circuits that have resistive components that get hot and increase in resistance, but otherwise this is true.

Now in circuits that are Reactive and have Reactive components much of the above two paragraphs are no longer true. Reactive components such as Capacitors and Inductors have ***two basic modes*** of operation, they are as follows:

Mode 1. *They can take voltage and current, and charge, and store energy.* When they are in this mode they have a tendency to look like a variable resistor. However unlike a resistor power does not end up as heat, but rather it gets stored in an energy field.

Mode 2. *They can discharge stored energy back into the circuit.* When they are in this mode they have a tendency to look like a variable power source. They can and will drive and discharge electrical energy and power back into the circuit.

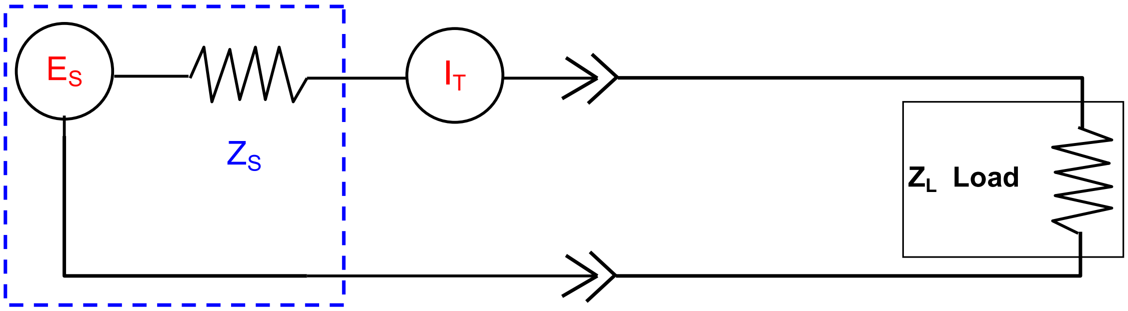
These two above characteristics when present within a Reactive load will then ADD additional complexities to "Source to Load Matching". The basic tenants that we covered within "Section 1" (first three worksheets) are still true, but now the Math formulas will contain more variables, and are more then just a simple "Source to Load Impedance Ratio".

Very generally, within an A.C. sine wave circuit, Voltage and current starts at zero (0) and begins to climb to a maximum positive value. Generally (but not entirely) Reactive components will look like a variable resistor in that they accept power (voltage & current) and store energy (rather then change it to heat like a resistor). -THEN- When the sine wave begins to fall back to zero (0) (not entirely but approximately) the Reactive component will supply energy back into the circuit as if it were a power supply.

Basically the same will happen during the negative half cycle. Now the in the above statement we said "Generally" and "Approximately" because depending on the ratio of circuit reactance -to- resistance, this determines the number of degrees (within 360) that the charging and discharging current does not overlap with the applied voltage waveform to the circuit. This becomes what is called the Voltage to Current phase shift.

The whole point is that when Reactance is part of a load to be matched to a source, that the match will not generally be perfect. Also the math to determine what is the level of match or mismatch does become a bit more extended.

In this worksheet (Reactive Loads) we will begin to discover and explore what it means to "*Load Match to the Source*" when there is a complex / reactive load.

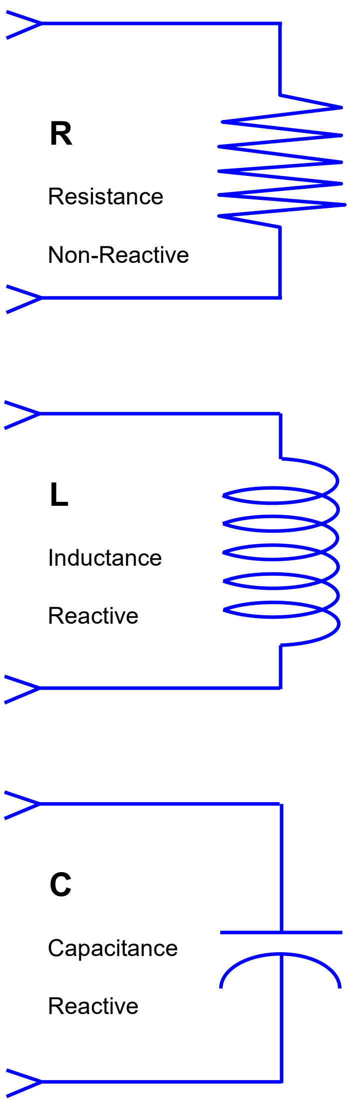


Previously we discovered Load Matching (using the above example circuit) when the Load (Z_L) is a pure resistive load with no reactive characteristics.

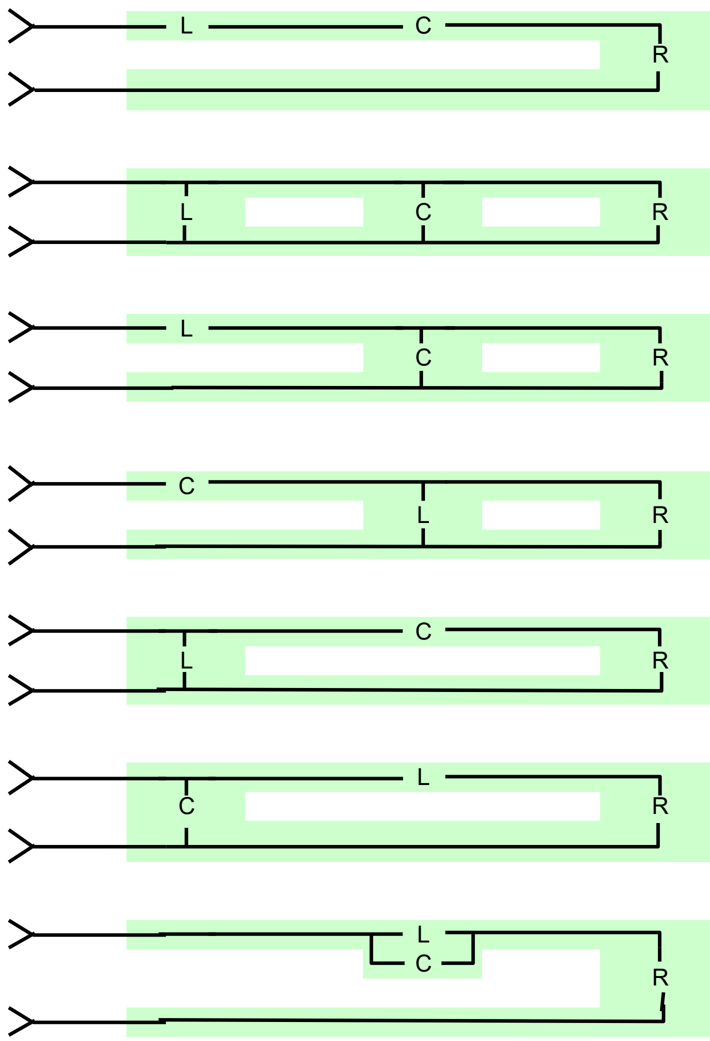
Below and to the left are three schematic symbols that represent a RESISTOR, INDUCTOR and a CAPACITOR. The INDUCTOR and the CAPACITOR are Reactive electrical components.

Unlike a Resistor that converts electrical power / energy into heat, Reactive components take in electrical energy, store it, and then return it back into the circuit as Reverse Power.

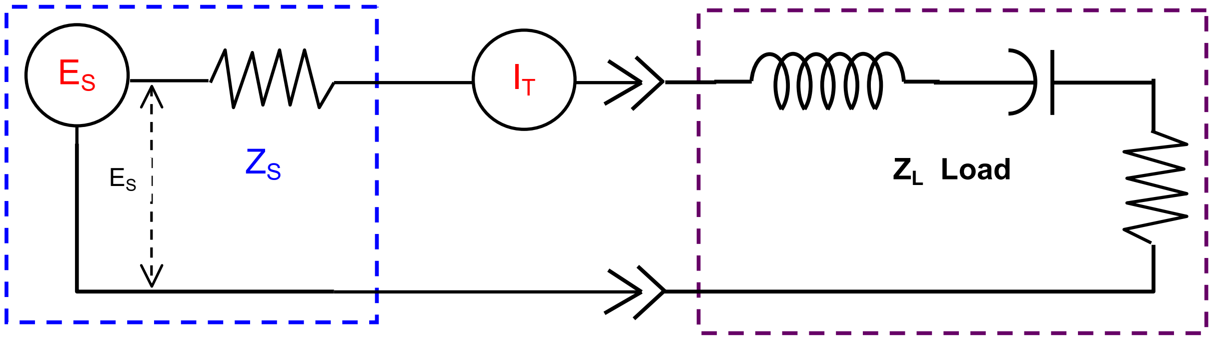
Reverse Power may be a new concept to you, don't worry right now. Next, we ask you to imagine that any of the *below* R, L, C, circuit combinations may be in the above circuit's Load box and represent a complex load. Again, this load it directly connected to the power source (i.e. no transmission line). Within the next several worksheets we will begin some basic explanation.



Reactive / Complex Load Circuit Examples



Reactive Loads Explained (part 1)



Within the above purple dotted line load area are three components connected in series. The inductor, capacitor and resistor make up and form a complex reactive load. There are many ways these components can be interconnected. For now we will just use this series load circuit.

Previously when the load was purely resistance it did not matter if the Voltage Source was, AC, RF or DC. Now as we advance into complex reactive loads, the Voltage Source E_S will strictly be AC or RF and we will also assume some fixed frequency for our fundamental discussions. We do not need to specify it (not now), we just need to know that it is fixed.

When any kind of a load impedance is connected to an AC or RF power source, current will begin to flow within the circuit. Generally and regardless how complex the load circuit may be the circuit will present itself to the power source (E_S) as having a resistance characteristic and also either a composite capacitive or inductive characteristic value.

Generally, capacitive and inductive reactance characteristics will negate and cancel each other (partially or entirely). It is beyond the scope of this presentation to cover that math. Just know that we will be using their numerical reactive difference value in Ohms.

Lets go back and talk just a bit about a pure resistive load. In such a load the voltage waveform and the current waveform are in phase. That means at all times within any given 360 degrees, the voltage waveform matches the current waveform in all respects except perhaps for their respective amplitudes.

Now in a complex reactive and resistive load, the load's feed point voltage and current waveforms are not In-Phase with each other. Not only are they out of phase but twice during any 360 degrees there are times when the voltage may be at positive voltage points and the current is at a negative current points (and vice versa).

Ok, now at such times it would appear that the circuit's current is flowing in a direction opposite to the direction that the Voltage Source (E_S) it trying to push it. So yes, that is exactly what is happening during that period of time (twice) within each full cycle..

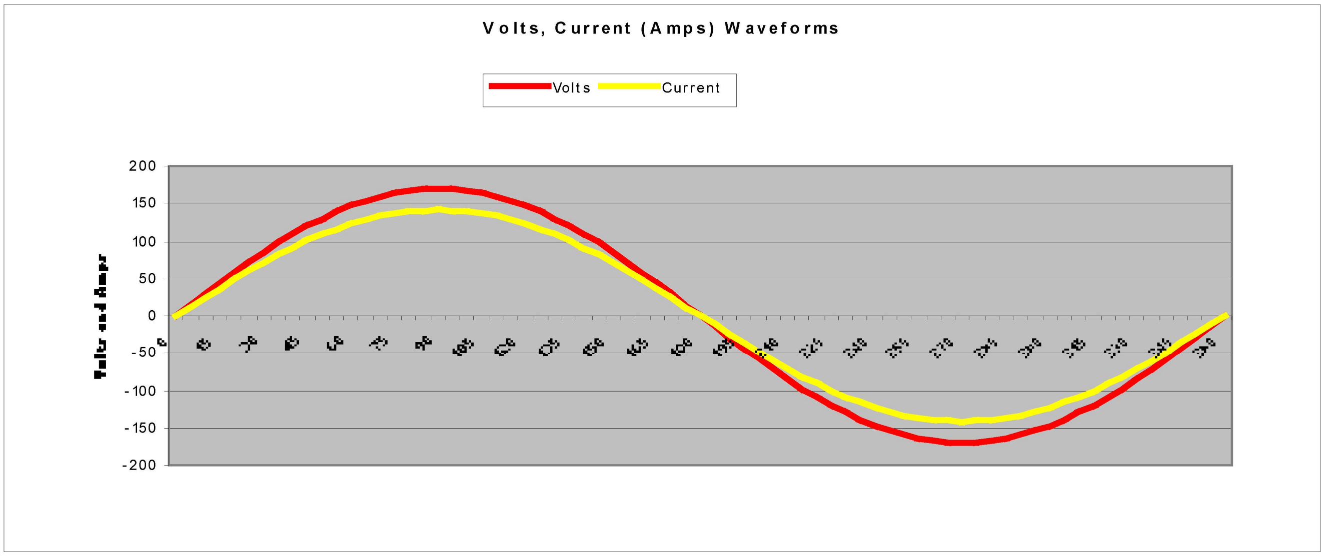
When we previously stated that "Reactive components take in electrical energy, store it and then return it back into the circuit as Reverse Power", then yes, this is when it happens, that being when the source voltage waveform is the opposite polarity as the current waveform.

Actually the energy return from a reactive circuit starts a bit before the above statement. That being when the Voltage (in a capacitive circuit) or Current (in a inductive circuit) is larger in amplitude then what the Power Source is putting out. This happens twice per cycle, each time being from 0 to 90 degrees in duration. The next worksheets will tie it all together.

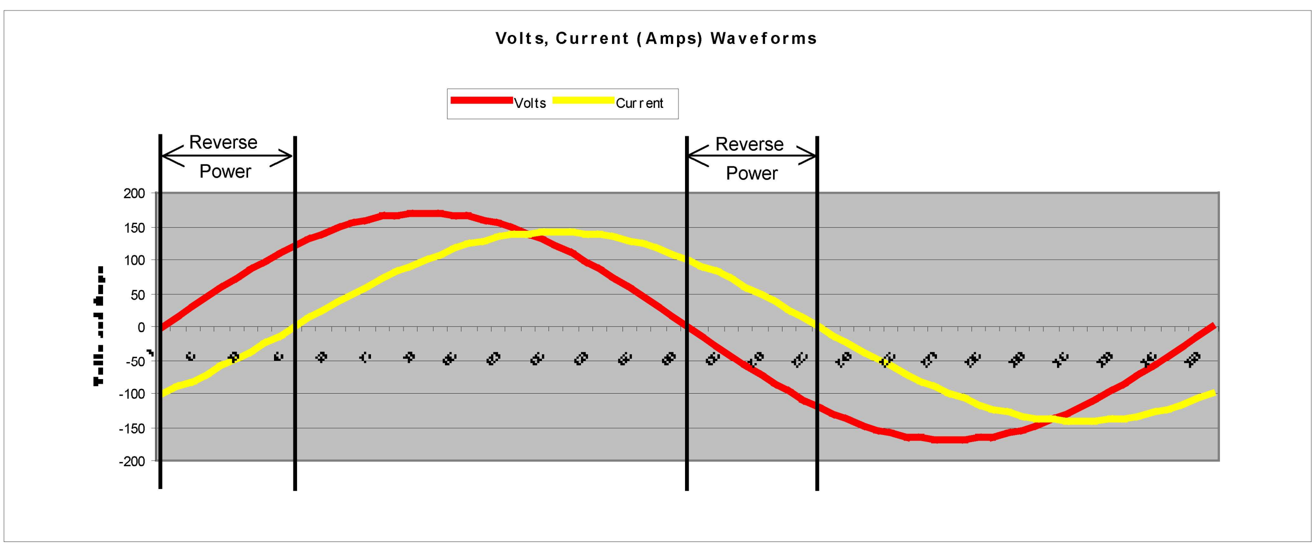
Reactive Loads Explained (part 2)

In the previous worksheet it was stated "in a pure resistive load the voltage waveform and the current waveform are in phase" and it was also stated "in a complex / reactive load at the feed point the voltage and current waveforms are not In-Phase with each other". To that extent the following waveform plots will help illustrate these points.

In the waveform below the RED voltage plot is in phase with the YELLOW current plot. Their respective amplitudes were made different so they would not plot over top of each other. This plot represents what could be from a pure Resistive Load.



In the example waveform below the RED voltage plot is OUT of phase with the YELLOW current plot. This plot represents what could be from an Inductive Reactive Load. The Yellow current waveform is Out of Phase (or delayed) by 45 degrees from the leading voltage waveform. (acutal out of phase values can be from 0 to 90 degrees).

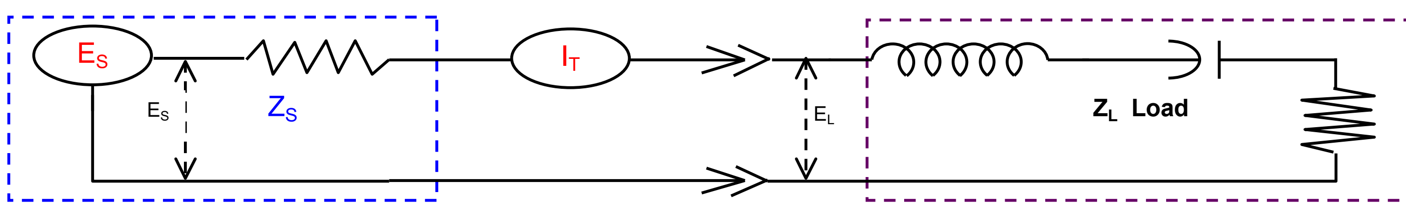


In AC power circuits, this would be referred to as having a "Power Factor" of less then one. In RF circuits, this would be referred to as a Non-Matching load with reactance present. Other then that, they are basically the same thing. Just different terms for different areas of electrical technology.

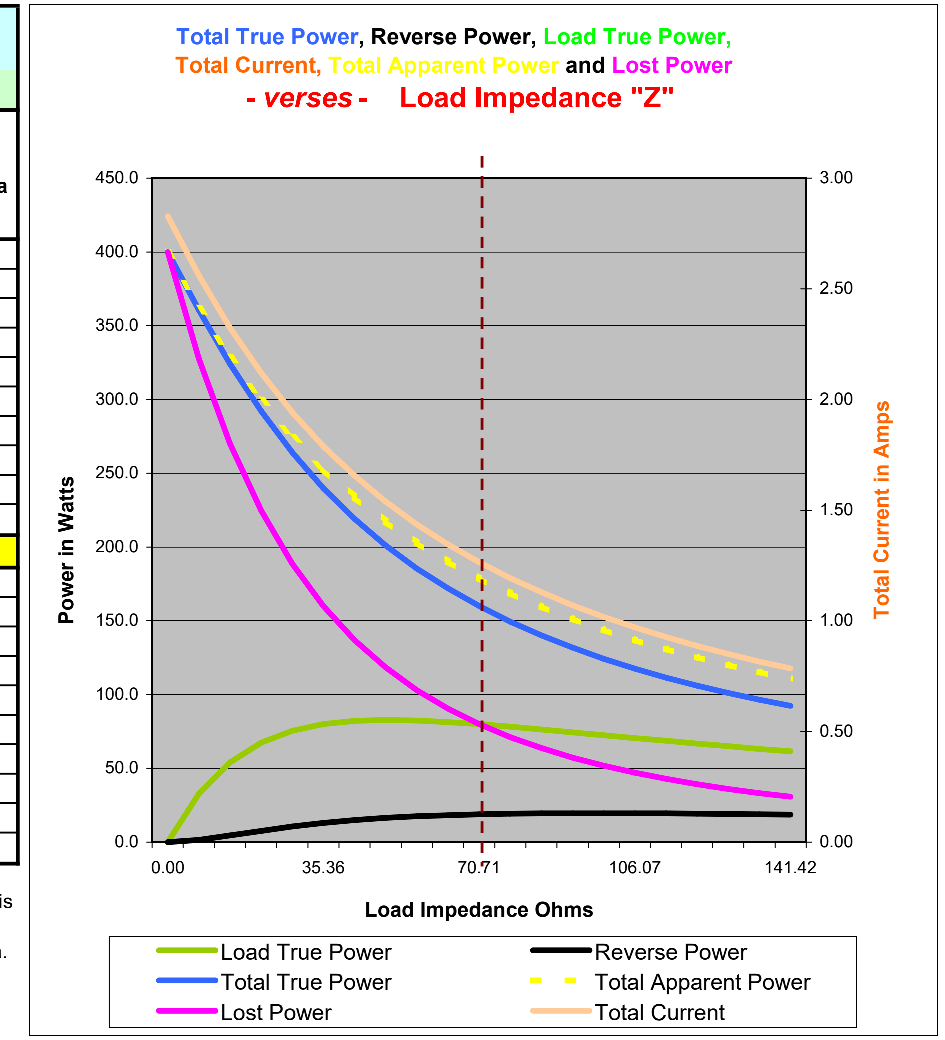
Compute the SWR and Reflection Coefficient & Plot Total True Power, Reverse Power, Load True Power, Total Current, Total Apparent Power, and Lost Power as a function of User Selected Values of Source Voltage, Source Z, Load R and Load X.

Insert your selected Source Voltage, Source Z, Load R and Load X values within the four center row orange cells

E_S	Z_S	Load Characteristics					ρ	I_T	P_A	P_T	P_R	P_{Lost}	P_L		
Source Voltage	Source Z_S	Load Z_T	Load L_R	Load L_X	SWR	Power Factor	Reflection Coefficient	Total Current	Total Apparent Power	Total True Power	Reverse Power	Lost Power	Load True Power	Load True Power as a % of Total True Power	Load True Power % compared to a 100% Match
141.4	50	0.00	0	0	Infinity	1.00	1.00	2.83	399.9	399.9	0.00	399.9	0.0	0.00%	0.00%
141.4	50	7.07	5	5	10.10	1.00	0.82	2.56	362.0	360.5	1.49	327.8	32.8	9.09%	32.79%
141.4	50	14.14	10	10	5.21	0.99	0.68	2.32	328.7	324.2	4.47	270.2	54.0	16.67%	54.05%
141.4	50	21.21	15	15	3.66	0.97	0.57	2.12	299.7	292.0	7.68	224.7	67.4	23.08%	67.42%
141.4	50	28.28	20	20	2.96	0.96	0.50	1.94	274.6	264.1	10.57	188.6	75.4	28.57%	75.47%
141.4	50	35.36	25	25	2.62	0.95	0.45	1.79	252.9	239.9	12.98	160.0	80.0	33.33%	80.00%
141.4	50	42.43	30	30	2.46	0.94	0.42	1.65	234.0	219.1	14.90	136.9	82.2	37.50%	82.19%
141.4	50	49.50	35	35	2.41	0.92	0.41	1.54	217.5	201.1	16.38	118.3	82.8	41.18%	82.84%
141.4	50	56.57	40	40	2.44	0.91	0.42	1.44	203.0	185.5	17.50	103.1	82.4	44.44%	82.47%
141.4	50	63.64	45	45	2.51	0.90	0.43	1.35	190.2	171.9	18.31	90.5	81.4	47.37%	81.45%
141.4	**50**	**70.71**	**50**	**50**	**2.62**	**0.89**	**0.45**	**1.26**	**178.8**	**160.0**	**18.88**	**80.0**	**80.0**	**50.00%**	**80.00%**
141.4	50	77.78	55	55	2.74	0.89	0.47	1.19	168.7	149.4	19.26	71.2	78.3	52.38%	78.29%
141.4	50	84.85	60	60	2.89	0.88	0.49	1.13	159.6	140.1	19.48	63.7	76.4	54.55%	76.43%
141.4	50	91.92	65	65	3.04	0.87	0.50	1.07	151.4	131.8	19.59	57.3	74.5	56.52%	74.50%
141.4	50	98.99	70	70	3.20	0.86	0.52	1.02	143.9	124.3	19.60	51.8	72.5	58.33%	72.54%
141.4	50	106.07	75	75	3.37	0.86	0.54	0.97	137.2	117.6	19.55	47.0	70.6	60.00%	70.59%
141.4	50	113.14	80	80	3.54	0.85	0.56	0.93	131.0	111.6	19.43	42.9	68.6	61.54%	68.67%
141.4	50	120.21	85	85	3.72	0.85	0.58	0.89	125.3	106.1	19.27	39.3	66.8	62.96%	66.80%
141.4	50	127.28	90	90	3.90	0.84	0.59	0.85	120.1	101.1	19.08	36.1	65.0	64.29%	64.98%
141.4	50	134.35	95	95	4.08	0.84	0.61	0.82	115.3	96.5	18.86	33.3	63.2	65.52%	63.23%
141.4	50	141.42	100	100	4.27	0.83	0.62	0.78	110.9	92.3	18.63	30.8	61.5	66.67%	61.54%



In the circuit to the right, the load portion of this circuit shows an Inductor, Capacitor and Resistor. Assume that this is a dipole antenna. The Resistor "Load L_R" will be the (i.e. radiation resistance). The "Load L_x" is difference between the antenna's capacitive reactance and it's inductive reactance. Note: At resonance L_X is Zero (0).



Blue plot is the "Total True Power" from the source. The Green plot is "Load Power" and the Red plot is "Power Lost" and they ADD up vertically to equal the Blue plot at any horizontal axis Load Impedance value. Also if you ADD the Black plot to the Blue plot it will = the Yellow plot. The Orange plot tracks the change in Total circuit Current flow.

Notes and comments about this presentation.

This worksheet's Table and the Plot is a bit busy, however we will explain the above table from left to Right.

The left two columns "Source Voltage E_S" and "Source Z_S" represent the voltage level of the RF or AC power source and it's output impedance. The user of this tool can change and specify these two values within the ORANGE cells within each of these two left most columns. Mostly these two values, are just left in their default values.

The next group of three columns in light blue, define the Characteristics of the Load within the Purple dotted line box "Load Z_L". Column "Load Z_T" is the total complex impedance as computed from the next two right columns for each row. These next two rows are; Load L_R (Load Resistance) and Load L_X (Load Reactance). Again, the user of this tool can also change and specify these two values (L_R & L_X) within the ORANGE cells within these two respective columns.

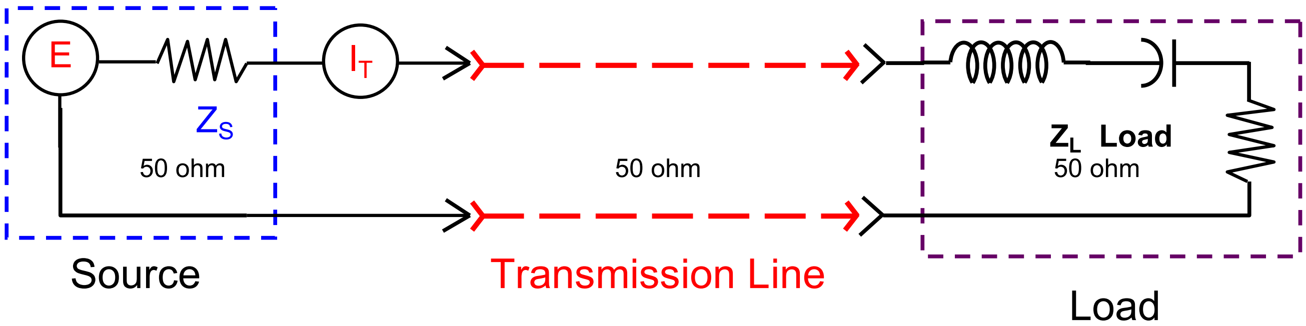
Regarding the "Load L_X" column, this reactive property is in Ohms of either Capacitive or Inductive reactance. In the example circuit both a capacitor and inductor are shown in series. It needs to be clear that the value in the "Load L_X" column is the math difference of the capacitive reactance and the inductive reactance, if both are in the circuit. Otherwise if there is only capacitive reactance or inductive reactance in the circuit, then use that value. Also, this value is not sign sensitive, not at this time in this table's use of the reactive value.

Regarding the column "SWR", the term "SWR" is still not yet a perfect fit, that being for not yet having a transmission line within the above circuit. However since we are now largely examining circuit behavior in the context of an RF signal coming from the power source, so we will use and compute for SWR, this being, as if the power source is an antenna analyzer, that is connected to load Z_L. SWR is indeed a measure of load matching but technically it is the ratio of voltage or current, Max / Min points within a transmission line.

The column "Power Factor" was included because this circuit could in reality be a 60 Hz power circuit. In the low frequency (60 & 50 Hz) power world where the load may have a measurable amount of reactance (capacitive or inductive) this can and will cause a phase shift between its respective voltage and the current waveforms. Power Factor is equal to the ratio of "Real Power" -over- "Apparent Power". Power Factor is also equal to the Cosine (Cos) of the phase angle difference between the voltage and current waveforms.

Note: Don't forget to read and checkout the CELL comments where they appear. (i.e. **Orange triangle** in top right side of a cell) Hover (or place) your courser over these cells for the cell notes to appear.

What is a Transmission Line -1



Previously the Load had been connected directly to the Source. In the above circuit drawing there is now some distance separating the Load from the Source. This distance could be a couple of feet -or- miles. The above RED dotted line cabling is the Transmission Line.

There are many different types of Transmission Lines. The more popular types are round Coax and dual Flat-Line. The job of a Transmission Line is to carry or transport an electrical signal from the Source -to- Load with minimum amount of signal loss and/or interference.

Transmission Lines have many electrical characteristics to describe and define them. The main characteristic that is usually first referenced is it's impedance value. The most common values of Impeadence are 50 & 75 ohm for coax and 300, 400 & 500 for dual Flat-Line.

It is almost always a design requirement that the Source, Transmission Line and Load impedance values all match. If they do and if we theoretically have a perfect no-loss transmission line, then there will be a good match and most if not all of the source signal will get delivered to the load (except of course for the Z_S "Source Impedance" losses).

The most common issue and challenge is where the load has an impedance mis-match and/or has a measurable reactive component as part of its load impedance.

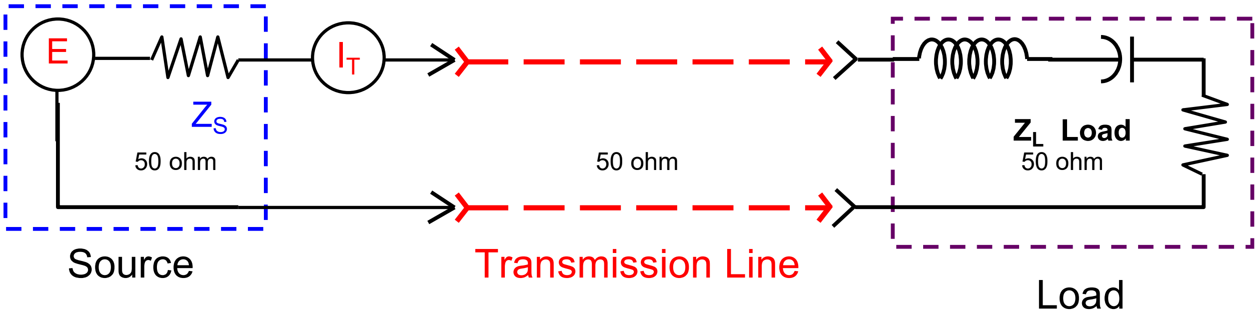
The previous two sections of this workbook have done a pretty good job of covering this condition when the load is connected directly to the source. Now, however, there is a new fly in the ointment when there is a transmission line who's length is a measurable size compared to the wavelength of the signal that it is carrying.

Ok, now as previously covered there will be reflected energy returned to the source when the load impedance has Reactance (i.e. its not pure resistance). This reflected energy will now be a return wave to the source via a transmission line <u>at the same time</u> there are ongoing forward moving signals coming from the source to the load. (i.e. they cross each other).

There will now be a new complication with the reflected signal and the forward signal both occupying the transmission line as complete waves or partial waves at the same time and on top of each other, as they pass each other by. This will result in algebraic combining in different ways along the Transmission Line.

It is beyond the scope of this presentation to go into mathematical detail -but- we do need to continue on a bit more within the next work sheet "What is a Transmission Line -2"

What is a Transmission Line -2

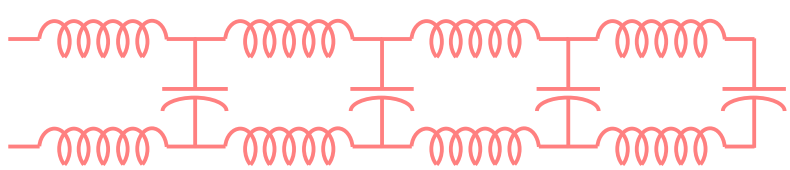


Continuing on from the previous worksheet, and given a mis-match situation of having reactance within the load and now having a transmission line, our worksheet plots and computed table values will likely have different results then if the load were directly connected to the signal source. This is because the load's L_R and L_X values are changed by the Transmission Line, as seen by the Source that is feeding the Transmission Line.

The amount of difference in the plots and table values will be a function of the length of the transmission line and its relationship to the wavelength and/or fractional wavelength of the signal that it is carrying. Now the very interesting thing is that sometimes the SWR improves and sometimes it gets worse. It just depends how the load reactance is able to work with or against the resulting transmission line's effective reactance as a function of the mis-match causing forward and reverse signals to combine within the transmission line. The result is that a mis-match causes Transmission line Impedance Transformations.

There are indeed formulas and ways to predict and compute how a match condition can improve for a given custom length of transmission line for a given mis-match condition. This is beyond the scope of this basic presentation.

Electrically a transmission line for carrying AC and RF signals looks like a series of inductors along the line's length and capacitors shunted across the line and in-between the inductors. This is approximately as per the diagram below.

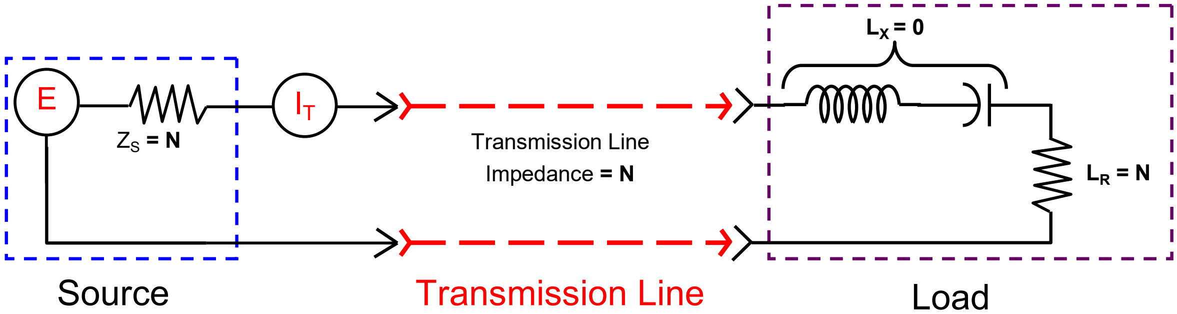


Transmission Line Electrical Equivalence

As normal wave energy moves along a transmission line, sections of the transmission line become charged and discharged. The transmission line is a kind of reservoir of moving tanks of energy or in the case of a short transmission line a fractional tank of energy.

Now there can be a mis-match condition where the Load is a pure resistance that is a different value then the source and the transmission line's characteristic impedance. So in this case its not reactance within the load that is trying to return or reflect energy -but- it is a situation that the load cannot properly accept all of the energy moving forward within the transmission line. Power has a profile. P=IE is one of them. Source E and Z values when driving into a matched transmission line establish levels of I & E. If the load matches, then the profile remains intact. If the load does not match, it will (along with the transmission line) alter the values of I and E that the load receives and accepts. This is a reduction in the power and energy that started out from the source. That being the case, the difference amount of energy must now be reflected back to the Source.

Review -and- Conclusion



Consider the following three review statements.

Review

If the Source Z_S is "N" value of pure resistance and the Load L_R is "N" value and the L_X value is "0" zero and the transmission line (of any length) has a characteristic impedance of "N", then: there is a perfect match (given if the transmission line's resistance losses are very low).

Most Amateur Radio operators strive to reach this condition as may be doable, that being for their antenna's center operating frequency. In many cases their antenna's L_X value is not at "0" zero. So for a given antenna it may have some capacitive or inductive reactance at where the operator wants it's center operating frequency to be. Often a new wire antenna needs to be extend or shorten in length.

Review

Let's say the following exist: There is a Signal Source, a Transmission Line, a Load, and there is a mis-match condition (for some reason). Let's also say that the transmission line is then extended or shortened by a random length. Ok, now there will still very likely be a mis-match but it is unknown if the degree of the mis-match will be better or worse after changing the Transmission Line's length.

When reverse energy (voltage and current) exist in a transmission line it will combine with the forward signal. If the length of the transmission line is then changed, sometime the new result of the reverse and forward signals combining is an improvement in SWR and sometimes it will get worse.

Review

Regarding the last review statement just above it needs to be stated there are many mis-match conditions where with the right knowledge about the mis-match condition and the right impedance transformation formulas at hand, that a custom length and type of replacement transmission line can improve or entirely correct the mis-match condition.

Reflections within a transmission line and what the outcome will be are a function of many things such as and not limited to the following: Where is the mis-match? Is it in the Source, Transmission Line or the Load? What is the frequency's wavelength relationship to the Transmission line and/or the Load?

There are many types of impedance matching means and methods that are beyond the scope of this basic presentation, such as Tuners, Transformers, Tuning stubs, etc, etc. This presentation is mostly geared to first understanding basic load matching, the subject is vast. However, we have been able to scratch the surface and reach a point where we can begin to participate in the subject with others. Study resources such as the ARRL "Antenna Book" is rich in clearly presented concepts.

Final Comments

This entry coverage presentation into "Load to Source Matching" is intended to help with gaining a basic understanding of energy and signal transfer from a source to a load. It is important to note that there are circuits and applications where it is intended to have reactive properties within the load. So we don't want to plant the idea that load reactance is always a negative characteristic. Enjoy using the tables and the resulting plots. Use them in discussion groups with others. There are lots of great points that folks can share and review with each other -AND- remember "Max Power Transfer is when there is a Match Condition".