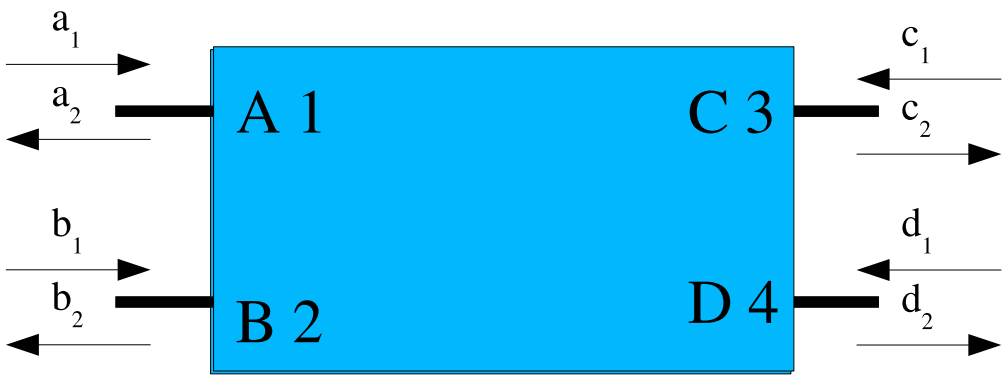
More on Four Ports

- Theorems of four port networks
- 180^o and 90^o Hybrids
- Directional couplers
- Transmission line transformers, Four port striplines
- 90^o phase shifters.
- Baluns
- Wilkinsons, Magic-T's

Fundamentals of Four Port Devices

- Consider the four port network with scattering matrix...

$$\begin{pmatrix} a_2 \\ b_2 \\ c_2 \\ d_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix} \begin{pmatrix} a_1 \\ b_1 \\ c_1 \\ d_1 \end{pmatrix}$$



Power Dividers and Combiners

- Assume the four port is matched then $S_{11} = 0$,$S_{22} = 0$,$S_{33} = 0$ and $S_{44} = 0$
- Assume that from any port, half the power appears at two other ports. For example consider waves propagating from ports A and B to ports C and D with phase shifts ϕ_{AC}, ϕ_{AD}, ϕ_{BC} and ϕ_{BD}.

$$V_C = \frac{1}{\sqrt{2}} \exp j\phi_{AC} + \frac{1}{\sqrt{2}} \exp j\phi_{BC}$$

$$V_D = \frac{1}{\sqrt{2}} \exp j\phi_{AD} + \frac{1}{\sqrt{2}} \exp j\phi_{BD}$$

- Power conservation implies that

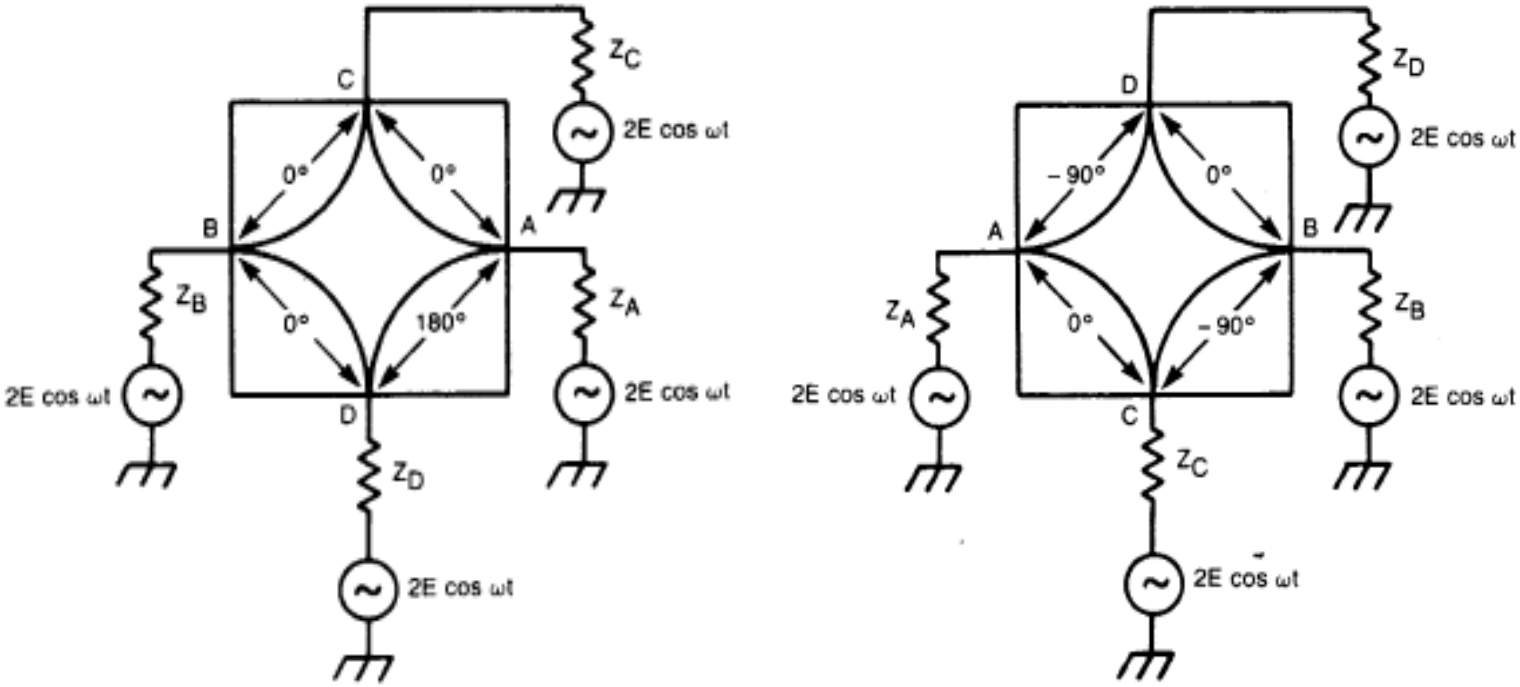
$$2 = 2 + \cos(\phi_{AC} - \phi_{BC}) + \cos(\phi_{AD} - \phi_{BD})$$

or

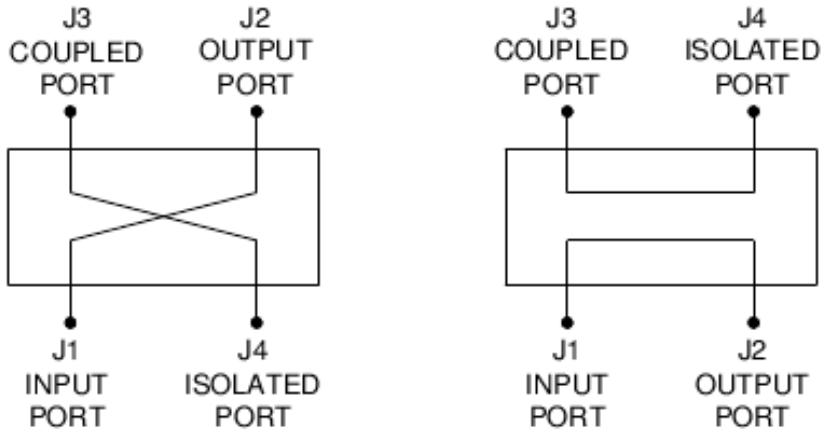
$$\cos(\phi_{AC} - \phi_{BC}) + \cos(\phi_{AD} - \phi_{BD}) = 0$$

The 180^o and 90^o Hybrids

- We distinguish two cases, ($\phi_{AC} = 0^o$, $\phi_{AD} = 0^o$) and ($\phi_{AC} = 0^o$, $\phi_{AD} = 90^o$).



The 90^{o} Hybrids

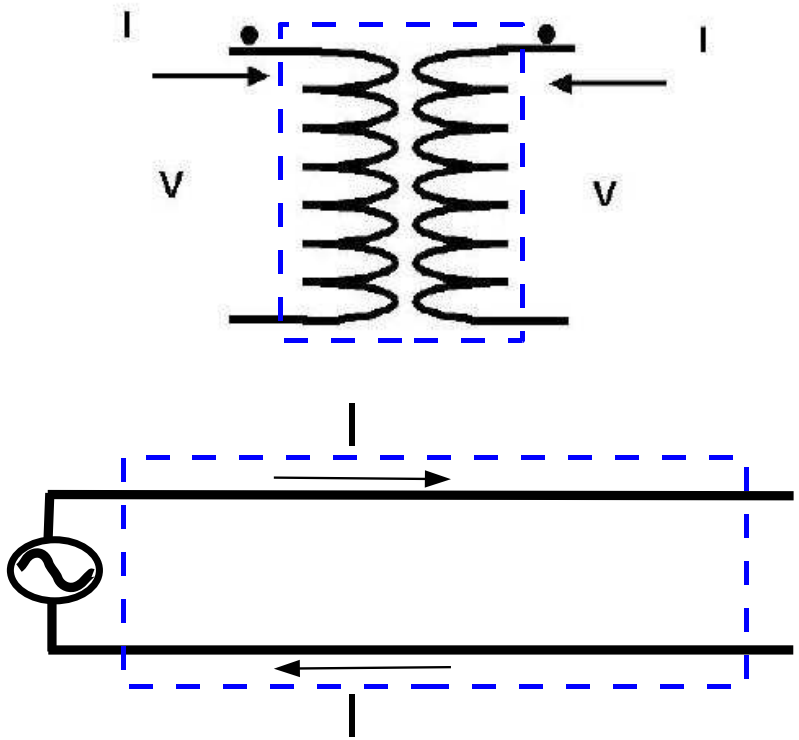


	J1	J2	J3	J4
J1	X	-90°	0°	ISO
J2	-90°	X	ISO	0°
J3	0°	ISO	X	-90°
J4	ISO	0°	-90°	X

Figure 6. Microwave Frequency 90° Hybrid Schematics and Phase Truth Table

Transmission Line Transformers

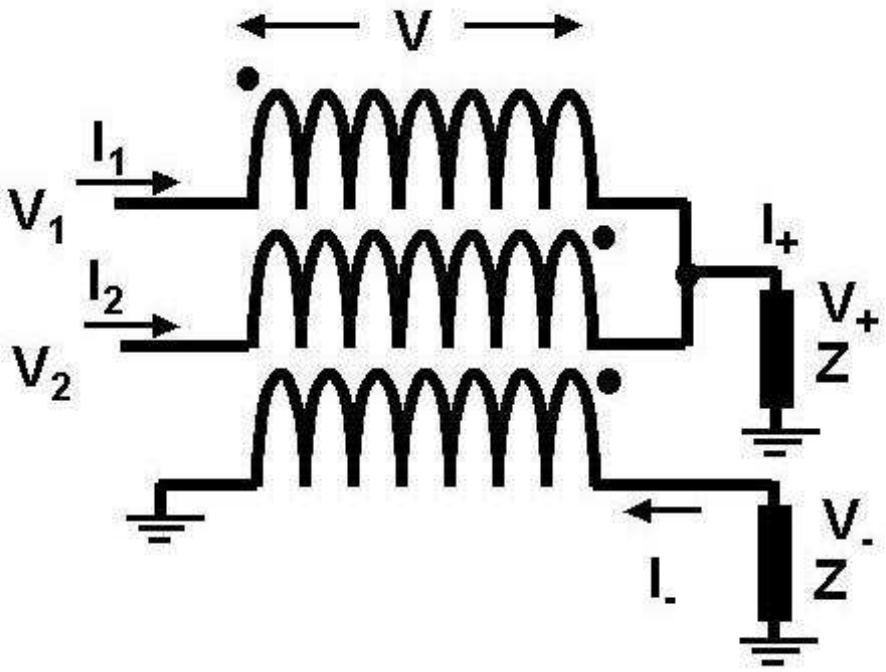
- One way to make 180^o Hybrids.
- Transformers and transmission lines are equivalent at Radiofrequency!



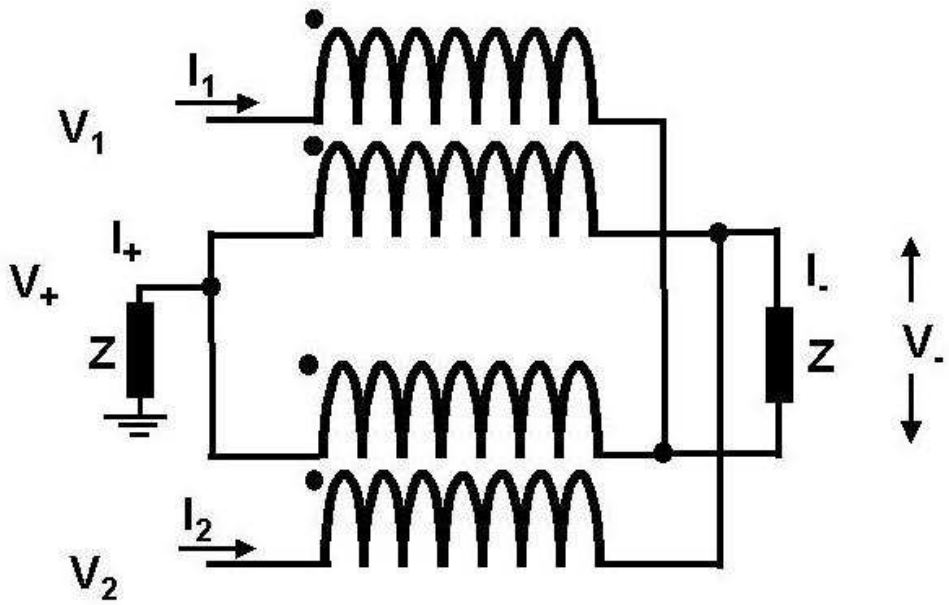
Rules for Transmission Line Transformers

- Always wind the windings in multifilar fashion.
- Can use either toroidal or linear or whatever shaped ferrites. Toroidal ferrites are usually the best.
- The dot on the transformer diagram points to one end of the wires at one end of the transformer.
- The voltage drop across all windings must be same. **WHY?**
- The currents in the same direction in the windings must sum to zero. **WHY?**
- Respects phase delays along the transmission line when doing its sums?

Transmission Line Transformer 180^{o} Hybrid

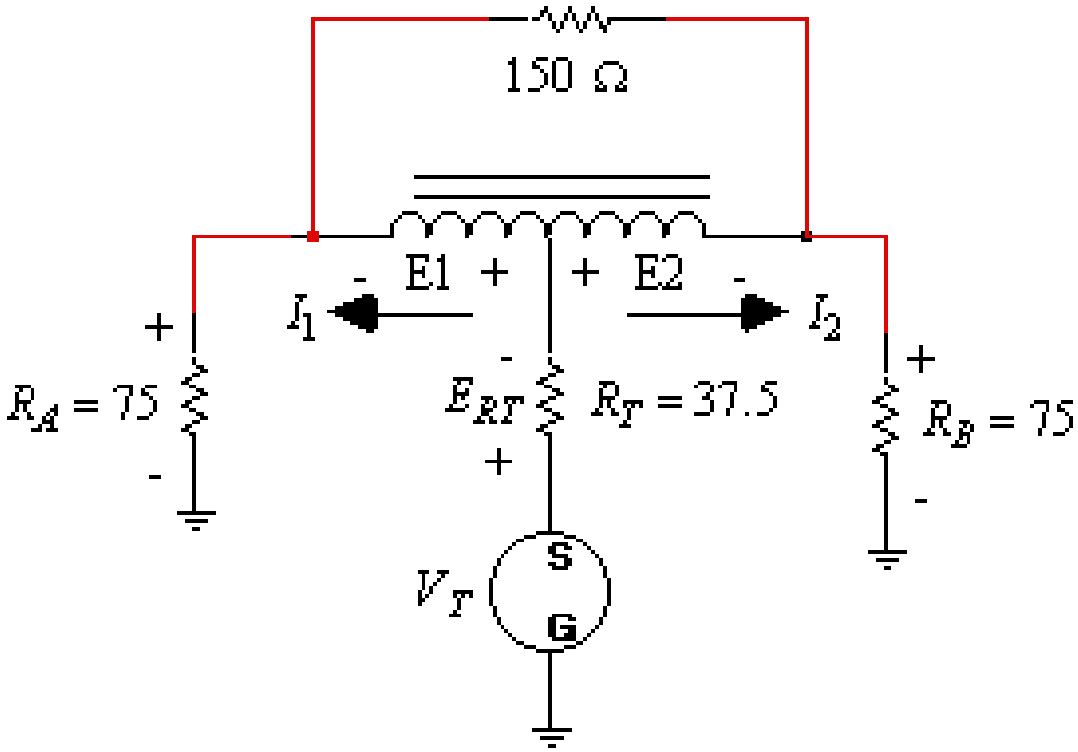


The Linear Phase Shift Combiner.

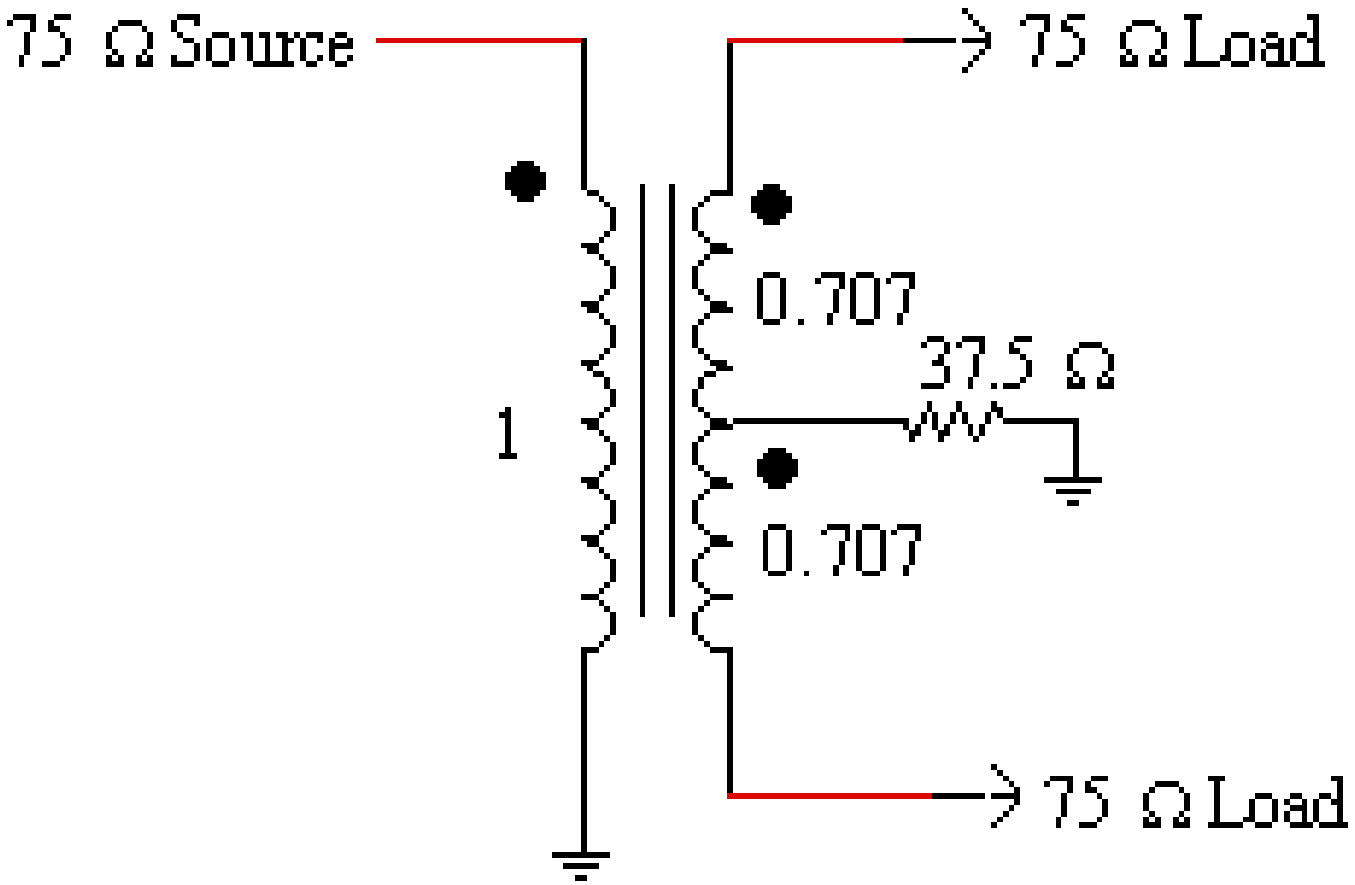


The Magic-T (Wilkinson)

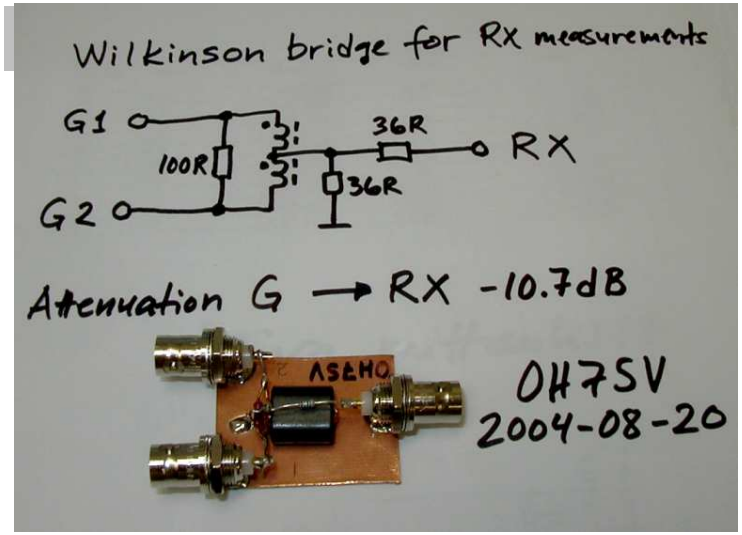
- The magic-T is a three port device that uses lossiness in order to achieve reciprocity and matching.

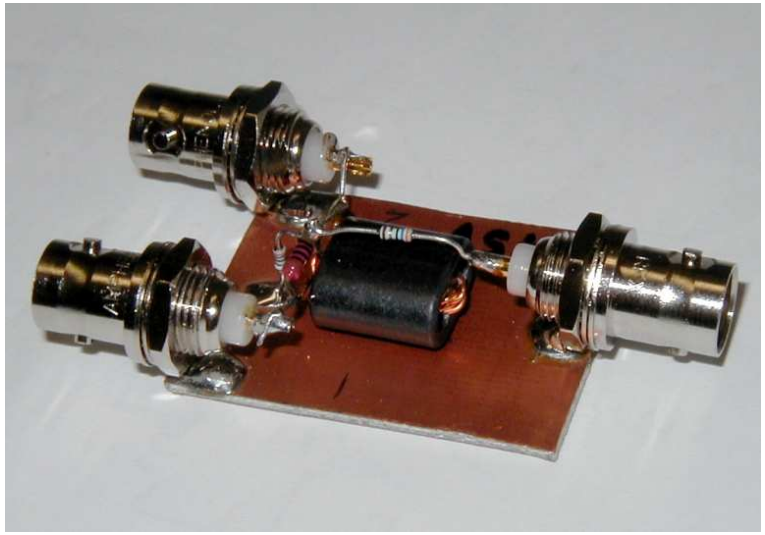


The Magic-T (Wilkinson)

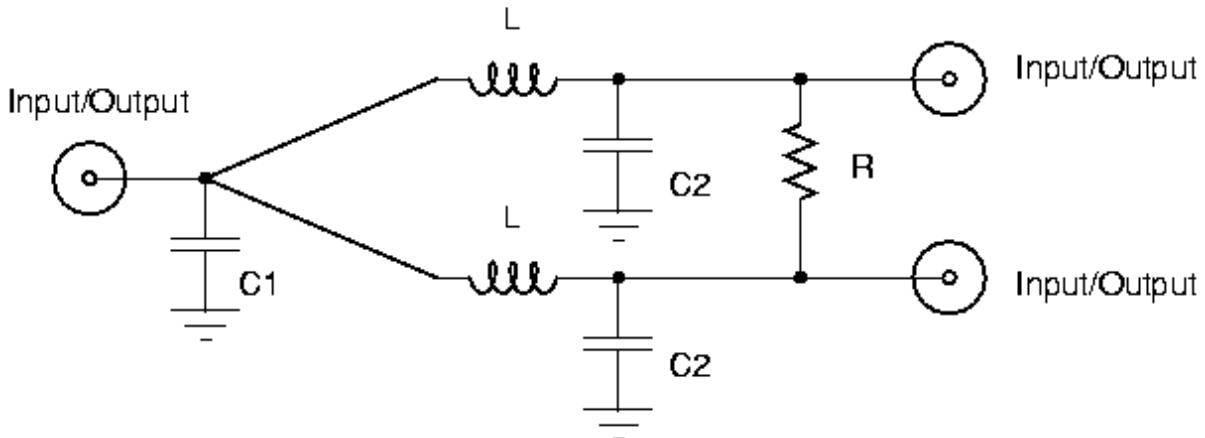


Wilkinson Combiner



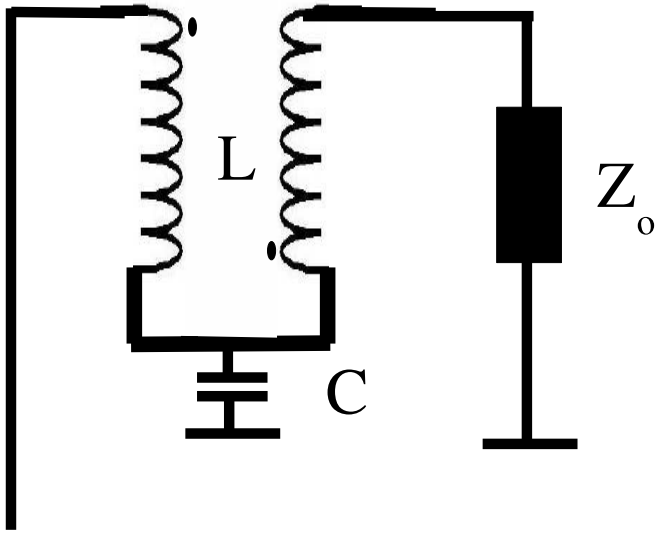


Lumped Component Wilkinson Splitter/Combiner



A 90^o Phase Shifter

- Basic building block as shown.
- Need to use two of these in parallel arms to get a *relative* phase shift of a fixed amount over a wide range of frequencies.
- Ideal for connecting to a 180^o hybrid in order to make a 90^o hybrid.

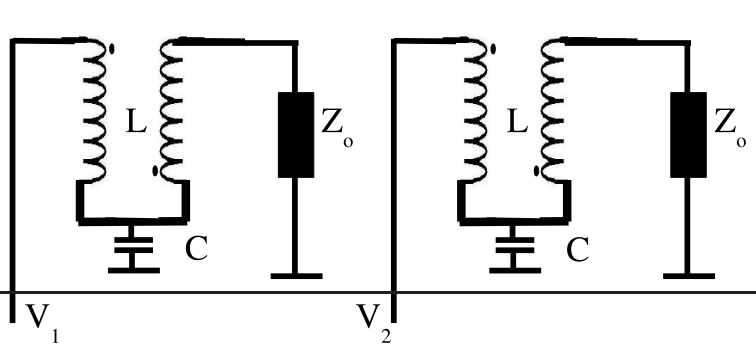


A 90^o Phase Shifter

- To design let ω_p designate the operating frequency, $C = 2/(\omega_p Z_o)$ and $L = Z_o/(2\omega_p)$, then it can be shown that the transfer function of one stage is given by,

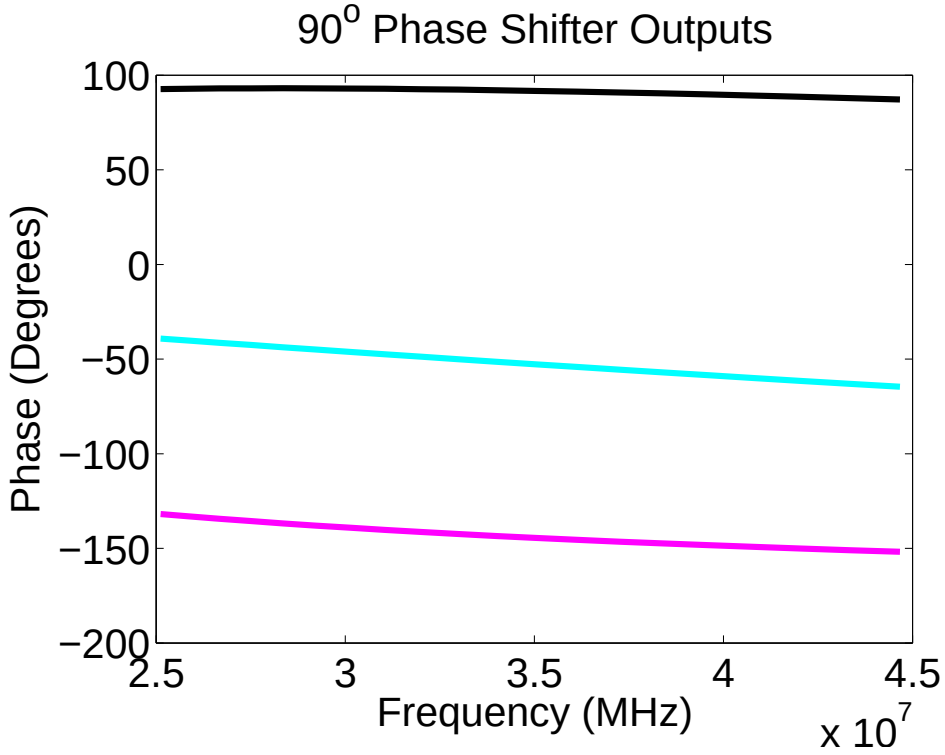
$$\frac{V_o}{V_i} = \frac{1 + \omega^2 LC}{1 - \omega^2 LC + 4j\omega L/Z_o} = \frac{1 - j\omega/\omega_p}{1 + j\omega/\omega_p}$$

- Usually use two of these driven in parallel so that the output phases track each other. Need to stagger ω_p values.
- Input impedance exactly Z_o if terminated in Z_o.
- If V_1 and V_2 are in phase then the outputs are 90^o out of phase (in quadrature). **Note that the phase of each output with repect to either input is quite variable.**

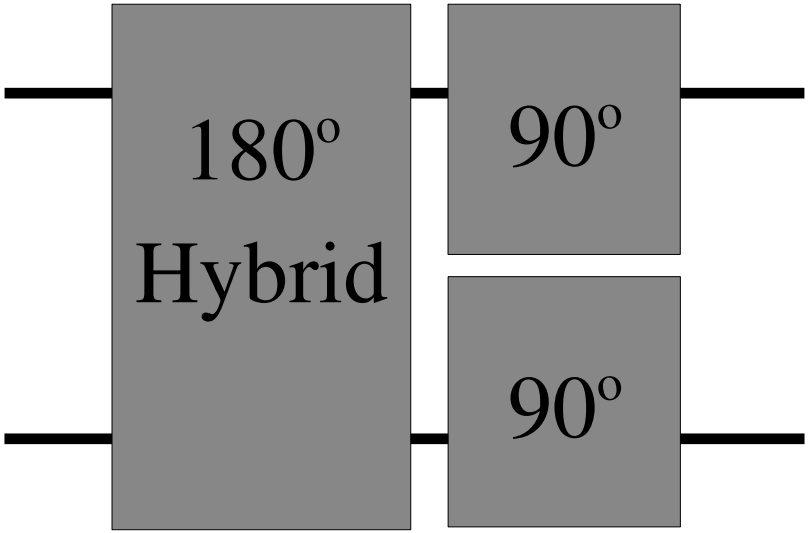


A 90^{o} Phase Shifter

- ω_p = 4.4383e+08 and 7.0529e+07 rads/sec

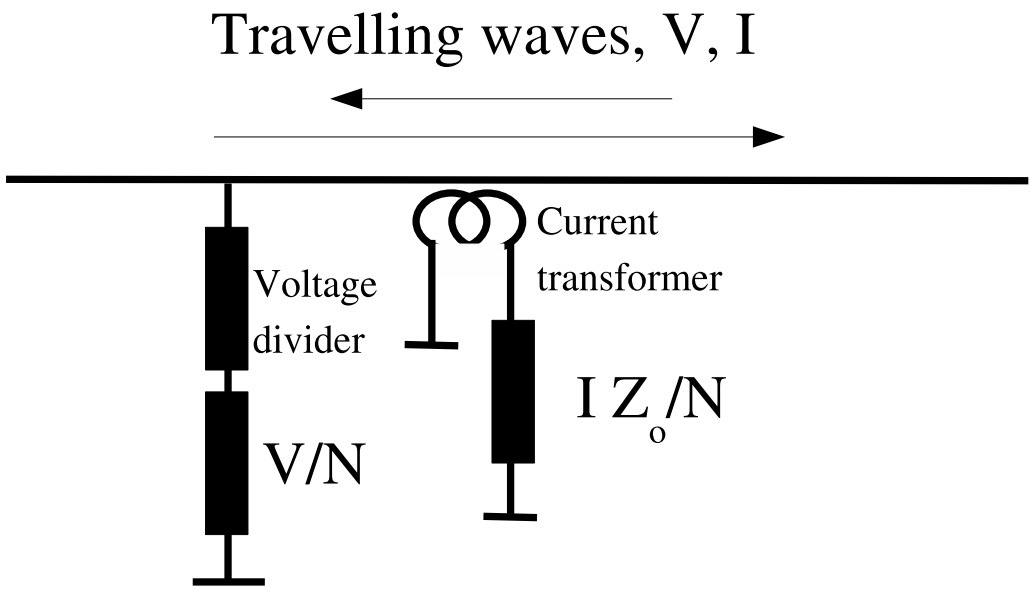


A 90^o Phase Hybrid Implementation



A Simple Directional Coupler

- Travelling waves on the line obey $V_f = Z_o I_f$ and $V_r = -Z_o I_r$
- Thus a linear combination of the total voltage V and I can be used to separately obtain V_f and V_r.



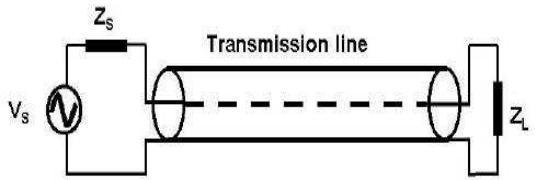
BALUNS

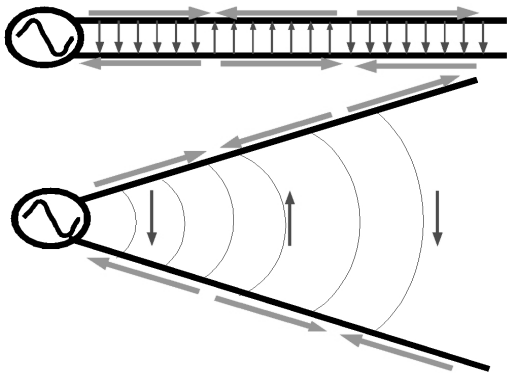
- Used to transform impedance and balance.
- Respects phase: Guanella G. ’Novel Matching Systems for High Fequencies,’ Brown-Boverie Review, Vol 31, September 1944, Pages 327-329
- Does not respect phase: Ruthroff CL, ’Some Broad-Band Transformers’, Proc IRE, Vol 47, August 1959, pages 1337-1342
- BALUNS - Use to match unbalanced to balanced lines (vice versa).

- UNUNS - Use to match unbalanced to unbalanced lines.

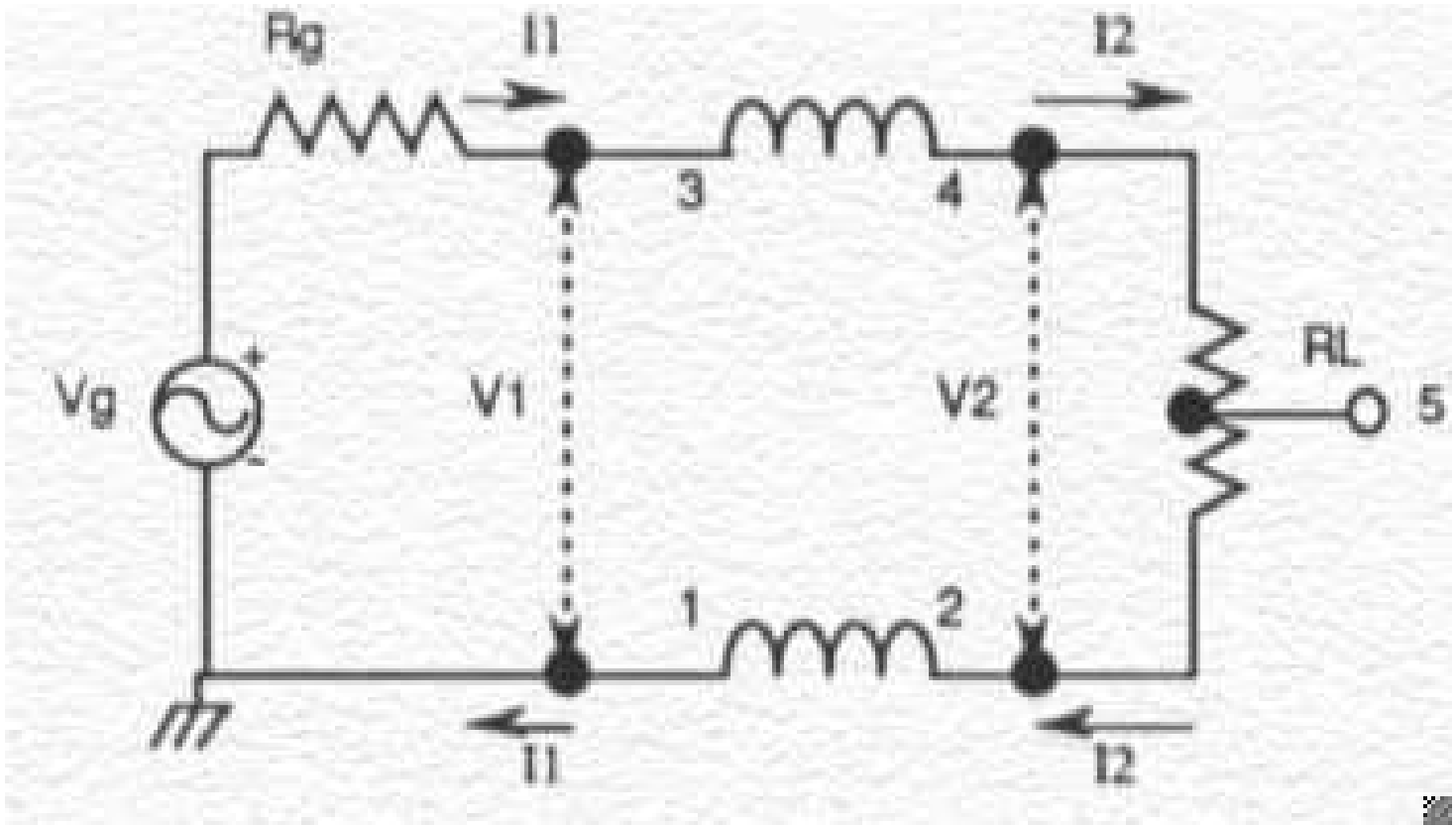
Balanced and Unbalanced Systems

- A *Balanced* system is one which is *symmetric* or *push-pull* with respect to voltage drive. An *Unbalanced* system usually means one which is connected to earth and therefore **cannot** be driven.
- How do we connect the balanced antenna or trasnmission line to the unbalanced coaxial transmission line?
- **Need to respect the differential voltage drive required by balanced loads when driving from an unbalanced source.**



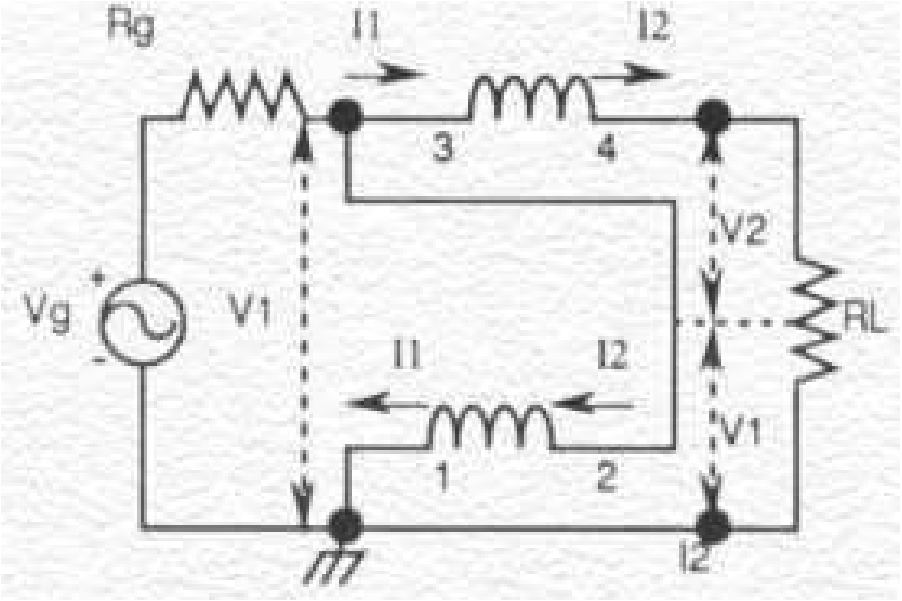


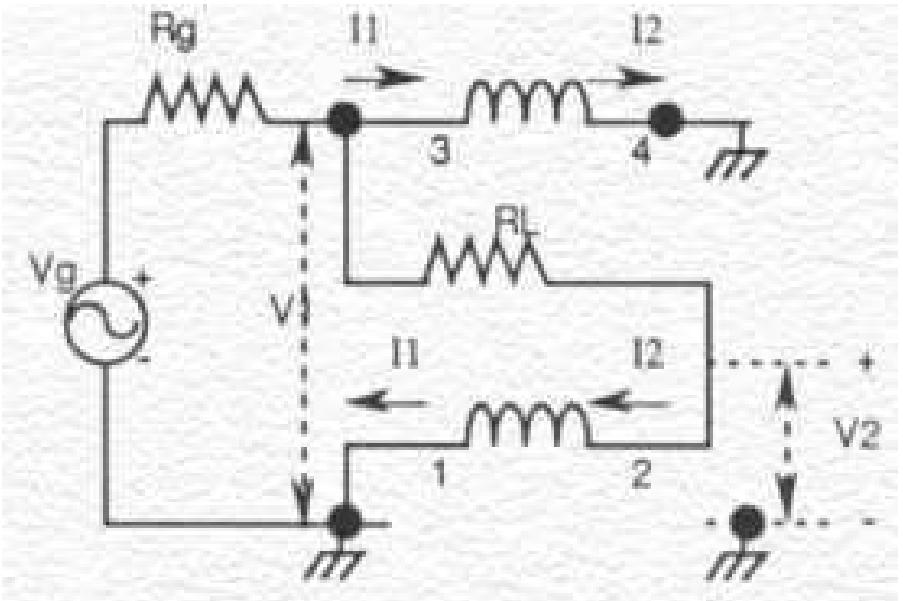
1:1 BALUN



Ruthroff Baluns

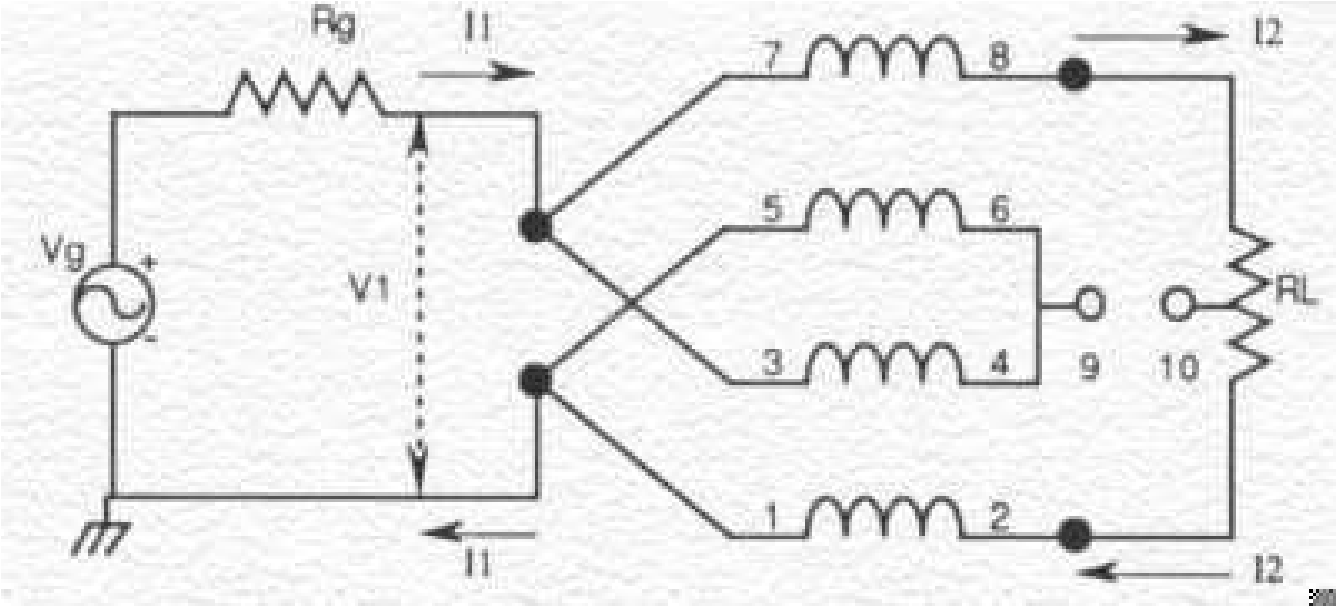
- Do not repect phase delays.
- 1:4 Impedance matching unun (left) and balun (right).





Guanella Baluns

- Do repect phase delays.
- 1:4 Impedance matching balan.



EXAMPLE WELL KNOWN BALUN

- Use the following to connect your unbalanced 300 Ω antenna or cable to a balanced 75 Ω cable or TV set.