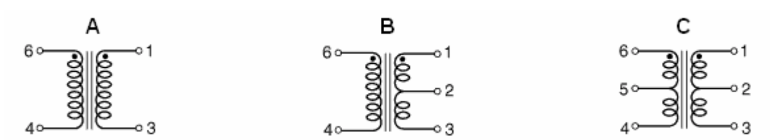
RF/Microwave Circuits I

Baluns

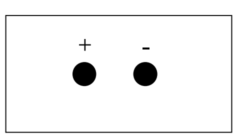
Fall 2007

Baluns



- **A balun (balanced-to-unbalanced) is a transformer used to connect balanced transmission line circuits to unbalanced ones**
  - **Two conductors having equal and opposite potential constitute a "balanced" line**
  - **Microstrip and coaxial cables use conductors of different dimensions – these are "unbalanced"**

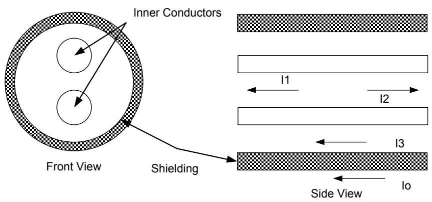
Ground shield



This "shielded 2-wire line" is balanced – no current will flow through the shield

Baluns

- There are many different types of baluns – the different designs that have been developed generally depend on
  - The bandwidth required
  - The operating frequency
  - The physical architecture of the network (what types of components are being connected and in what configuration)
- In some cases "active" baluns (using transistors) are used but these are typically only found in integrated circuits



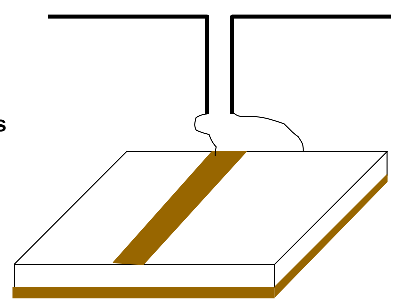
$I_1 = I_2, I_3=0$

Baluns

- When do you need a balun?
  - Balanced mixers
  - Push-pull amplifiers
  - Balanced frequency multipliers
  - Phase shifters
  - Balanced modulators
  - Dipole antenna feeds
  - Etc…..
  - → Whenever a circuit design requires signals on two lines that are equal in magnitude and 180 degrees out of phase

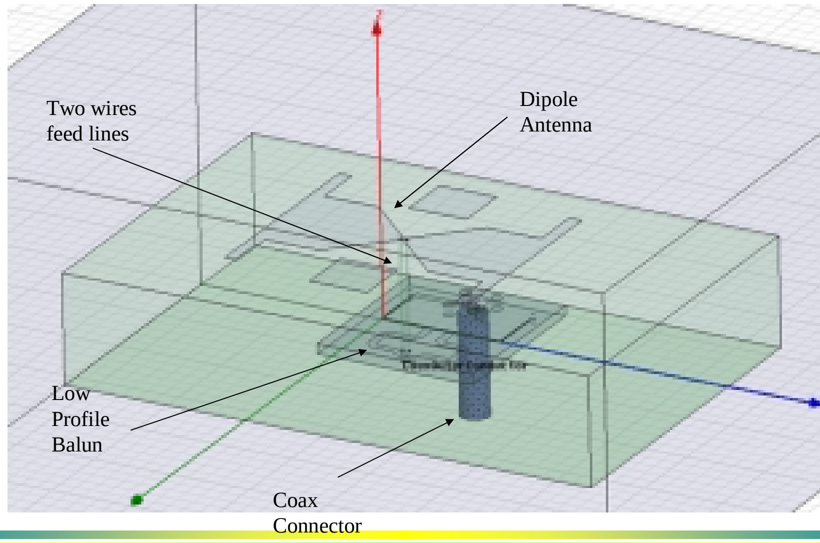
If you just connect one arm of the dipole to ground the antenna does not work properly!

Dipole antenna



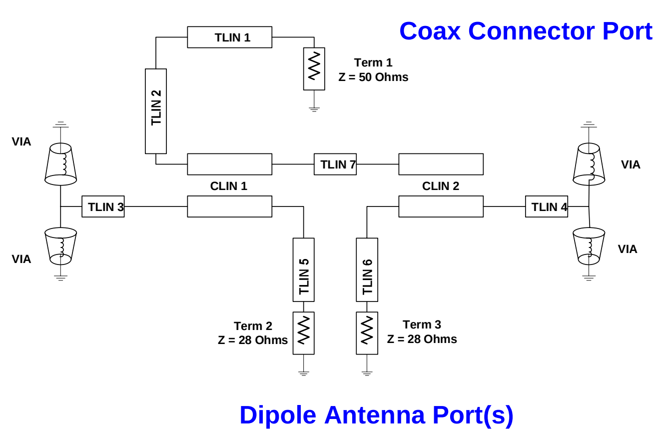
Microstrip "feed line"

Baluns - Example

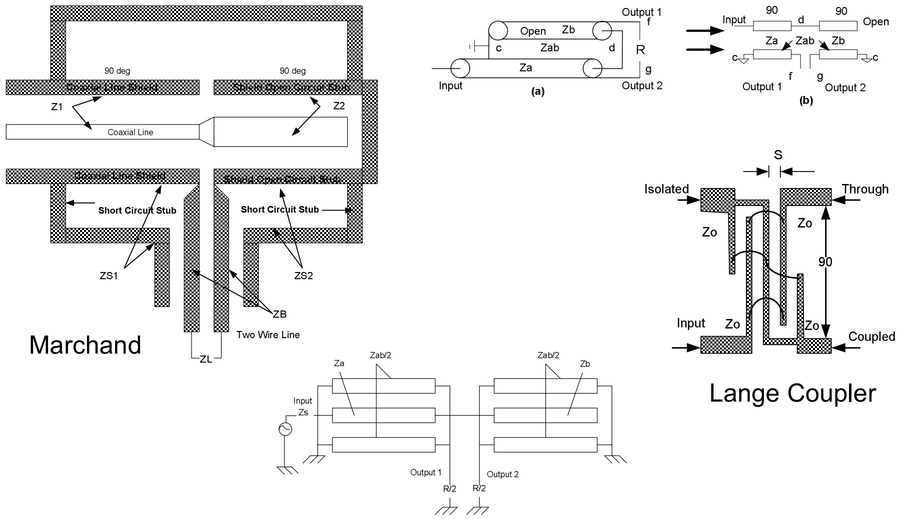


Balun - Example

- Schematic of the balun from the previous slide….



Balun – Other Examples



Surface Mount Baluns

- The basics – a transformer is two windings linked by a magnetic field
  - As current passes through the primary coil and creates magnetic flux, a current in the secondary coil arises to generate an opposing field – this you know from basic EM theory, right-hand rule, etc.
  - An implication of this fact is that a polarity difference exists between terminals on either side of the transformer
  - Many times you cannot SEE how the coils are wound, so you need to rely on how the vendor has marked the package
    - In-phase terminals are usually marked with a dot

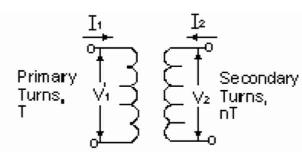


Figure 1

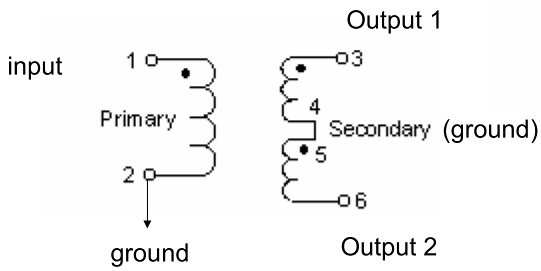
$V_2 = nV_1$

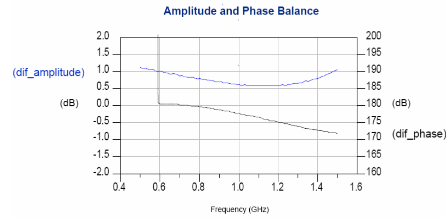
$I_2 = I_1/n$

$$Z_2 = \frac{V_2}{I_2} = \frac{nV_1}{I_1/n} = n^2 \frac{V_1}{I_1} = n^2 Z_1$$

Surface Mount Baluns

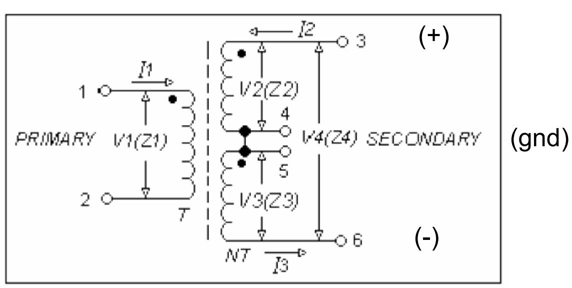
- Important terms:
  - Amplitude balance – how closely matched are the amplitudes of the two output signals
  - Phase balance – how well does the phase of one output track the phase of the second output
  - Insertion loss – (we know this one)





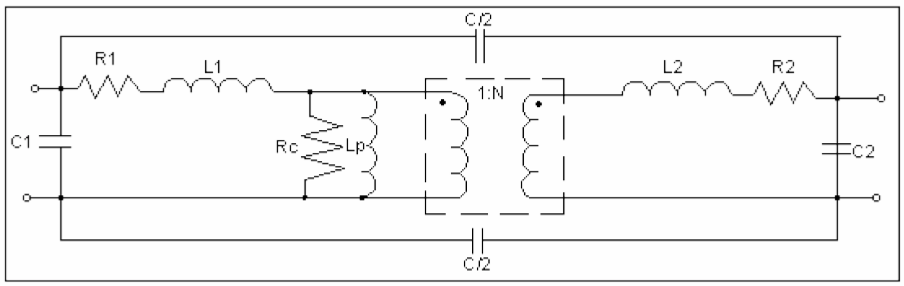
Surface Mount Baluns

- Baluns are commonly made using the center-tapped transformer below
  - Each output is terminated by $N^2Z_1/2$
  - The center tap (nodes 4,5) is grounded
  - This provides a 180-degree phase difference between nodes 3 and 6



Surface Mount Baluns

- Typical equivalent circuit with parasitic elements (these should look somewhat familiar…)



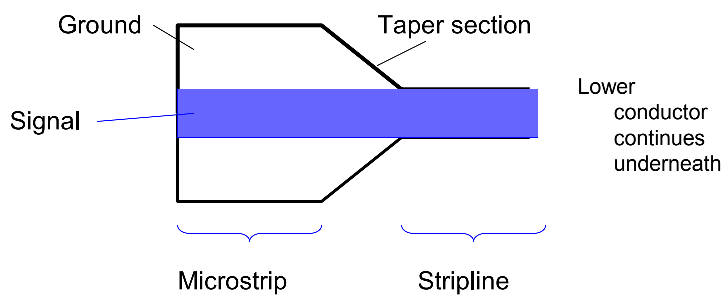
Surface Mount Baluns

- Do we need anything other than surface mount baluns?

- Answer = of course, sometimes
  - Non-planar components may not be ideal
  - Frequency range may be limited
  - Integrated designs are sometime required
  - Configuration may not work in architecture for other reasons

Distributed Balun Designs

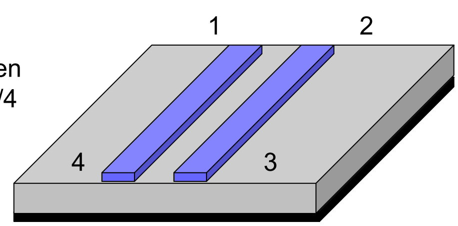
- **A simple example is a transition between a microstrip line (unbalanced) and a stripline (balanced)**
  - **A stripline is similar to microstrip, except both conductors have the same dimension**
  - **Various techniques for tapering the dimensions of the lower conductor have been developed**



Distributed Balun Designs

- **Coupled microstrip lines can also be used to realize a balun:**

Analyze at f_c, when the length = $\lambda/4$

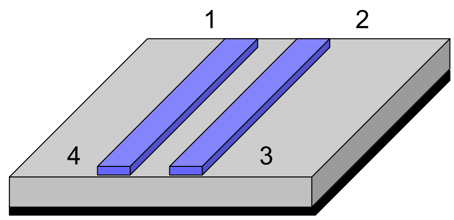


If a short circuit is placed at port 2: $\frac{S_{31}}{S_{41}} = \frac{-(Y_{0,odd} - Y_{0,even})}{(Y_{0,odd} + Y_{0,even})}$

We want this ratio to be -1 over a wide bandwidth, which requires $Z_{0,even} = \infty$

S_{11} is zero if $Z_{o,odd} = Z_o/\sqrt{2}$

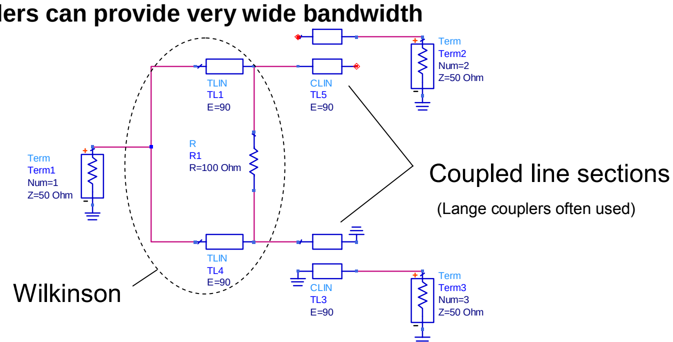
Distributed Balun Designs



- <u>Achieving a high even-mode impedance</u> (when both strips are at the same potential) means the ground plane has little effect
  - Thick, low dielectric constant substrates
  - Very thin conductors
- Achieving this in practice can be difficult, so this type of balun is not always the best solution

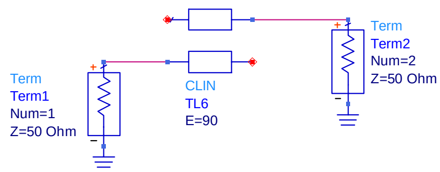
Distributed Balun Designs

- Planar Transmission Line Baluns – consist of two sections
  - The first section divides the signal into two signals with equal amplitude and phase
  - The second section provides -90 degrees and +90 degrees phase shift for the signals, so the total phase difference between outputs is 180 degrees
- A Wilkinson divider is often used for the first section; multi-section Wilkinson dividers can provide very wide bandwidth



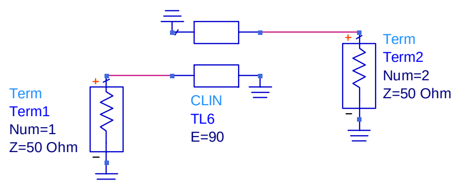
Distributed Balun Designs

$$[S]_{open} = \begin{bmatrix} 0 & -j \\ -j & 0 \end{bmatrix}$$



180 degree phase difference

$$[S]_{short} = \begin{bmatrix} 0 & j \\ j & 0 \end{bmatrix}$$



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