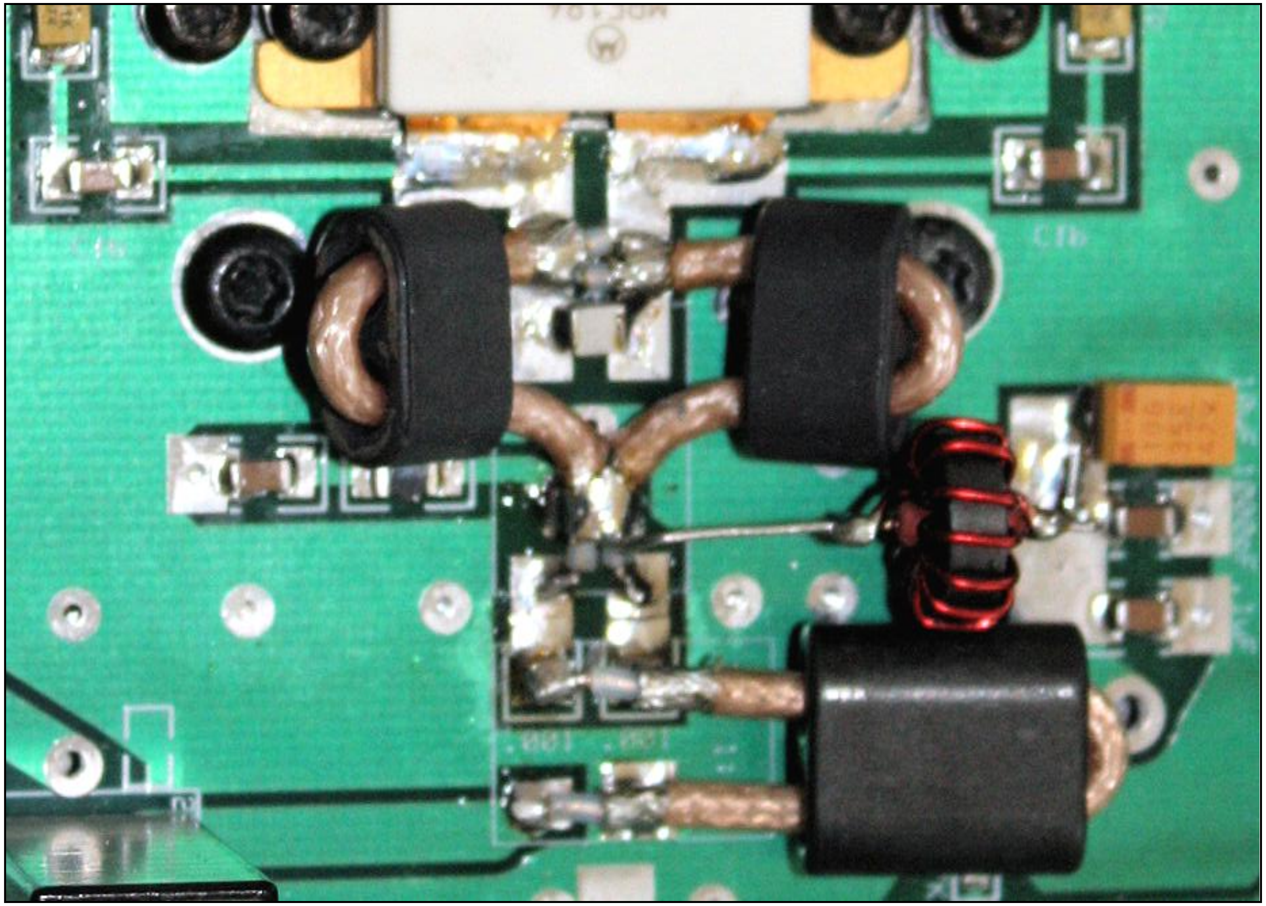
Transmission-Line Transformers



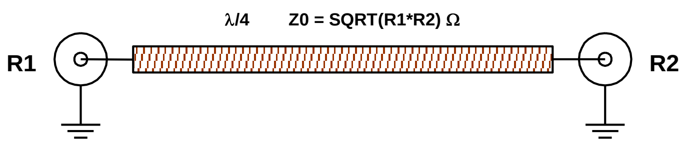
K5TRA

Categories of Transmission-Line Transformers

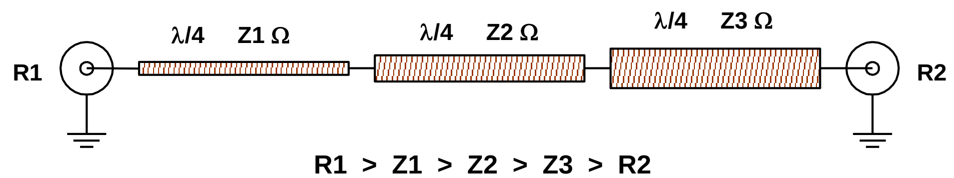
- Single $\lambda/4$ lines and cascades of $\lambda/4$ lines
- Distributed element approximations of lumped element (LC) designs
- Short, highly coupled unit element structures
  - Ruthroff
  - Guanella

¼ λ and Stepped ¼ λ Transformers

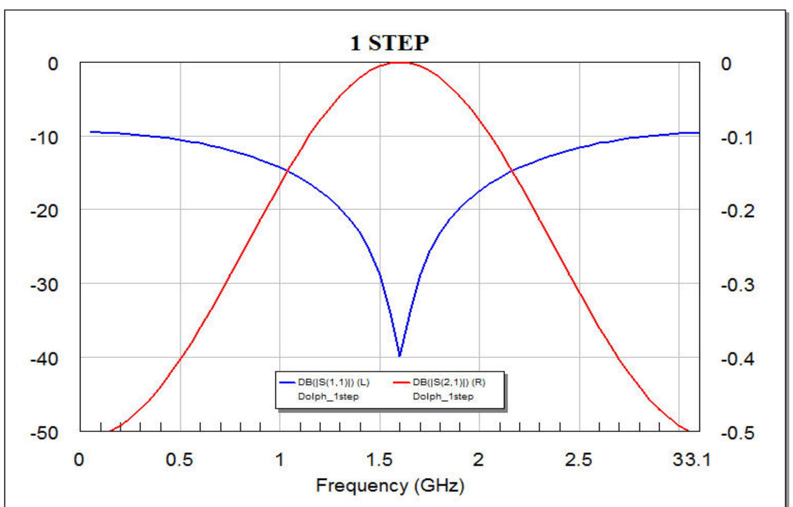
- Half octave performance from single quarter-wave line transformer
- Nearly 2-octave performance from 3 stepped quarter-wave lines
- Comparison for 50Ω to 100Ω transformation (BW also depends on this)

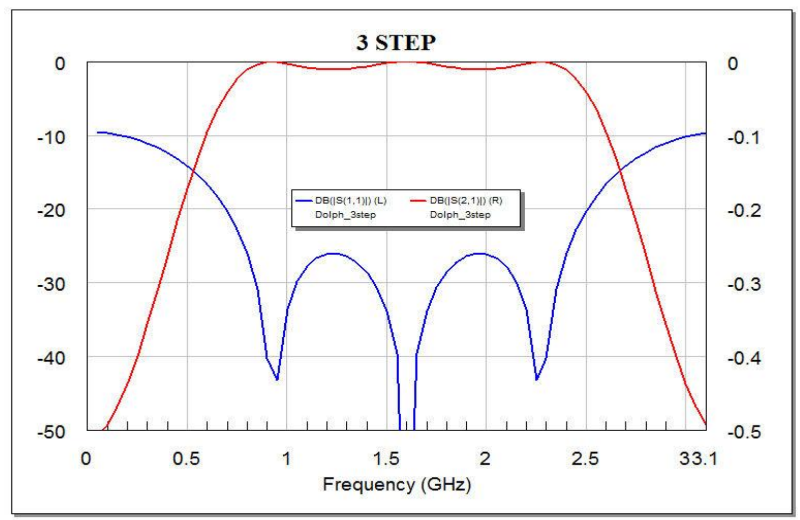


¼ λ Z INVERTER

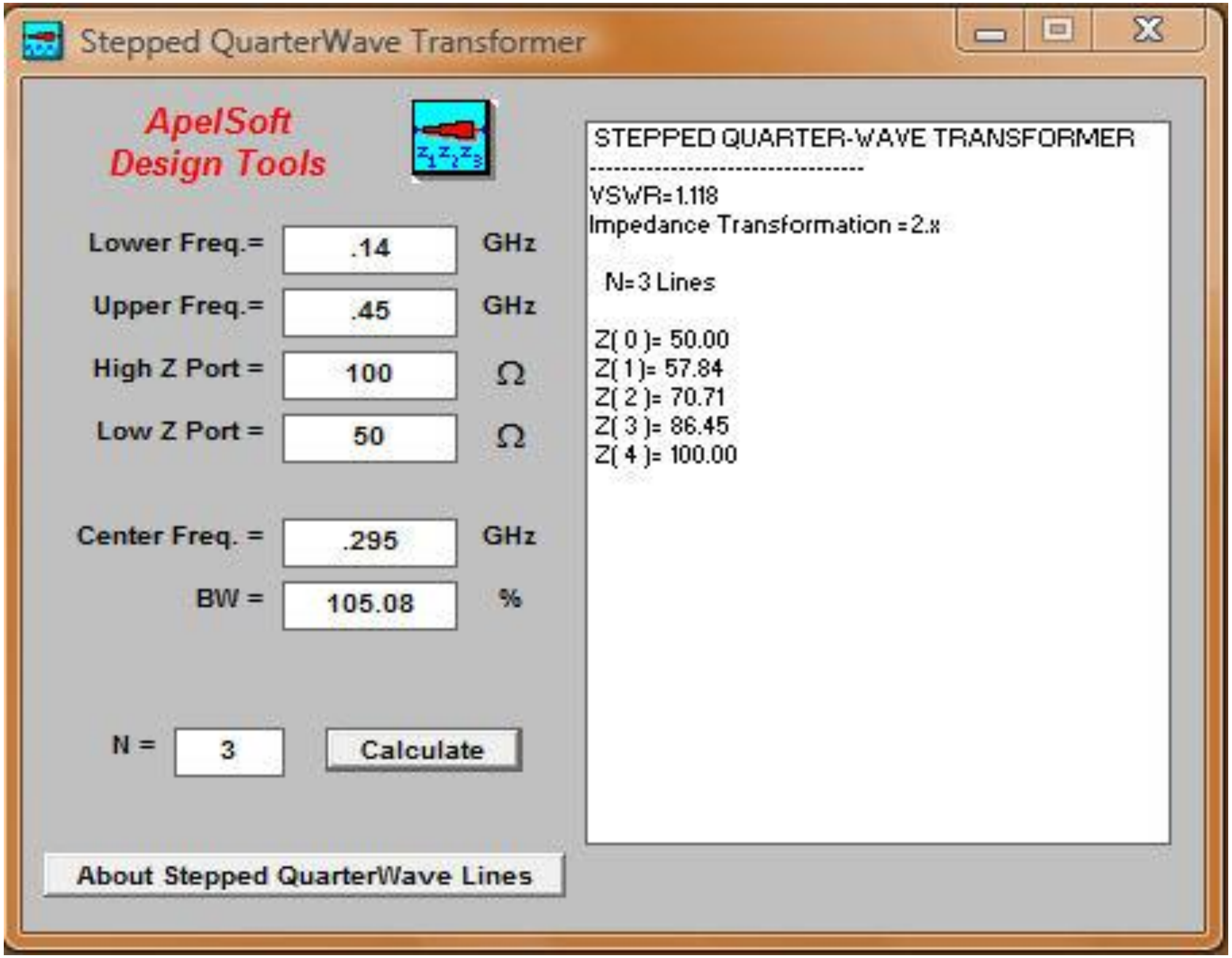


STEPPED Z TRANSFORMER





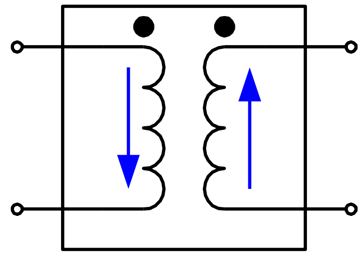
Stepped ¼ λ Transformer Calculation



DOWNLOAD FROM: http://k5tra.net/

Transmission-Line Transformer – Elements

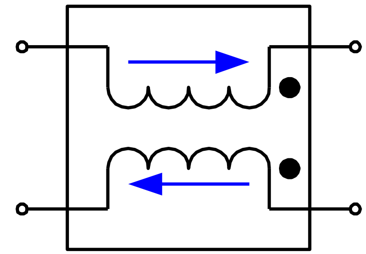
1:1



CONVENTIONAL TRANSFORMER

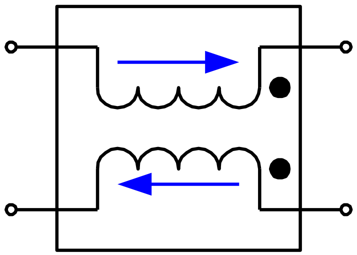
=

1:1



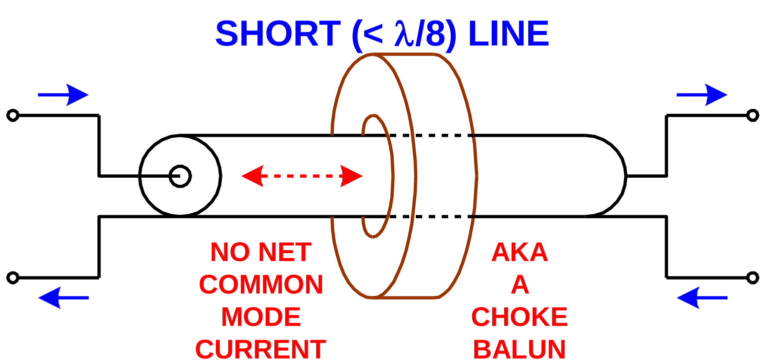
TRANSMISSION-LINE TRANSFORMER

1:1



SYMBOLIC

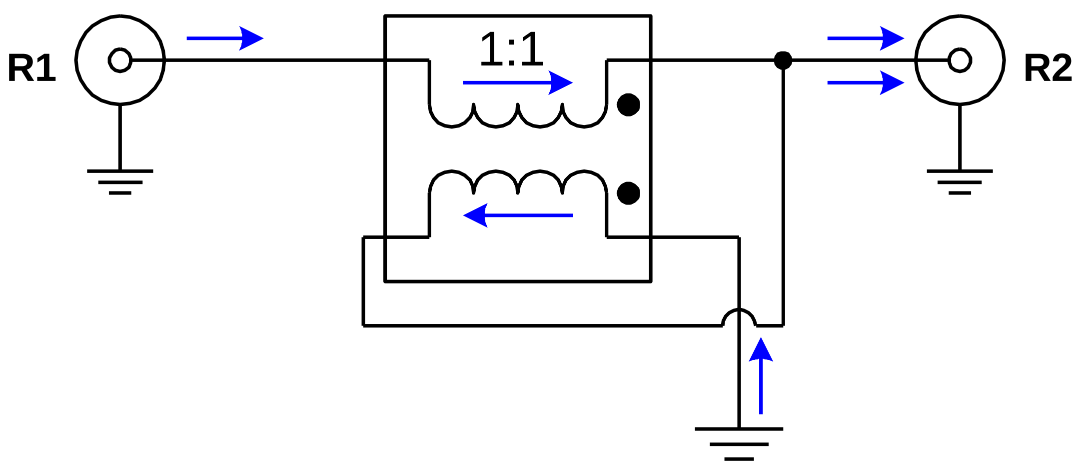
=



PHYSICAL

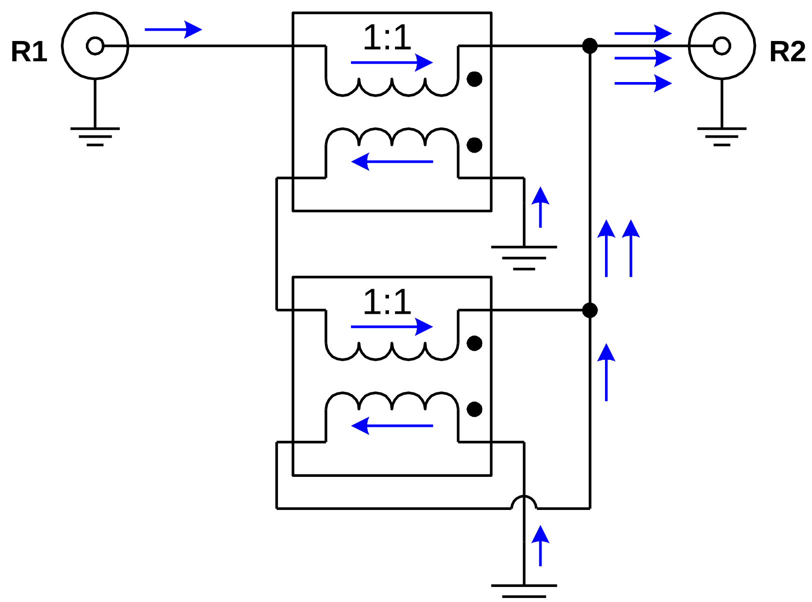
Ruthroff Transformers

- Transmission line ‘unit’ element
- Physically short lines (length < λ / 8)
- Analysis based on currents
- $R_1 / R_2 = (I_2 / I_1)^2 = 4$
- Ferrite loading extends bandwidth (low end)



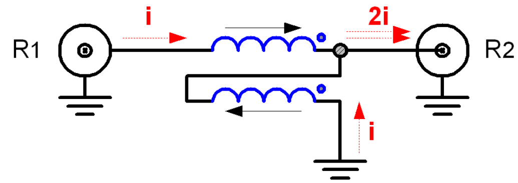
Ruthroff Type 9:1 Transformer

- Transmission line ‘unit’ elements
- Physically short lines (length < λ / 8)
- Analysis based on currents
- $R_1 / R_2 = (I_2 / I_1)^2 = 9$
- Ferrite loading extends bandwidth (low end)



Various Unbalanced Transformers

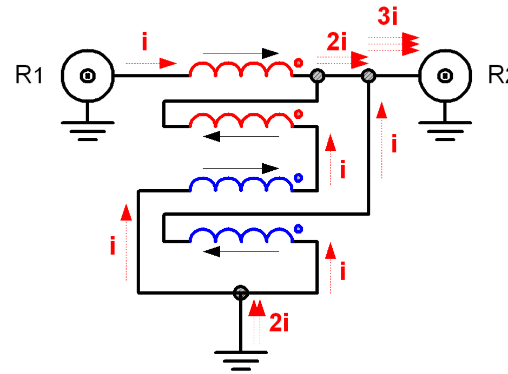
- Transmission line unit element building blocks
- Parasitic even mode characteristic impedance should be large (k → 1)
- Z ratio available as squares of integer ratios
- First order analysis on basis of port current ratio
- Multiple line structures must have at least one shared current path
- DC path is present



$i^2 R1 = (2\ i)^2 R2$

$R1 = 4\ R2$

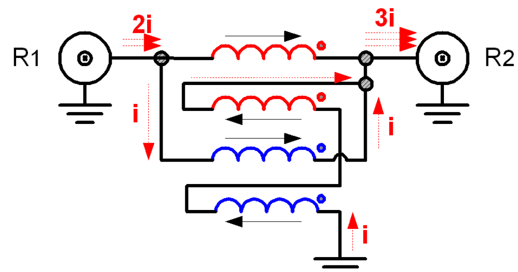
4:1 Transformer



$i^2 R1 = (3\ i)^2 R2$

$R1 = 9\ R2$

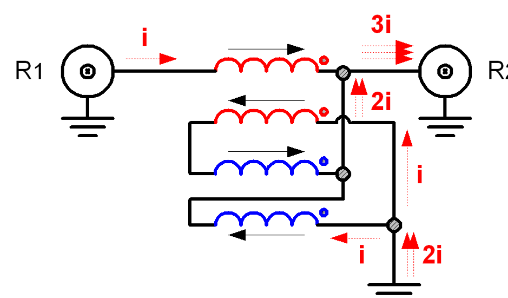
9:1 Transformer version - A



$(2\ i)^2 R1 = (3\ i)^2 R2$

$R1 = 4\ R2$

4:9 Transformer (approx. 1:2)



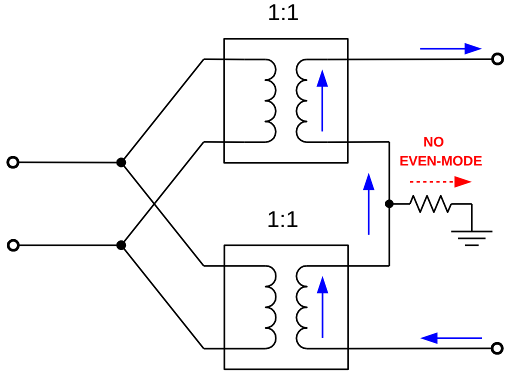
$i^2 R1 = (3\ i)^2 R2$

$R1 = 9\ R2$

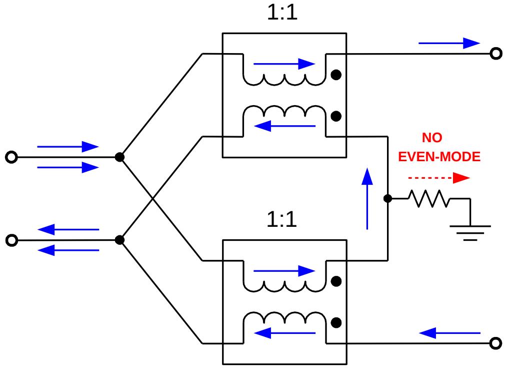
9:1 Transformer version - B

Guanella (4:1) Balanced Transformer

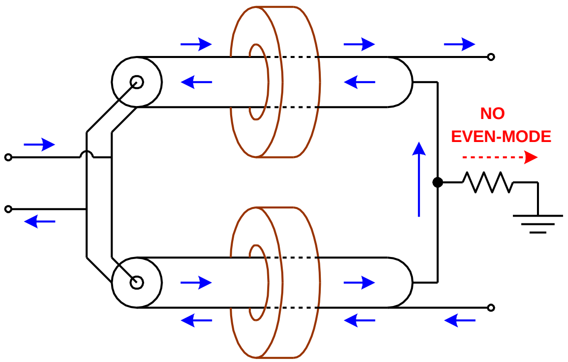
- Two ‘unit’ elements can be used to form a balanced 4:1 transformer
- Analysis based on currents
- $R_1 / R_2 = (I_2 / I_1)^2 = 4$
- Ferrite loading extends bandwidth (low end)



CONVENTIONAL 4:1 BALANCED TRANSFORMER



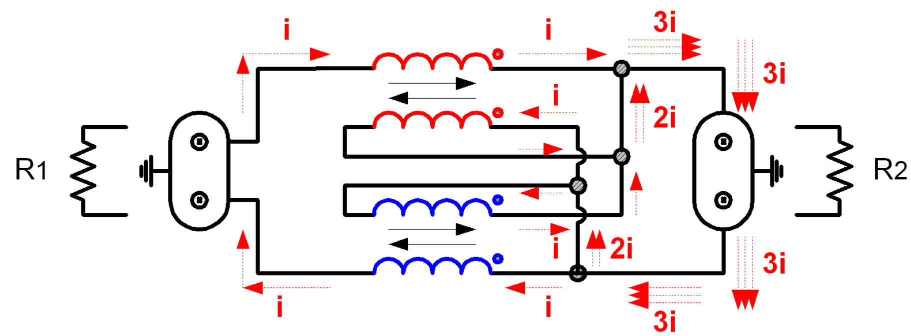
GUANELLA 4:1 SYMBOLIC



GUANELLA 4:1 PHYSICAL

Several Balanced Transformers

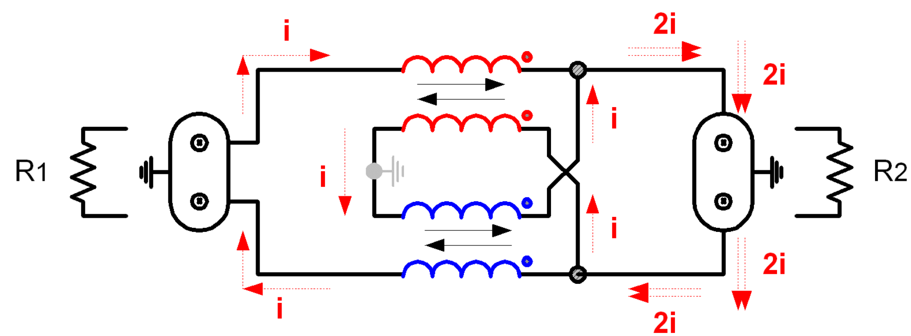
- Transmission line unit element building blocks
- Parasitic even mode characteristic impedance should be large (k → 1)
- Z ratio available as squares of integer ratios
- First order analysis on basis of port current ratio
- Multiple line structures must have at least one shared current path
- DC path is present



$i^2 R_1 = (3\ i)^2 R_2$

$R_1 = 9\ R_2$

9:1 Transformer



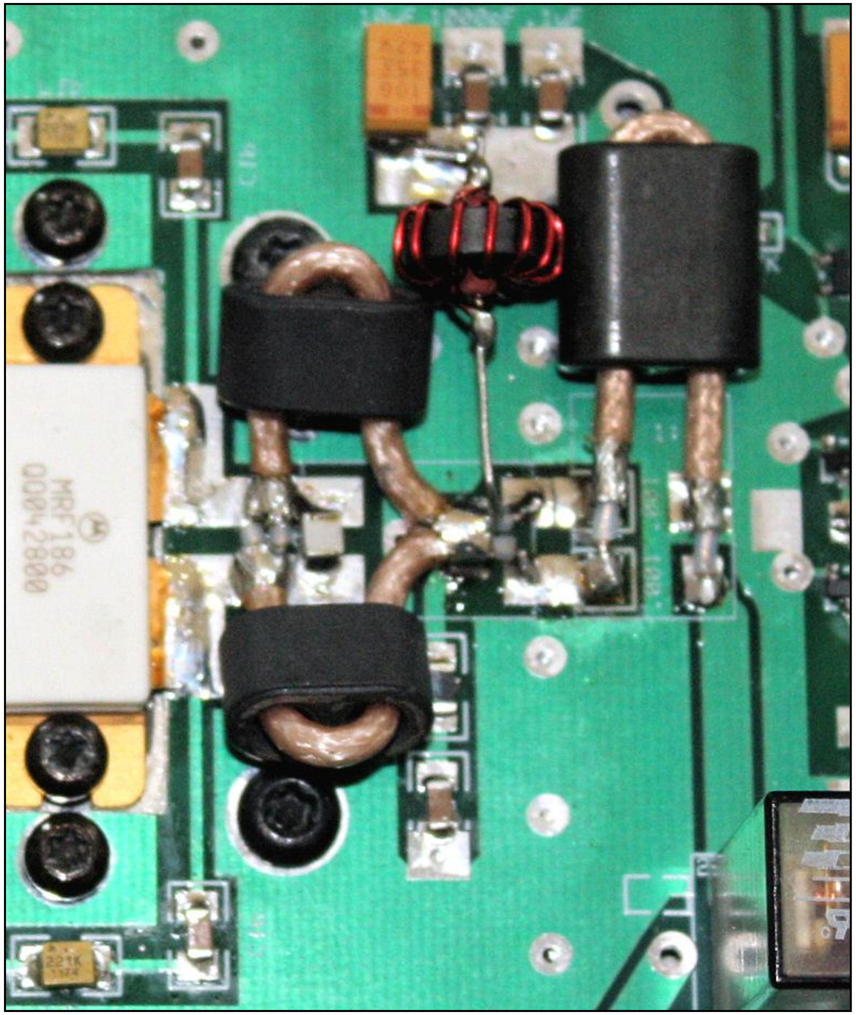
$i^2 R_1 = (2\ i)^2 R_2$

$R_1 = 4\ R_2$

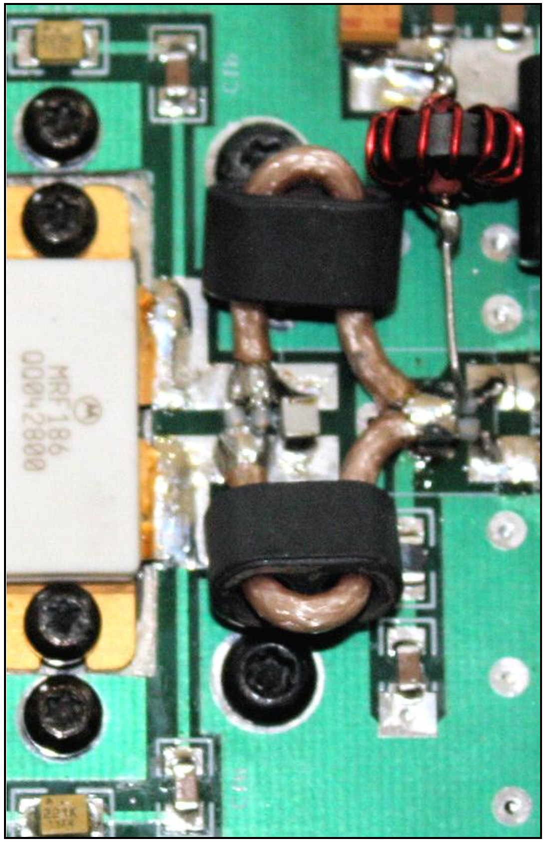
4:1 Transformer

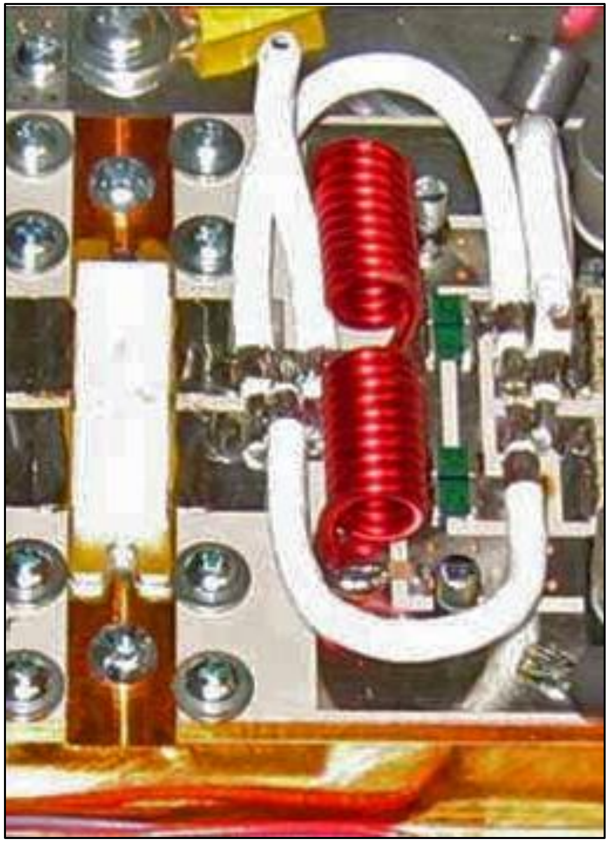
Guanella Transformer and Choke Balun

- Pushpull PA match example
- Ferrite loaded 'unit' elements
- Guanella transformer from coax
- Choke balun (1:1) from coax



More Guanella Transformers in PA Output

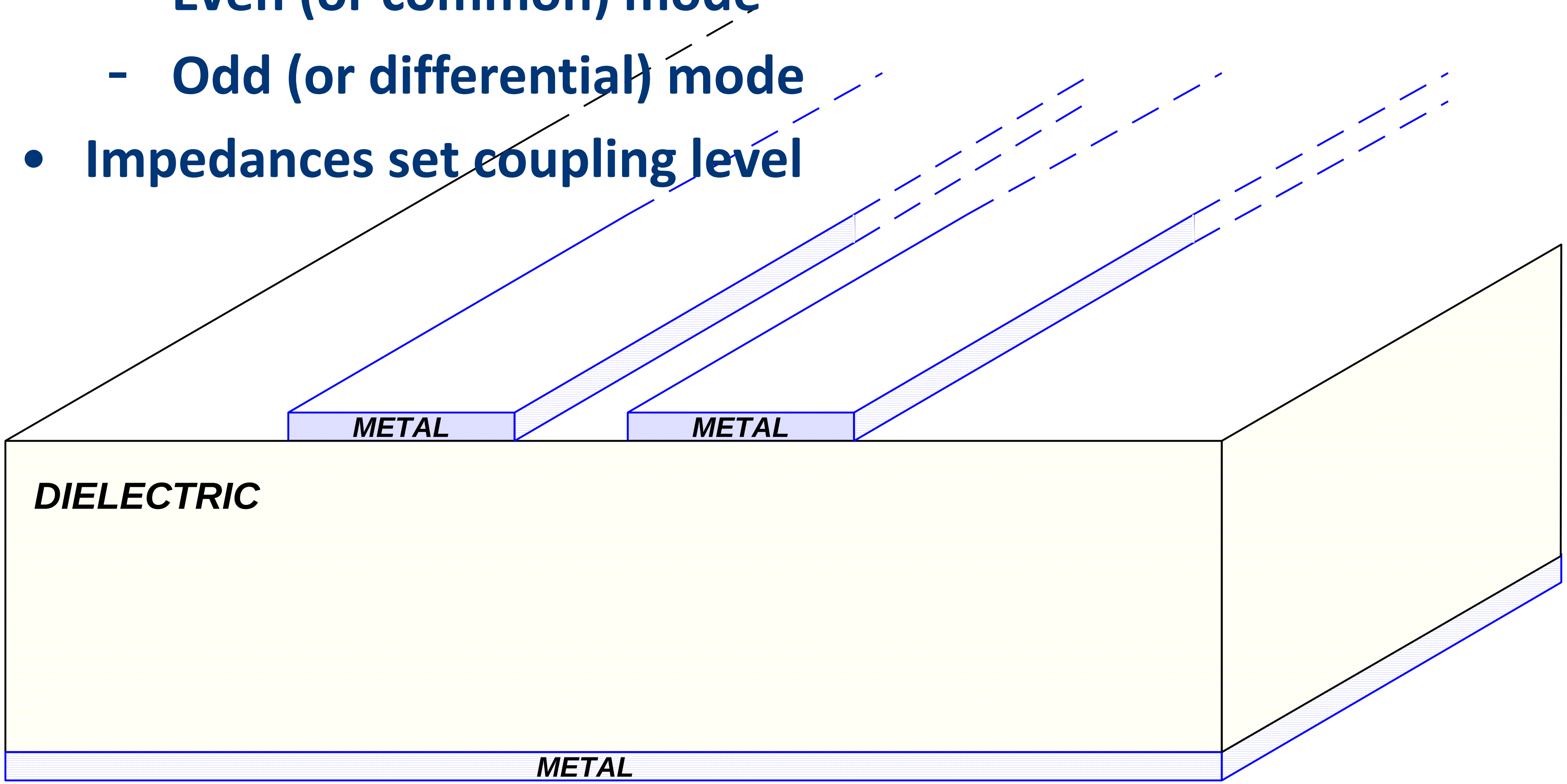




- Guanella transformer from coax
- ‘Unit’ elements with and without ferrite loading

Coupled Lines - Symmetric

- **Two transmission-line modes**
  - **Even (or common) mode**
  - **Odd (or differential) mode**
- **Impedances set coupling level**



Coupling Coefficient

$$Zoe/Zoo = (C+2C_M)/C$$

$$k = \frac{Zoe/Zoo - 1}{Zoe/Zoo + 1}$$

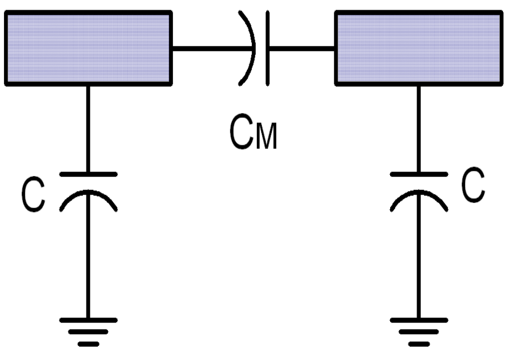
$$k = \frac{C_M}{C_M + C}$$

$$k = \frac{C_M}{C_M + C} = \frac{\frac{C_M}{C}}{\frac{C_M}{C} + 1}$$

$$Zoe/Zoo \rightarrow \infty \Rightarrow K \rightarrow 1$$

$$C_M/C \rightarrow \infty \Rightarrow K \rightarrow 1$$

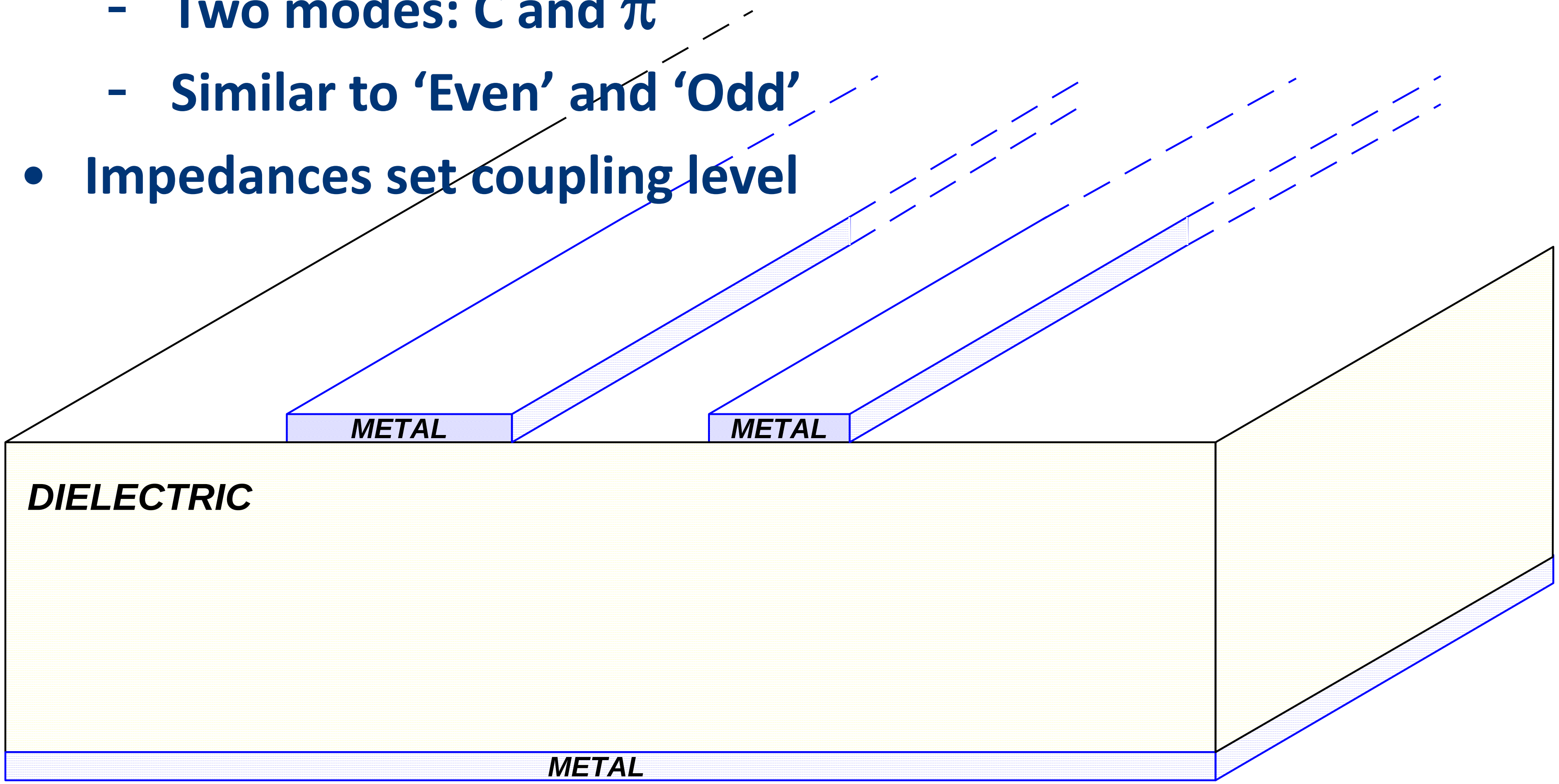
- **Zoo sets the desired Zo**
- **Zoe should be large !**



STATIC CAPACITANCE
REPRESENTATION FOR
SYMMETRIC STRUCTURES

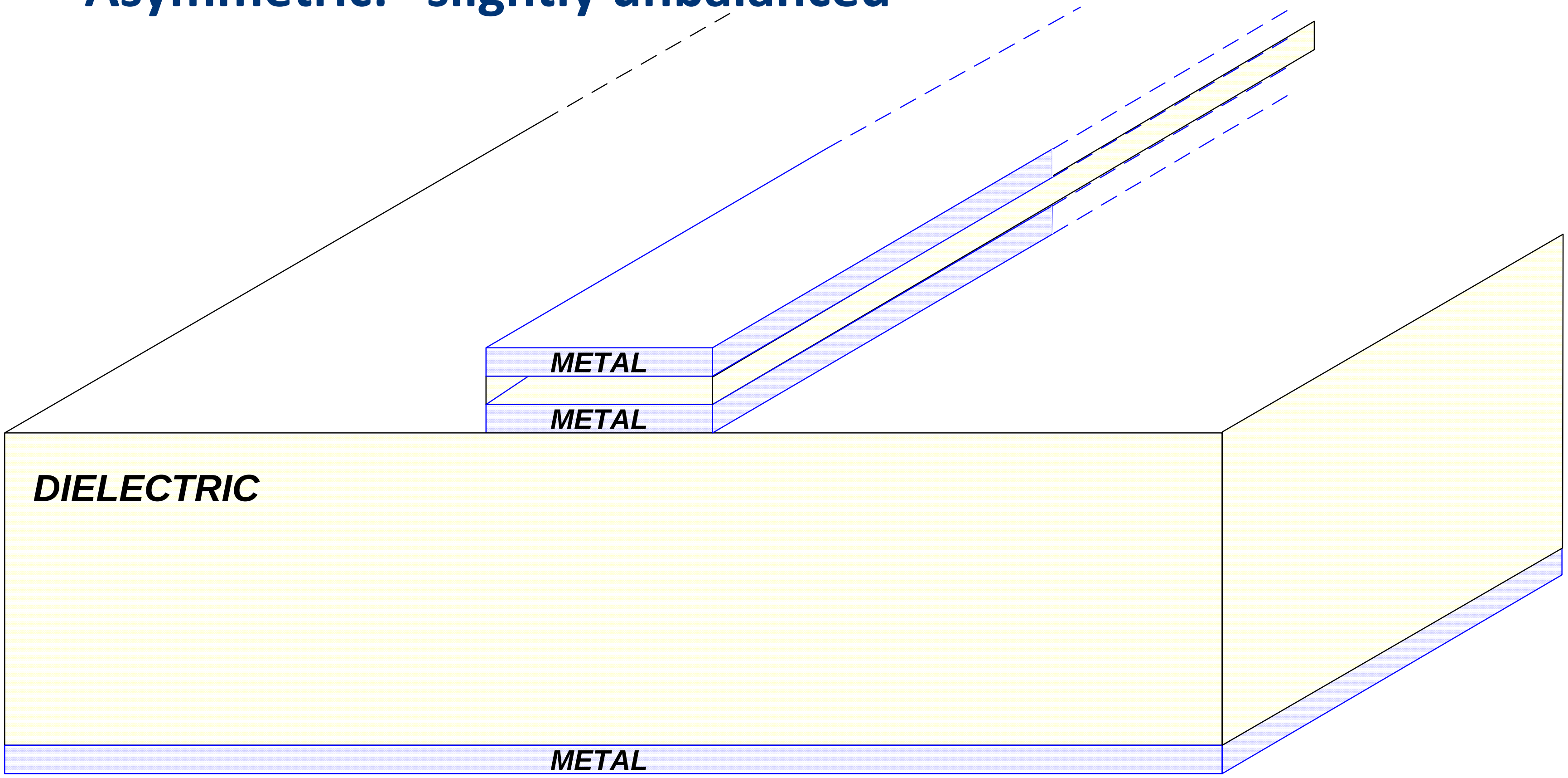
Coupled Lines - Asymmetric

- **Asymemetric coupled lines**
  - **Two modes: C and π**
  - **Similar to 'Even' and 'Odd'**
- **Impedances set coupling level**



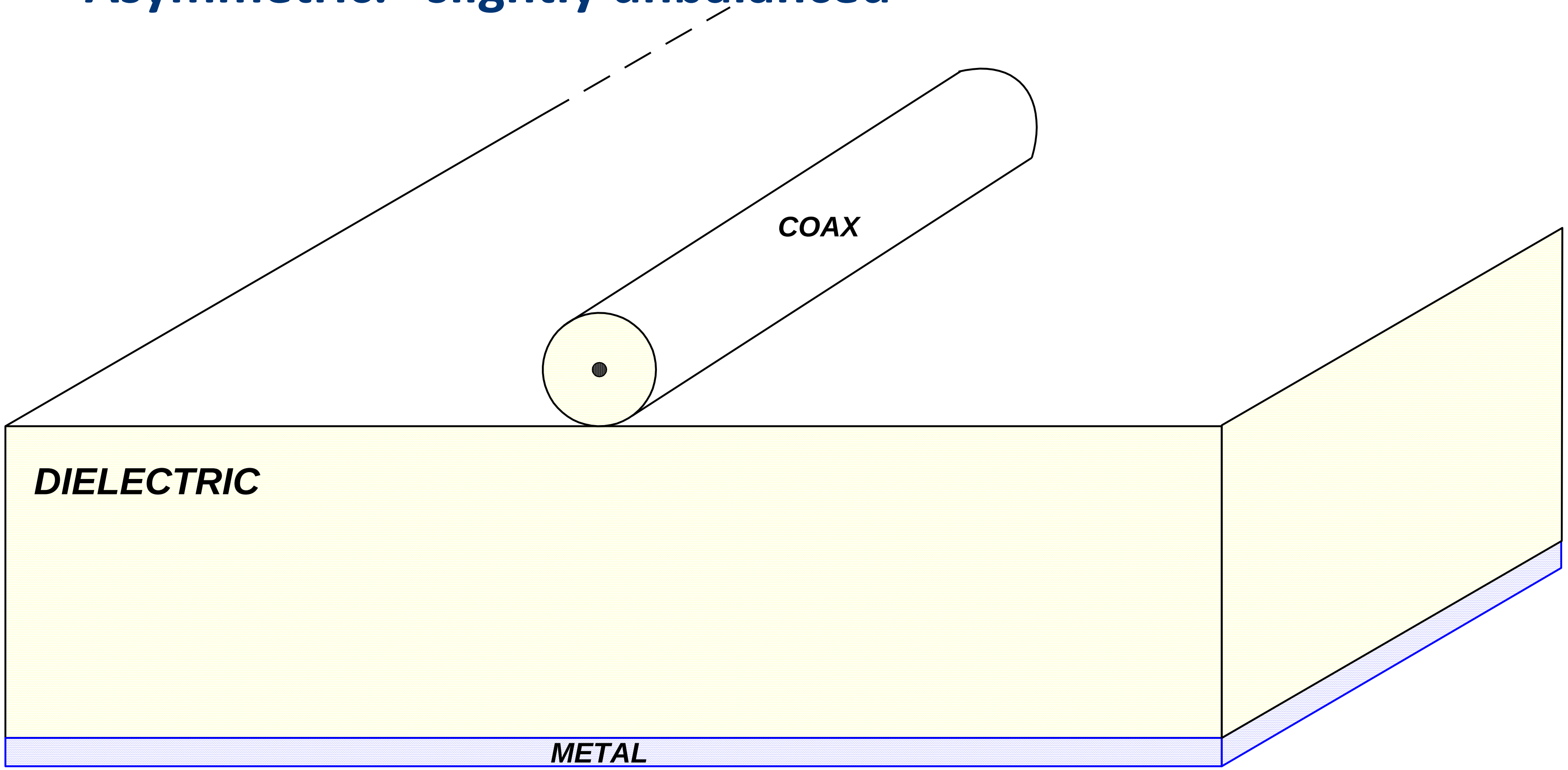
Coupled Lines - Asymmetric

- **Broadside coupling is better**
- **Asymmetric: slightly unbalanced**

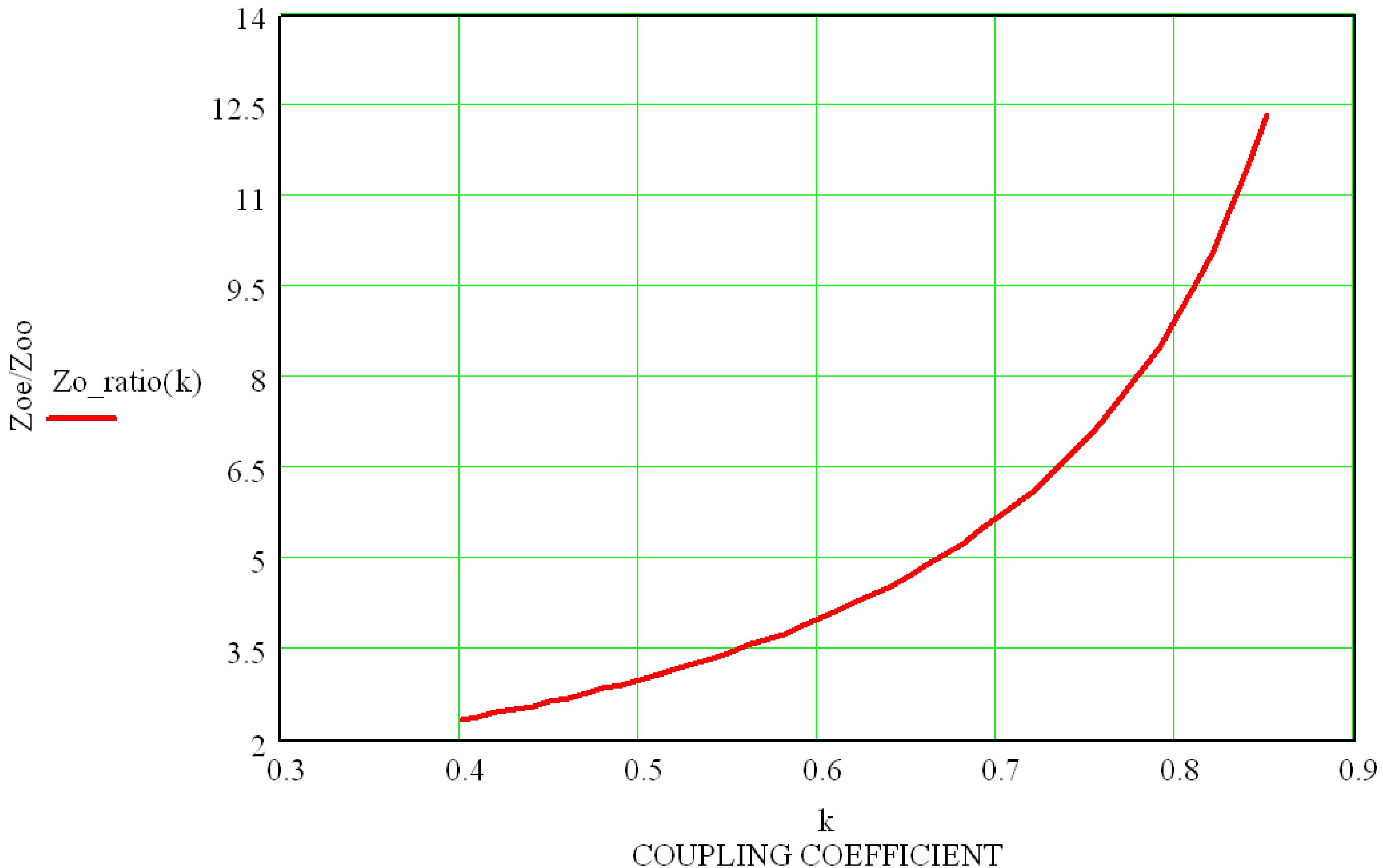


Coax Over Ground

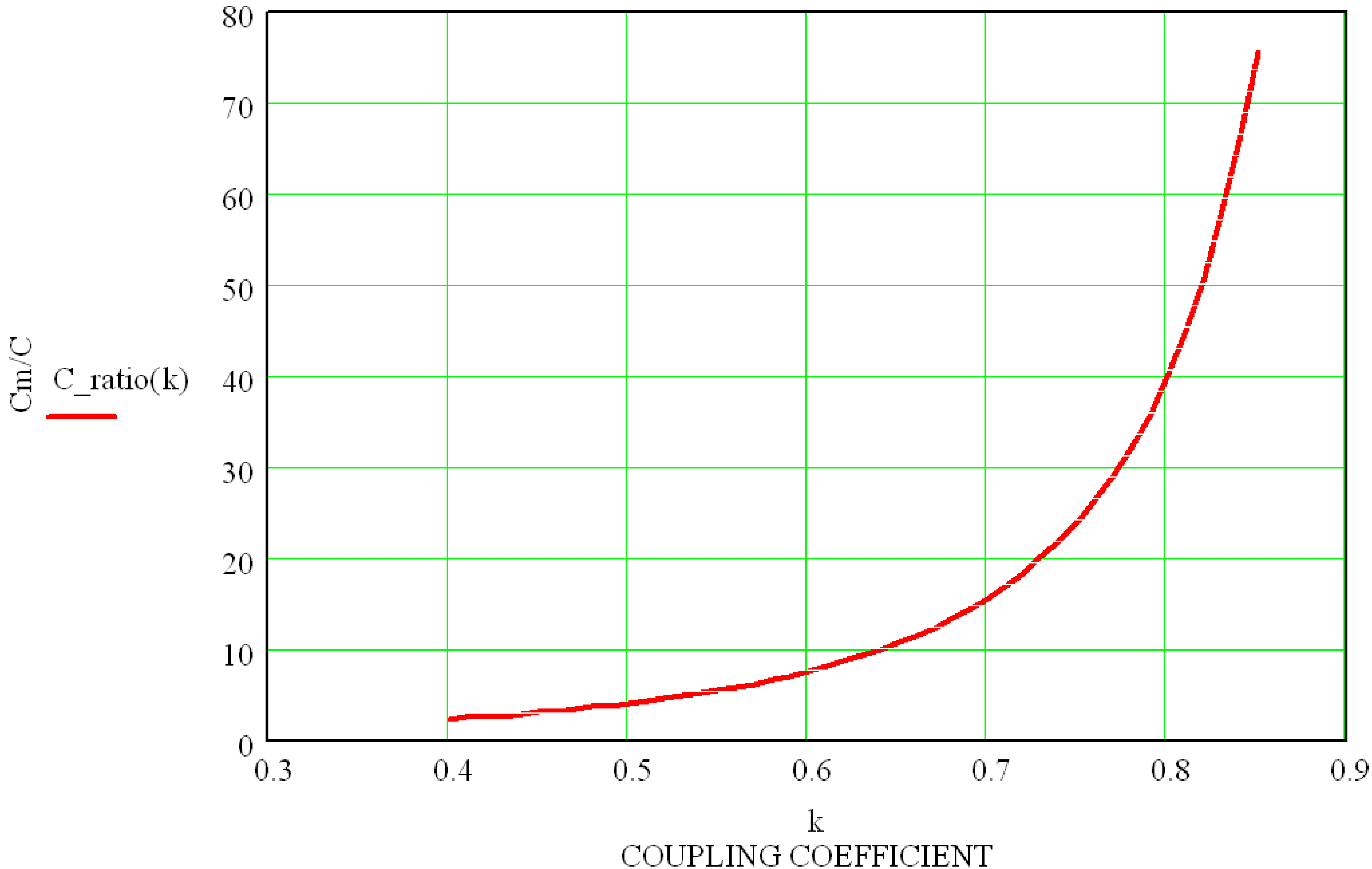
- **Coax coupling is very good**
- **Asymmetric: slightly unbalanced**



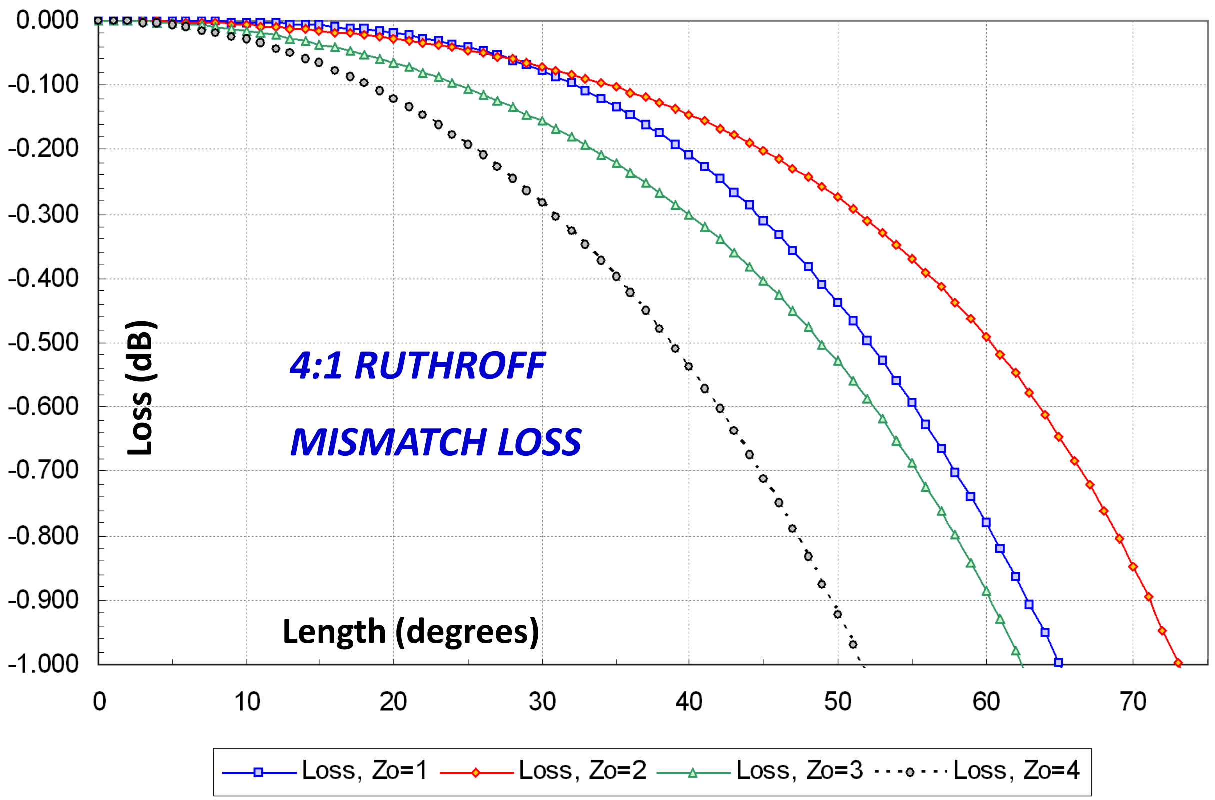
Coupling Coefficient Relationship to Zoe/Zoo

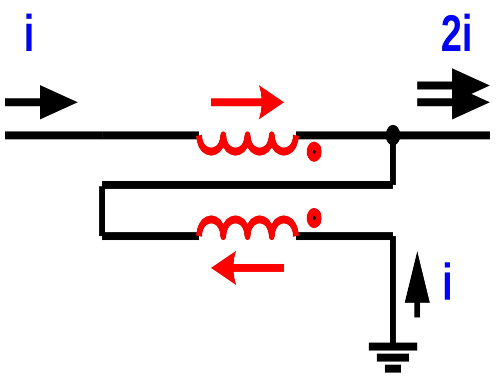


Coupling Coefficient Relationship to C_m/C



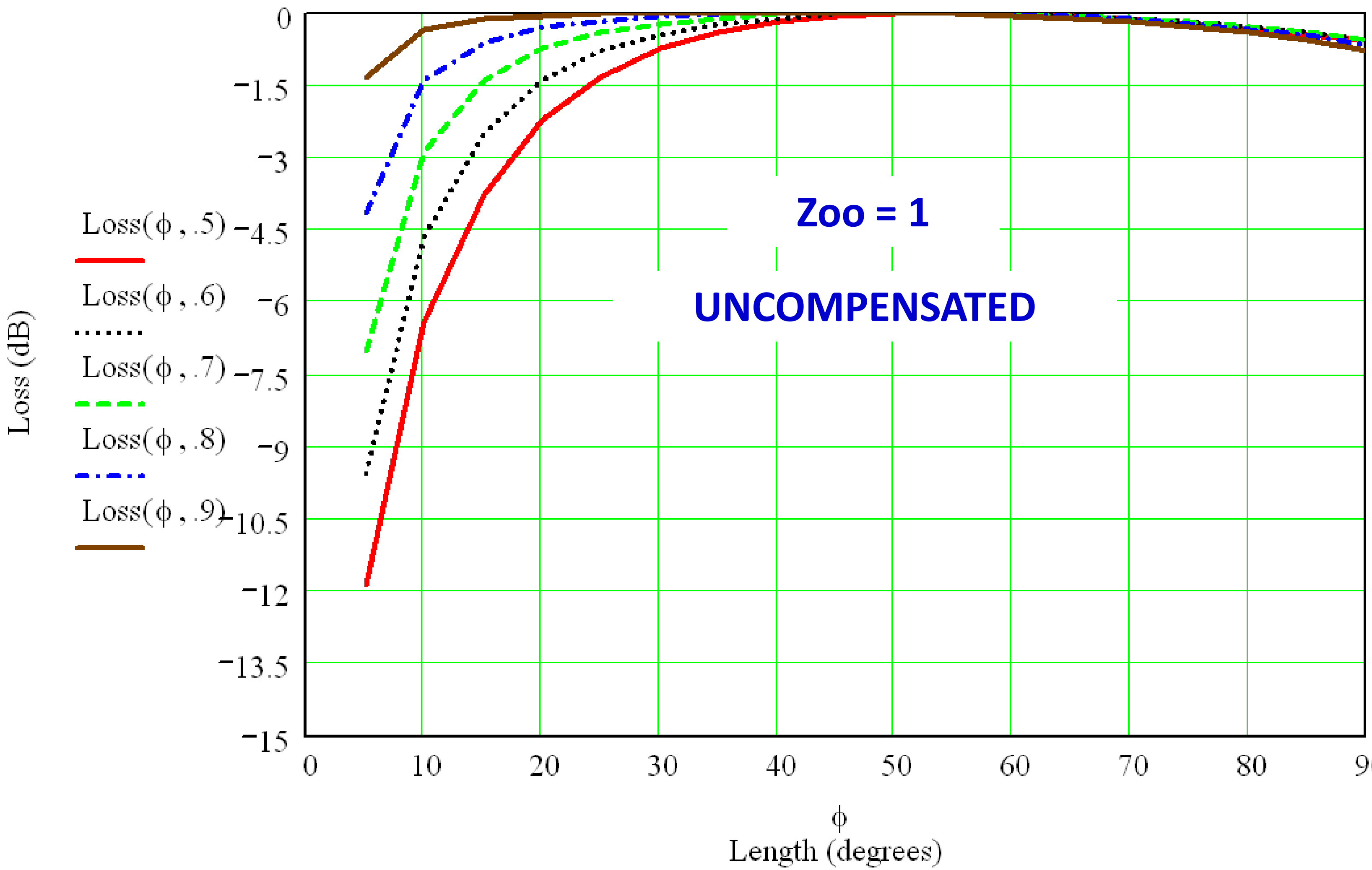
Ideal Ruthroff Loss vs Length (and Zo)



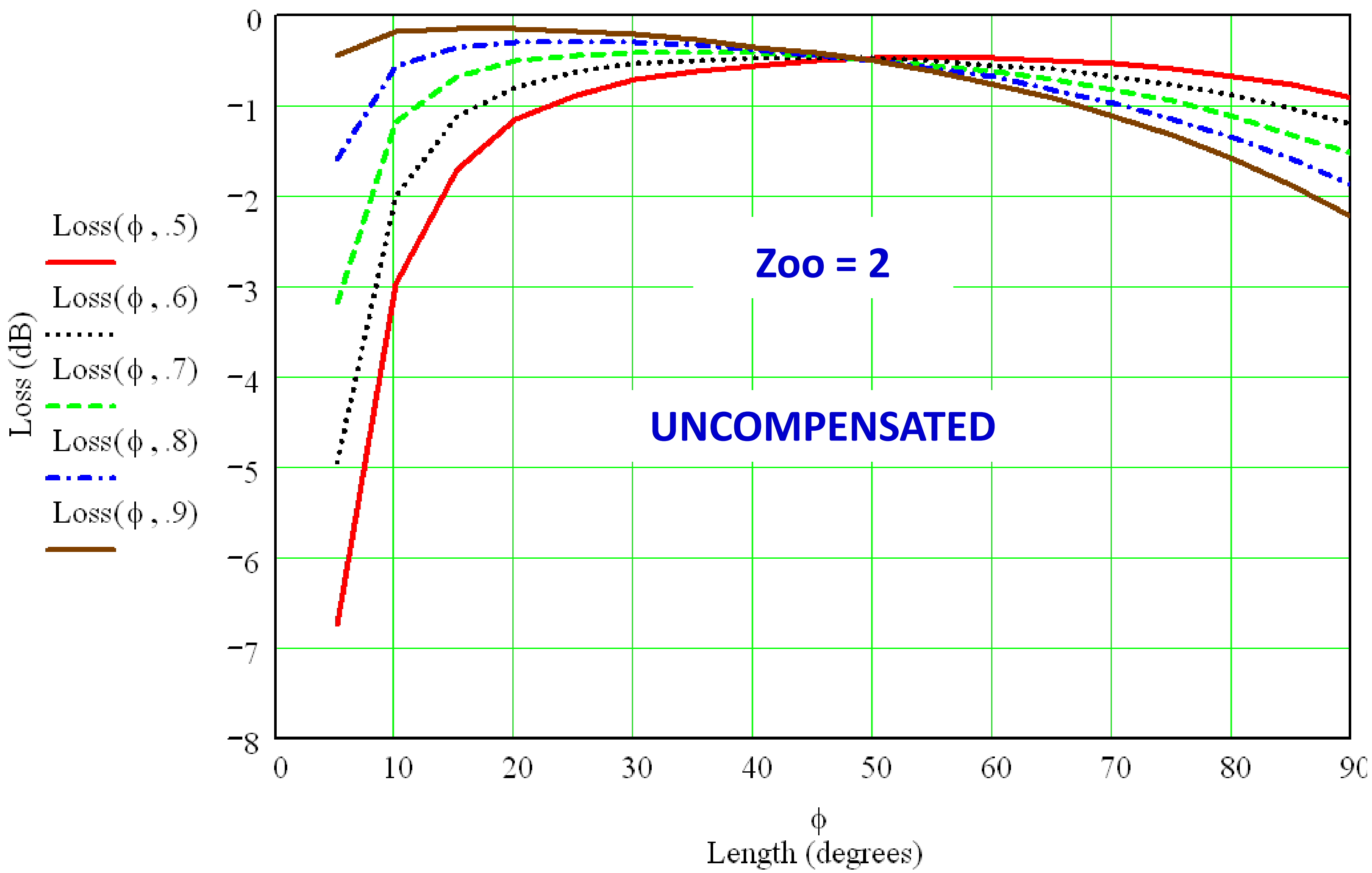


- Analysis of original 4:1 Ruthroff transformer (k = 1)
- Normalized port impedances (1Ω and 4Ω)
- Best BW from Zo=2
- Lowest loss over less BW from Zo=1

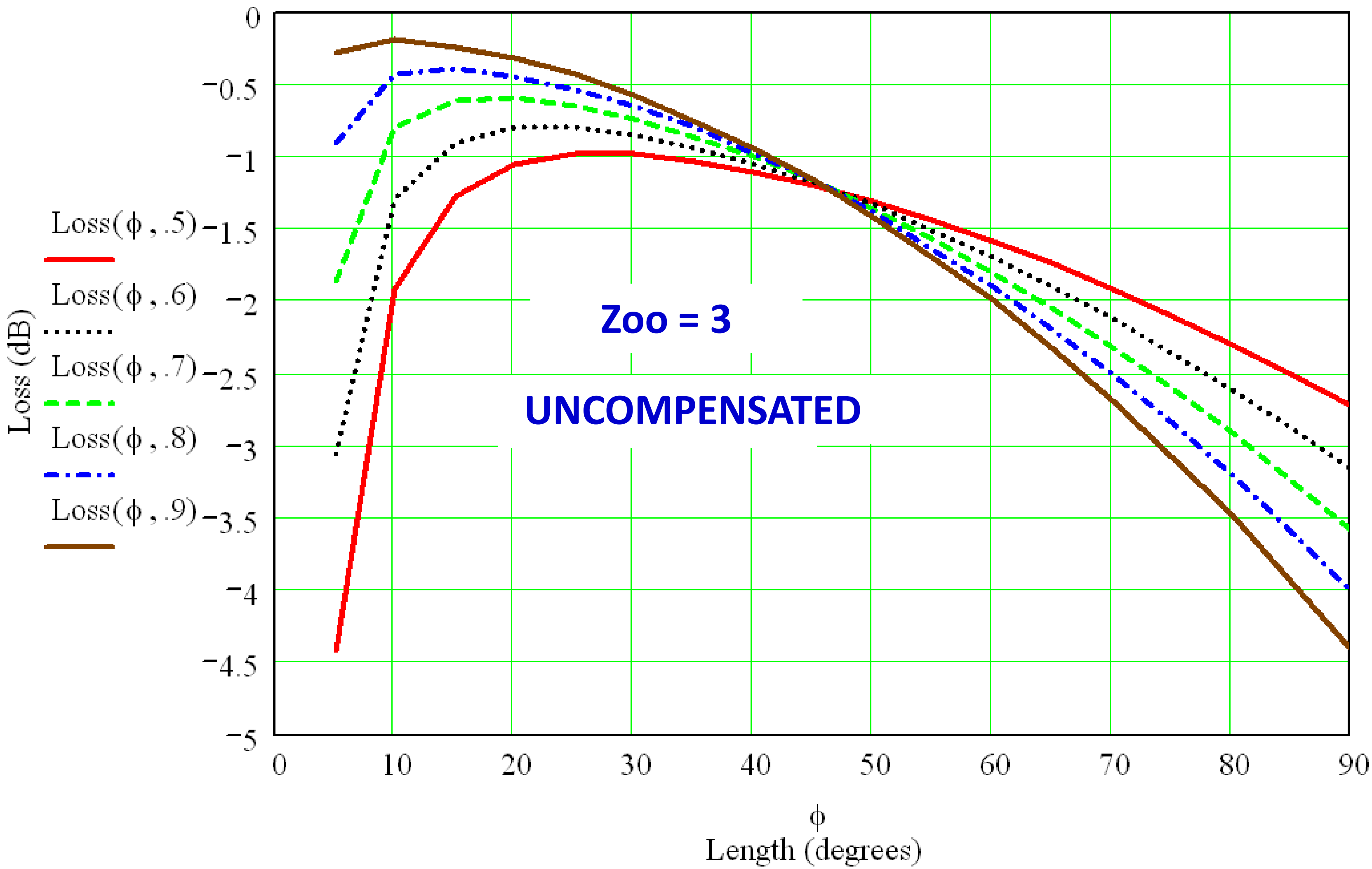
Ruthroff Loss vs Length (and k)



Ruthroff Loss vs Length (and k)

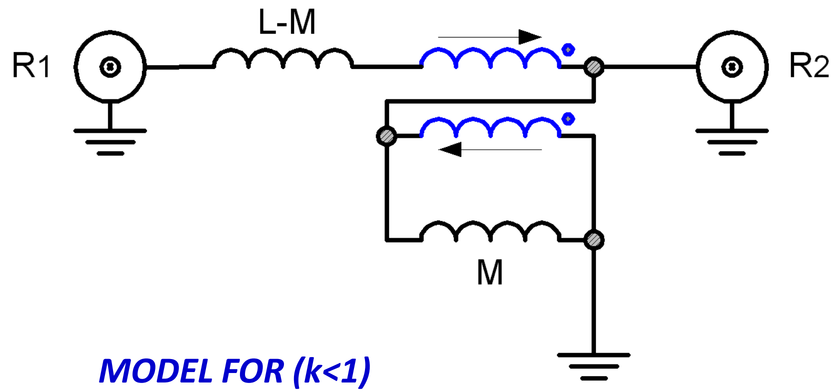


Ruthroff Loss vs Length (and k)

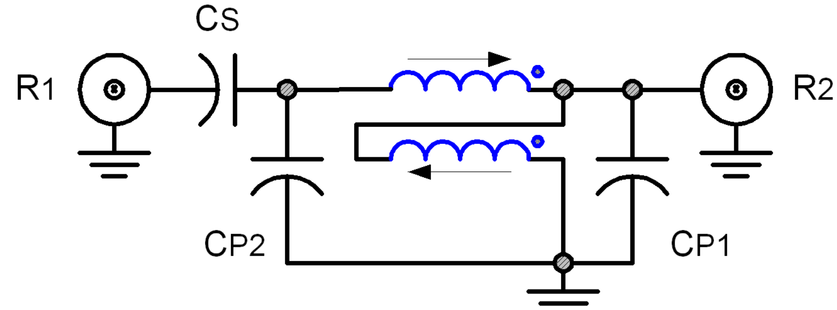


Ruthroff Transformer Frequency Compensation

- Non-ideal coupling is modeled by leakage and magnetizing inductance
- Cs provides DC block and low frequency compensation
- CP1 and CP2 provide high frequency compensation
- If coupling is poor, or Zoo is not optimal, Cp can be used to tune the transformer for the desired frequency band

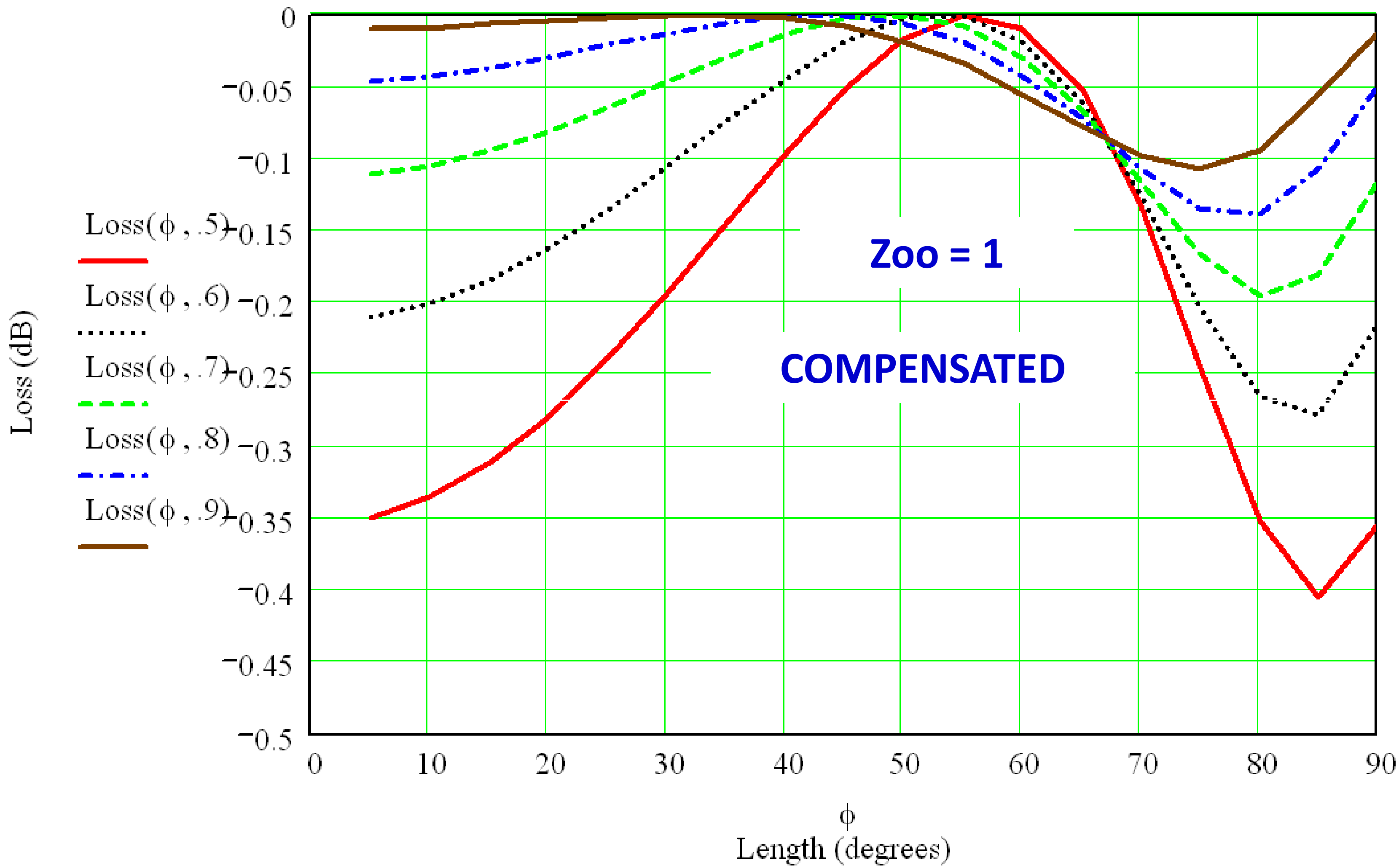


MODEL FOR (k<1)
UNDERCOUPLED LINES

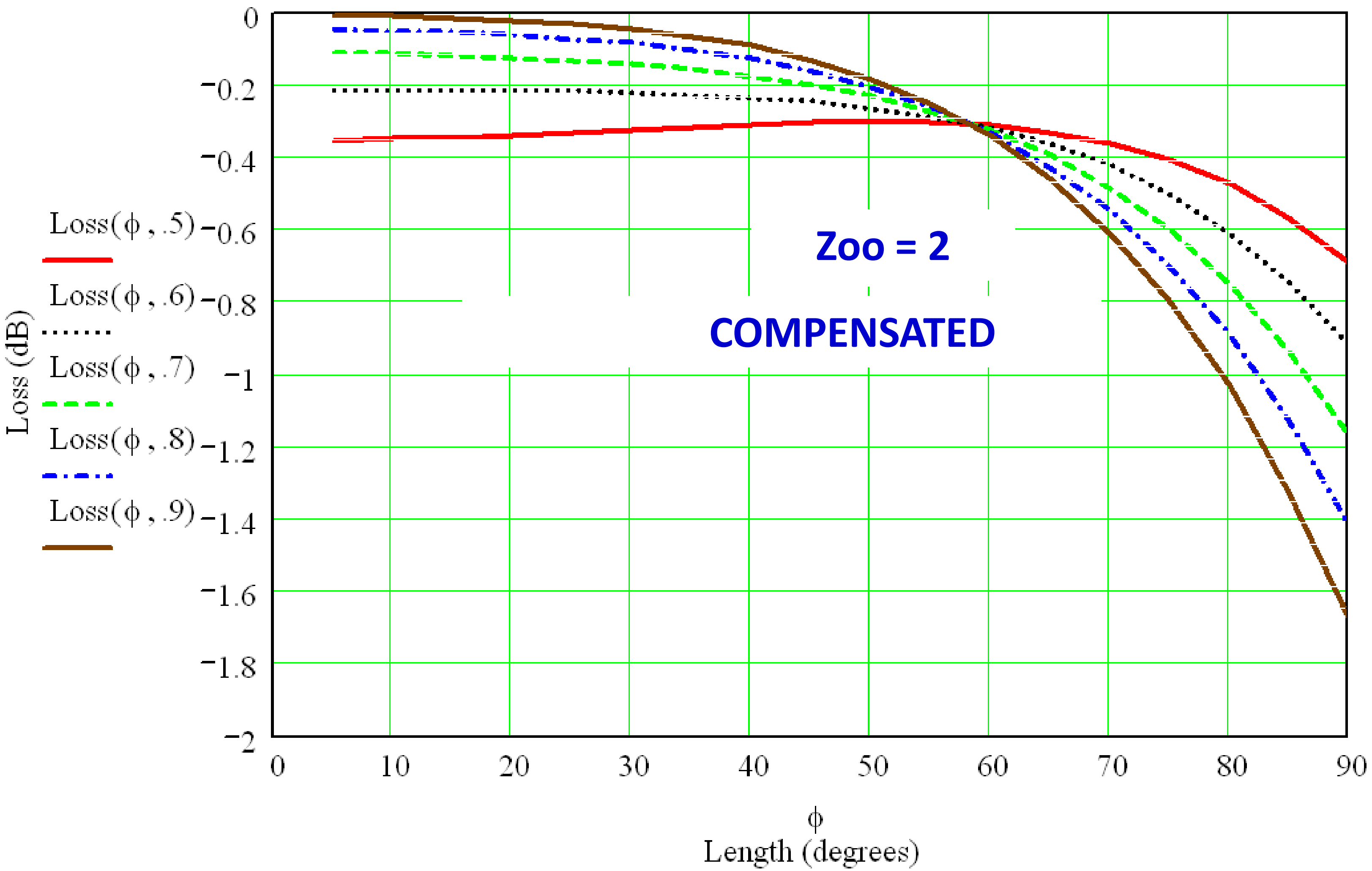


FREQUENCY
COMPENSATION

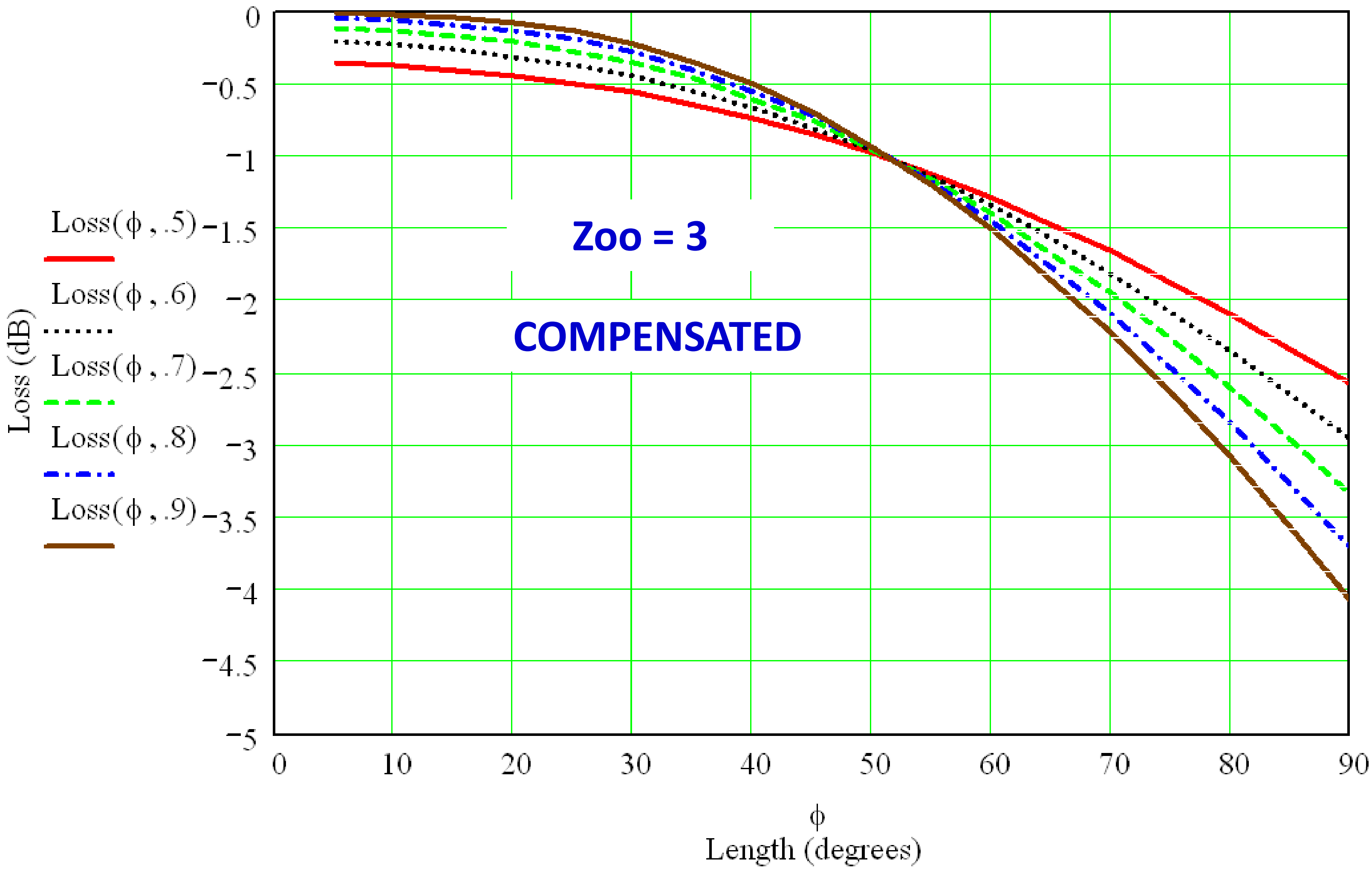
Ruthroff Loss vs Length (and k)



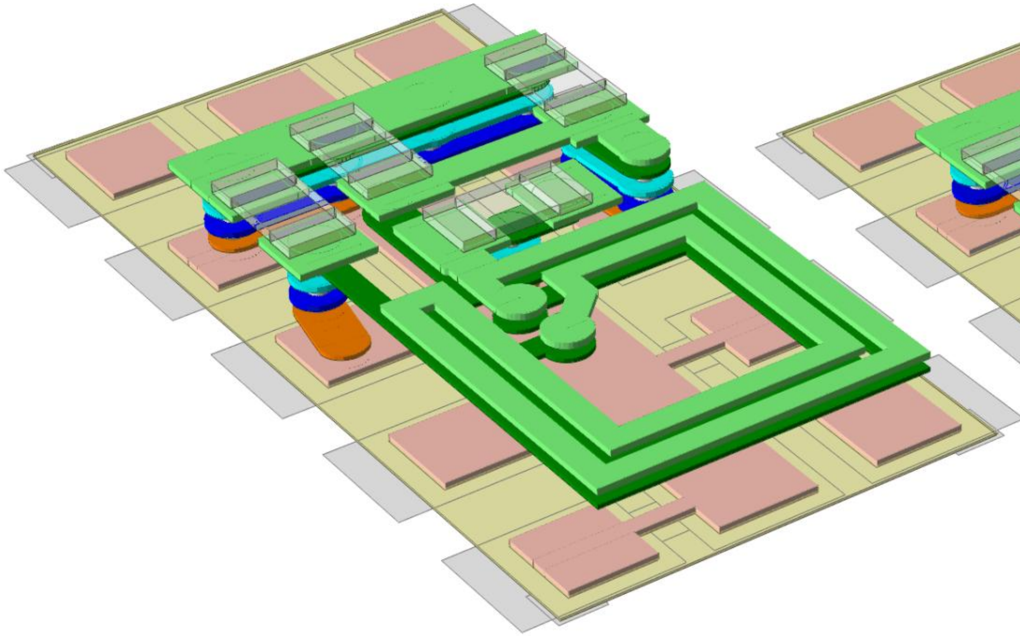
Ruthroff Loss vs Length (and k)



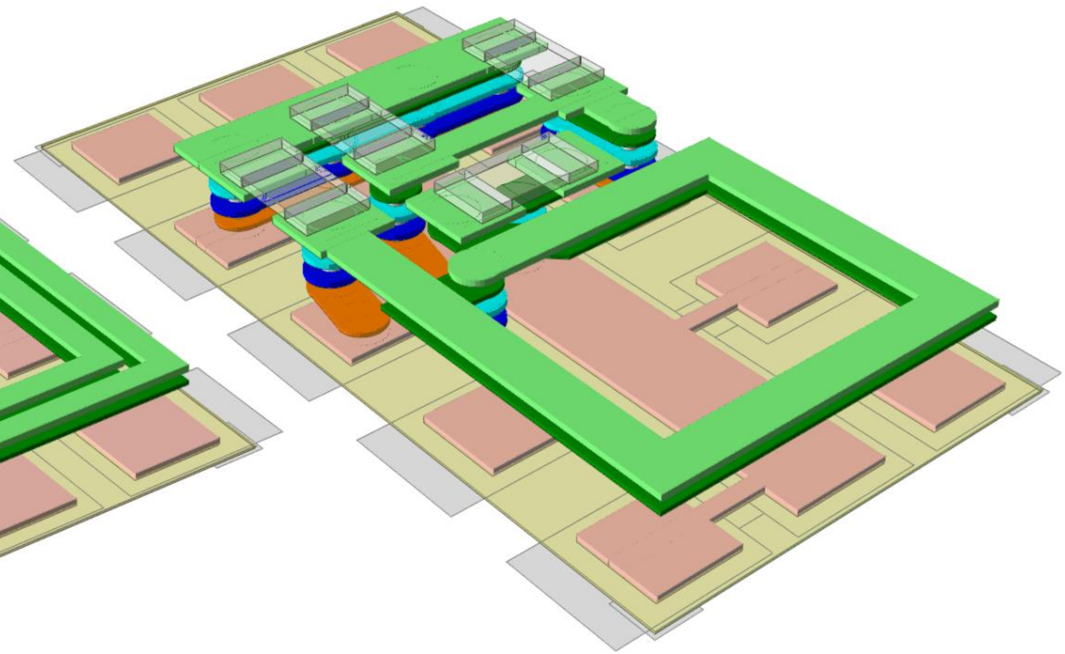
Ruthroff Loss vs Length (and k)



Ruthroff Transformer Test Laminates

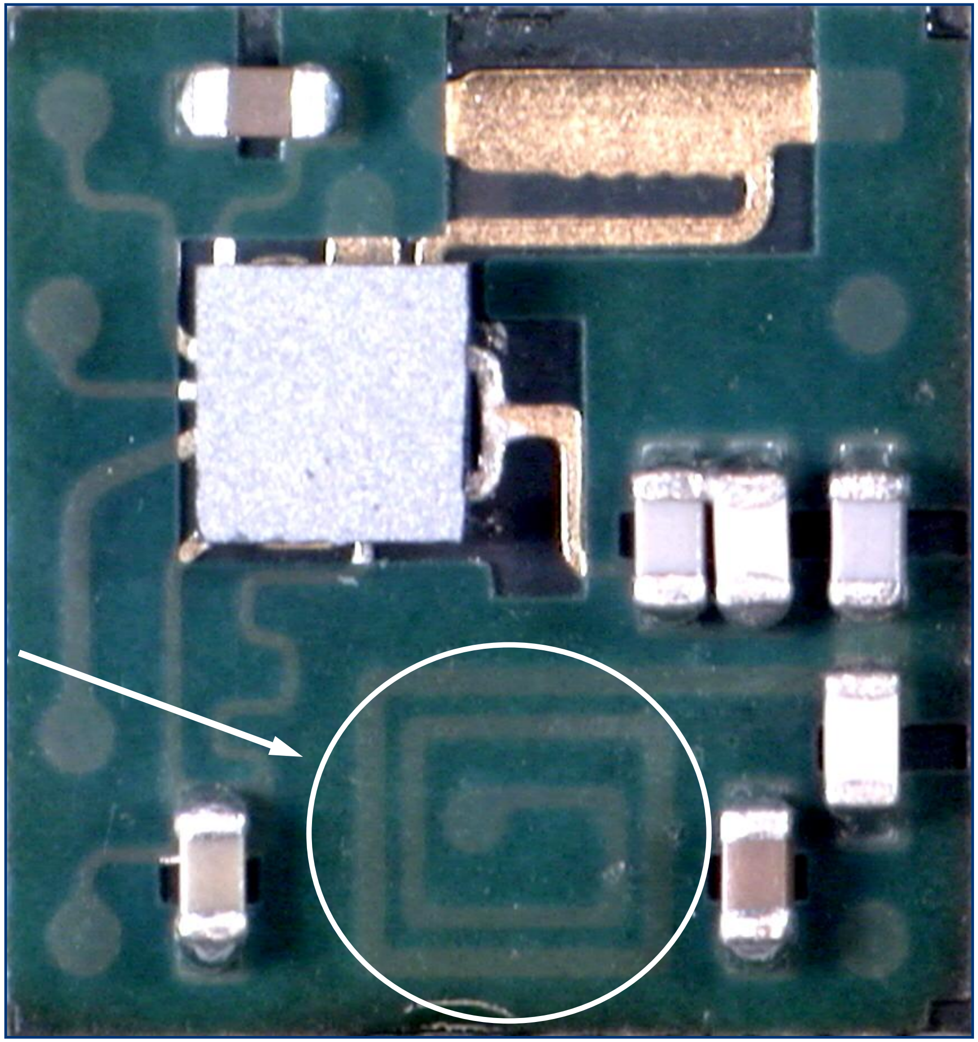


9:1 TRANSFORMER



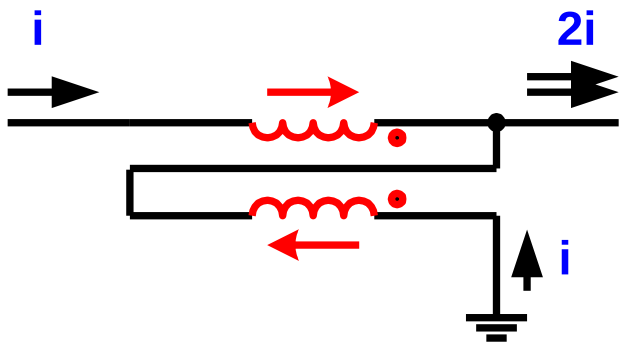
4:1 TRANSFORMER

Flip Chip Multiband PA with Ruthroff 4:1

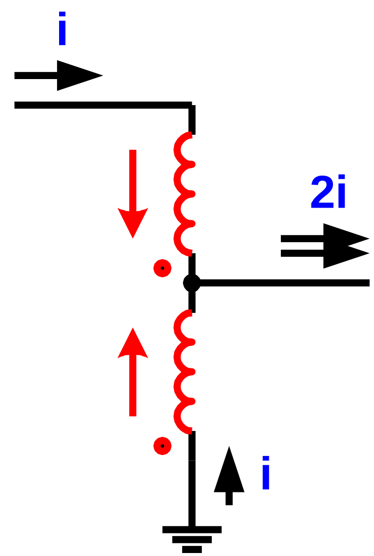


RUTHROFF 4:1 TRANSFORMER

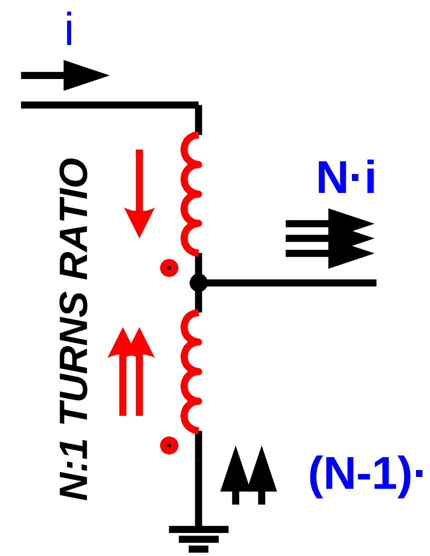
Ruthroff Relationship to Auto Transformers



RUTHROFF 4:1
UNBALANCED TRANSFORMER



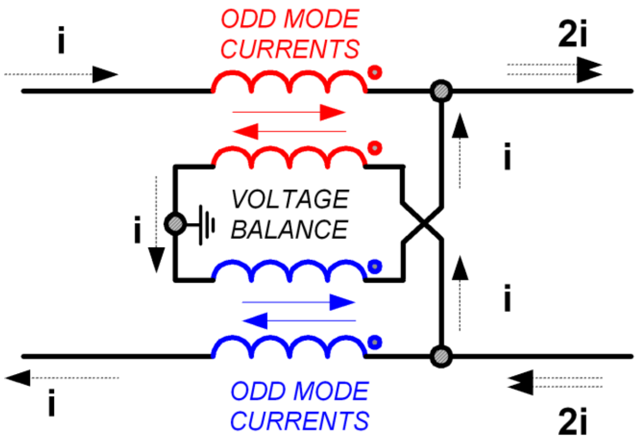
RUTHROFF 4:1
SHOWN AS AUTO
TRANSFORMER



GENERAL N:1
UNBALANCED AUTO
TRANSFORMER

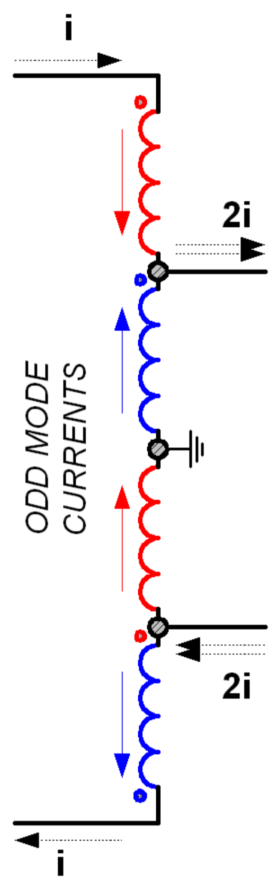
- The Ruthroff structure can be redrawn as an auto transformer special case (N=2).
- Transformation can be set by setting the tap (1/N is tapped fraction of total primary)

Guanella Relationship to Auto Transformers

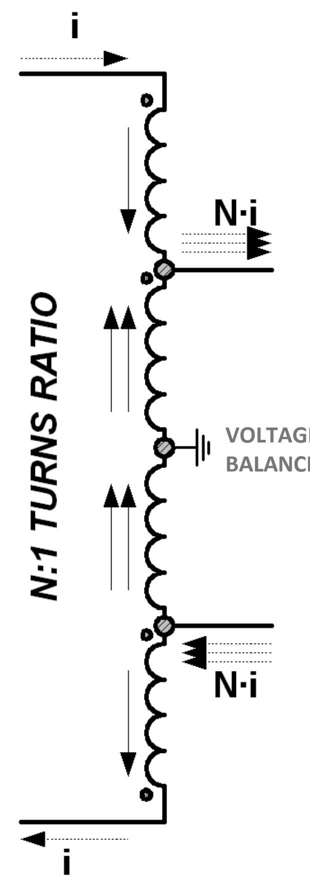


GUANELLA 4:1 BALANCED TRANSFORMER (BALBAL)

- The Guanella balanced structure can be redrawn as an auto transformer special case (N=2). - note couplings –
- A more general auto transformer has secondary coupled to both primary segments
- Transformation can be set by setting the taps (1/N is tapped fraction of total primary)

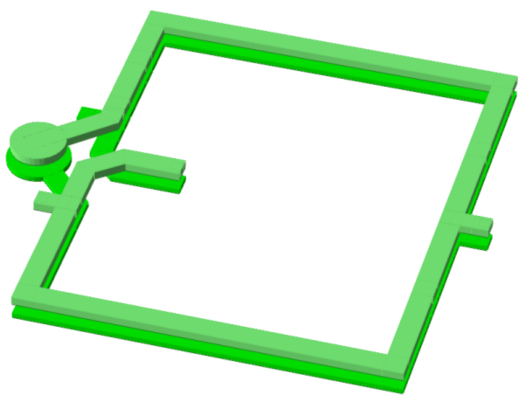


GUANELLA 4:1 SHOWN AS AUTO TRANSFORMER

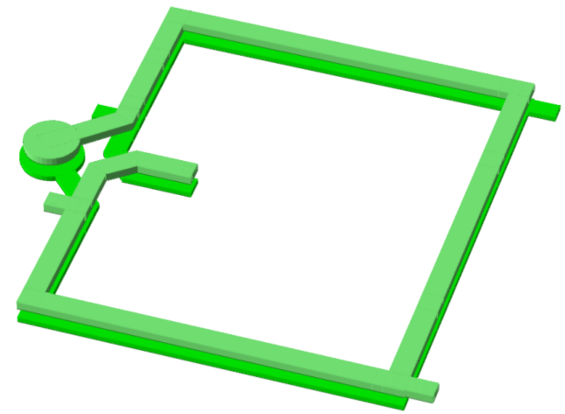


GENERAL N:1 BALANCED AUTO TRANSFORMER

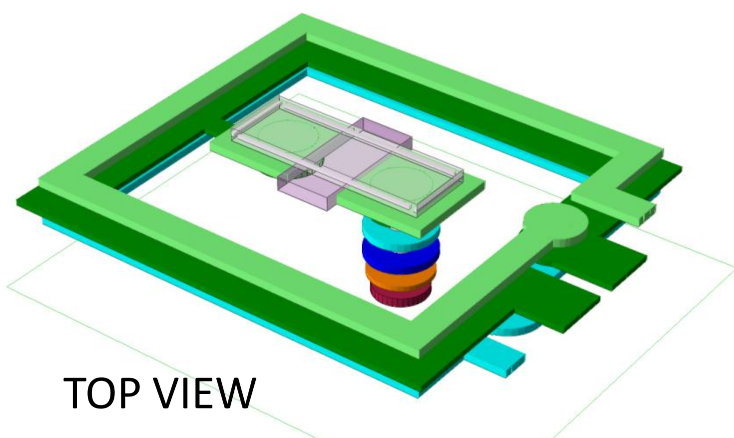
Guanella and Auto Transformers



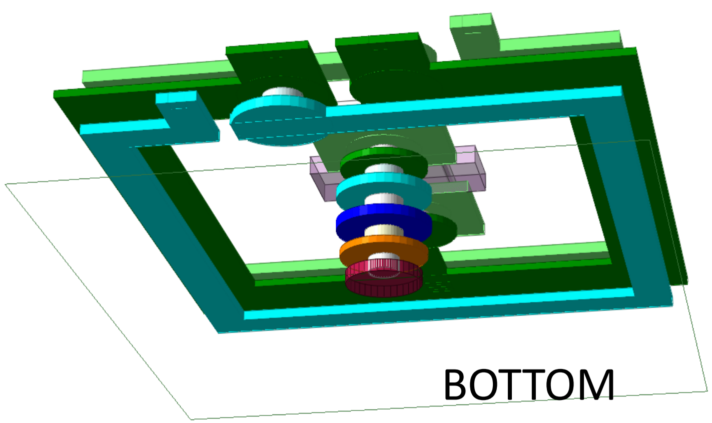
GUANELLA BALANCED TRANSFORMER (4:1 BALBAL)



MODIFIED GUANELLA BALANCED TRANSFORMER (2.5:1)



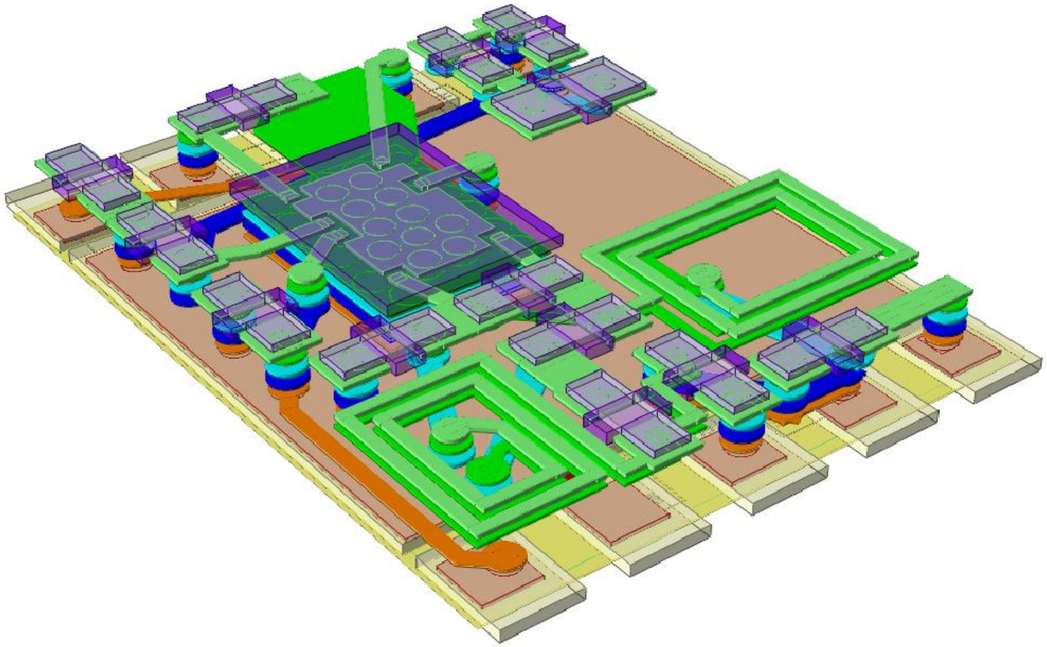
TOP VIEW

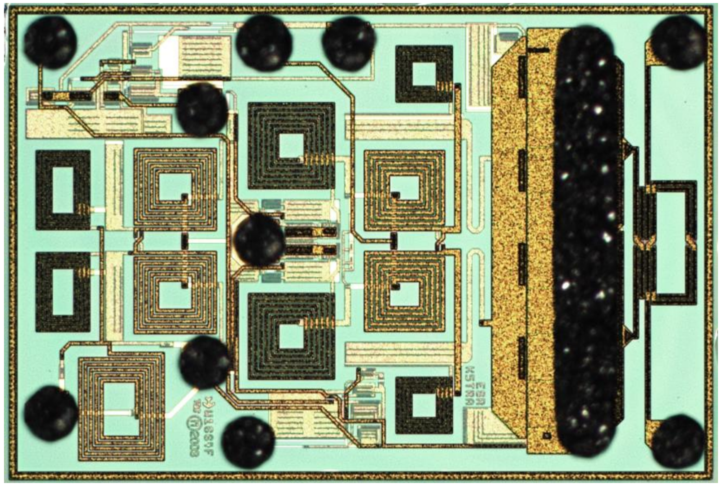


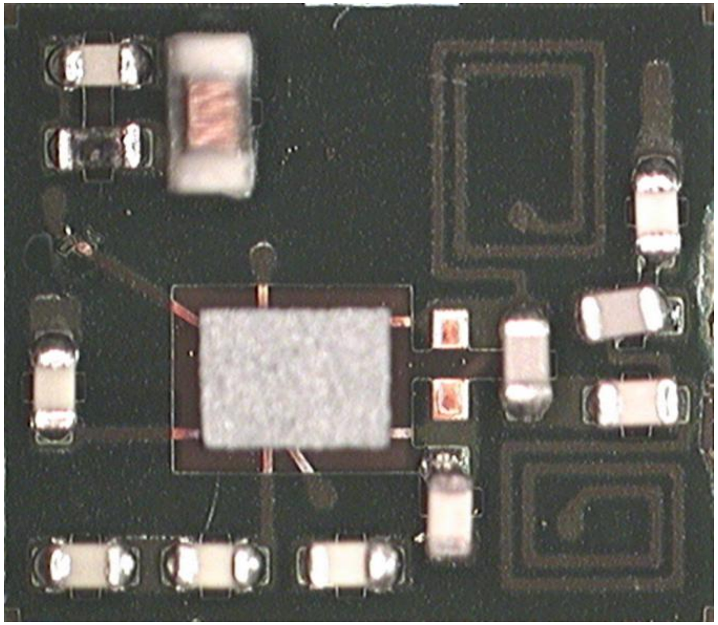
BOTTOM VIEW

AUTO TRANSFORMER (9:1)

Wideband Flip Chip PA Module

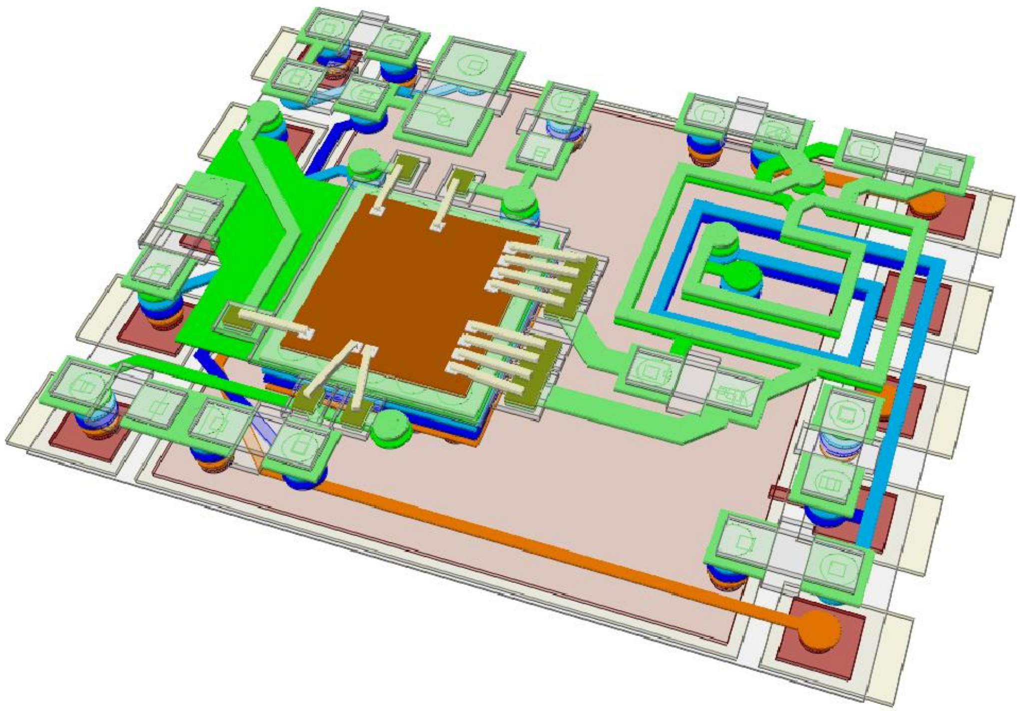


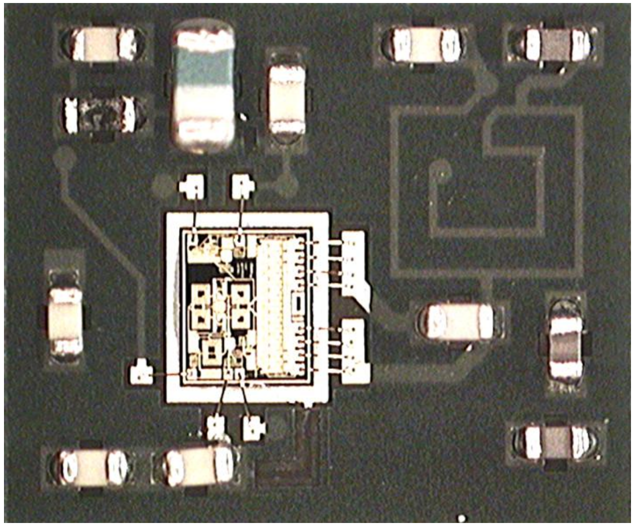


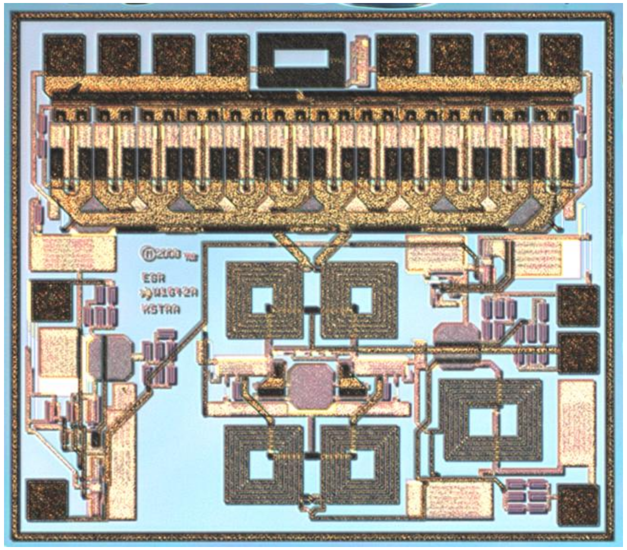


- 800 MHz – 2 GHz
- WCDMA operation

Pushpull Multimode PA

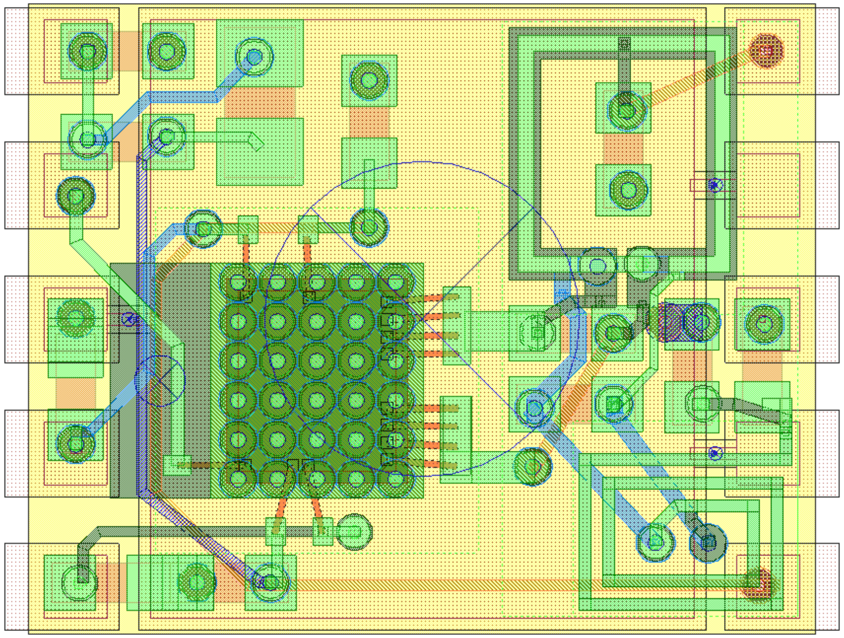






- Laminate contains modified Guanella transformer stacked with choke balun
- Full 824 - 915 MHz operation
- WCDMA, EDGE, and GSM

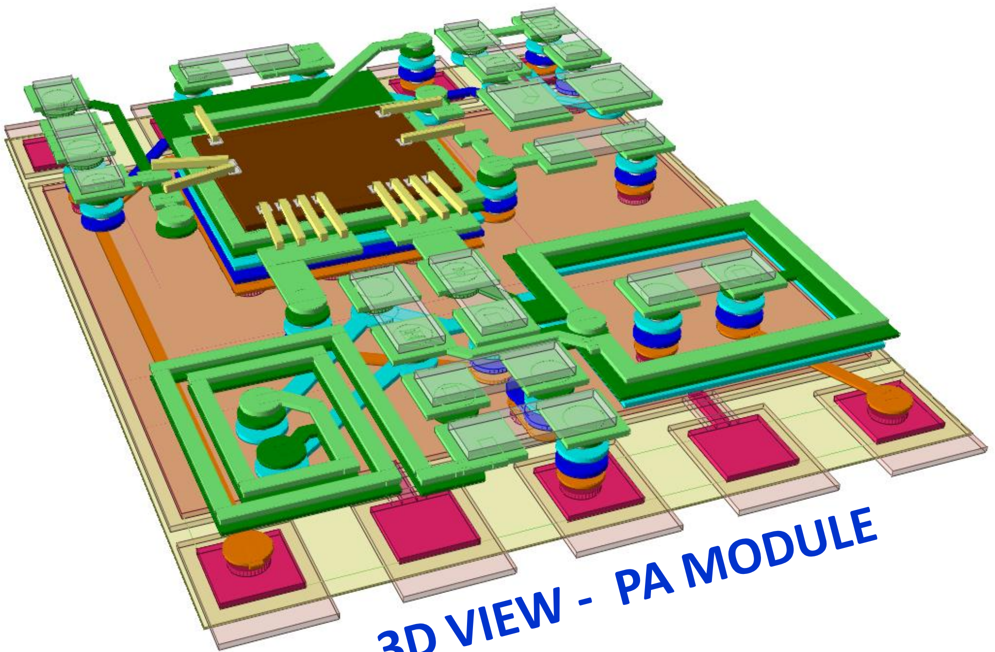
Low V Pushpull Multimode PA



5mm x 4mm PA MODULE

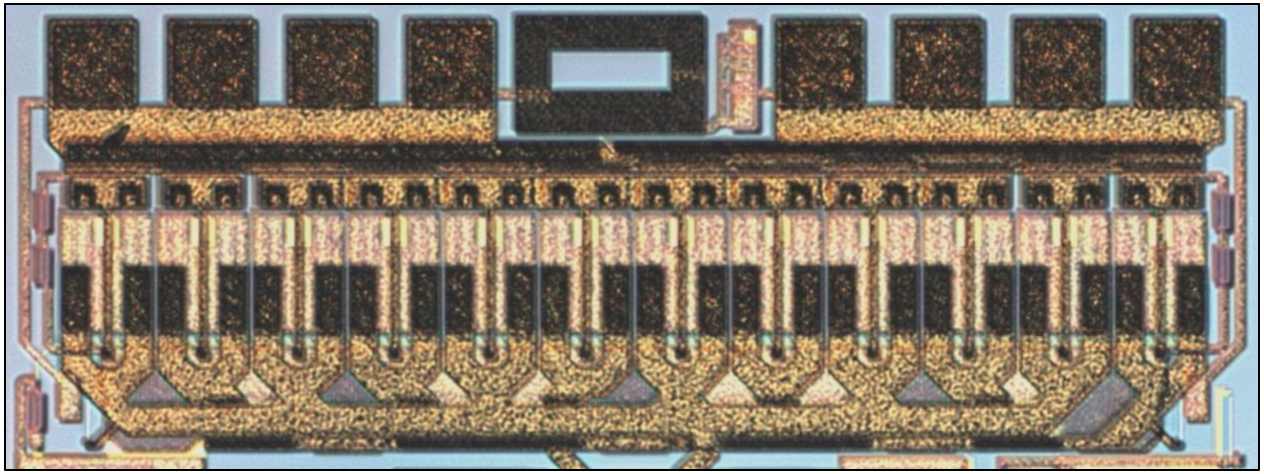
(.20” x .16”)

- Low Vcc operation provided by high ratio transformer
- Three metal layers are used in a 9:1 auto-transformer
- Choke balun

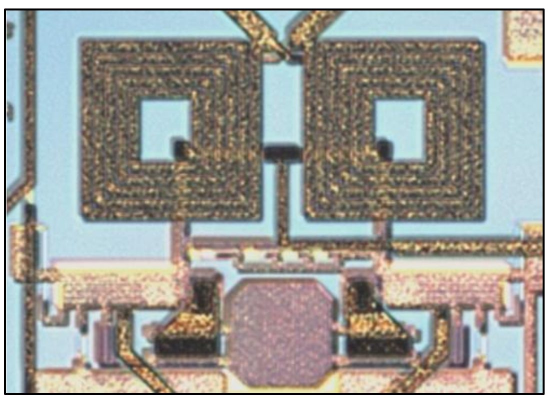


3D VIEW - PA MODULE

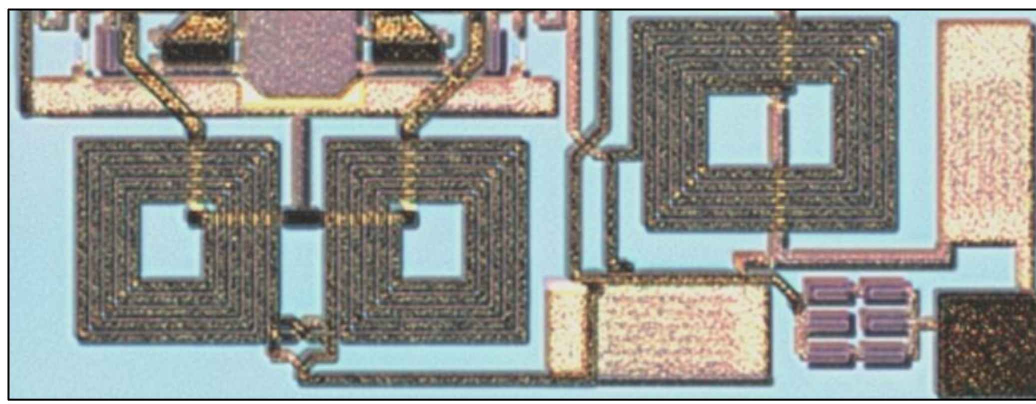
GaAs Pushpull PA Circuit Blocks



ARRAY OF OUTPUT CELLS WITH INTERLEAVED MANIFOLD AND 3RD HARMONIC TUNING



INTERSTAGE GUANELLA TRANSFORMER



INPUT CHOKE BALUN and GUANELLA TRANSFORMER

Summary

- Transmission-line transformers
  - 3 categories
- Coupled lines
  - Coupling coefficient
  - Capacitive compensation
- Unbalanced or balanced forms
  - Ruthroff : unbalanced
  - Guanella: balanced
- Autotransformers
- Some examples