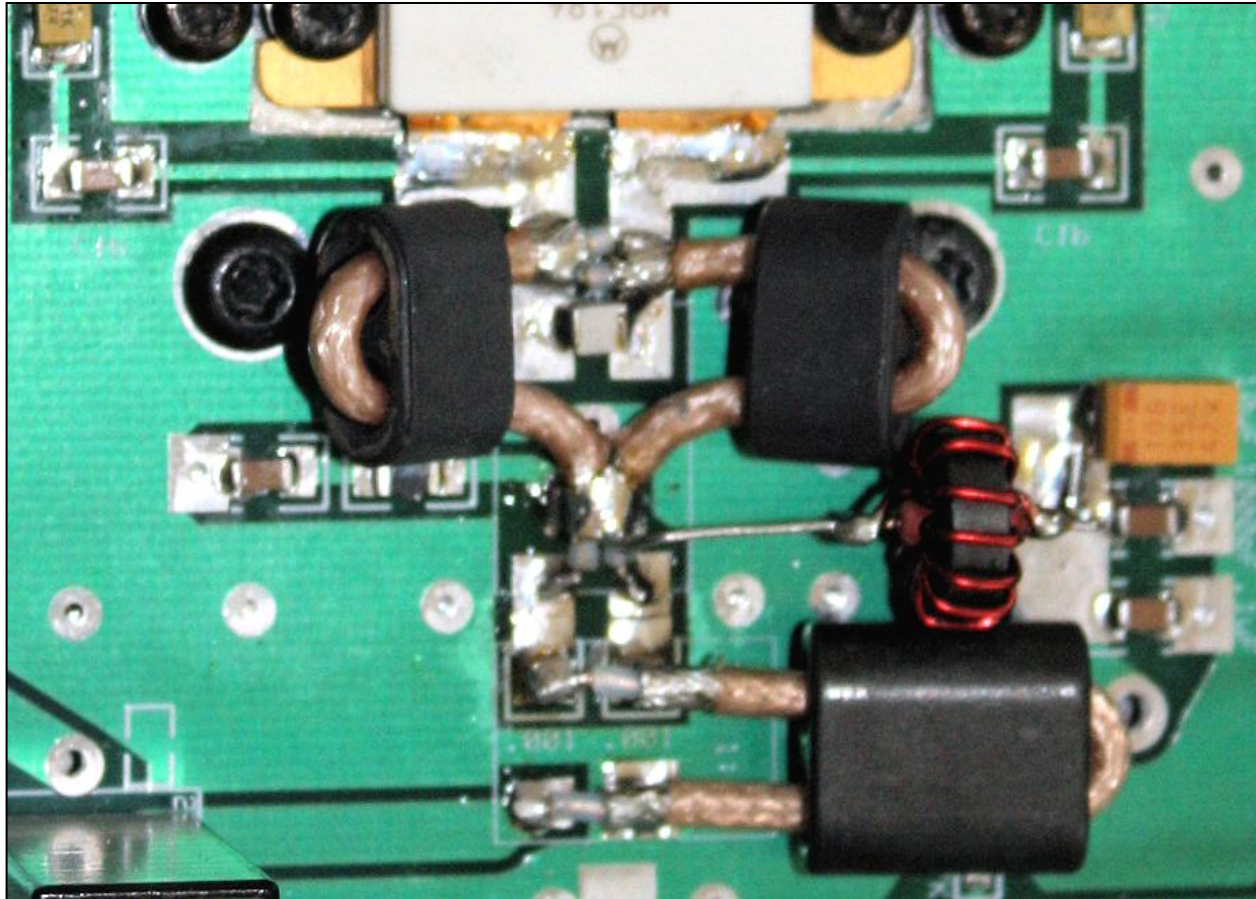


Transmission-Line Transformers



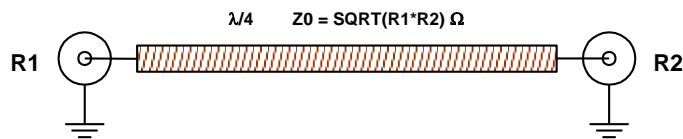
K5TRA

Categories of Transmission-Line Transformers

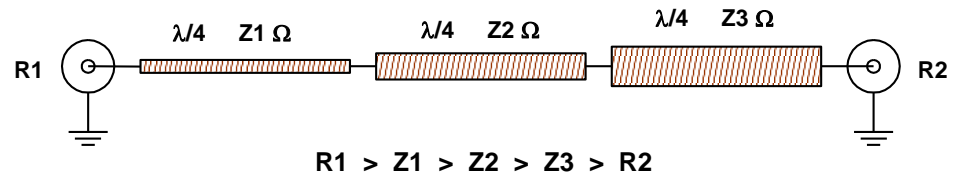
- Single $\lambda/4$ lines and cascades of $\lambda/4$ lines
- Distributed element approximations of lumped element (LC) designs
- Short, highly coupled unit element structures
 - Ruthroff
 - Guanella

$\frac{1}{4} \lambda$ and Stepped $\frac{1}{4} \lambda$ Transformers

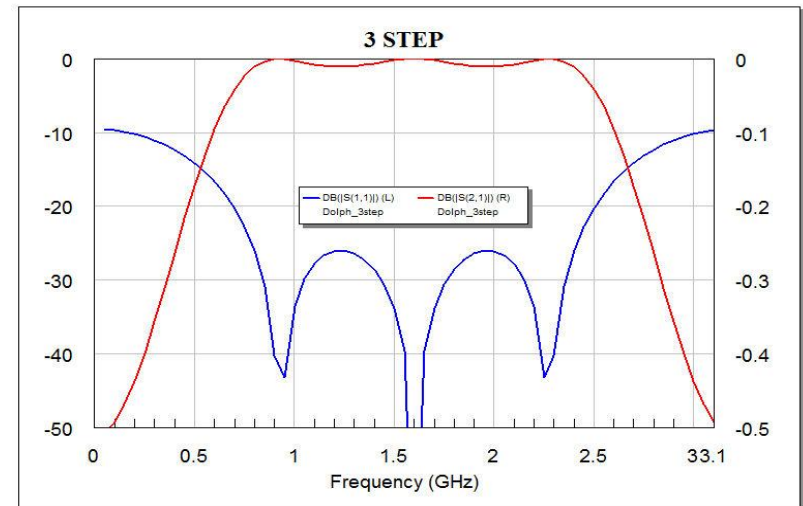
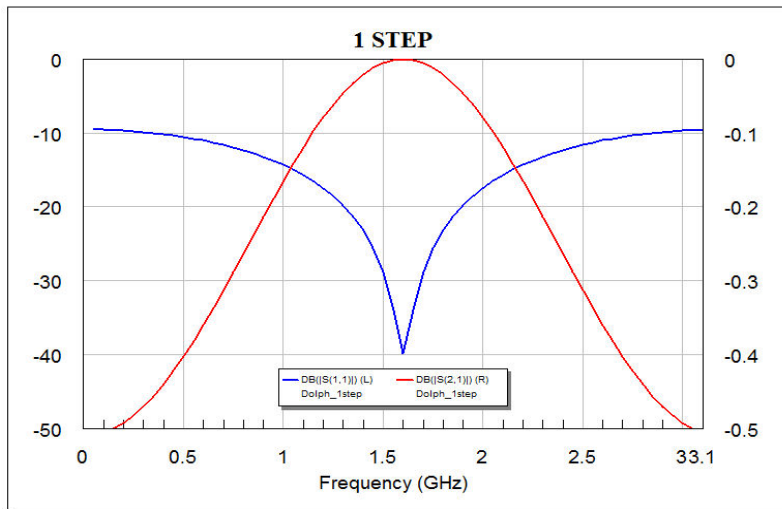
- Half octave performance from single quarter-wave line transformer
- Nearly 2-octave performance from 3 stepped quarter-wave lines
- Comparison for 50Ω to 100Ω transformation (BW also depends on this)



$\frac{1}{4} \lambda$ Z INVERTER



STEPPED Z TRANSFORMER



Stepped $\frac{1}{4} \lambda$ Transformer Calculation

ApelSoft Design Tools

Lower Freq. = .14 GHz

Upper Freq. = .45 GHz

High Z Port = 100 Ω

Low Z Port = 50 Ω

Center Freq. = .295 GHz

BW = 105.08 %

N = 3

STEPPED QUARTER-WAVE TRANSFORMER

VSWR=1.118

Impedance Transformation = 2.x

N=3 Lines

Z(0)= 50.00

Z(1)= 57.84

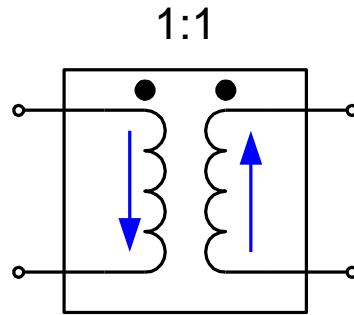
Z(2)= 70.71

Z(3)= 86.45

Z(4)= 100.00

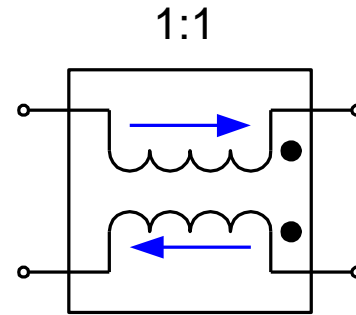
DOWNLOAD FROM: <http://k5tra.net/>

Transmission-Line Transformer – Elements

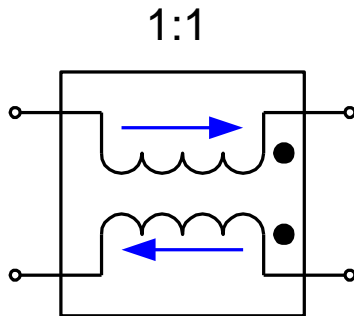


CONVENTIONAL
TRANSFORMER

=

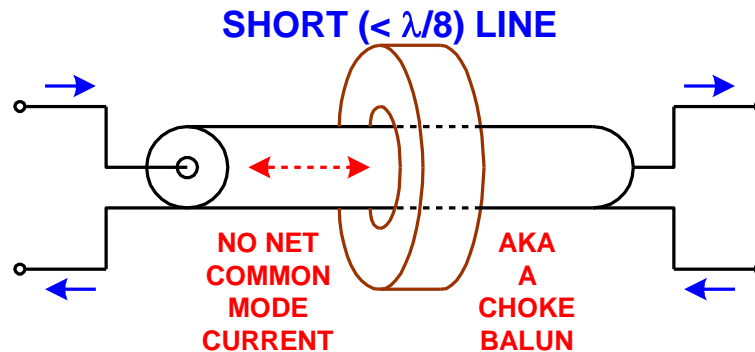


TRANSMISSION-LINE
TRANSFORMER



SYMBOLIC

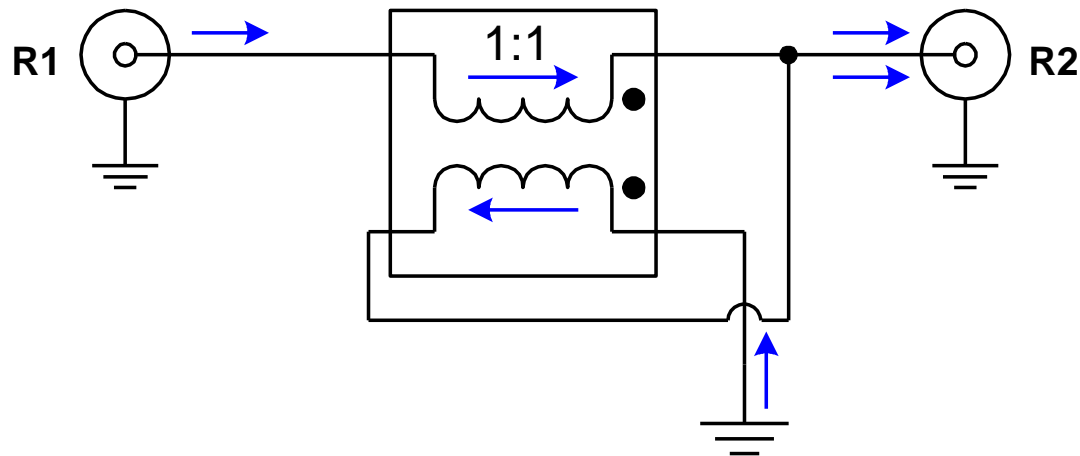
=



PHYSICAL

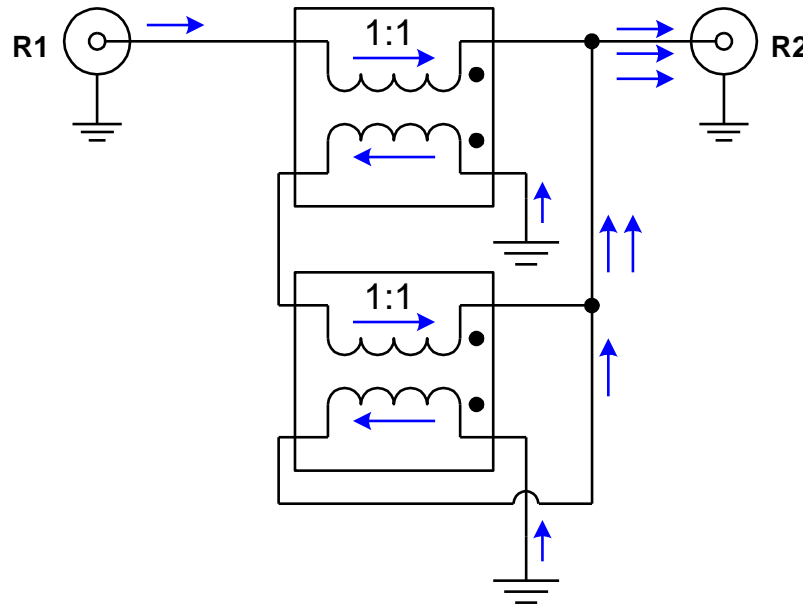
Ruthroff Transformers

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



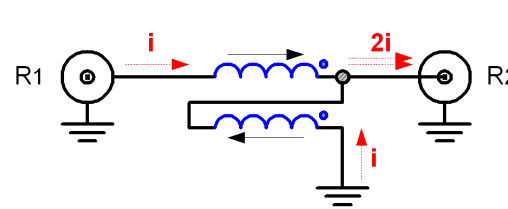
Ruthroff Type 9:1 Transformer

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



Various Unbalanced Transformers

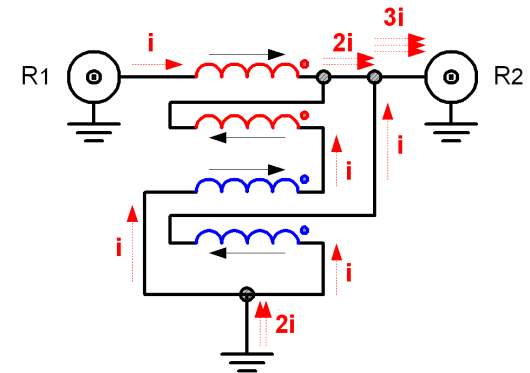
- Transmission line unit element building blocks
- Parasitic even mode characteristic impedance should be large ($k \rightarrow 1$)
- Z ratio available as squares of integer ratios
- First order analysis on basis of port current ratio
- Multiple line structures must have at least one shared current path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



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

$$R_1 = 4 R_2$$

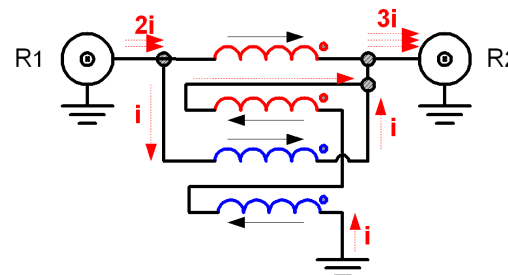
4:1 Transformer



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

$$R_1 = 9 R_2$$

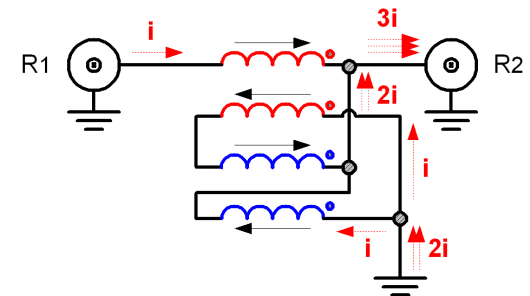
**9:1 Transformer
version - A**



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

$$R_1 = 4 R_2$$

**4:9 Transformer
(approx. 1:2)**



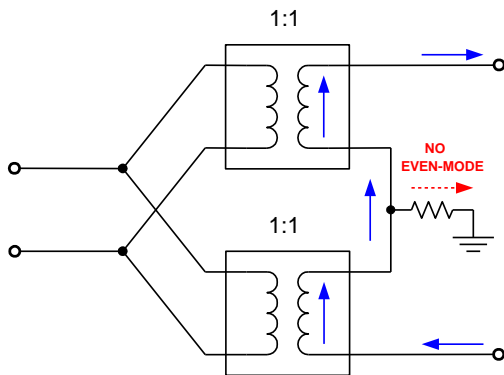
$$i^2 R_1 = (3i)^2 R_2$$

$$R_1 = 9 R_2$$

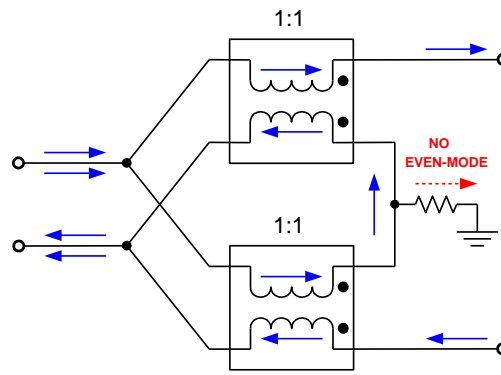
**9:1 Transformer
version - B**

Guanella (4:1) Balanced Transformer

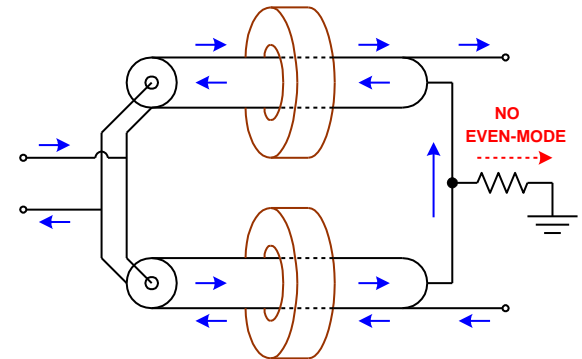
- Two 'unit' elements can be used to form a balanced 4:1 transformer
- Analysis based on currents
- $R_1 / R_2 = (I_2 / I_1)^2 = 4$
- Ferrite loading extends bandwidth (low end)



**CONVENTIONAL
4:1 BALANCED
TRANSFORMER**



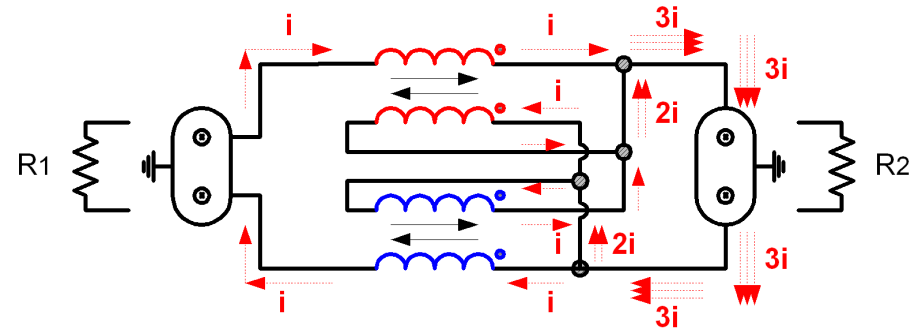
**GUANELLA 4:1
SYMBOLIC**



**GUANELLA 4:1
PHYSICAL**

Several Balanced Transformers

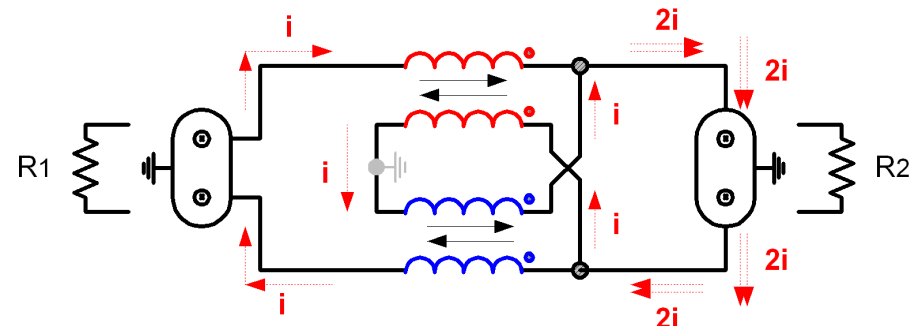
- Transmission line unit element building blocks
- Parasitic even mode characteristic impedance should be large ($k \rightarrow 1$)
- Z ratio available as squares of integer ratios
- First order analysis on basis of port current ratio
- Multiple line structures must have at least one shared current path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



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

$$R_1 = 9 R_2$$

9:1 Transformer



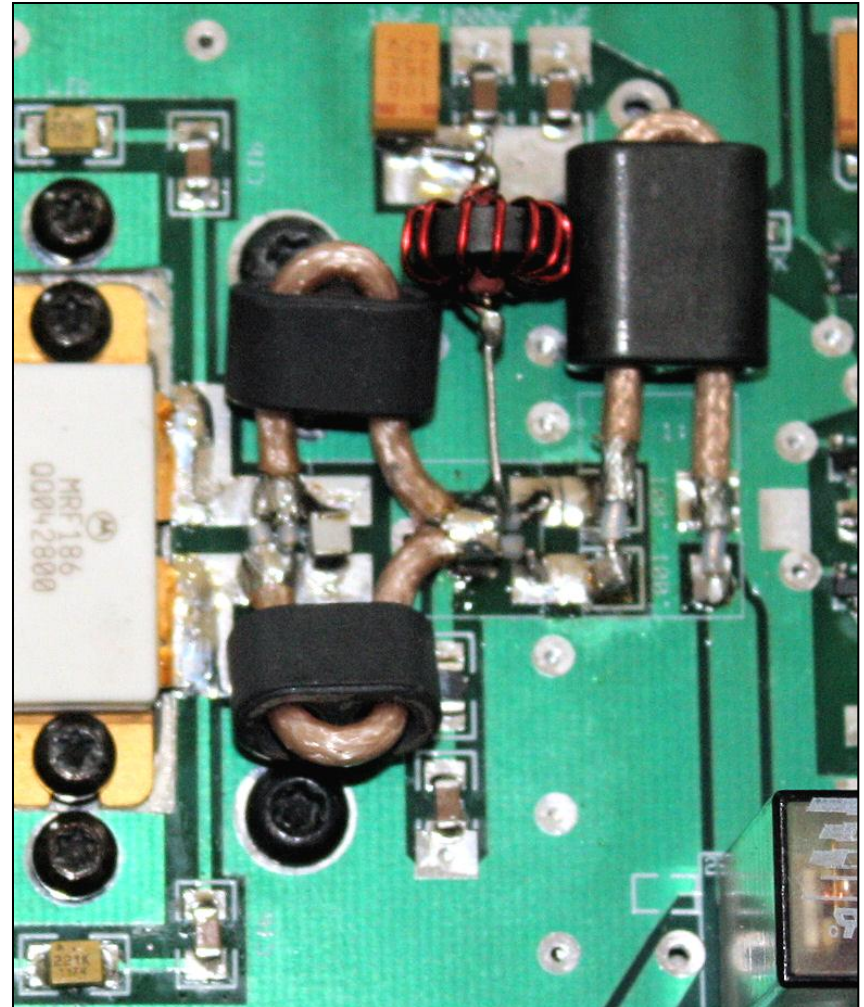
$$i^2 R_1 = (2 i)^2 R_2$$

$$R_1 = 4 R_2$$

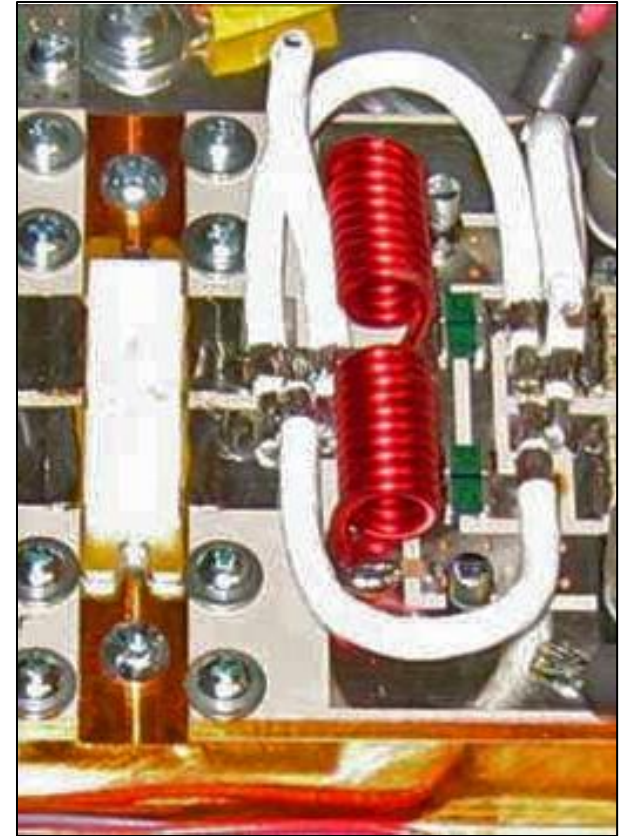
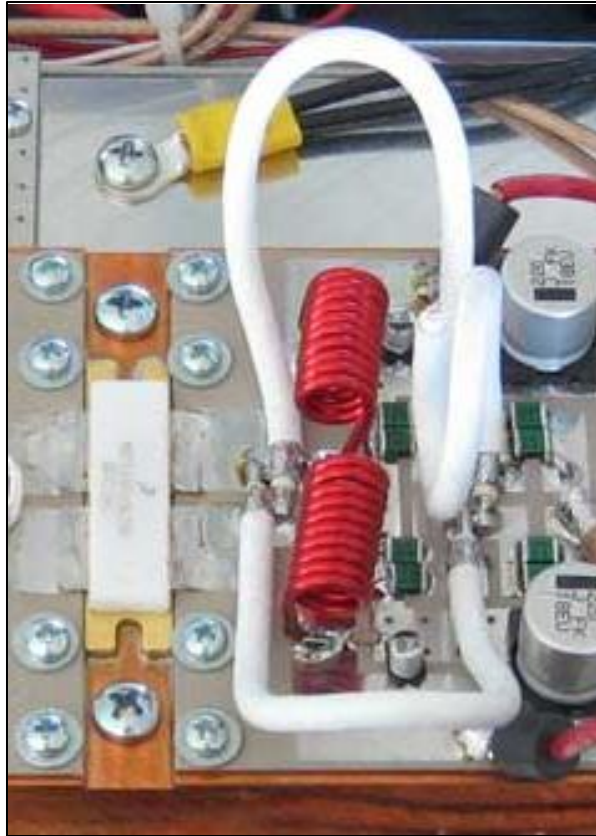
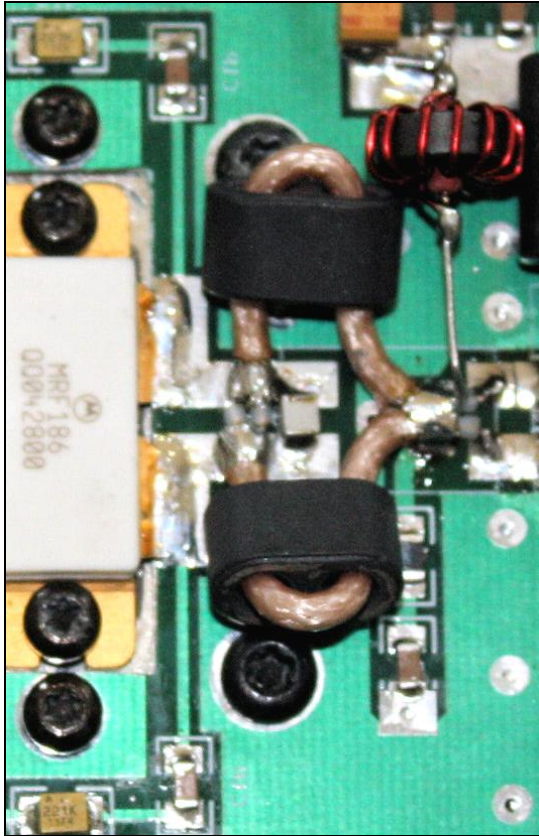
4:1 Transformer

Guanella Transformer and Choke Balun

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



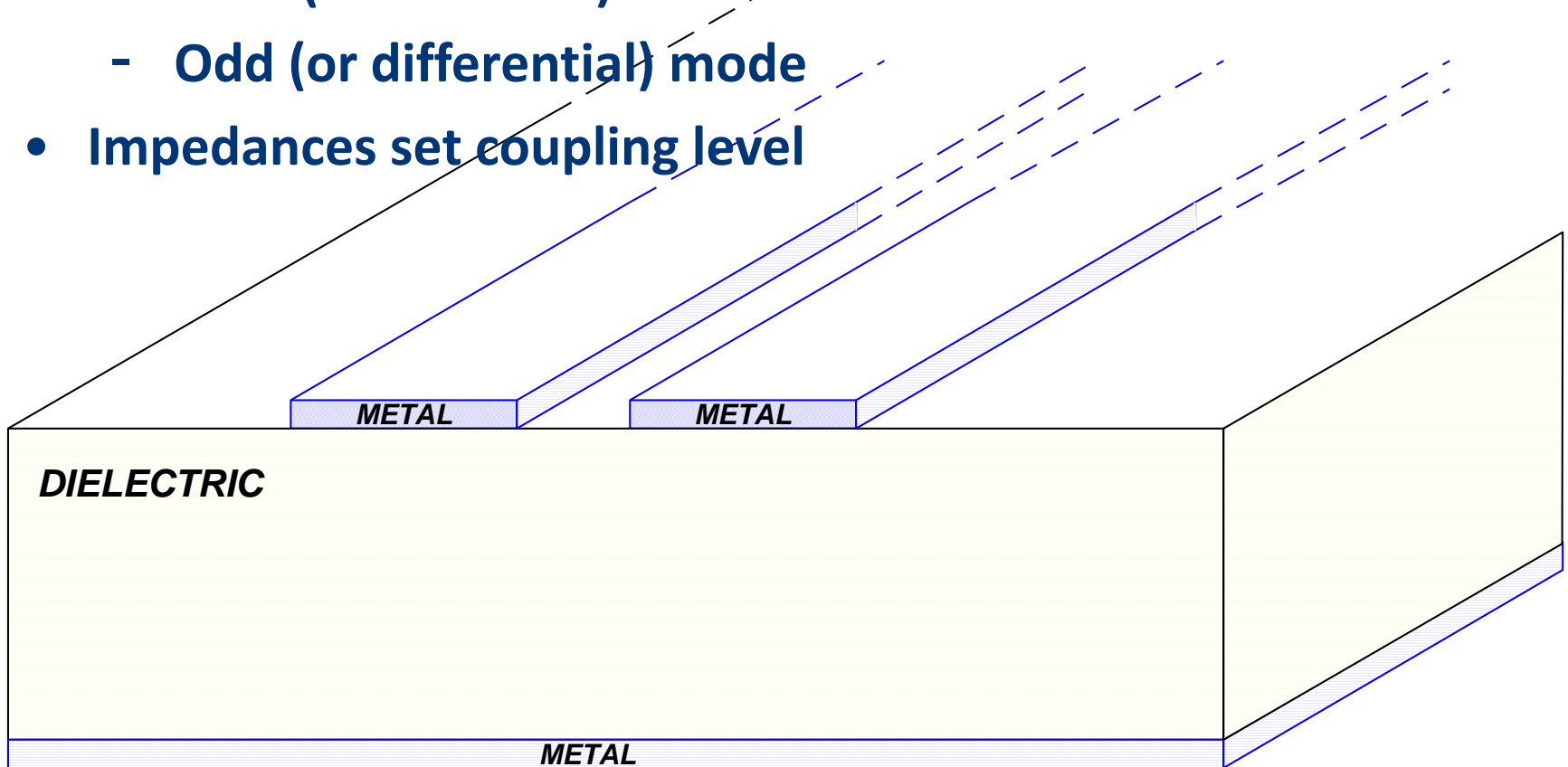
More Guanella Transformers in PA Output



- 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

$$Z_{oe}/Z_{oo} = (C+2C_M)/C$$

$$k = \frac{Z_{oe}/Z_{oo} - 1}{Z_{oe}/Z_{oo} + 1}$$

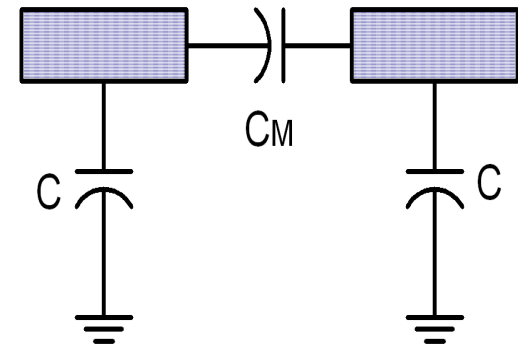
$$k = \frac{C_M}{C_M + C}$$

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

$$Z_{oe}/Z_{oo} \rightarrow \infty \Rightarrow K \rightarrow 1$$

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

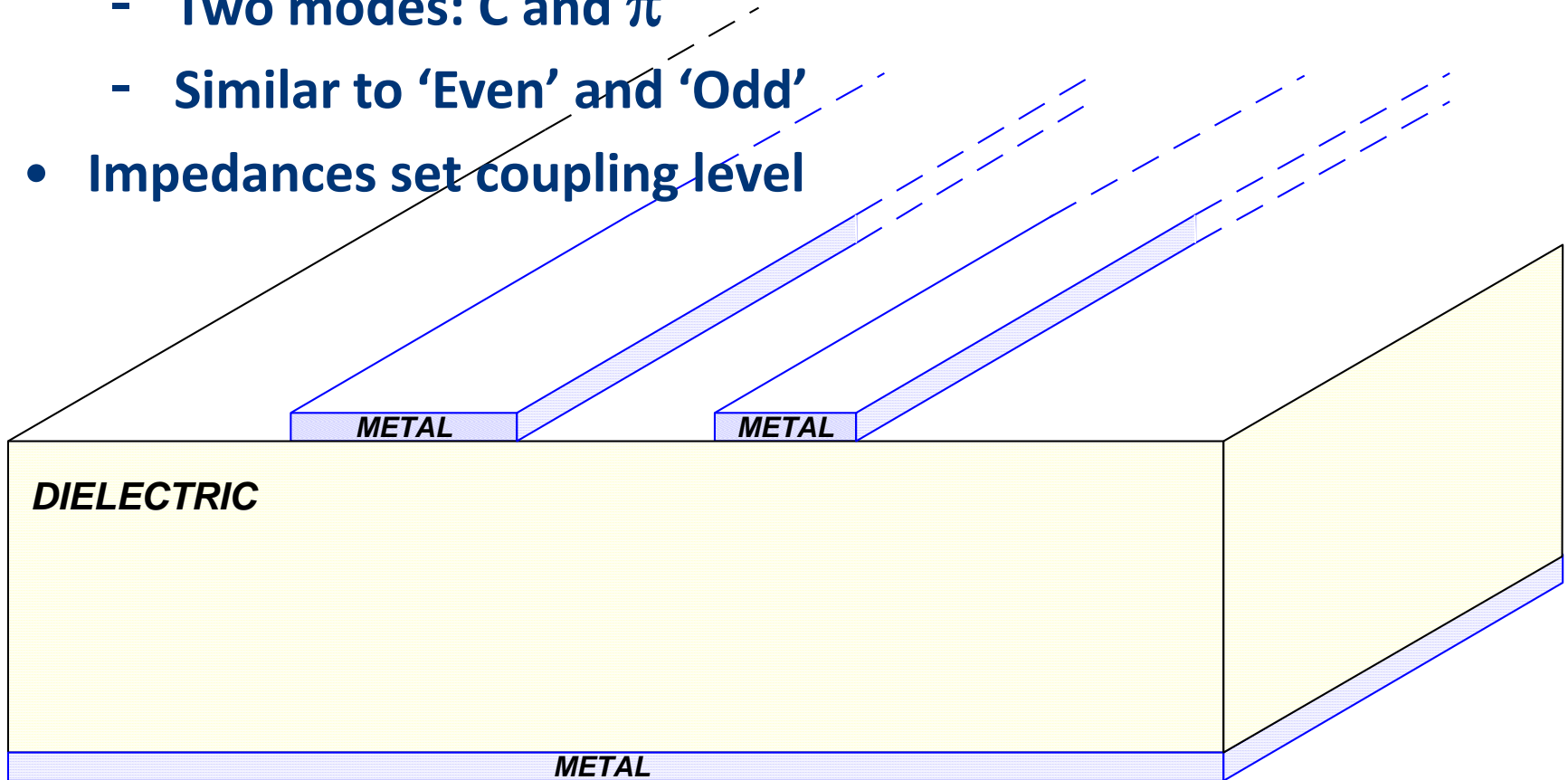
- Z_{oo} sets the desired Z_o
- Z_{oe} should be large !



STATIC CAPACITANCE
REPRESENTATION FOR
SYMMETRIC STRUCTURES

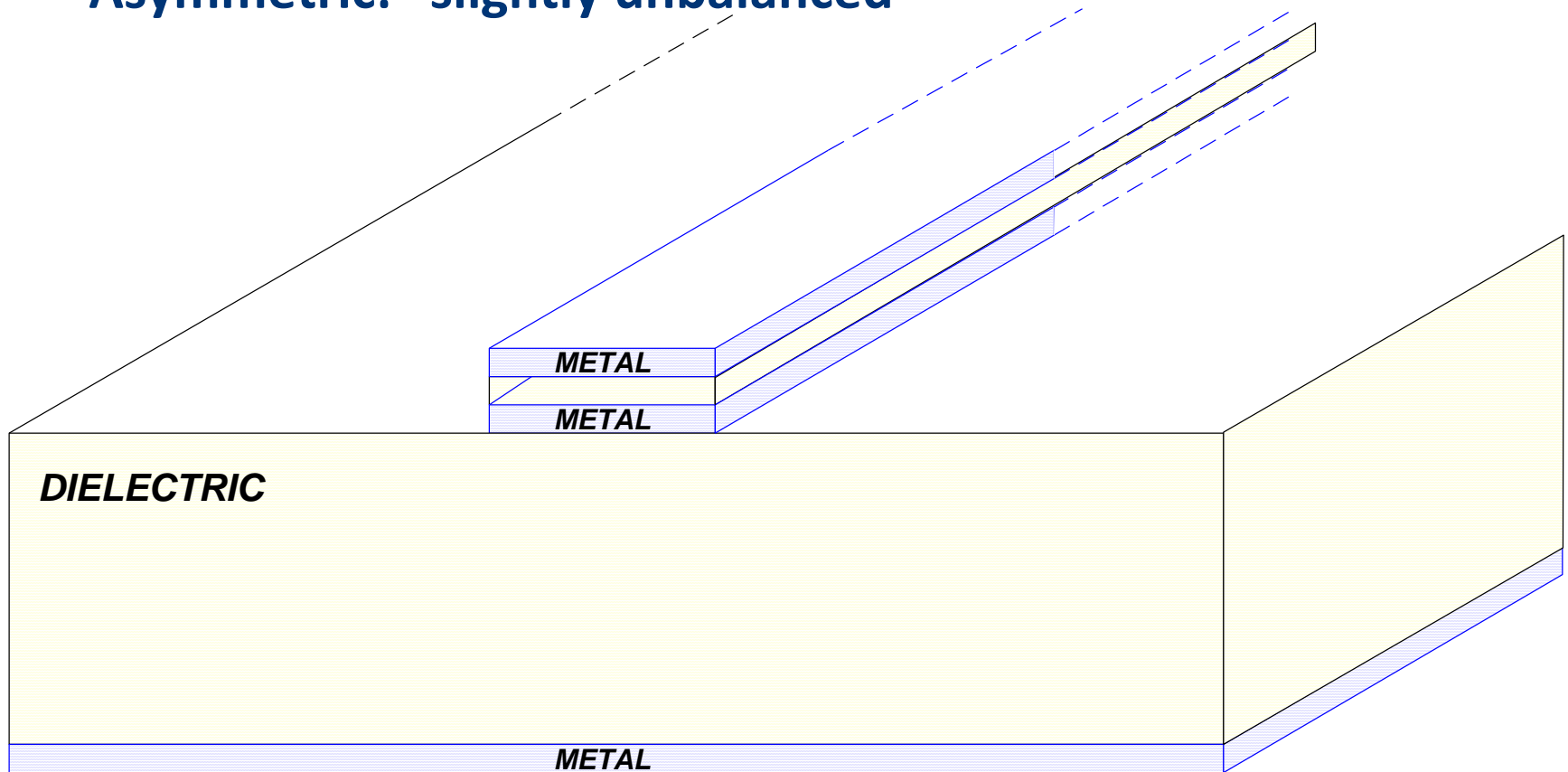
Coupled Lines - Asymmetric

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



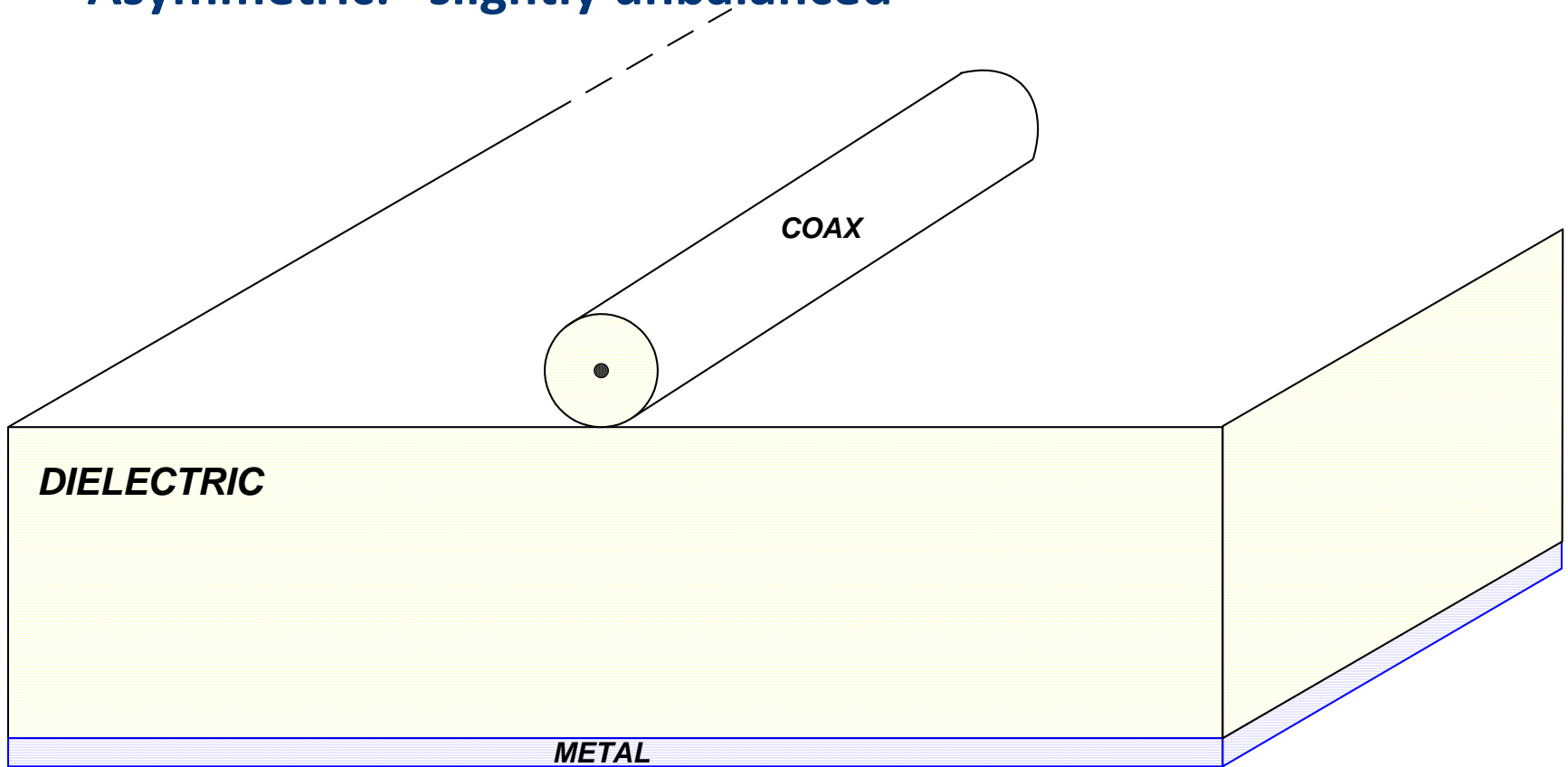
Coupled Lines - Asymmetric

- Broadside coupling is better
- Asymmetric: slightly unbalanced

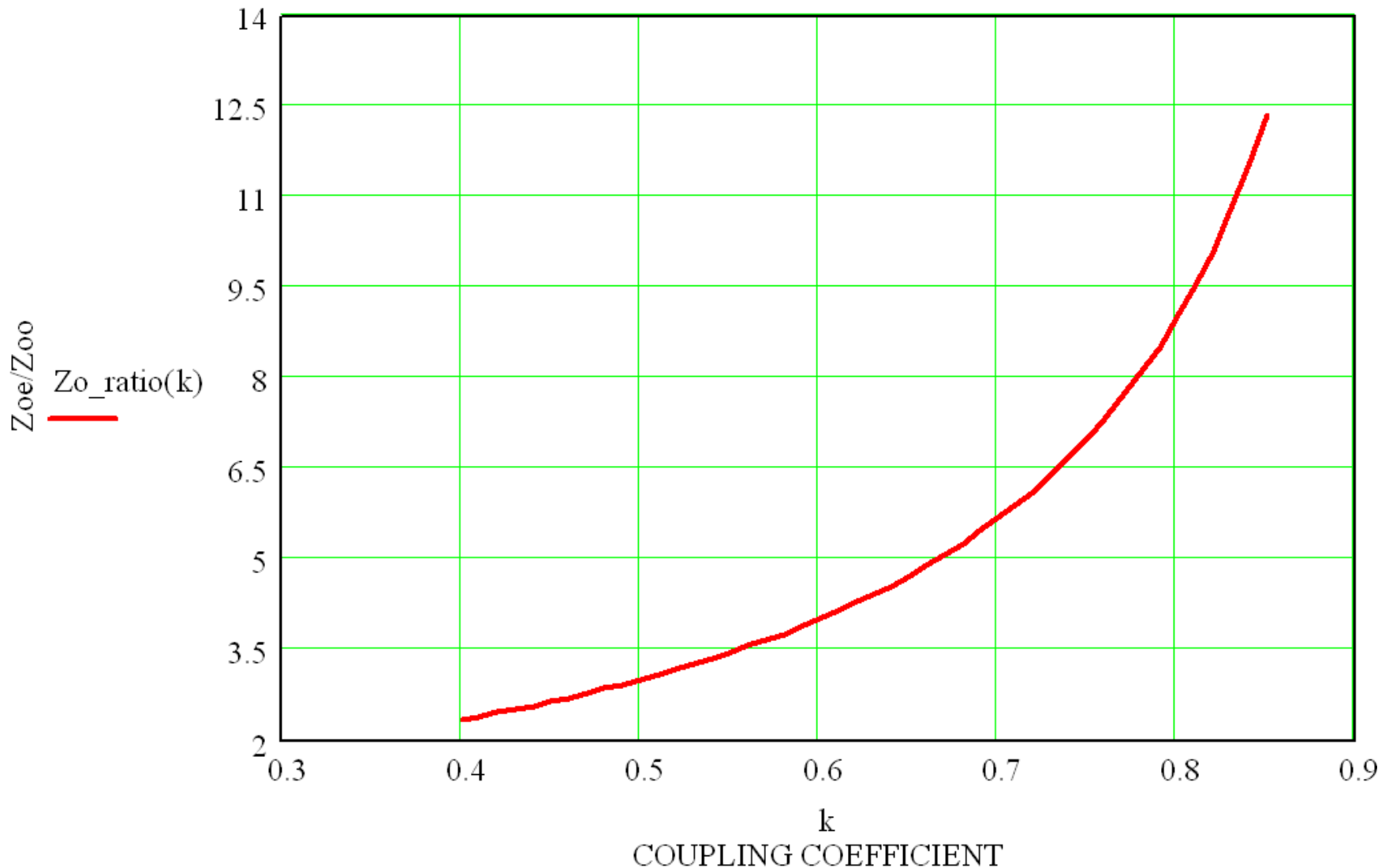


Coax Over Ground

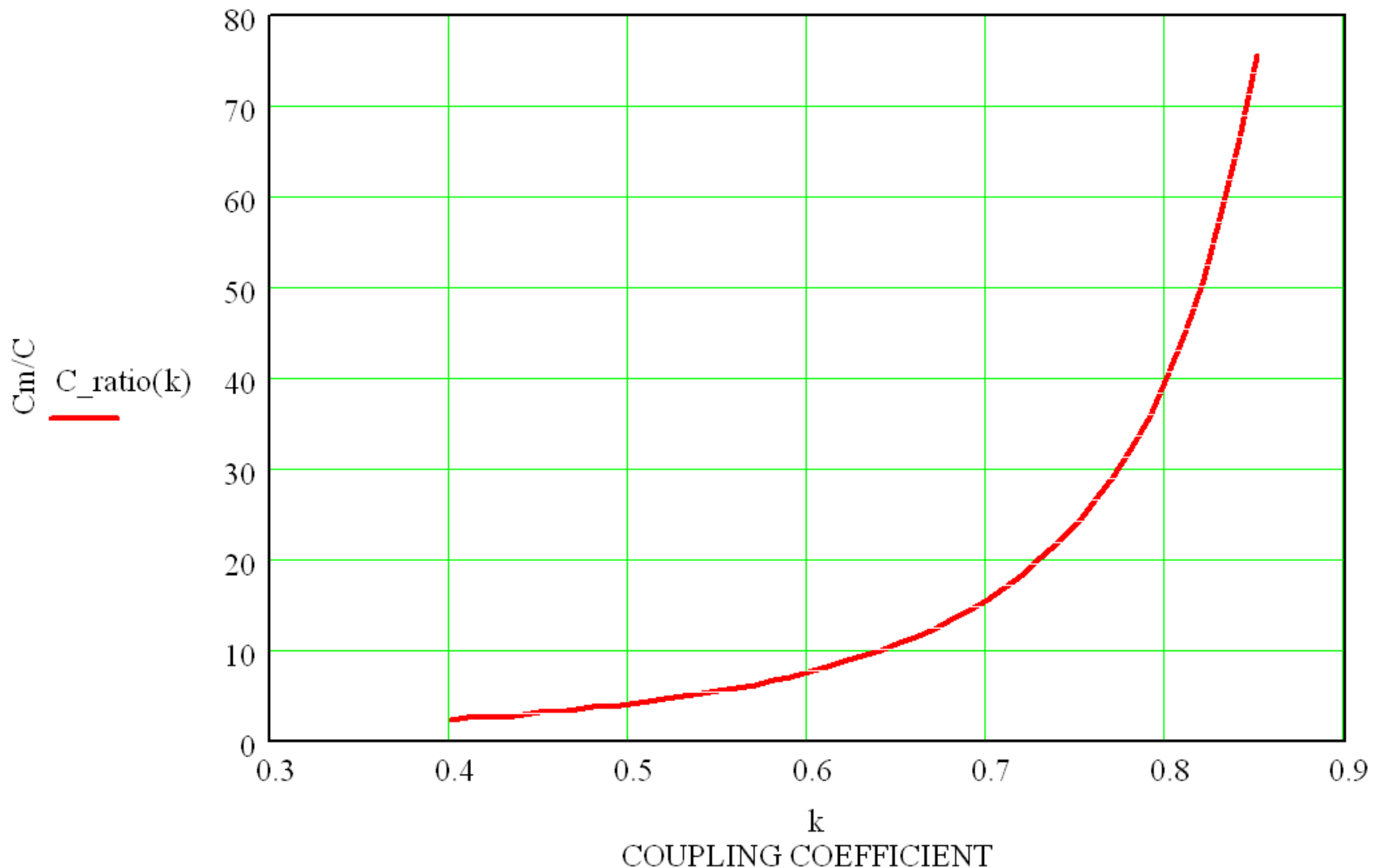
- Coax coupling is very good
- Asymmetric: slightly unbalanced



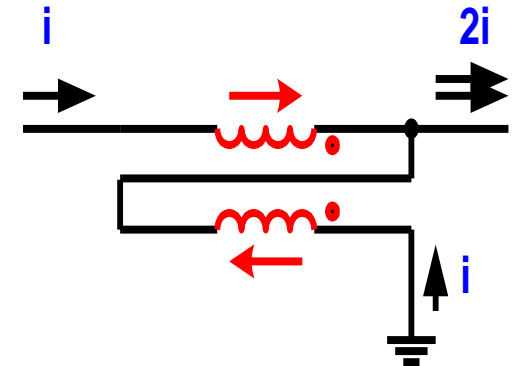
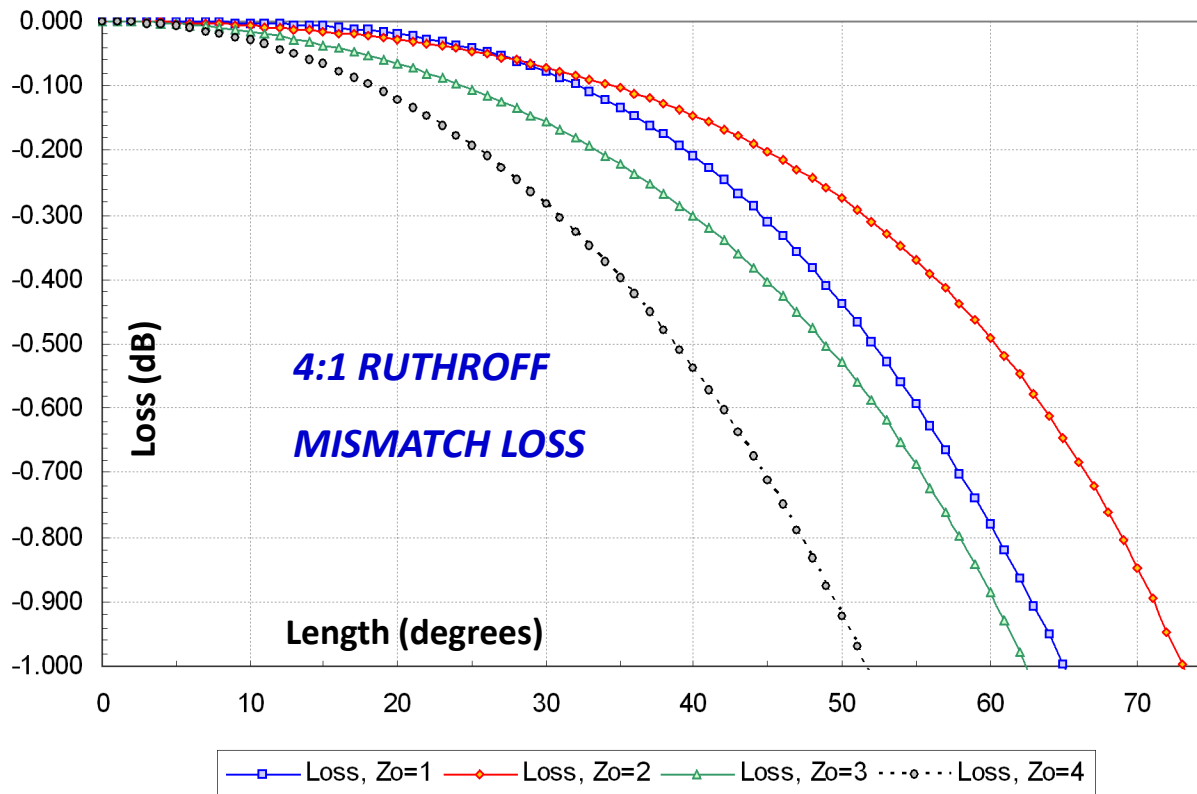
Coupling Coefficient Relationship to Zoe/Zoo



Coupling Coefficient Relationship to C_m/C

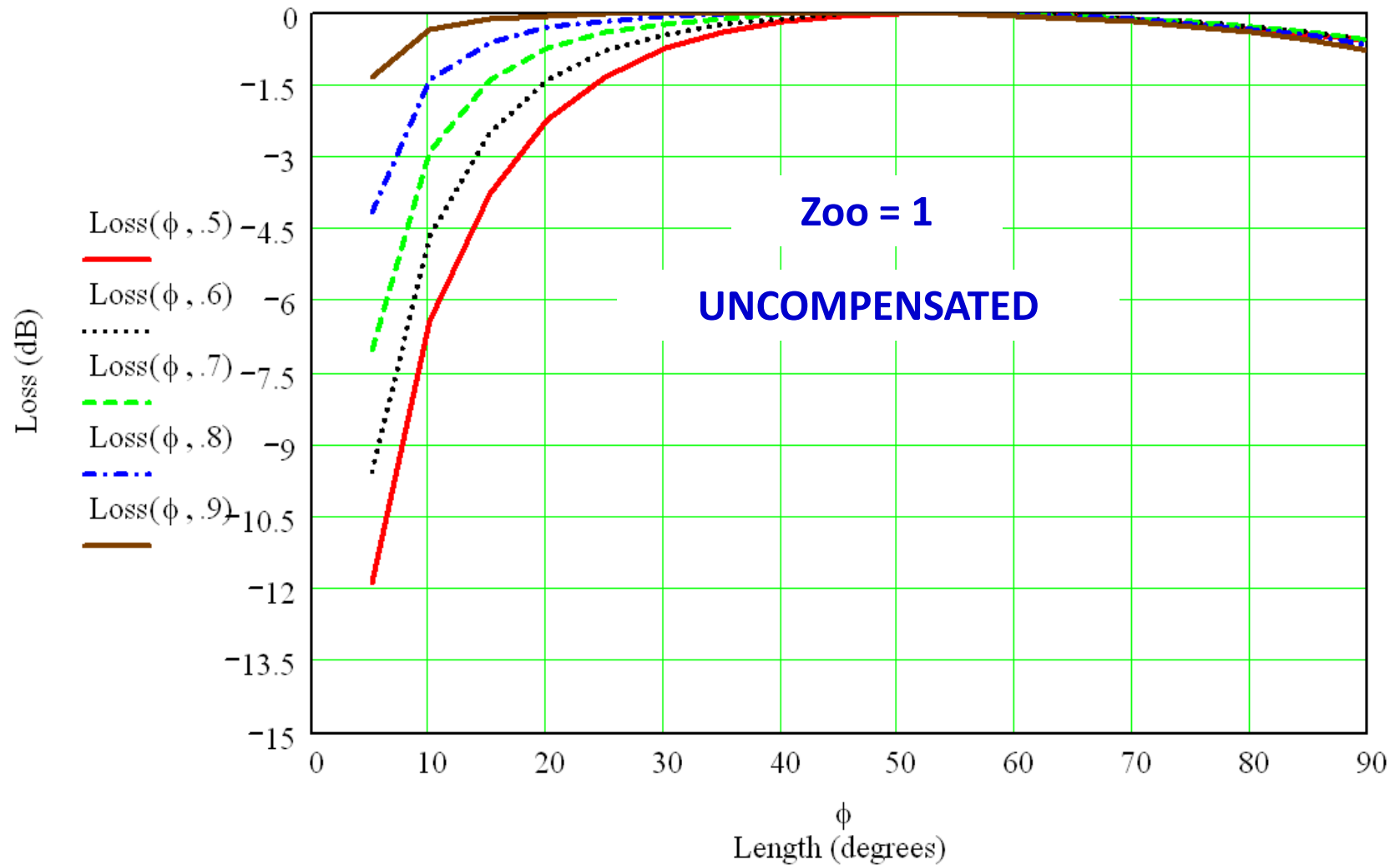


Ideal Ruthroff Loss vs Length (and Zo)

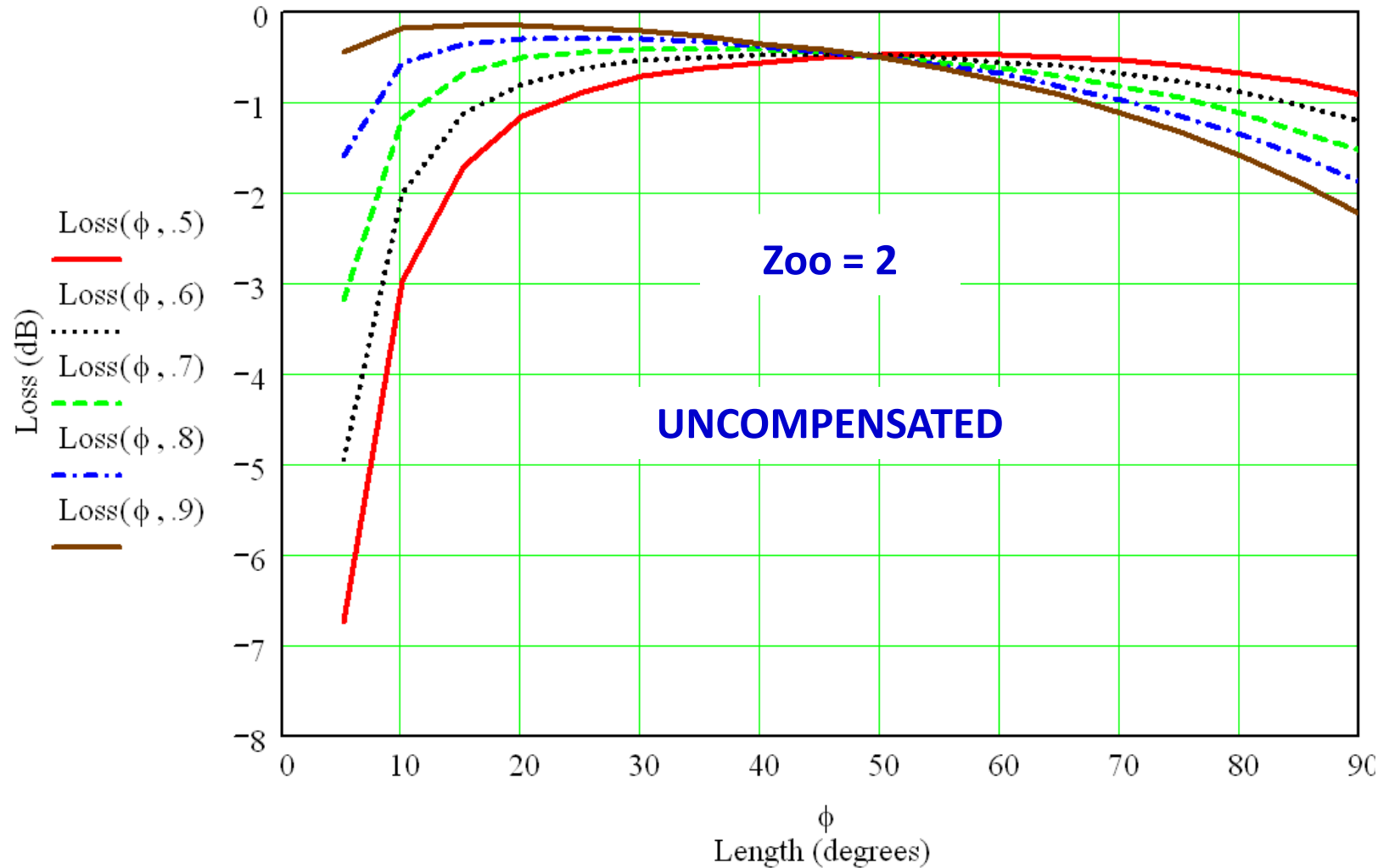


- Analysis of original 4:1 Ruthroff transformer ($k = 1$)
- Normalized port impedances (1Ω and 4Ω)
- Best BW from $Z_o=2$
- Lowest loss over less BW from $Z_o=1$

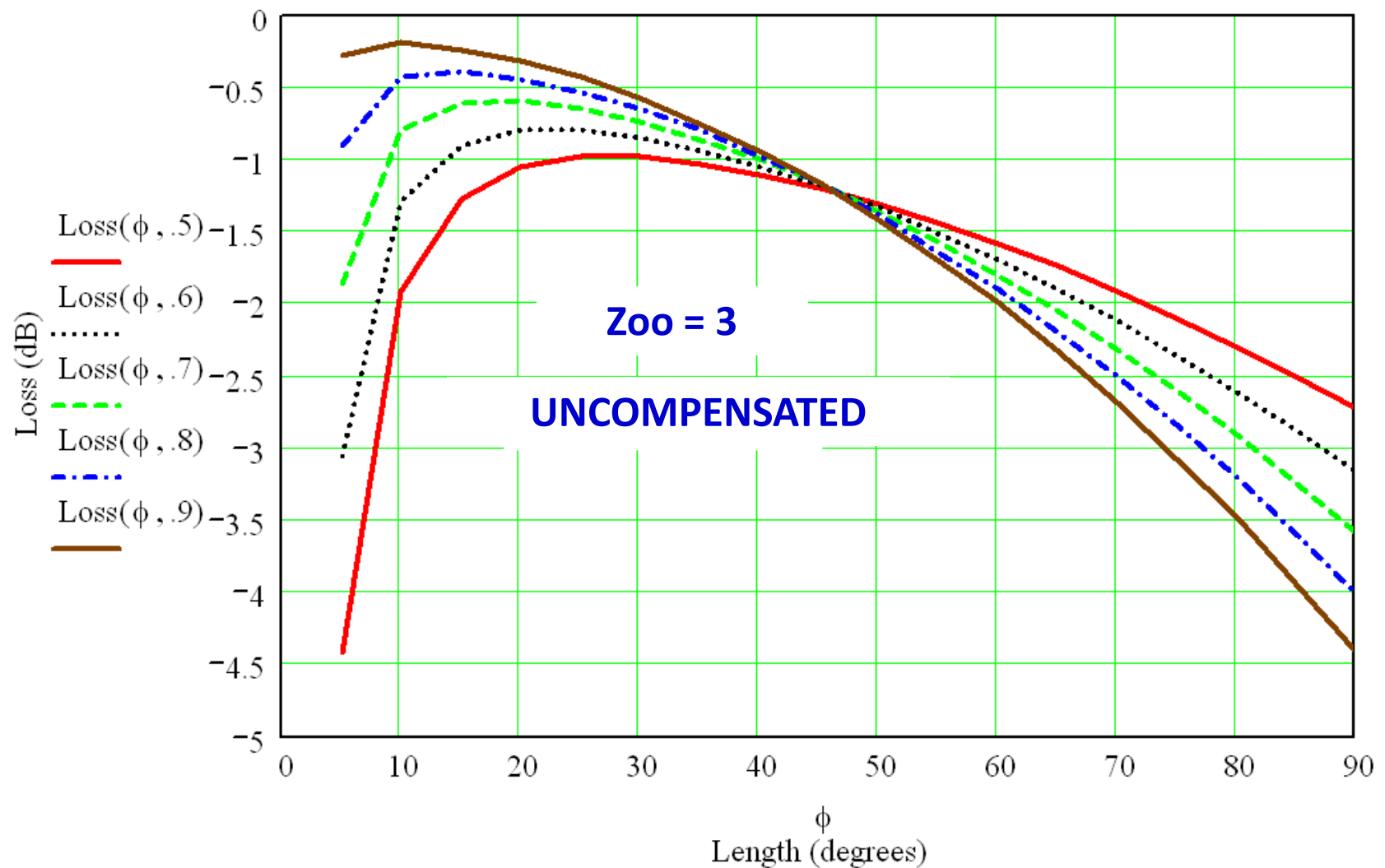
Ruthroff Loss vs Length (and k)



Ruthroff Loss vs Length (and k)

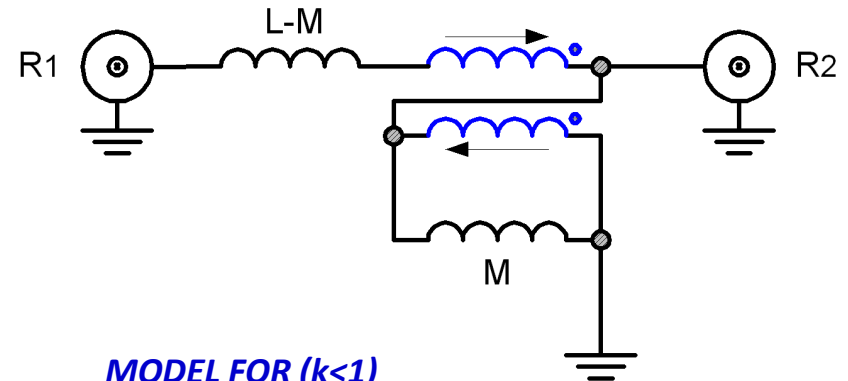


Ruthroff Loss vs Length (and k)

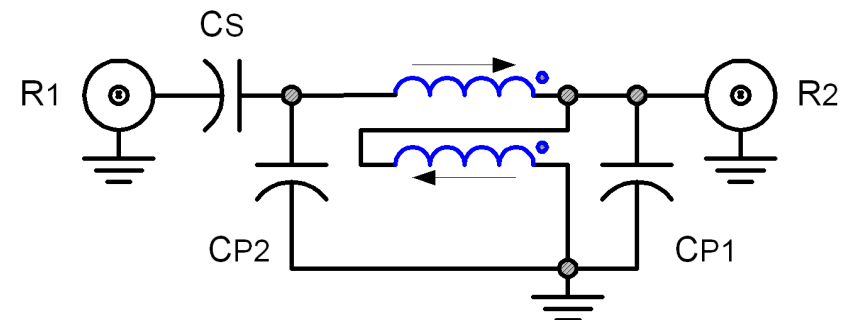


Ruthroff Transformer Frequency Compensation

- Non-ideal coupling is modeled by leakage and magnetizing inductance
- C_S provides DC block and low frequency compensation
- C_{P1} and C_{P2} provide high frequency compensation
- If coupling is poor, or Z_{00} is not optimal, C_p can be used to tune the transformer for the desired frequency band

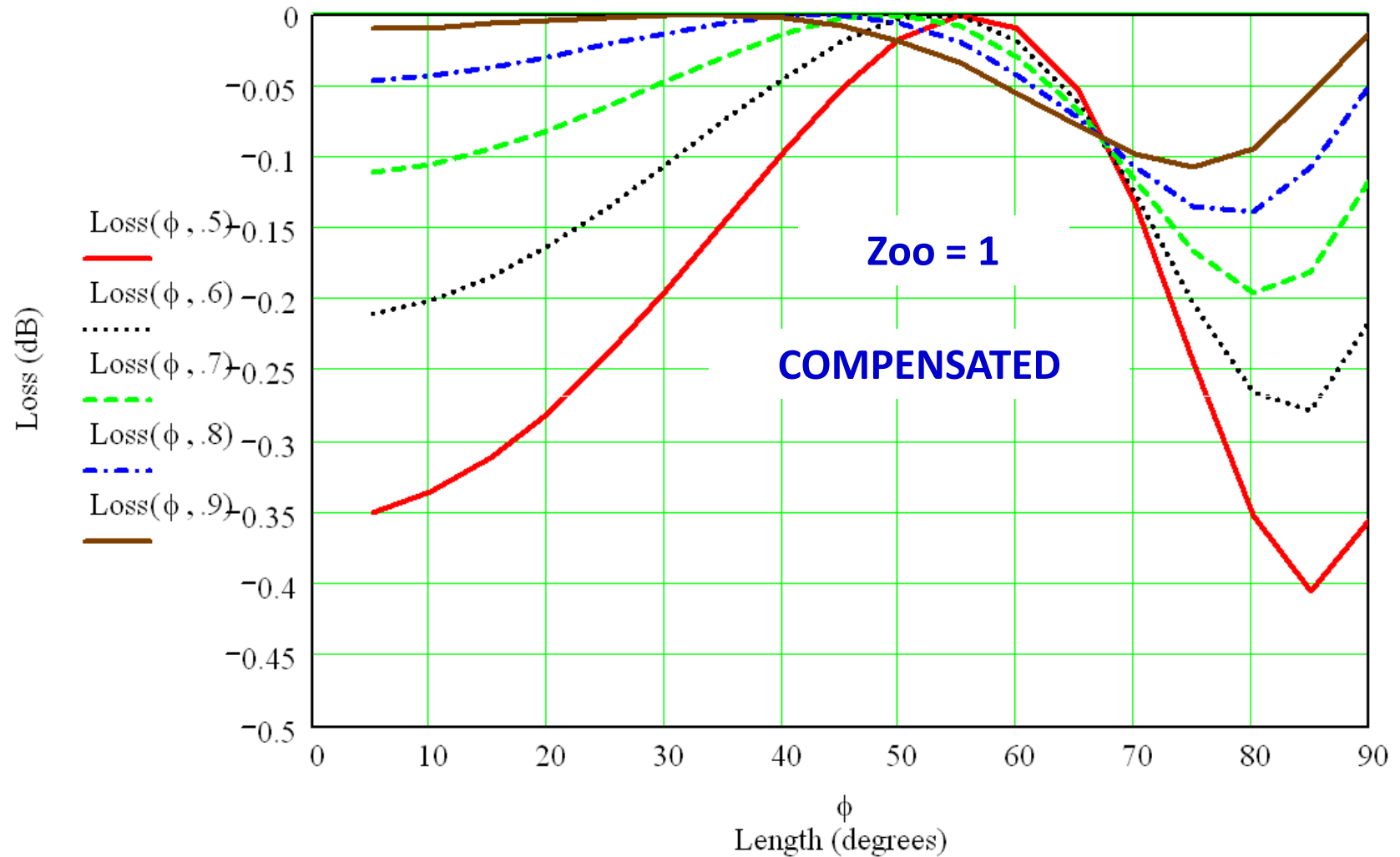


*MODEL FOR ($k < 1$)
UNDERCOUPLED LINES*

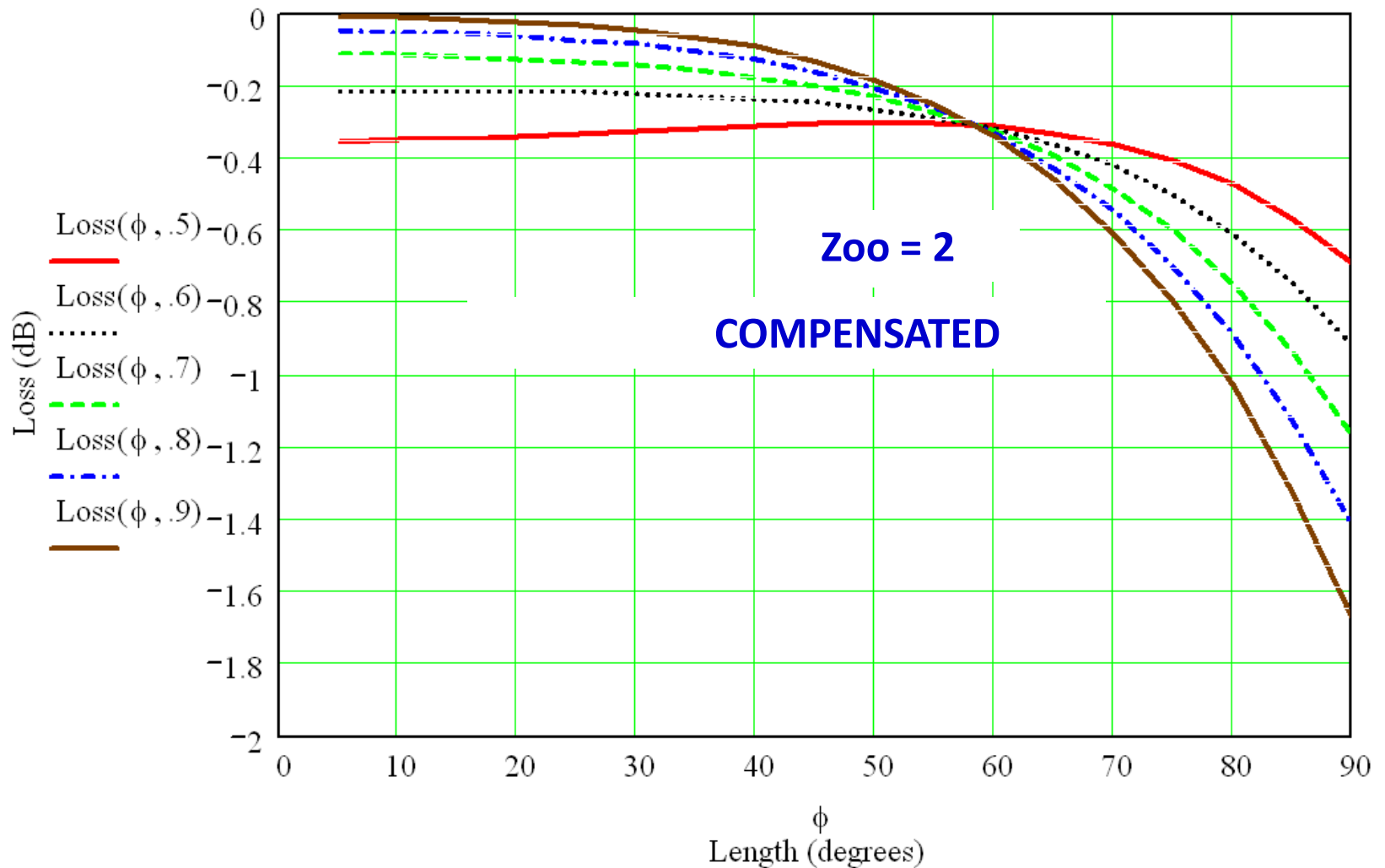


*FREQUENCY
COMPENSATION*

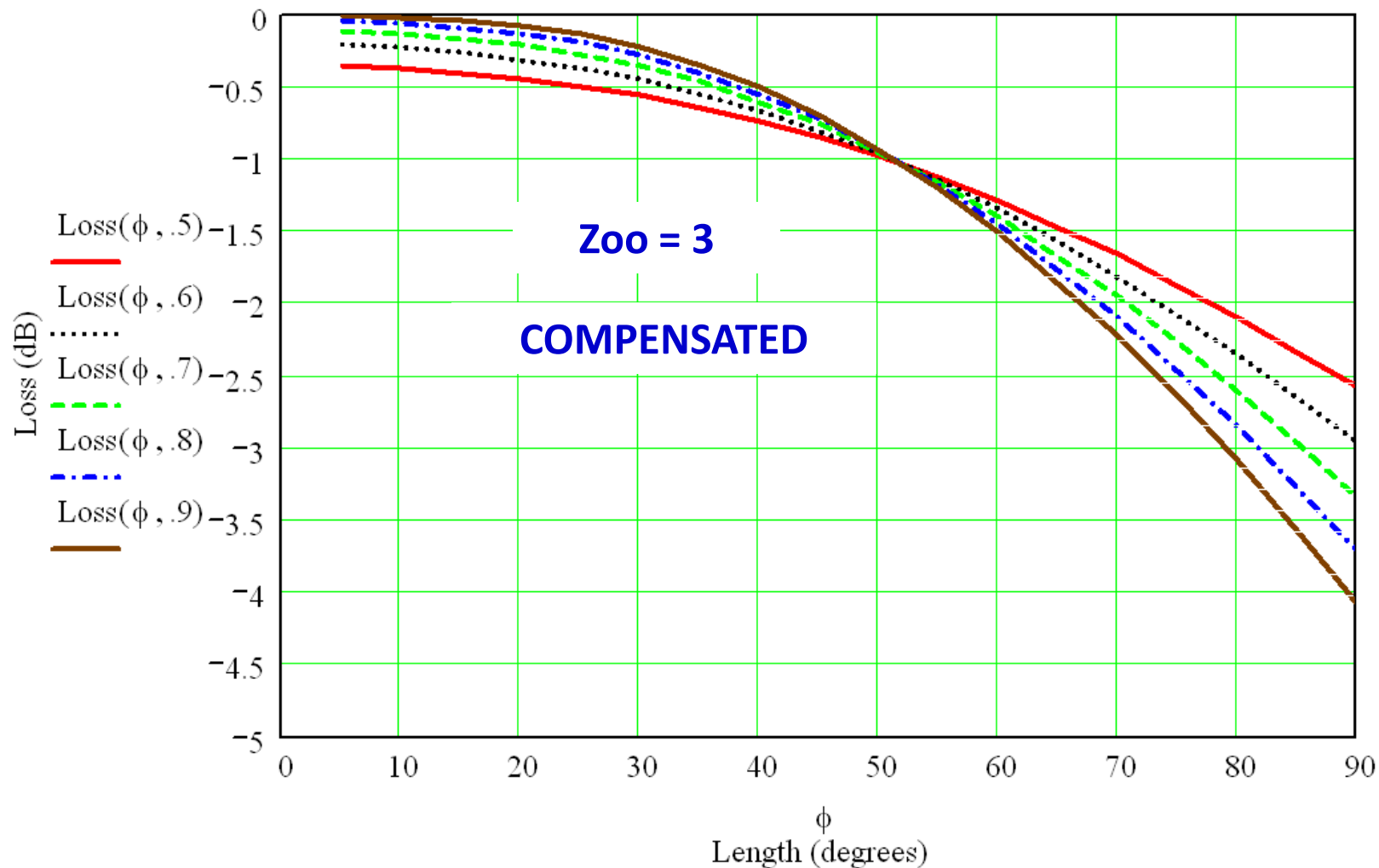
Ruthroff Loss vs Length (and k)



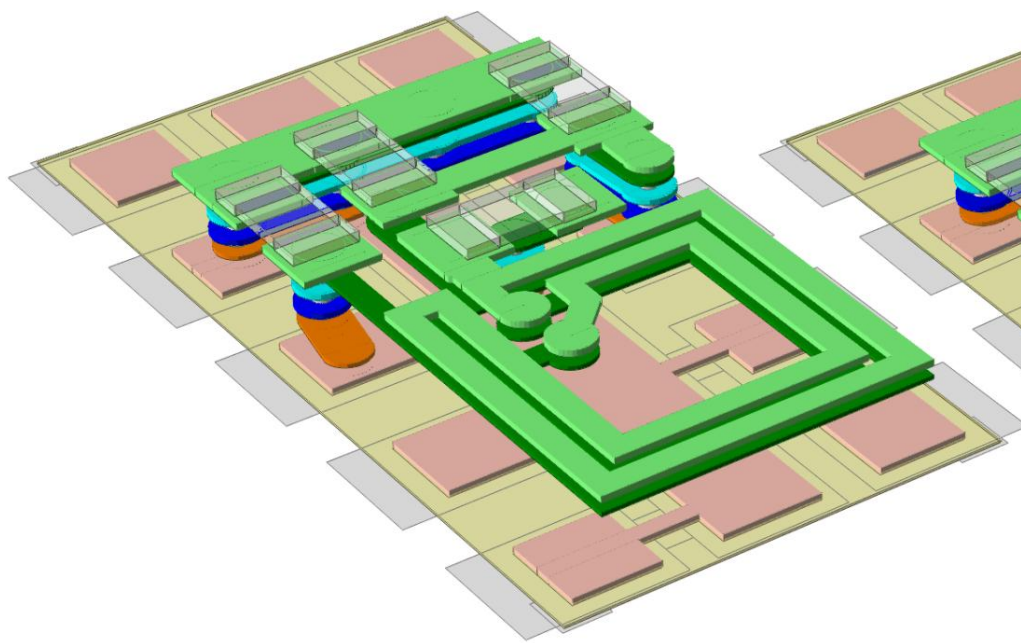
Ruthroff Loss vs Length (and k)



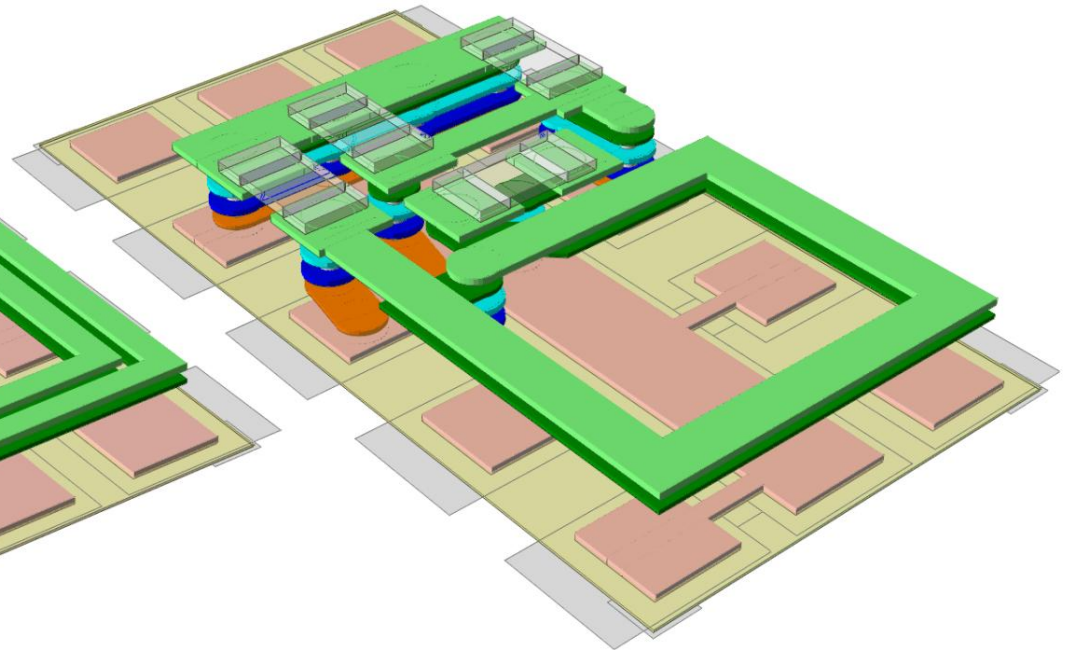
Ruthroff Loss vs Length (and k)



Ruthroff Transformer Test Laminates



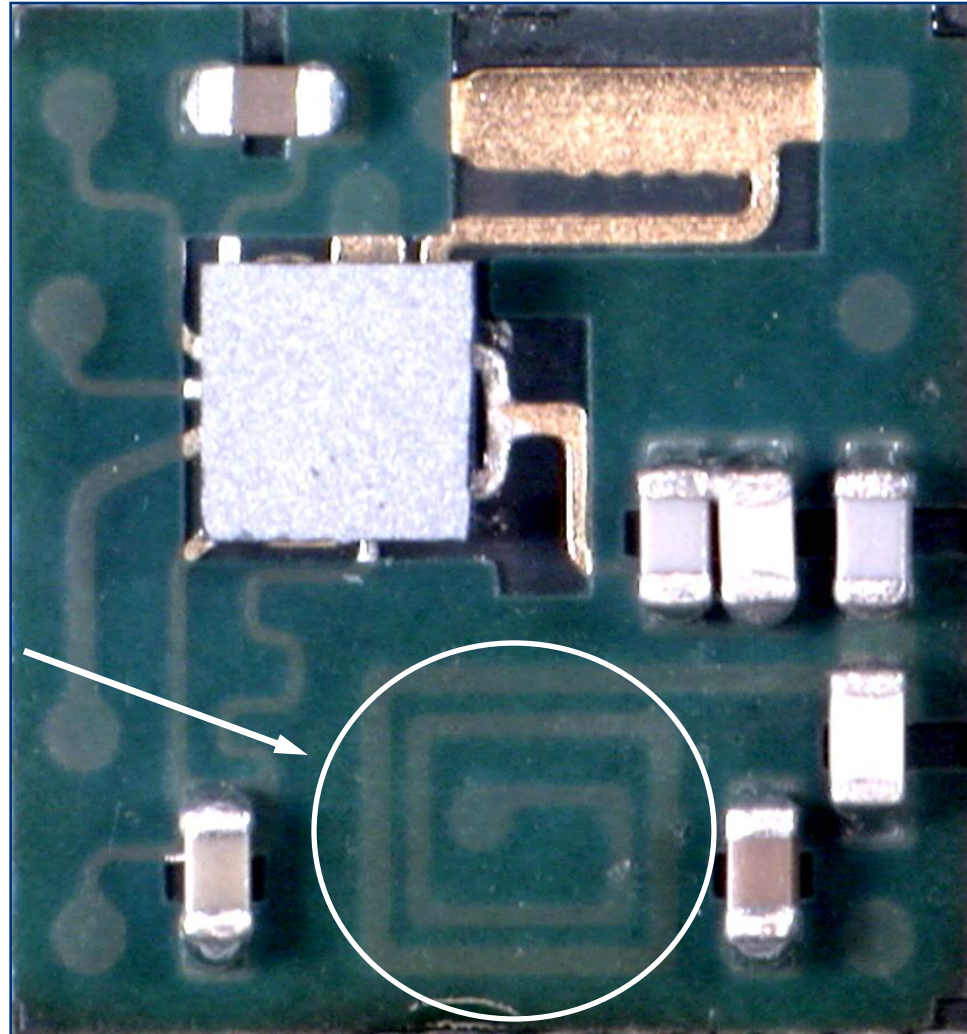
9:1 TRANSFORMER



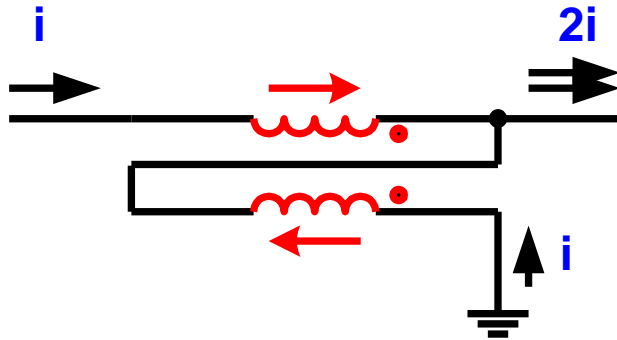
4:1 TRANSFORMER

Flip Chip Multiband PA with Ruthroff 4:1

***RUTHROFF 4:1
TRANSFORMER***

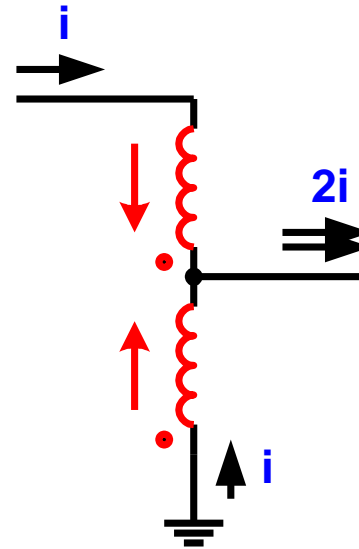


Ruthroff Relationship to Auto Transformers

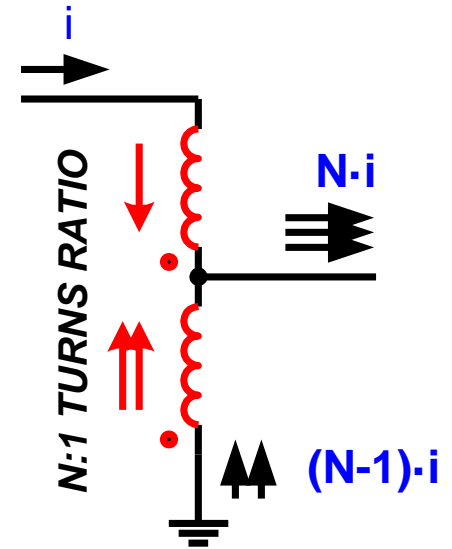


RUTHROFF 4:1
UNBALANCED TRANSFORMER

- 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)

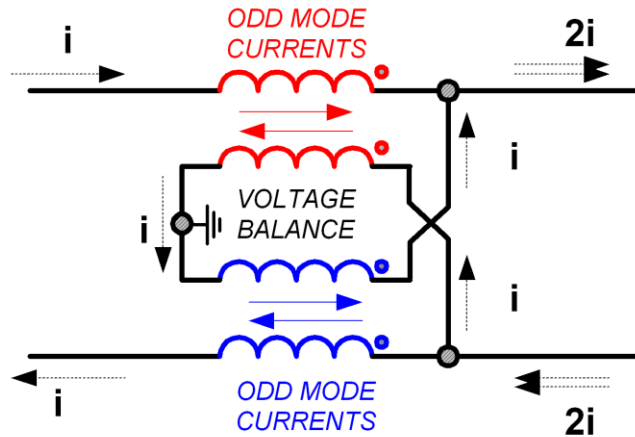


RUTHROFF 4:1
SHOWN AS AUTO
TRANSFORMER



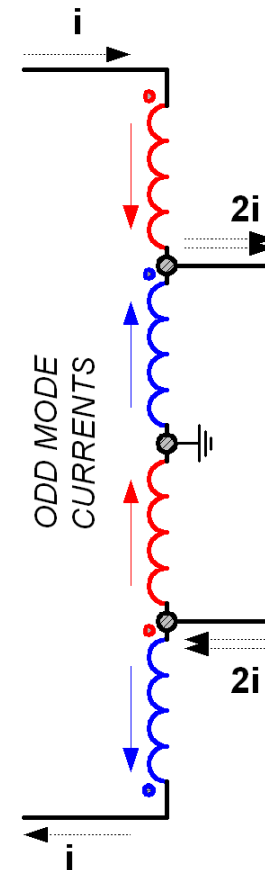
GENERAL $N:1$
UNBALANCED AUTO
TRANSFORMER

Guanella Relationship to Auto Transformers

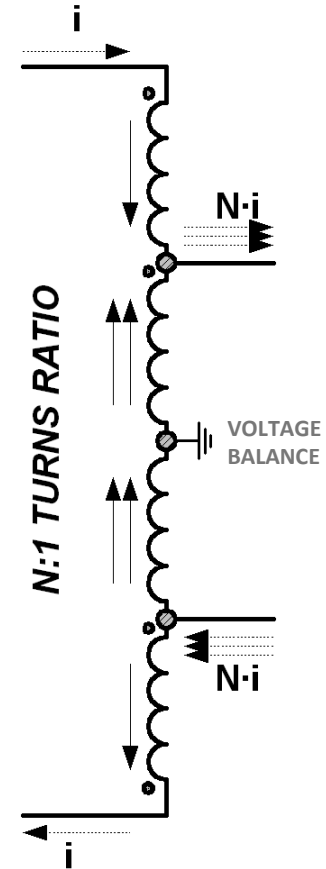


GUANELLA 4:1 BALANCED TRANSFORMER (BALBAL)

- 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)

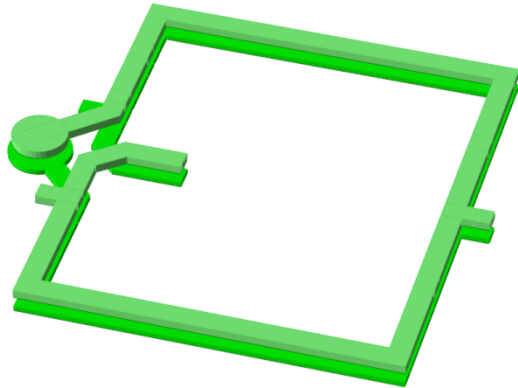


GUANELLA 4:1 SHOWN AS AUTO TRANSFORMER

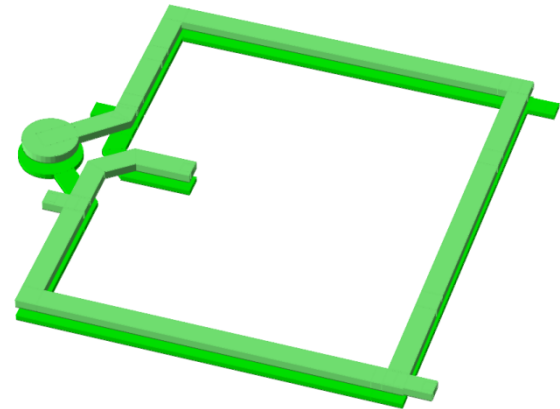


GENERAL $N:1$ BALANCED AUTO TRANSFORMER

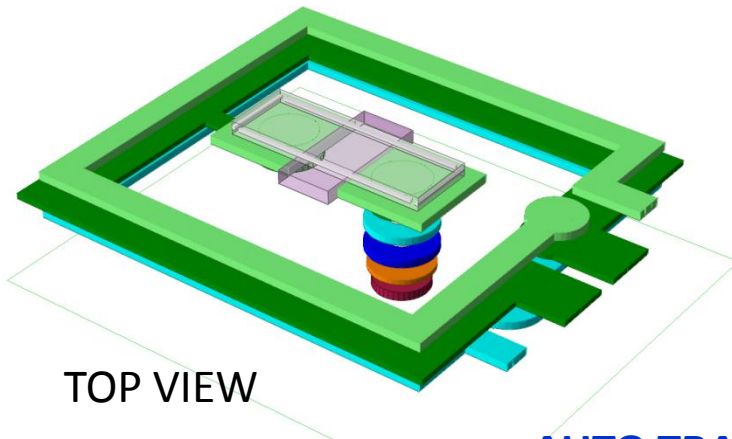
Guanella and Auto Transformers



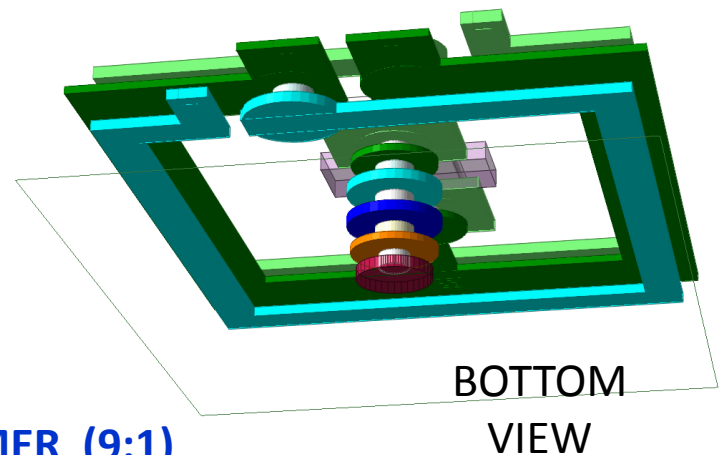
**GUANELLA BALANCED TRANSFORMER
(4:1 BALBAL)**



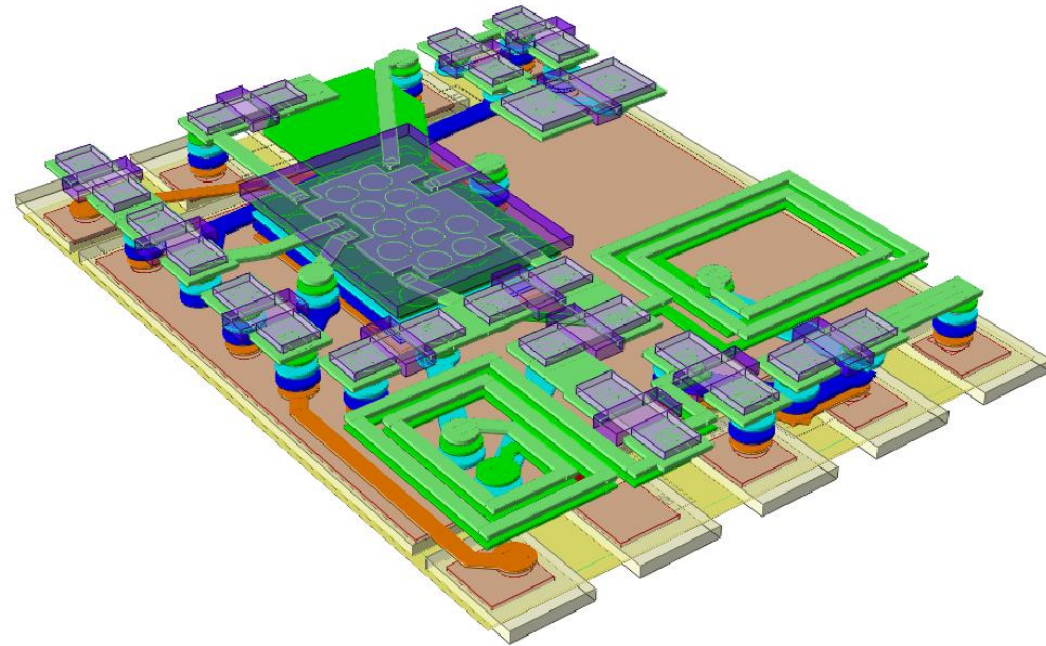
**MODIFIED GUANELLA BALANCED
TRANSFORMER (2.5:1)**



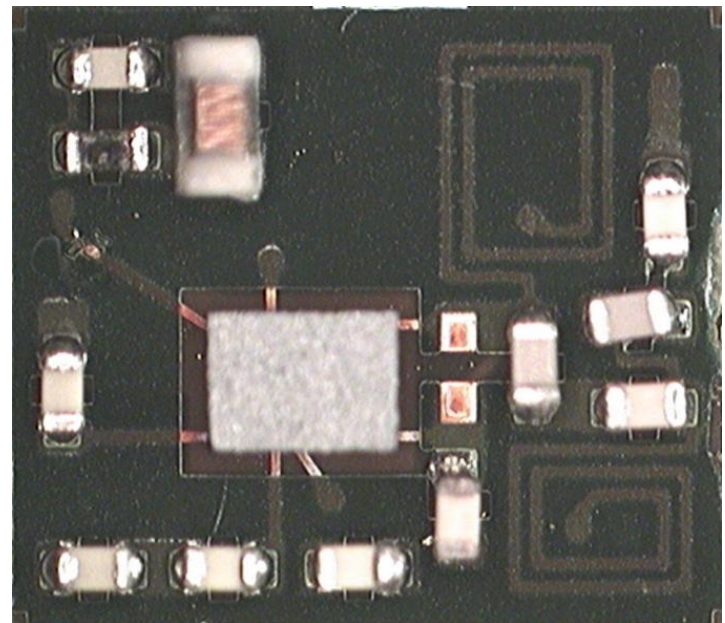
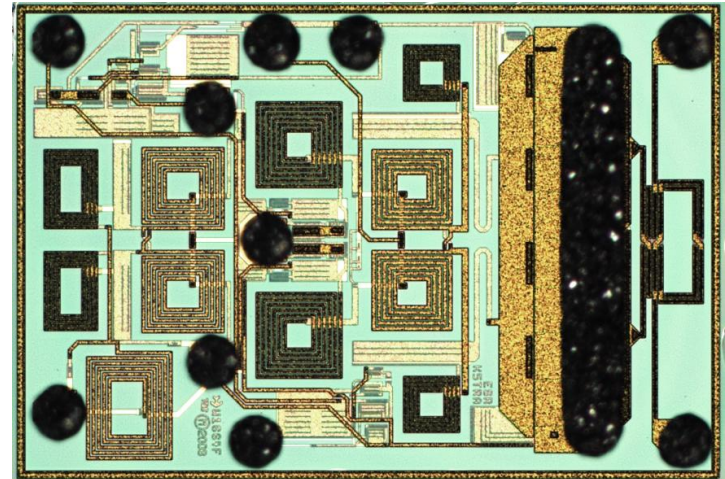
AUTO TRANSFORMER (9:1)



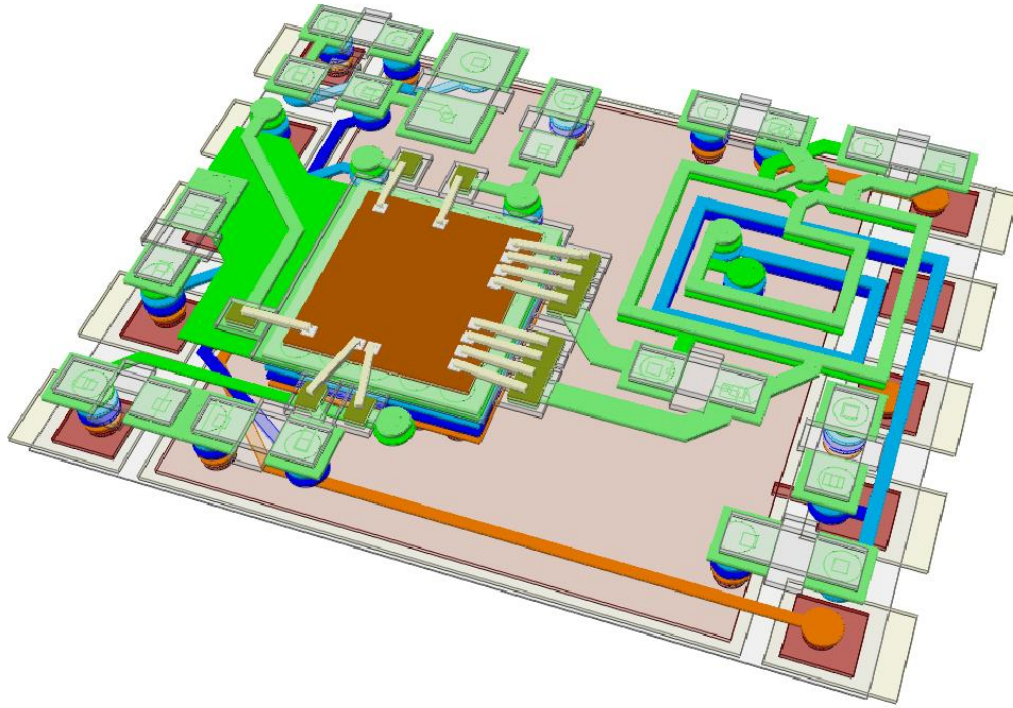
Wideband Flip Chip PA Module



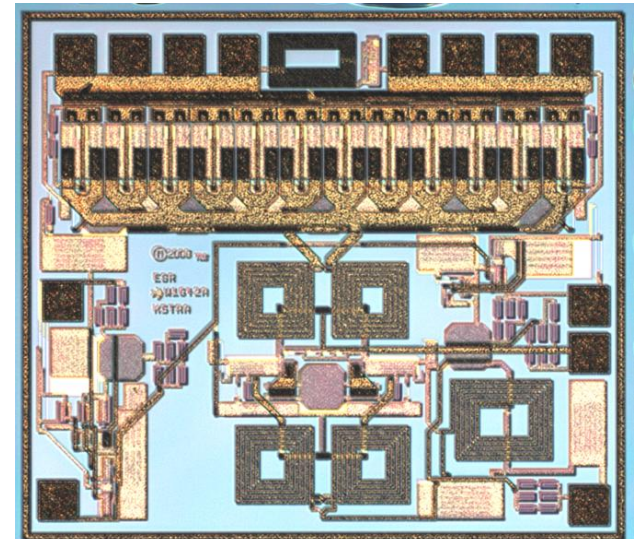
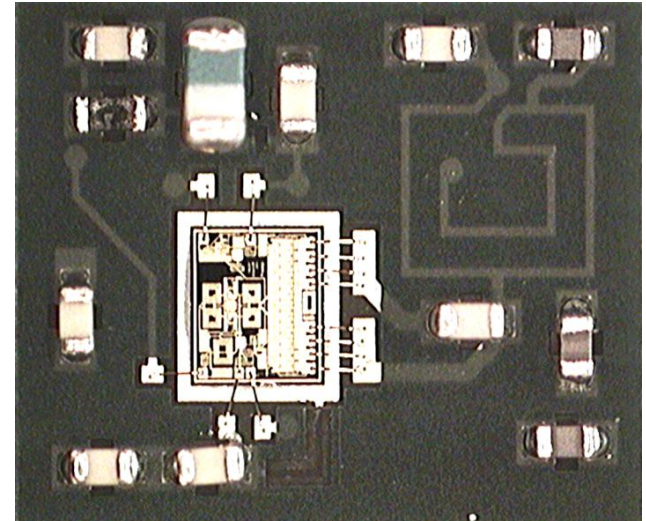
- 800 MHz – 2 GHz
- WCDMA operation



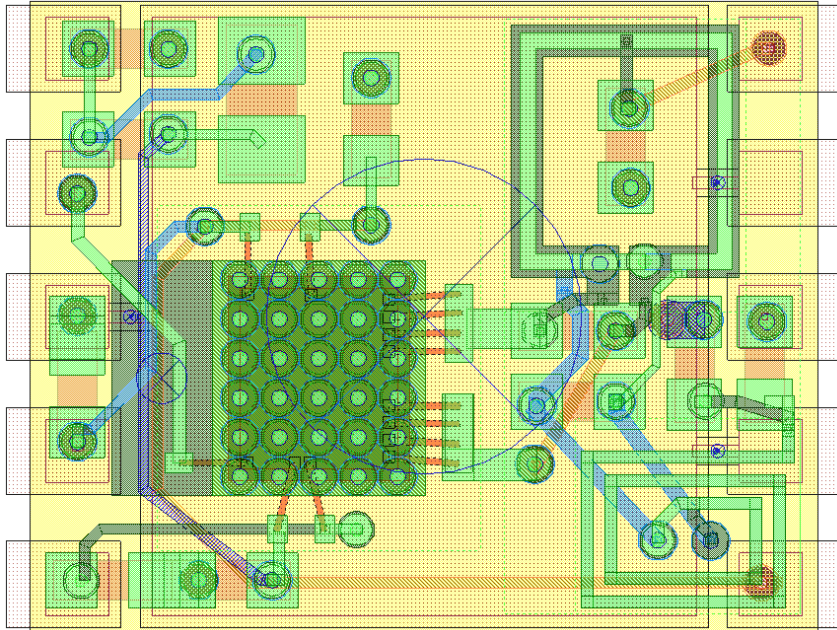
Pushpull Multimode PA



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

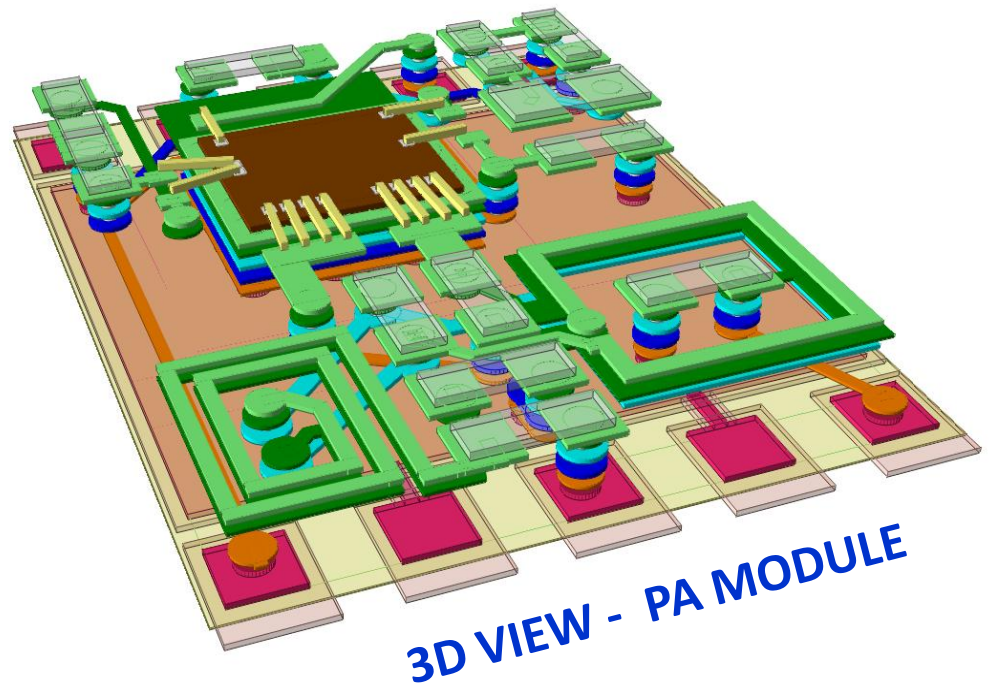


Low V Pushpull Multimode PA



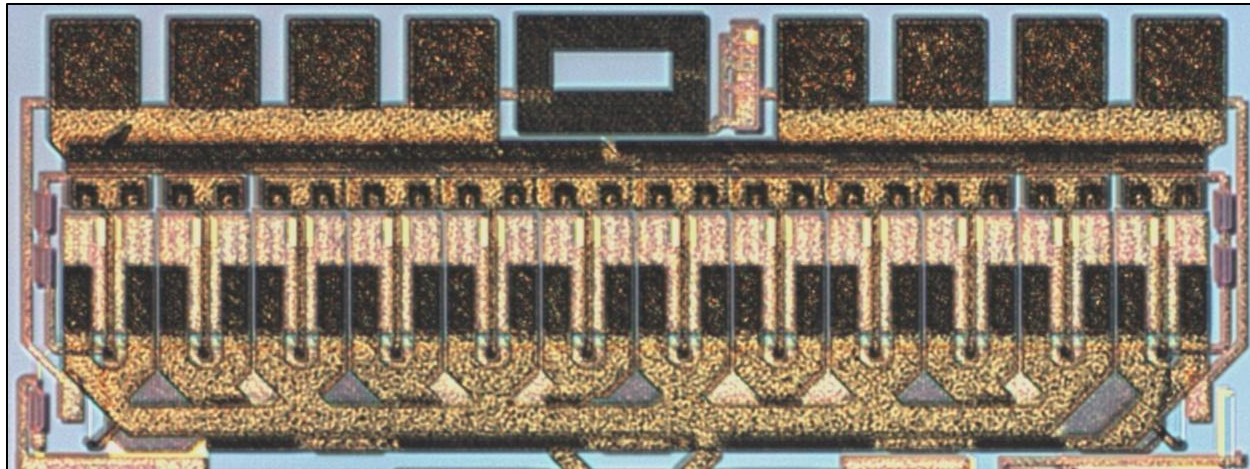
5mm x 4mm PA MODULE
(.20" x .16")

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

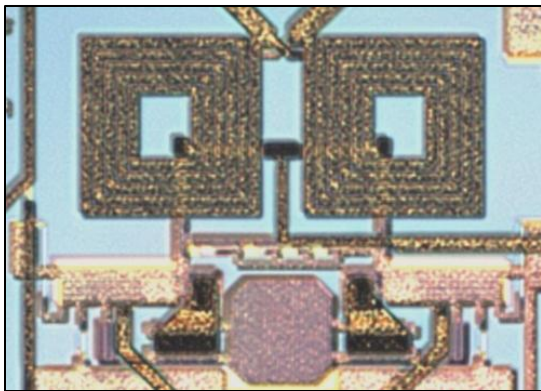


3D VIEW - PA MODULE

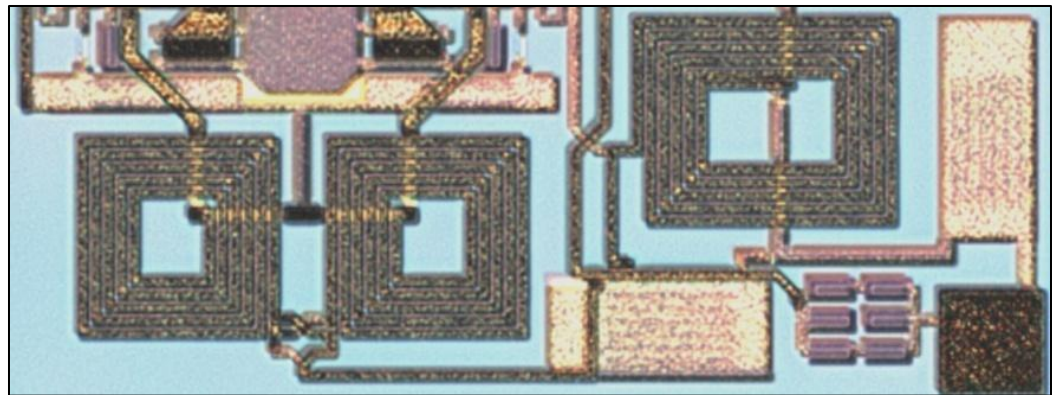
GaAs Pushpull PA Circuit Blocks



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

