
Demystifying
the hybrid coupler
Picture: 4-squares at NR5M
by ON4UN

Demystifying the hybrid coupler

- **Let's define the Operational Bandwidth Criteria for a directional array:**

  – **Gain:** constant +/- 0.5 dB
  – **F/B:** min 20 dB over entire band
  – **SWR:** max 1.8/1 at band edges

  If 4-square array fed with a hybrid coupler we add:

  – **Power dump:** min 10 dB at band edges

Demystifying the hybrid coupler

- Ways of assessing the **Operational Bandwidth**:
  - through antenna **modeling**
  - or by **measuring**

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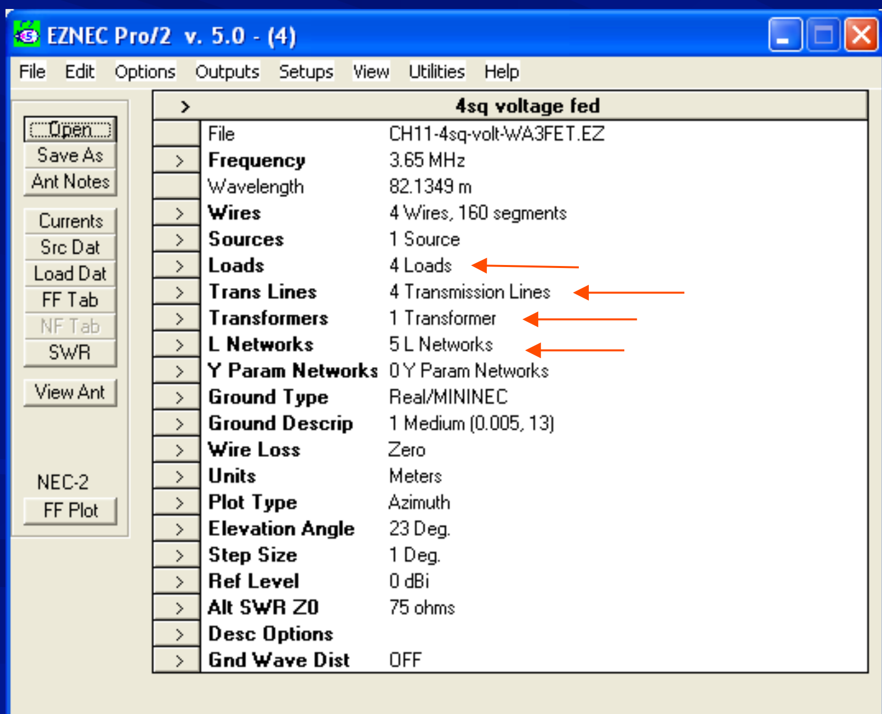
"Antenna *System*" Modeling

- EZNEC modeling software can now incorporate feed lines, L, C, R, transformers etc.



This means we can include all the components of our LC network fed ANTENNA SYSTEM in the mathematical model

…and run the model across the band (using the EZNEC ***sweep function***)…

to assess its performance

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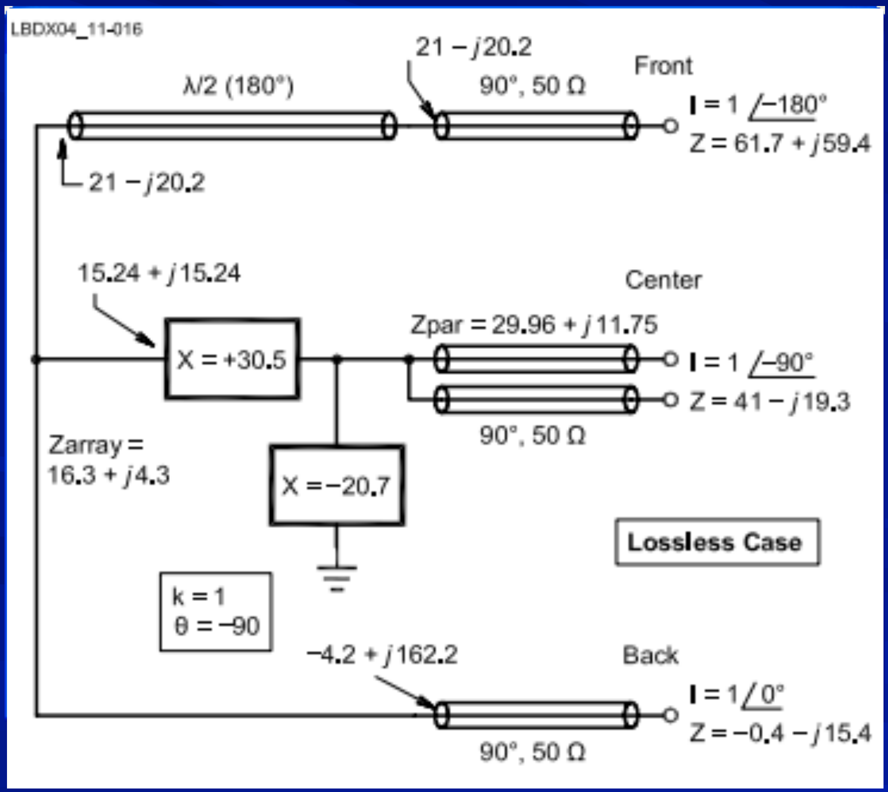

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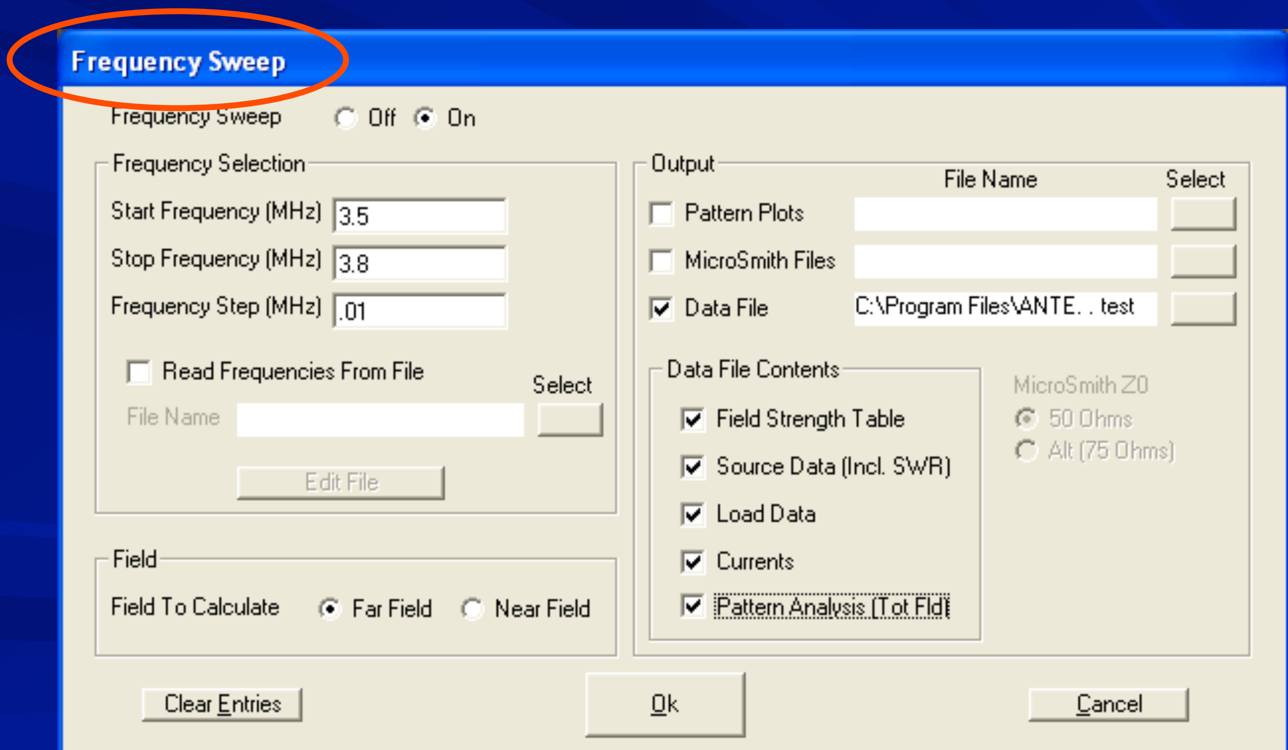
- EZNEC modeling software incorporates a **frequency sweep** function



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- The EZNEC modeling software creates a **.txt file** with all data in selected frequency steps

EZNEC Pro/2 ver. 5.0

2el-end-fire quad +feedlines 3/25/2010

--------------- FAR FIELD PATTERN DATA ---------

Frequency = 3.5 MHz

Reference = 0 dBi

Azimuth Pattern Elevation angle = 23 deg.

Deg	V dB	H dB	Tot dB	V Pha	H Pha
0	2.93	-99.99	2.93	120.28	0.00
1	2.93	-99.99	2.93	120.27	0.00
2	2.93	-99.99	2.93	120.25	0.00
3	2.92	-99.99	2.92	120.22	0.00
4	2.92	-99.99	2.92	120.18	0.00
5	2.91	-99.99	2.91	120.13	0.00
6	2.90	-99.99	2.90	120.07	0.00
7	2.89	-99.99	2.89	119.99	0.00
8	2.88	-99.99	2.88	119.91	0.00
9	2.86	-99.99	2.86	119.81	0.00
10	2.85	-99.99	2.85	119.70	0.00
11	2.83	-99.99	2.83	119.58	0.00
12	2.81	-99.99	2.81	119.45	0.00
13	2.79	-99.99	2.79	119.31	0.00
14	2.77	-99.99	2.77	119.16	0.00
15	2.74	-99.99	2.74	118.99	0.00
16	2.72	-99.99	2.72	118.82	0.00
17	2.69	-99.99	2.69	118.63	0.00
18	2.66	-99.99	2.66	118.44	0.00
19	2.62	-99.99	2.62	118.23	0.00
20	2.59	-99.99	2.59	118.01	0.00
21	2.55	-99.99	2.55	117.78	0.00

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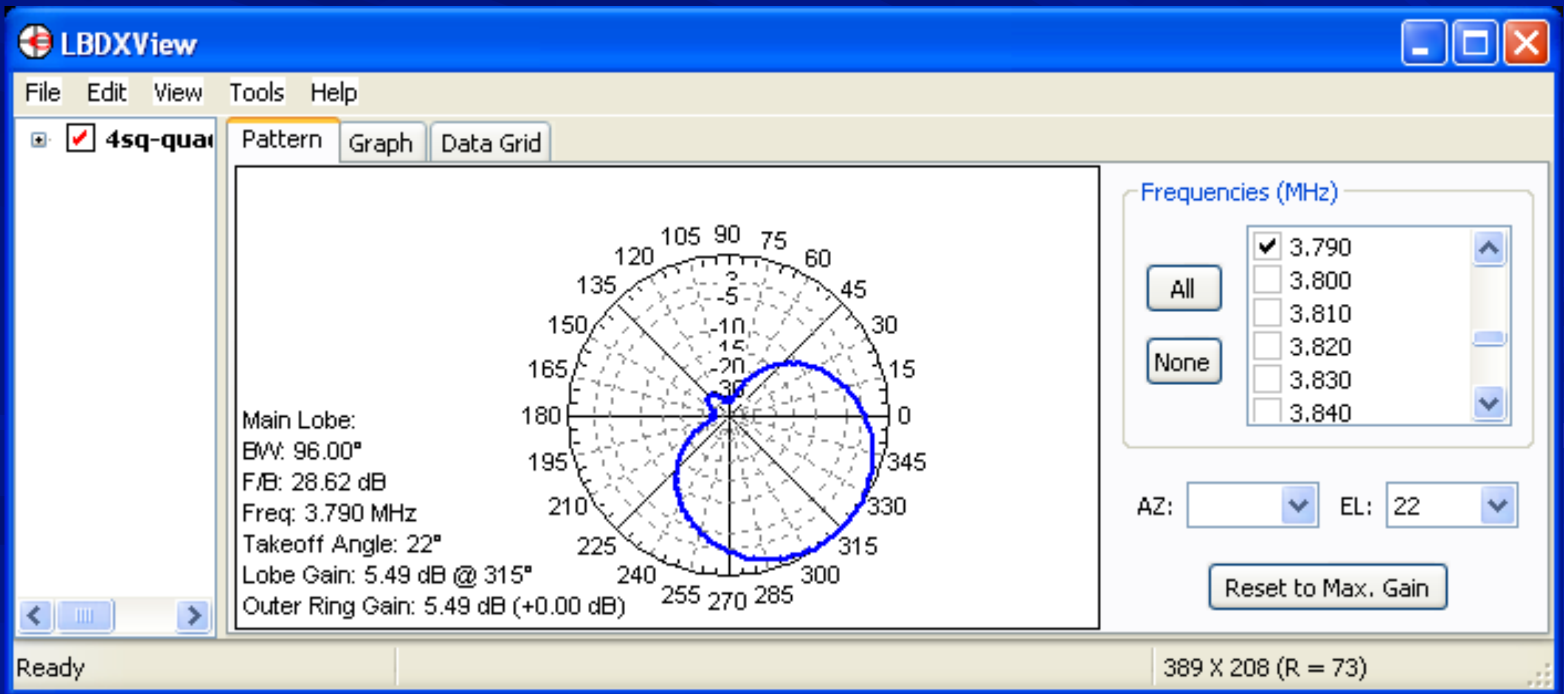
- The EZNEC modeling software creates a **.txt file** with all data in selected frequency steps…
- …which can be used as input to ***LBDXView*** (written by W8WWV, available on the book's CD)



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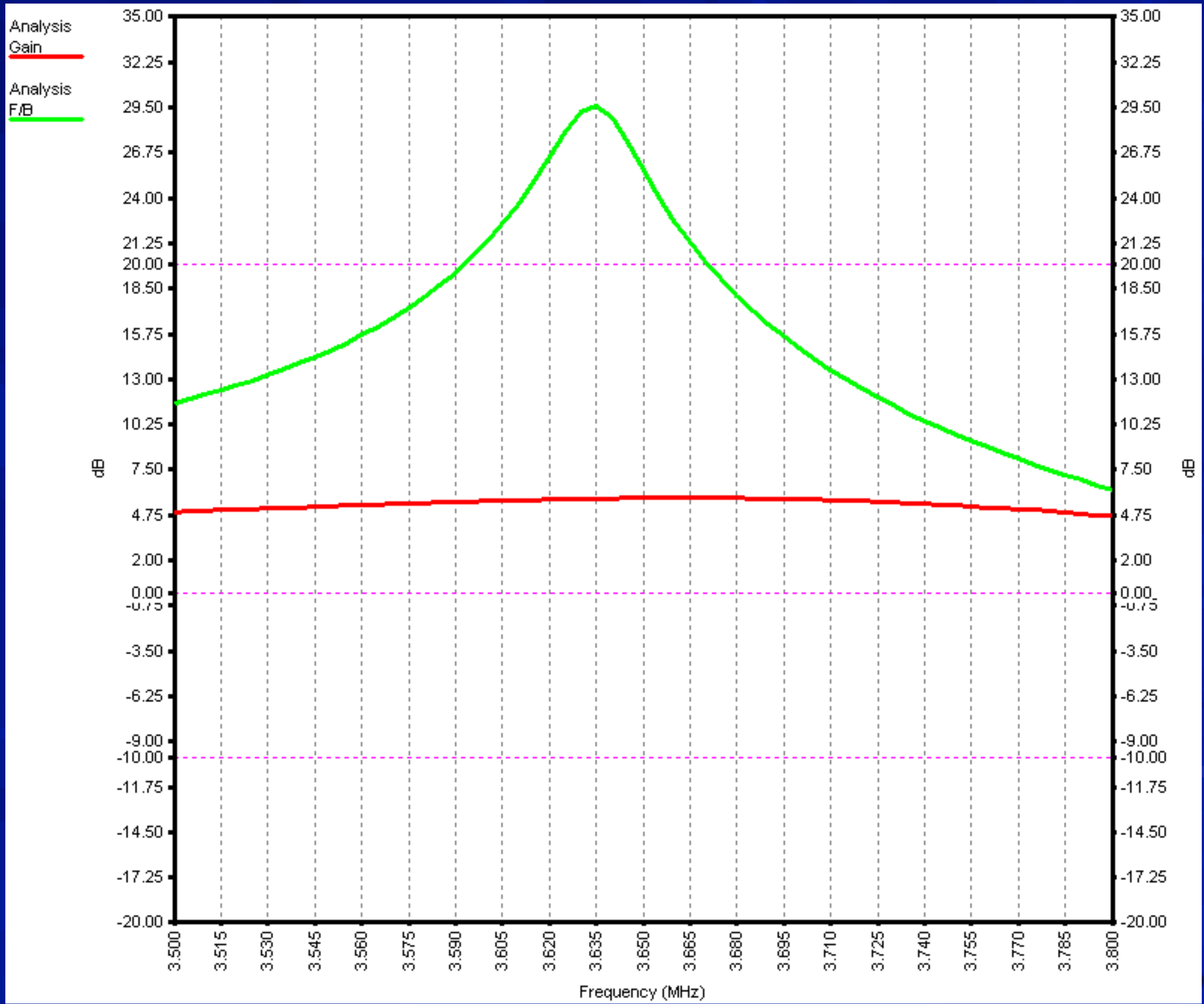
LBDXView



Gain and

F/B Bandwidth

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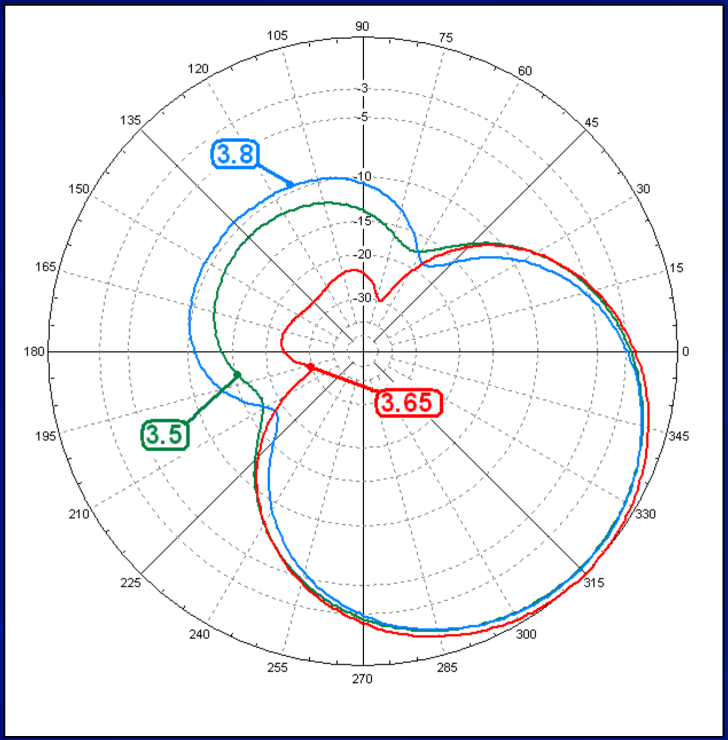
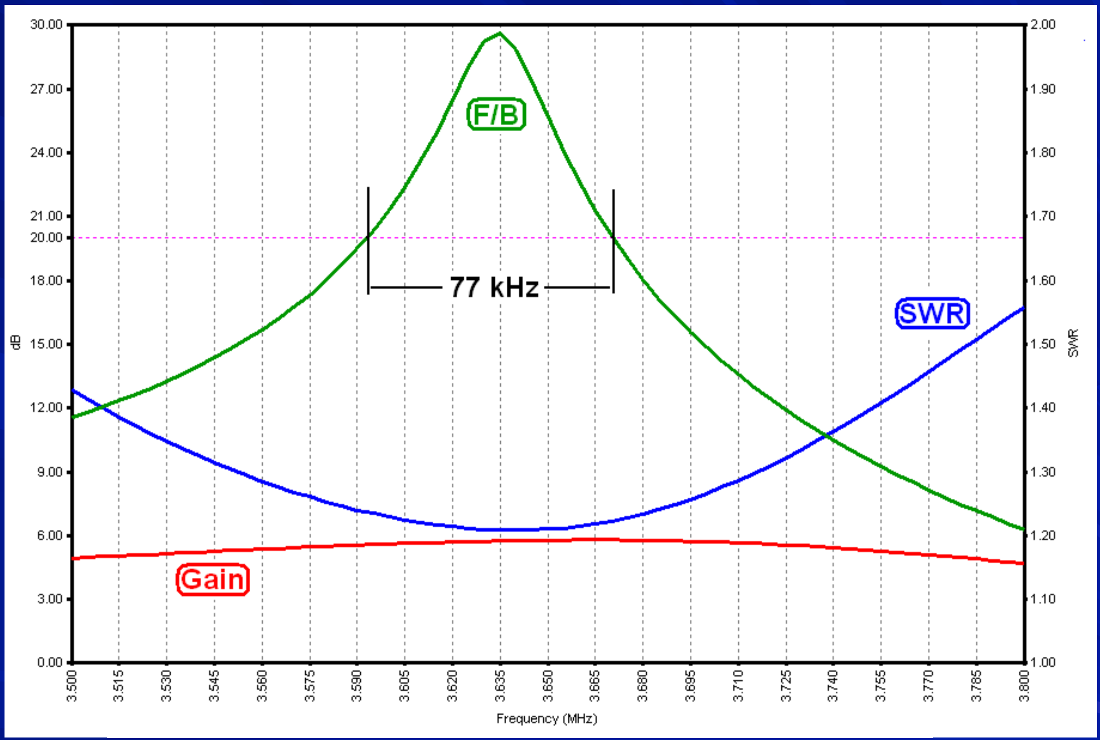
L-network fed 4-square





Conclusion: Operational Bandwidth <<<

Graphs / Plots made with **LBDXView** by W8WWV

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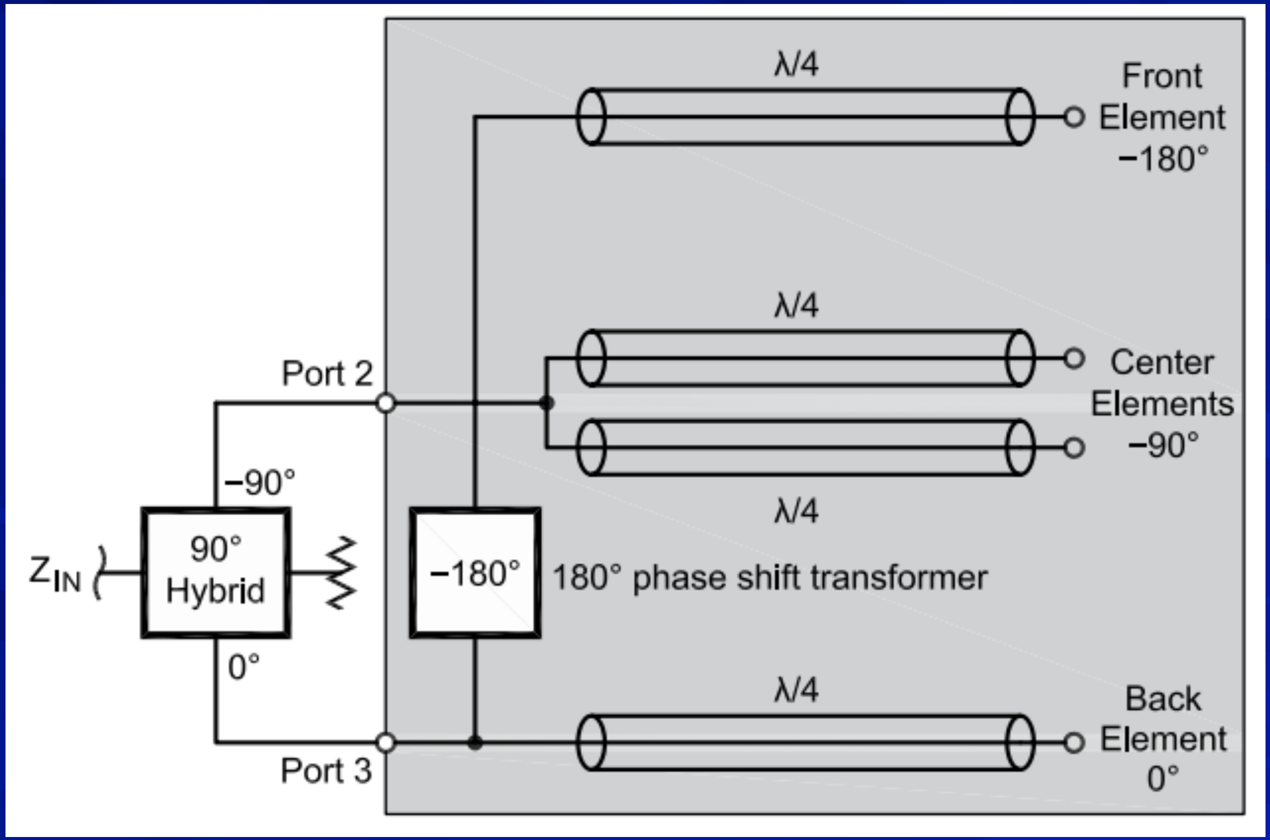
- Let's look at the ***hybrid coupler*** **fed 4-square system**



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- Let's run a model in sweep mode
- Remember, model must include **ALL** components of the array (= the entire system)

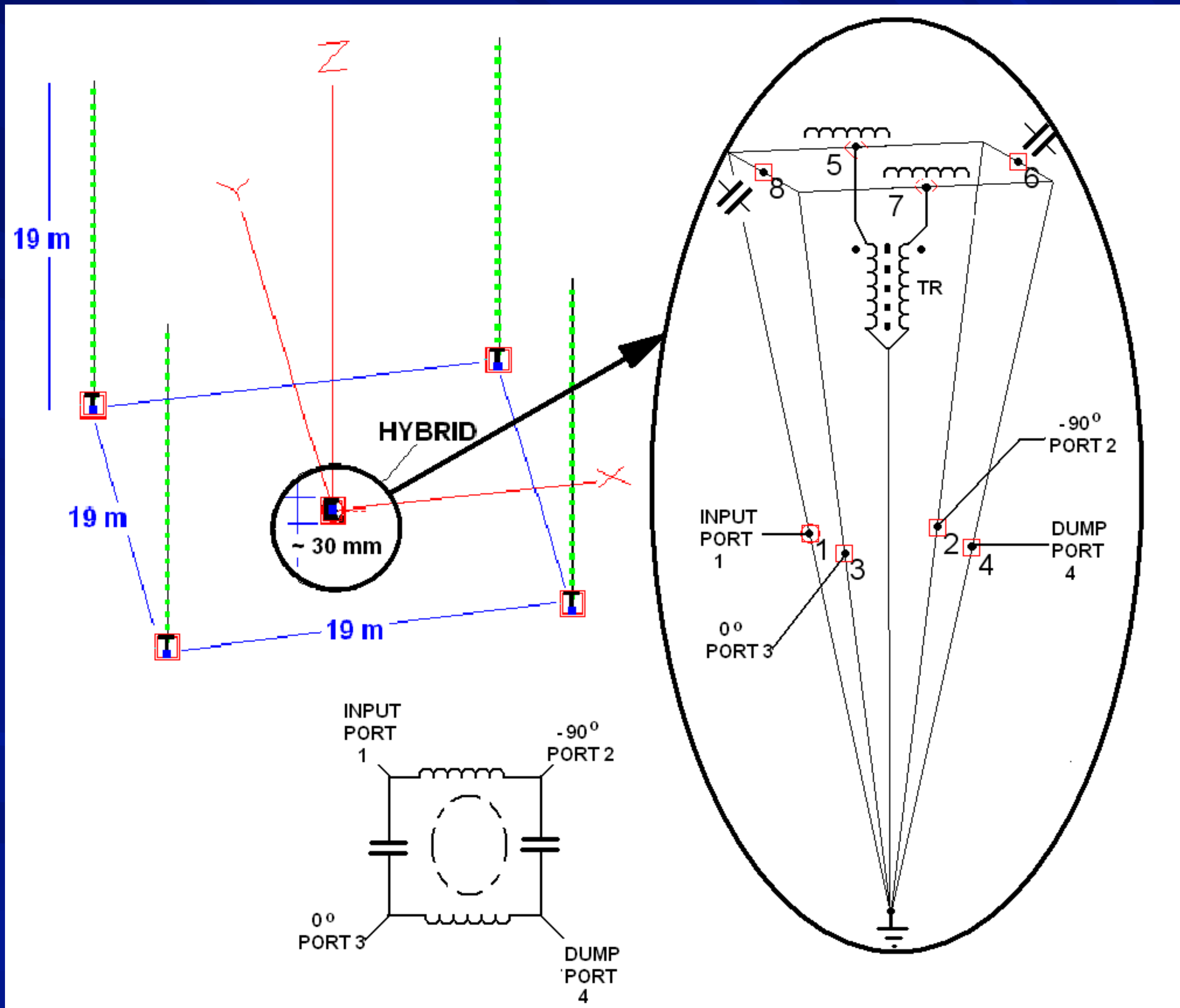
That means the hybrid coupler also should be included in the model !

Demystifying the hybrid coupler

Until now a **hybrid** was NEVER included in an **antenna model**

- **W7EL** simply included the wiring of the hybrid (components and connections) in the center of the array at ground level
- Height of the construction: < 3 mm (~0.1 inch)
- Hence: the wires radiate little or NOTHING

Demystifying the hybrid coupler

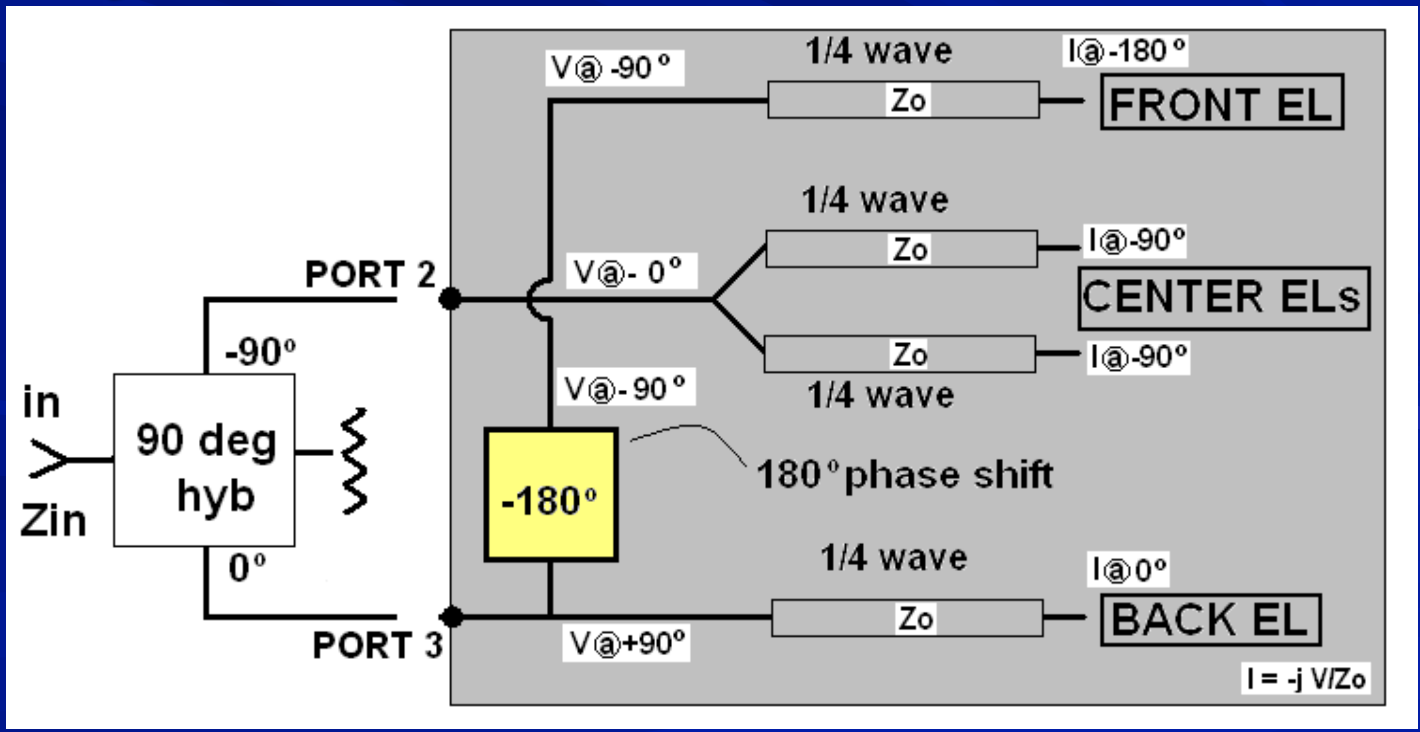


Hyb mod

Demystifying the hybrid coupler

THE FOUR-SQUARE BLACK BOX

- In order to simplify the analysis, W1MK suggested we reduce the 4-square to a 2-port **black box** and the **hybrid**



Hyb mod

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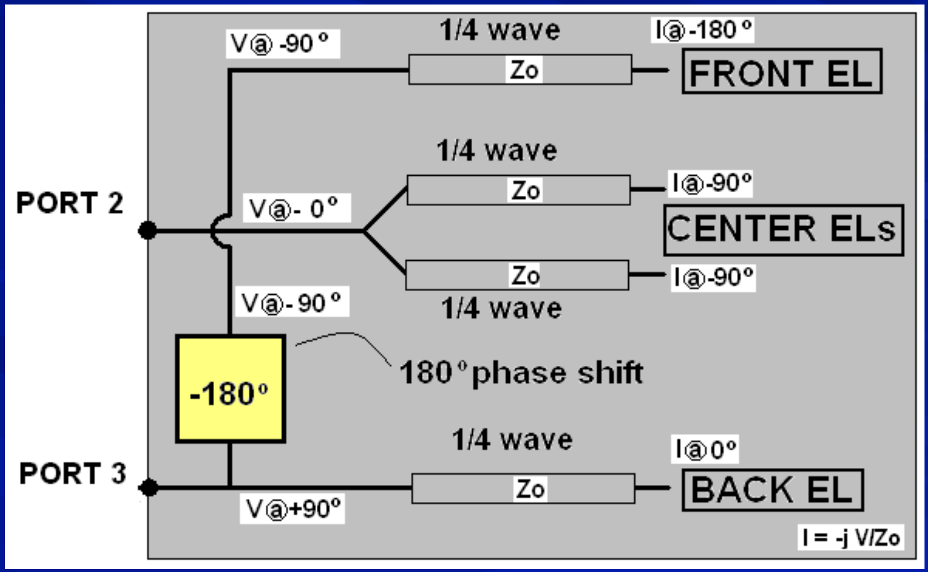
- W1MK noticed for the -90º/-180º 4-square that if the 4-sq is electrically and physically well balanced
- …there is **NO** effect on the impedance at one of these two ports, caused by changes at the other port. **The 2 ports are <u>independent and not coupled</u>**



Hyb mod

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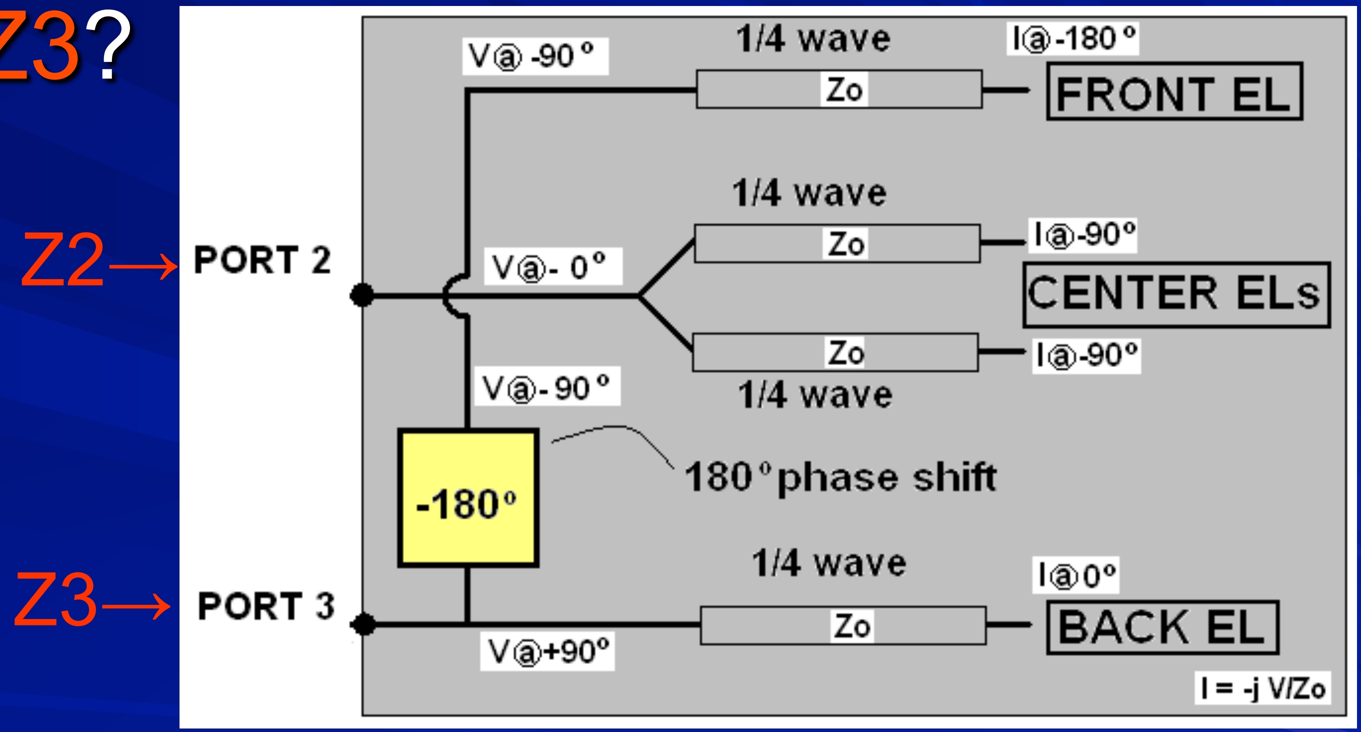
What are the VALUES of impedances Z2 and Z3?

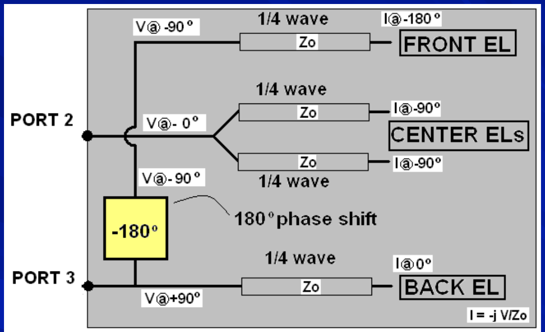


These can be **modeled** or **measured**

Demystifying the hybrid coupler

- THROUGH **MODELING**
  - Can easily **be modeled**, all black box components can be incorporated in an EZNEC model

Transmission Lines							
End 1 Specified Pos.		End 1 Act	End 2 Specified Pos.		End 2 Act	Length	Z0
Wire #	% From E1	% From E1	Wire #	% From E1	% From E1	(m)	(ohms)
2	50	50	9	0	2	20.5479	75
2	50	50	10	0	2	20.5479	75
3	50	50	11	0	2	20.5479	75
V6			12	0	2	20.5479	75



Transformers								
No.	Port 1 Specified		Port 1 Act	Port 2 Specified		Port 2 Act	Port 1
	Wire #	% From E1	% From E1	Wire #	% From E1	% From E1	Rel Z
1	V6			V2			50

```
Frequency = 3.65 MHz

Source 1      Voltage = 0.852 V at -82.7 deg.
              Current = 0.01463 A at -105.44 deg.
              Impedance = 53.69 + J 22.51 ohms
              Power = 0.0115 watts
              SWR (50 ohm system) =  1.548  (75 ohm system) =  1.622

Source 2      Voltage = 1 V at 0.0 deg.
              Current = 0.01417 A at 30.71 deg.
              Impedance = 60.68 - J 36.05 ohms
              Power = 0.01218 watts
              SWR (50 ohm system) =  1.954  (75 ohm system) =  1.764

              Total applied power = 0.02368 watts
```

$Z2 = 53.7 + j22.5$

$Z3 = 60.7 – j36.1$

Blk Bx

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- THROUGH **MEASURING**

Case 1: **perfectly symmetrical array** (physical and electrical symmetry)

  – Remember there is no effect at either port 2 or port 3 caused by changes at the other port

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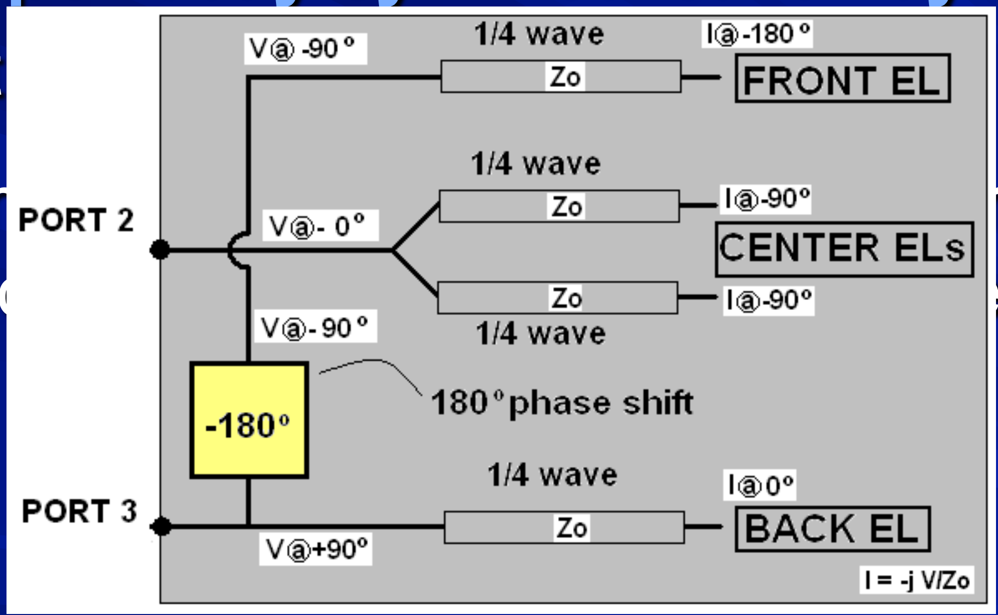
- THROUGH **MEASURING**

Case 1: **perfectly symmetrical array** (physical and elect

– Remer … port 2 or port 3 … r port



– **Which means we can simply measure Z2 and Z3 at ports 2 and 3 of the black box**

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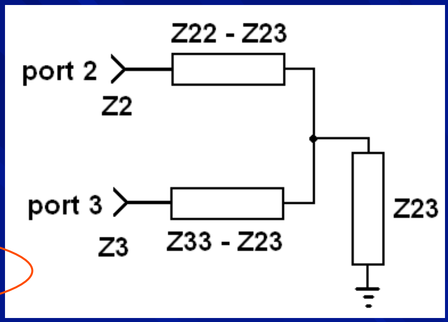
- THROUGH **MEASURING**

Case 2: non symmetrical array

- – USE SPREADSHEET PROGRAM ("*2 port coupling*") on the book's CD
- – Measure Z2 with Z3 open → Z22
- – Measure Z3 with Z2 open → Z33
- – Measure Z2 with Z3 shorted → Z2,3 (Z2,3 = coupled impedance)
- – The program calculates Z23 (mutual impedance
- – Measuring of Z2 and Z3 in parallel is required to determine the sign of Z23 (re: square root)
- – Program calculates **Z2** and **Z3**
- – …and also "diagonal isolation" in dB



BLACK BOX 2-PORT COUPLING (W1MK)			
A - INPUTS			
1	Enter k →	1	must be ≤1
2	Enter Angle θ →	-90	must be –
		real part	imag part
3	Enter Z22 →	93.93	44.26
4	Enter Z33 →	123.1	94.99
5	Enter Z2,3 →	91.05	42.04
6	Enter Zin parr Z2+Z3. →	43	21
B - CHOICE OF SIGN MUTUAL IMPEDANCE			
7	Z23 =	18.83	14.52
8	IF Zin parr =	63.58	38.01
OR			
9	Z23 =	-18.83	-14.52
10	IF Zin parr =	44.68	24.75
11	Enter Z23 →	-18.83	-14.52
C - OUTPUTS			
12	Z2 =	95.25	27.47
13	Z3 =	91.39	106.04
DIAGONAL ISOLATION			
14	Diagonal Isolation =	-21.0 dB	

Demystifying the hybrid coupler

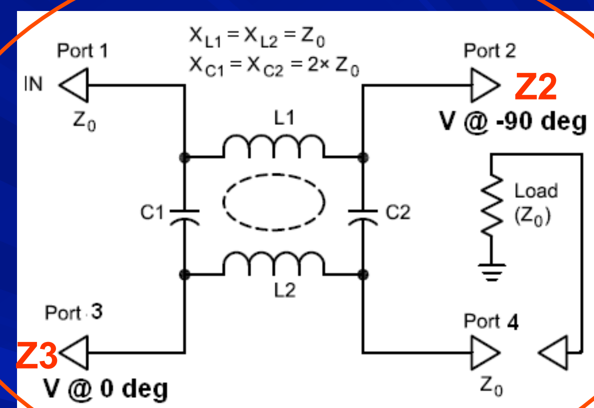
Now we know Z2 and Z3 (through modeling or via measuring)

- Will the hybrid coupler deliver voltages at ports 2 and 3 that are 90º out of phase (with same magnitude) for **any value** of Z2 and Z3?
- Obviously not!
- So what does it deliver?
- …**and what can we do so it does deliver what we want?**

Demystifying the hybrid coupler

The what and the how of the Hybrid

- Let's analyze the "mysterious" **lumped coupled 90º hybrid**
- Required split (**being k=1 and θ =90º**) occurs **only if Z2 and Z3 have specific relationship**
  - Which relationship?



- To be able to answer those questions W1MK developed a **mathematical model** for the hybrid coupler (a first!)

Demystifying the hybrid coupler

MATHEMATICS 90° LUMPED ELEMENT HYBRID COUPLER

By Robye L. Lahlum, W1MK

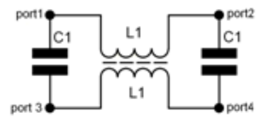
Port 1 Terms

$V_{IN} = V_1^+ + V_1^-$

$V_{IN} = V_1^+ (1 + \rho_{IN})$

$V_1^+ \rightarrow$ *forward voltage (incident voltage)*

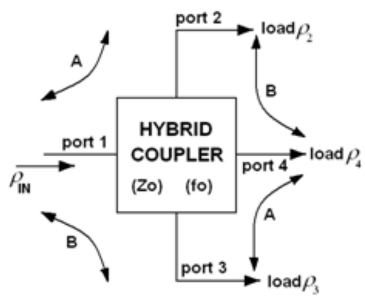
$V_1^- \rightarrow$ *reflected voltage*



Adjacent Ports Transfer Functions

$A = \sqrt{\frac{f_o}{f_a}}\ \underline{/\theta 1}$

$B = \sqrt{\frac{f_a}{f_o}}\ \underline{/\theta 2}$



ρ_{IN}, ρ_2, ρ_3 and ρ_4 are reflection coefficients and in general complex, as are the variables Y and Z

f_o = center frequency of hybrid coupler

f_a = operating frequency

$$\frac{V_2}{V_1^+} = 0.707 \cdot \sqrt{\frac{f_o}{f_a}} \cdot (1+\rho_2) \cdot X\ \underline{/\theta 1} \qquad (0.707 = \tfrac{\sqrt{2}}{2})$$

$$\frac{V_3}{V_1^+} = 0.707 \cdot \sqrt{\frac{f_a}{fo}} \cdot (1+\rho_3) \cdot Y\ \underline{/\theta 2} \qquad (0.707 = \tfrac{\sqrt{2}}{2})$$

$$\frac{V2}{V3} = -j\sqrt{\frac{f_0}{f_a}} \cdot \frac{(1+\rho_2)}{(1+\rho_3)} \cdot \frac{X}{Y}$$

$$\frac{V_4}{V_1^+} = \frac{(\rho_2+\rho_3) \cdot Z}{2}$$

$$\frac{V_1^-}{V_1^+} = \rho_{IN} = \left[\frac{\rho_2}{2} \cdot \left(\frac{f_o}{f_a}\right) \cdot X\right] \underline{/2\cdot\theta 1} + \left[\frac{\rho 3}{2} \cdot \left(\frac{f_a}{f_o}\right) \cdot Y\right] \underline{/2\cdot\theta 2} = \rho_r + j\rho_I$$

$$\rho_{IN} = \rho_r + j\rho_I = \left[\frac{\rho 2}{2} \cdot \left(\frac{f_o}{f_a}\right) \cdot X\right] \underline{/2\cdot\theta 1} + \left[\frac{\rho 3}{2} \cdot \left(\frac{f_a}{f_o}\right) \cdot Y\right] \underline{/2\cdot\theta 2}$$

$$Z_{IN} = \frac{1-\rho_{IN}}{1+\rho_{IN}} \cdot Zo$$

$$R_{IN} = Z_o \cdot \frac{(1-\rho_r^2-\rho_I^2)}{(1-\rho_r^2)+\rho_I^2}$$

$$X_{IN} = \frac{2 \cdot Z_o}{(1-\rho_r^2)+\rho_I^2}$$

where:

$$X = 1 + \left(\frac{f_o}{f_a}\right) \cdot \frac{(\rho_2+\rho_3)}{2} \cdot \rho_4 \cdot [\cos(\theta 2 - \theta 1) + j\sin(\theta 2 - \theta 1)]$$

$$Y = 1 + \left(\frac{f_a}{f_o}\right) \cdot \frac{(\rho_2+\rho_3)}{2} \cdot \rho_4 \cdot [\cos(\theta 2 - \theta 1) - j\sin(\theta 2 - \theta 1)]$$

$$Z = 1 + \rho_4$$

$$\theta_1 = -A \cdot ATAN\left(\frac{f_a}{f_o}\right) \text{ and } \theta_2 = A \cdot ATAN\left(\frac{f_o}{f_a}\right)$$

Conversion from $\left(\frac{V_4}{V_1^+}\right)$ to $\frac{Power\ Out\ Port4}{Power\ In\ Port1}$

ρ_{IN} = reflection coefficient at input

$$V_{IN} = V_1^+ + V_1^- = V_1^+ \cdot (1+\rho_{IN})$$

$$\rho_{IN} = \frac{V_1^-}{V_1^+} = \rho_r + j\rho_I$$

$$V_{IN}^2 = (V_1^+)^2 \cdot \left[(1+\rho_r)^2 + (\rho_I)^2\right]$$

$$Power\ In\ (Port1) = \frac{V_{IN}^2}{R\rho_{IN}}$$

$$R\rho_{IN} = \frac{Zo \cdot \left[(1+\rho_r)^2 + (\rho_I)^2\right]}{(1-\rho_r^2-\rho_I^2)}$$

$$\frac{Power\ Port4}{Power\ In} = \frac{V_4^2}{V_{IN}^2} \cdot \frac{Zo \cdot \left[(1+\rho_r)^2 + (\rho_I)^2\right]}{R\rho_4 \cdot (1-\rho_r^2-\rho_I^2)}$$

$$\frac{Power\ Port4}{Power\ In} = \frac{V_4^2}{(V_1^+)^2} \cdot \frac{Zo}{R\rho_4 \cdot (1-\rho_r^2-\rho_I^2)}$$

When $\rho_4 = 0$ (means: load port termination equals Zo)
then:
X=1, Y=1 and Z=1
and:

$$\frac{V_2}{V_3} = -j \cdot \left(\frac{f_o}{f_a}\right) \cdot \frac{(1+\rho_2)}{(1+\rho_3)}$$

$$\frac{V_4}{V_1^+} = \frac{(\rho 2 + \rho 3)}{2}$$

$$\frac{V_1^-}{V_1^+} = \rho_{IN} = \frac{\rho_2}{2} \cdot \left(\frac{f_o}{f_a}\right) \underline{/2\theta 1} + \frac{\rho_3}{2} \cdot \left(\frac{f_a}{f_o}\right) \underline{/2\theta 2}$$

Demystifying the hybrid coupler

Based on these mathematics **a hybrid circuit modeling tool** was developed

$$\frac{V_2}{V_3} = -j\left(\frac{1+\rho_2}{1+\rho_3}\right)\left(\frac{f_o}{f_a}\right)$$

$$\textit{Dump PWR} = [\ldots](\rho_2+\rho_3)^2$$

$$\textit{Refl. PWR} = [\ldots](\rho_2-\rho_3)^2$$

HYBRID COUPLER DESIGN (by W1MK)			
INPUTS			
ENTER fa (operating frequency) →	3.65	MHz	
ENTER fo (hybrid frequency) →	3.65	MHz	
ENTER Zo Design impedance hybrid →	50	Ω	
	Real Part	Imag Part	
ENTER Impedance load PORT 2 (Z2) →	50	0	Ω
ENTER Impedance load PORT 3 (Z3) →	50	0	Ω
RESULTS			
fo/fa =	1.000		
Hybrid L value (uH) =	2.18	µH	
Hybrid C value (pF) =	436	pF	
Ratio Voltage magnitude Port2/Port3 (k) =	1.000		
Phase angle Voltage port 2 vs. port 3 =	-90.00	°	
Power in Port 4 (vs. Pwr in Port 1) =	∞	dB	
Real part input impedance (port 1) =	50.00	Ω	
Imaginary part input impedance (port1) =	0.00	Ω	
Return loss (port 1) =	∞	dB	
SWR =	1.00		

the modeling tool does all of the above calculations based on the load impedances **Z2** and **Z3**

k = voltage ratio (v2/v3)

Demystifying the hybrid coupler

- For further calculations…
- …we will take the Z2 and Z3 results from our EZNEC model

```
Frequency = 3.65 MHz

Source 1        Voltage = 0.852 V at -82.7 deg.
                Current = 0.01463 A at -105.44 deg.
                Impedance = 53.69 + J 22.51 ohms
                Power = 0.0115 watts
                SWR (50 ohm system) =   1.548   (75 ohm system) =   1.622

Source 2        Voltage = 1 V at 0.0 deg.
                Current = 0.01417 A at 30.71 deg.
                Impedance = 60.68 - J 36.05 ohms
                Power = 0.01218 watts
                SWR (50 ohm system) =   1.954   (75 ohm system) =   1.764

                Total applied power = 0.02368 watts
```

and use them in our calculations

Demystifying the hybrid coupler

- RESULTS:
  - Θ = - 67º (target: -90º)
  - K = 0.9 (target = 1)

HYBRID COUPLER DESIGN (by W1MK)			
INPUTS			
ENTER fa (operating frequency) →	3.65	MHz	
ENTER fo (hybrid frequency) →	3.65	MHz	
ENTER Zo Design impedance hybrid →	50	Ω	
	Real Part	Imag Part	
ENTER Impedance load PORT 2 (Z2) →	53.7	22.5	Ω
ENTER Impedance load PORT 3 (Z3) →	60.7	-36.1	Ω
RESULTS			
fo/fa =	1.000		
Hybrid L value (uH) =	2.18	µH	
Hybrid C value (pF) =	436	pF	
Ratio Voltage magnitude Port2/Port3 (k) =	0.905		
Phase angle Voltage port 2 vs. port 3 =	-66.83	º	
Power in Port 4 (vs. Pwr in Port 1) =	-17.1	dB	
Real part input impedance (port 1) =	79.78	Ω	
Imaginary part input impedance (port1) =	8.84	Ω	
Return loss (port 1) =	-12.4	dB	
SWR =	1.63		

- But …

…**there are ways** to make
k=1 and θ = 90º

REMEMBER WHAT'S INPORTANT: THE DRIVE *CURRENT* AT THE BASE OF THE RADIATING ELEMENTS …

…OR THE DRIVE *VOLTAGE* AT THE END OF THE CURRENT FORCING LINES GOING TO THE RADIATING ELEMENTS !

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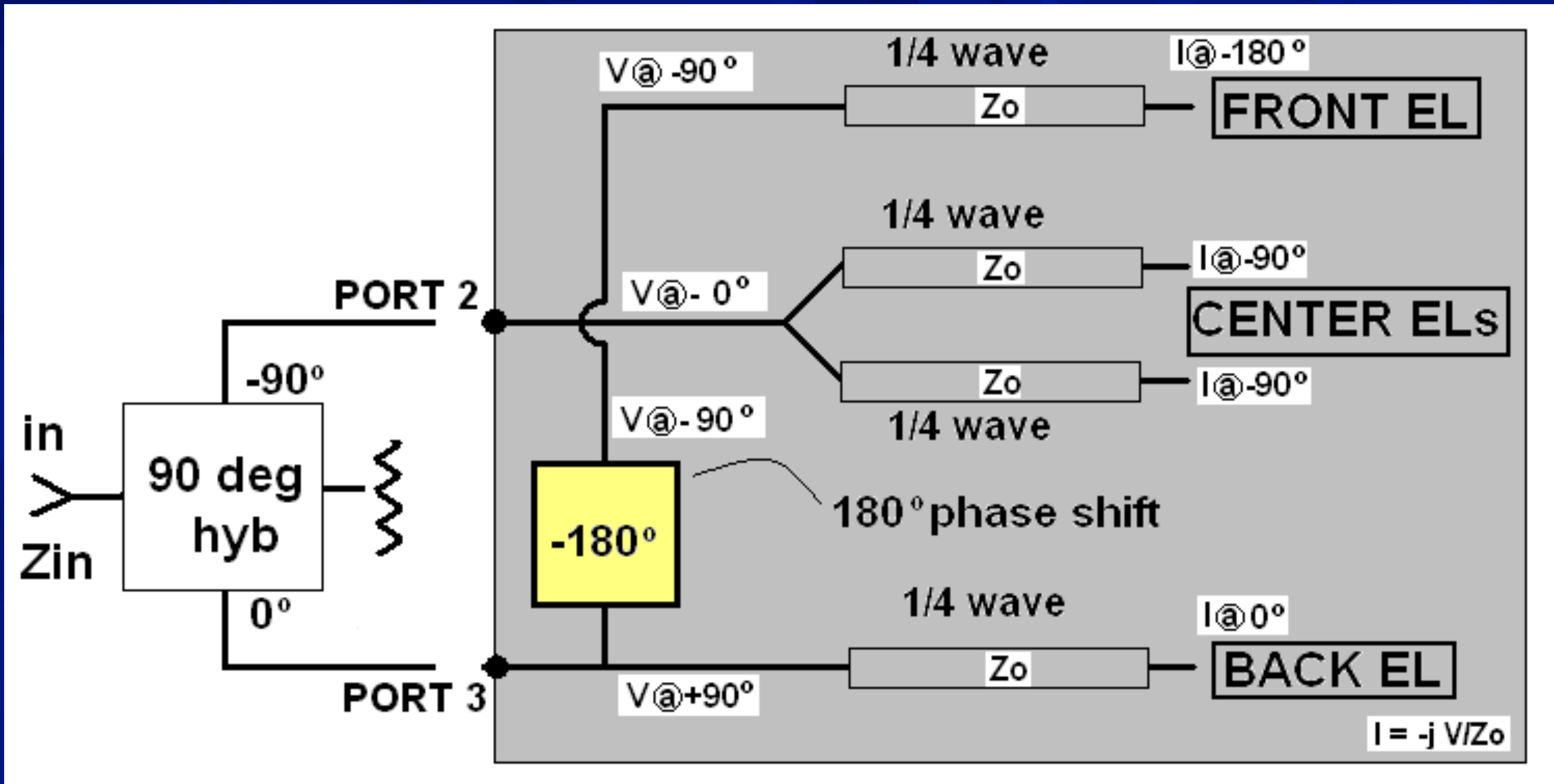


REMEMBER WHAT'S INPORTANT: THE **DRIVE *CURRENT*** AT THE BASE OF THE RADIATING ELEMENTS …

…OR THE **DRIVE *VOLTAGE*** AT THE END OF THE CURRENT FORCING LINES GOING TO THE RADIATING ELEMENTS !

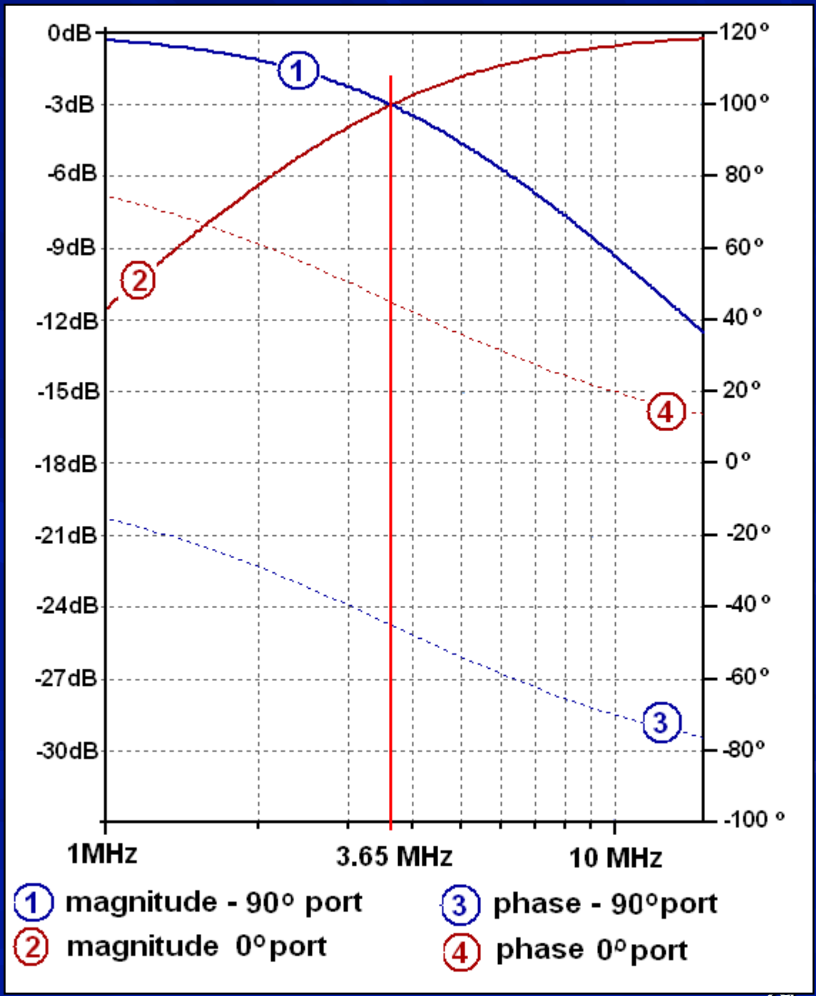
Hyb

Demystifying the hybrid coupler

Important special property of hybrid

Voltage magnitude ratio (k= v2/v3) can be changed by changing hybrid design frequency (Zo).

This unique property was first used by W8WWV in his "***Double network optimization***" approach, and has been the basis for the introduction of the other optimization systems for hybrid coupler feed systems. Thank you Greg!



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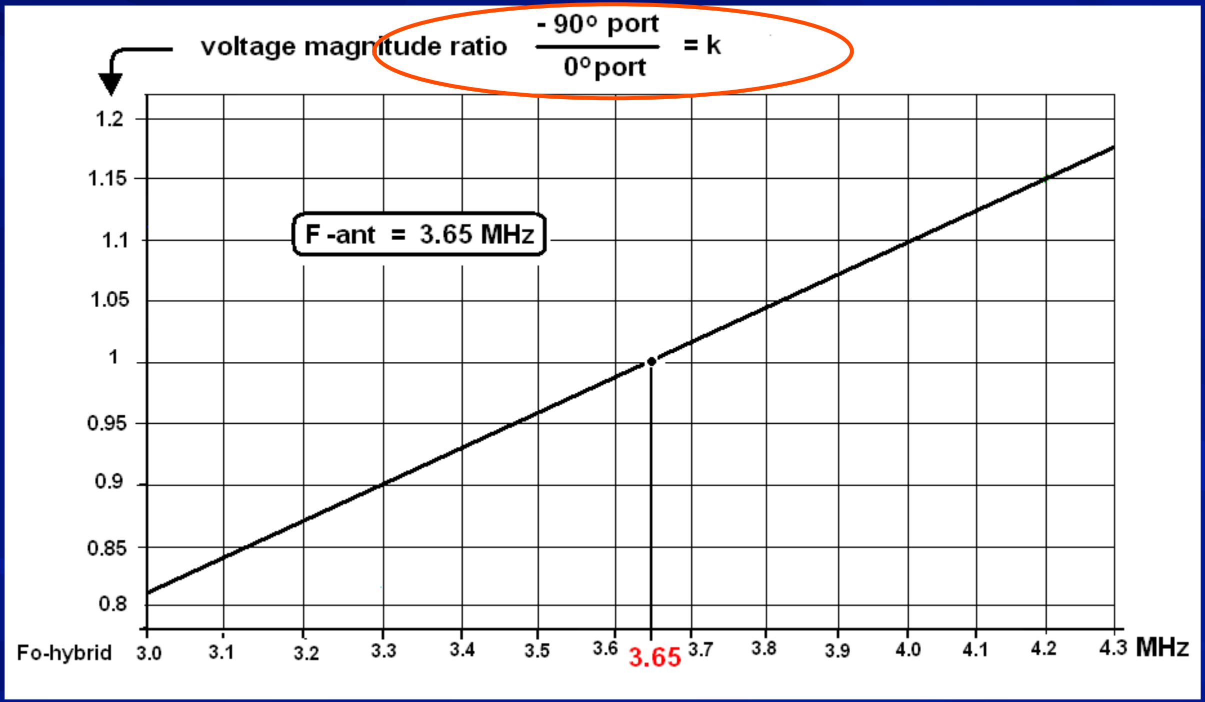
k = ratio of voltage magnitude at port 2 vs. voltage magnitude at port 3



With unequal resistive loads (Z_2,Z_3) we can obtain k=1 by shifting the design frequency of the hybrid

Presented at Dayton 2008, by W8WWV

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What are the properties of the signals (at ports 2 and 3) that we want the hybrid to deliver?

- 90º phase shift
- identical voltage magnitude (k=1)

Demystifying the hybrid coupler

Basic formula:

$$\frac{V_2}{V_3} = -j\left(\frac{1+\rho_2}{1+\rho_3}\right)\left(\frac{f_o}{f_a}\right)$$

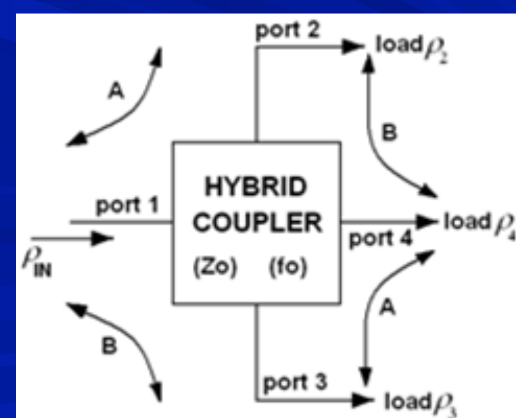
calculated with Hybrid design spreadsheet

- A few “special” cases

CASE	R2	X2	R3	X3	Zo	Port4	Port 1	k	θ	fa	fo	remarks
1	50	0	50	0	50	∞	∞	1	-90	3.65	3.65	both 50 Ω
2	68	0	68	0	50	-16.3	∞	1	-90	3.65	3.65	identical real impedances
3	54	0	39	0	50	-27.2	-21.8	1.185	-90	3.65	3.65	different real impedances
4	54	0	39	0	50	-27.2	-21.8	1	-90	3.65	**3.08**	as above but with fo/fa compensation
5	33	10	33	10	50	-12.5	∞	1	-90	3.65	3.65	identical complex impedances (matched mismatches)
6	53.7	22.5	60.7	-36	50	-17.1	-12.5	0.905	-66.8	3.65	3.65	random impedances

Note that there are a number of cases where θ = -90º

Port 1: → SWR (reflected PWR)
Port 4:→ dump power



2sh

Demystifying the hybrid coupler

- Let's look again at the 3 steps:

CASE	R2	X2	R3	X3	Zo	Port4	Port 1	k	θ	fa	fo	remarks
12	53.7	22.5	60.7	-36	50	-17.1	-12.5	0.905	-66.8	3.65	3.65	
13	63.1	0	82.1	0	50	-14.9	-22.7	0.898	-90	3.65	3.65	add -150 Ω across Z2 and +138 Ω across Z3
14	63.1	0	82.1	0	50	-14.9	-27	1	-90	3.65	**4.06**	change fo to 4.06 MHz (k compensation)

This is the **W1MK 2-shunt method**

This is a method which, when applied, ensures the hybrid does exactly what we want

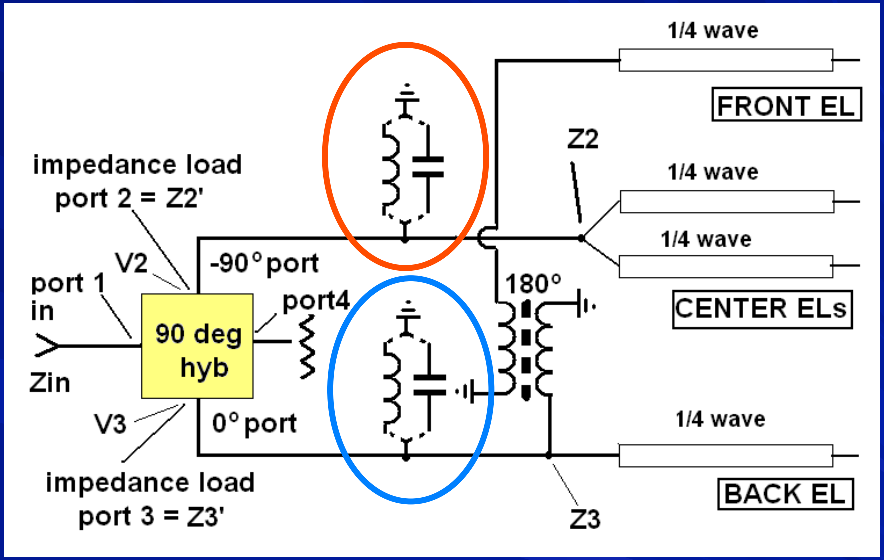
Remember the trick:

– turn both load impedances into REAL impedances by using parallel coil/cap

– correct the voltage magnitude by changing **fo**

Demystifying the hybrid coupler

- Every complex impedance can be transformed to a real impedance by a **shunt reactance**
- 53.7+j22.5 in parallel with –j168.4 gives a real Z2' = **66.14 Ω**
- 60.7-j36.1 in parallel with +138.2 gives Z3 = **82.17 Ω**
- Parallel reactances do NOT change the voltage magnitude! (same for element drive current)
- We developed **modeling software** that calculates these required parallel impedances



2sh

Demystifying the hybrid coupler

A special Modeling Tool

calculates the following data:

- X2 (across Z2) = -150.7 Ω

  X3 (across Z3) = 138.2 Ω

  to obtain resistive impedances Z2' and Z3' and Δφ = 90º :

  Z2' = 63.13 Ω

  Z3' = 82.05 Ω
- **New fo** to obtain the desired k-value (in this case k =1)

Also shown:

Dump power

Zin and SWR

	HYBRID COUPLER OPTIMIZATION PHASE COMPENSATED DESIGN SYSTEM -w1mk -			
	Enter data in yellow background cells	by W1MK - ON4UN		
	CALCULATING THE SHUNT ELEMENTS			
1	Enter fa (design freq) array →	3.650	MHz	
2	Enter k-value →	1		
		Real part	Imag part	
3	(-90 ° branch) Enter Z2 →	53.70	22.50	Ω
4	Branch 2 shunt element →	-150.66	Ω	
5	→	289.42	pF	
6	Z2' (at port 2) →	63.13	Ω	
		Real part	Imag part	
7	(0° branch) Enter Z3 →	60.70	-36.00	Ω
8	Branch 3 shunt element →	138.35	Ω	
9	→	6.03	uH	
10	Z3' (at port 3) →	82.05	Ω	
	HYBRID INPUT DATA			
11	Enter Zo Hybrid →	50.0	Ω	
	OUTPUT DATA			
12	Frequency corr. factor =	1.1135		
13	New Hybrid fo =	4.064	MHz	
14	L-Hybrid =	1.96	uH	
15	C-Hybrd =	392	pF	
16	Dump port (port 4) power ratio =	-14.9	dB	
17	Real part Zin (port 1) =	49.29	Ω	
18	Imag. part Zin (port1) =	4.37	Ω	
19	Port 1 return loss (dB) =	27.1	dB	
20	Port 1 SWR =	1.09		

Demystifying the hybrid coupler

Check it with the hybrid model spreadsheet

	HYBRID COUPLER OPTIMIZATION PHASE COMPENSATED DESIGN SYSTEM -w1mk-			
	Enter data in yellow background cells	by W1MK - ON4UN		
	CALCULATING THE SHUNT ELEMENTS			
1	Enter fa (design freq) array →	3.650	MHz	
2	Enter k-value →	1		
		Real part	Imag part	
3	(-90 ° branch) Enter Z2 →	53.70	22.50	Ω
4	Branch 2 shunt element →	-150.66	Ω	
5	→	289.42	pF	
6	Z2' (at port 2) →	63.13	Ω	
		Real part	Imag part	
7	(0° branch) Enter Z3 →	60.70	-36.00	Ω
8	Branch 3 shunt element →	138.35	Ω	
9	→	6.03	uH	
10	Z3' (at port 3) →	82.05	Ω	
	HYBRID INPUT DATA			
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19	Port 1 return loss (dB) =	27.1	dB	
20	Port 1 SWR =	1.09		

HYBRID COUPLER DESIGN (by W1MK)			
INPUTS			
ENTER fa (operating frequency) →	3.65	MHz	
ENTER fo (hybrid frequency) →	4.064	MHz	
ENTER Zo Design impedance hybrid →	50	Ω	
	Real Part	Imag Part	
ENTER Impedance load PORT 2 (Z2) →	63.13	0	Ω
ENTER Impedance load PORT 3 (Z3) →	82.02	0	Ω
RESULTS			
fo/fa =	1.113		
Hybrid L value (uH) =	1.96	µH	
Hybrid C value (pF) =	392	pF	
Ratio Voltage magnitude Port2/Port3 (k) =	1.000		
Phase angle Voltage port 2 vs. port 3 =	-90.00	°	
Power in Port 4 (vs. Pwr in Port 1) =	-14.9	dB	
Real part input impedance (port 1) =	49.34	Ω	
Imaginary part input impedance (port1) =	4.35	Ω	
Return loss (port 1) =	-27.1	dB	
SWR =	1.09		

Demystifying the hybrid coupler

HYBRID COUPLER DESIGN (by W1MK)			
INPUTS			
ENTER fa (operating frequency) →	3.65	MHz	
ENTER fo (hybrid frequency) →	3.65	MHz	
ENTER Zo Design impedance hybrid →	50	Ω	
	Real Part	Imag Part	
ENTER Impedance load PORT 2 (Z2) →	53.7	22.5	Ω
ENTER Impedance load PORT 3 (Z3) →	60.7	-36.1	Ω
RESULTS			
fo/fa =	1.000		
Hybrid L value (uH) =	2.18	µH	
Hybrid C value (pF) =	436	pF	
Ratio Voltage magnitude Port2/Port3 (k) =	0.905		
Phase angle Voltage port 2 vs. port 3 =	-66.83	°	
Power in Port 4 (vs. Pwr in Port 1) =	-17.1	dB	
Real part input impedance (port 1) =	79.78	Ω	
Imaginary part input impedance (port1) =	8.84	Ω	
Return loss (port 1) =	-12.4	dB	
SWR =	1.63		

Without shunt elements

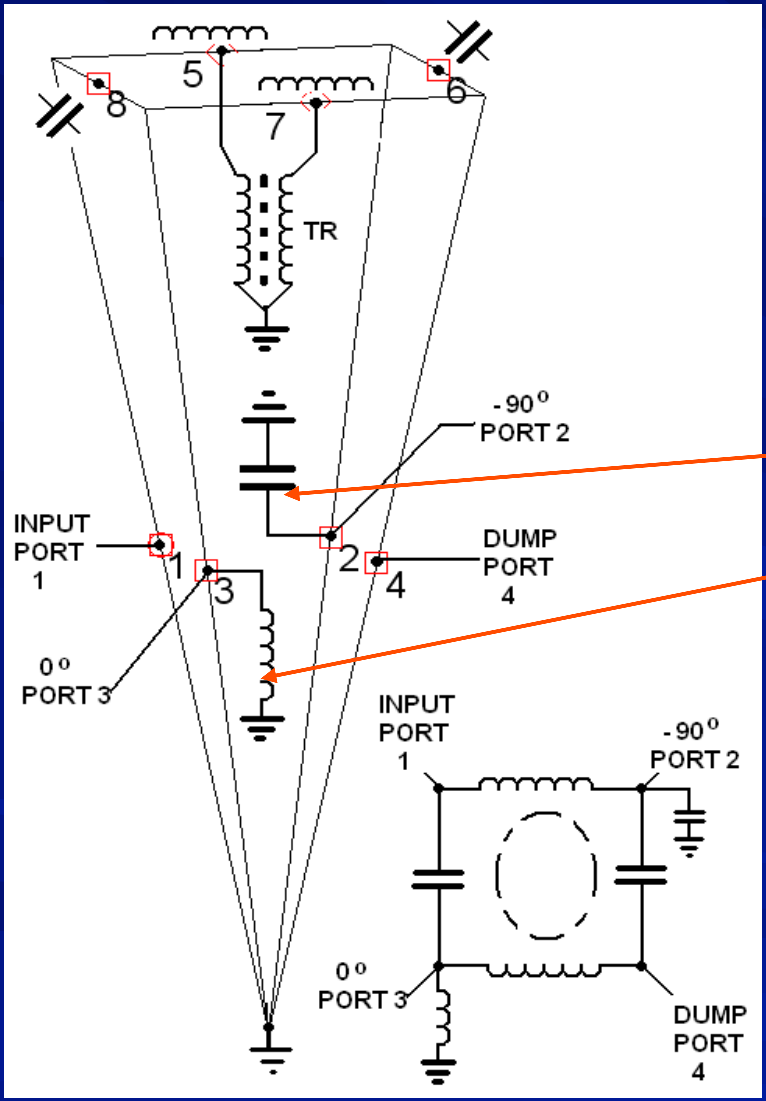
HYBRID COUPLER DESIGN (by W1MK)			
INPUTS			
ENTER fa (operating frequency) →	3.65	MHz	
ENTER fo (hybrid frequency) →	4.064	MHz	
ENTER Zo Design impedance hybrid →	50	Ω	
	Real Part	Imag Part	
ENTER Impedance load PORT 2 (Z2) →	63.13	0	Ω
ENTER Impedance load PORT 3 (Z3) →	82.02	0	Ω
RESULTS			
fo/fa =	1.113		
Hybrid L value (uH) =	1.96	µH	
Hybrid C value (pF) =	392	pF	
Ratio Voltage magnitude Port2/Port3 (k) =	1.000		
Phase angle Voltage port 2 vs. port 3 =	-90.00	°	
Power in Port 4 (vs. Pwr in Port 1) =	-14.9	dB	
Real part input impedance (port 1) =	49.34	Ω	
Imaginary part input impedance (port1) =	4.35	Ω	
Return loss (port 1) =	-27.1	dB	
SWR =	1.09		

With shunt elements

Demystifying the hybrid coupler

- And now the moment of truth..
  - To do **bandwidth assessment** …
  - … we will run the EZNEC model in **Sweep mode** (across the band)
  - … we require a model that includes the hybrid
  - and all other antenna system elements

Demystifying the hybrid coupler



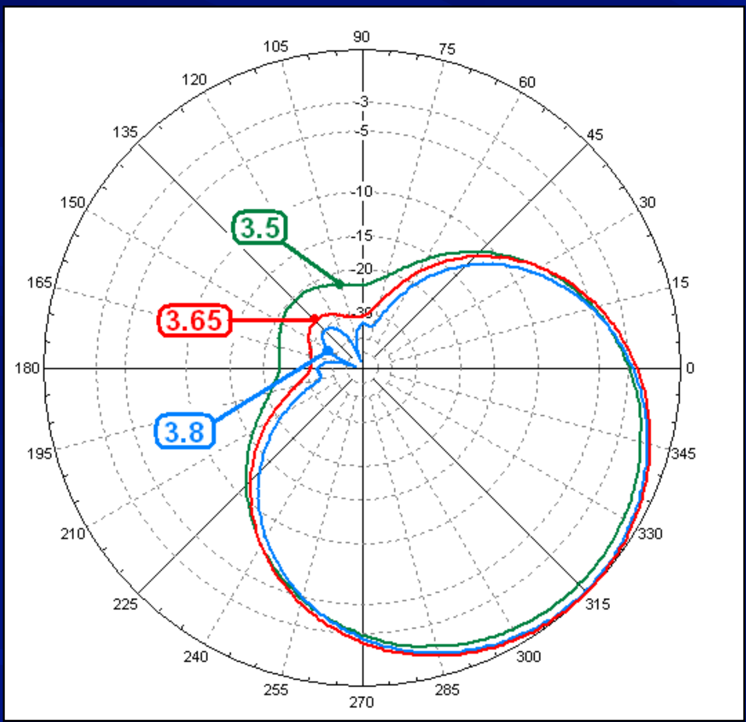
BANDWIDTH ASSESSMENT

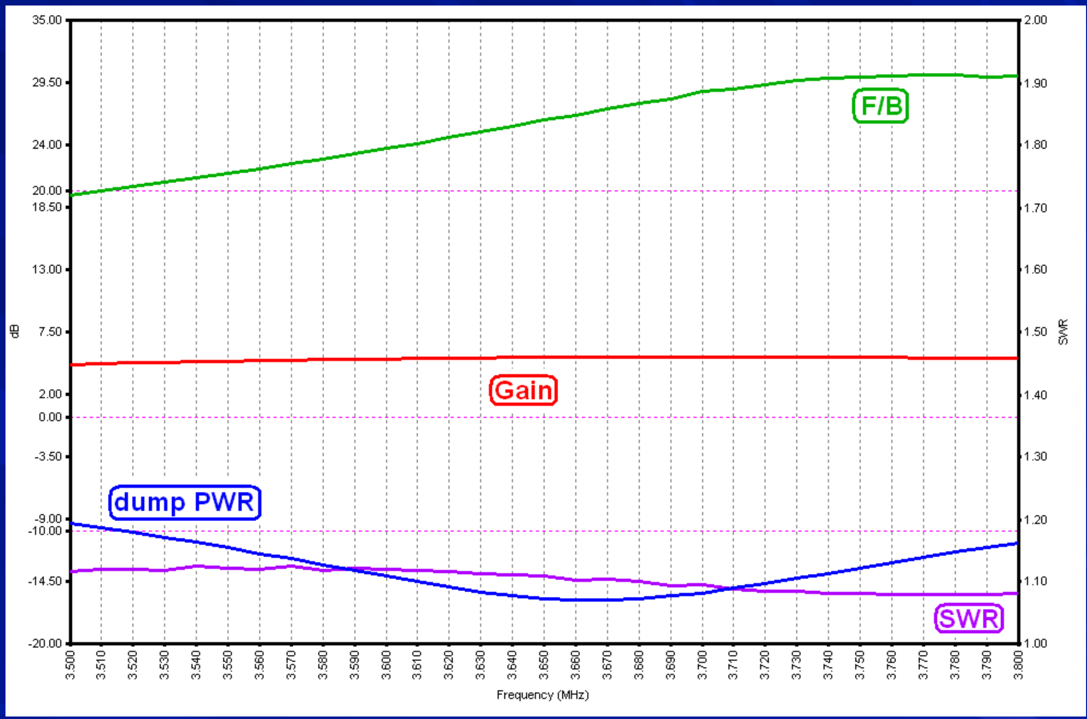
Specified Pos.		Actual Pos.		R	L	C
Wire #	% From E1	% From E1	Seg	(ohms)	(uH)	(pF)
1	50	50	2	0.01	Short	Short
2	50	50	2	100000	Open	289.4
3	50	50	2	100000	6	Open
4	50	50	2	50	Short	Short
5	50	50	2	Short	1.958	Short
6	50	50	2	Short	Short	391.6
7	50	50	2	Short	10000	Short
8	50	50	2	Short	Short	391.6

The EZNEC model now includes the hybrid **and** the shunt elements

Demystifying the hybrid coupler

Operational Bandwidth for W1MK's 2-shunt method





COMPARE WITH SLIDE 10

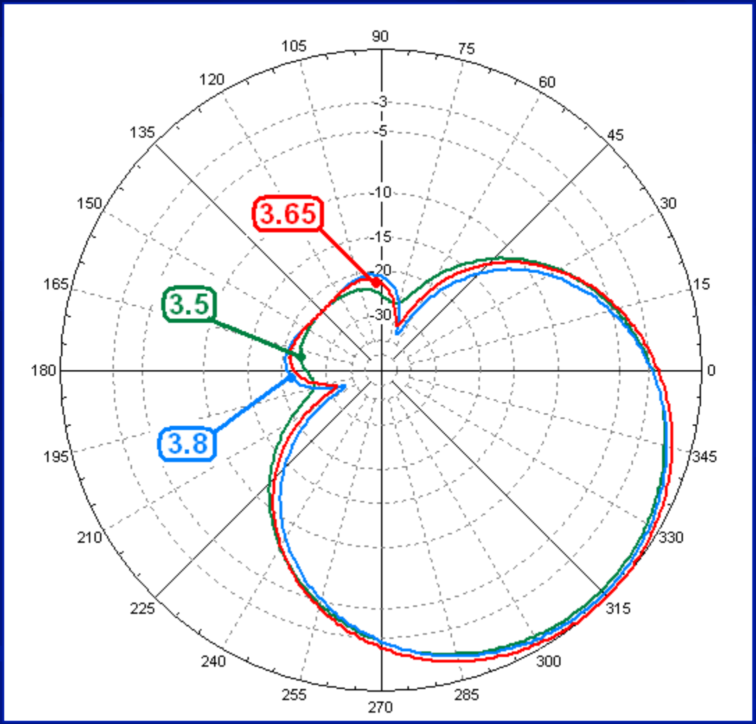
Demystifying the hybrid coupler

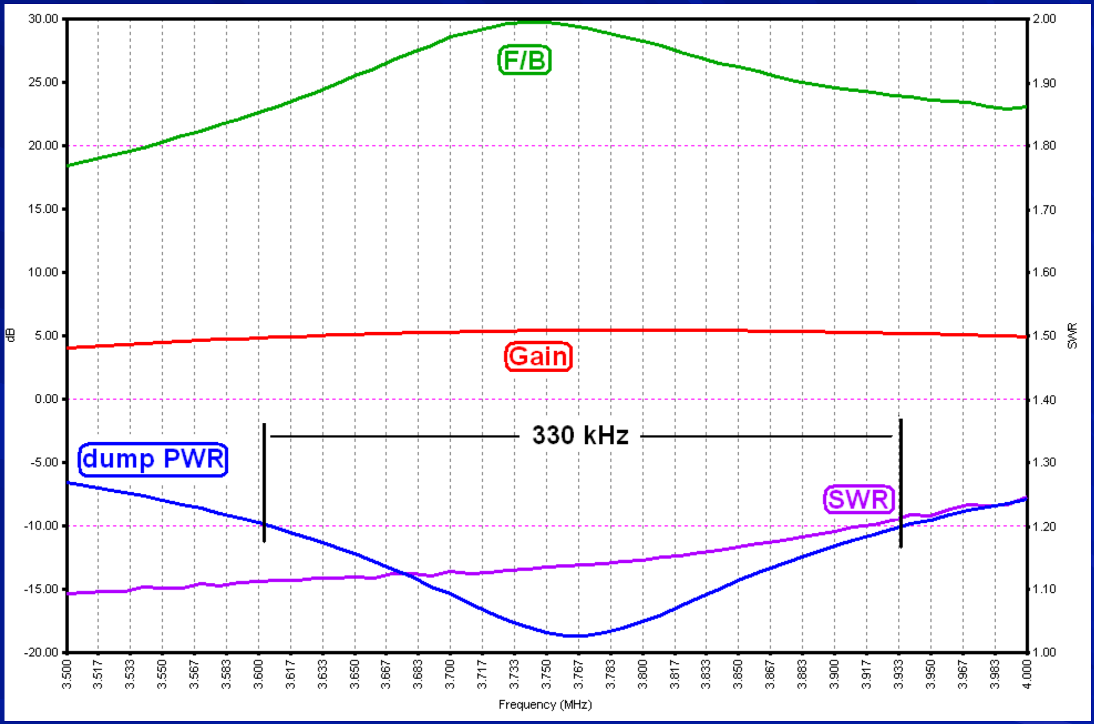
There are two other methods

- The W1MK single shunt method
- The W8WWV double network system

Demystifying the hybrid coupler

Operational Bandwidth for W1MK's single shunt method



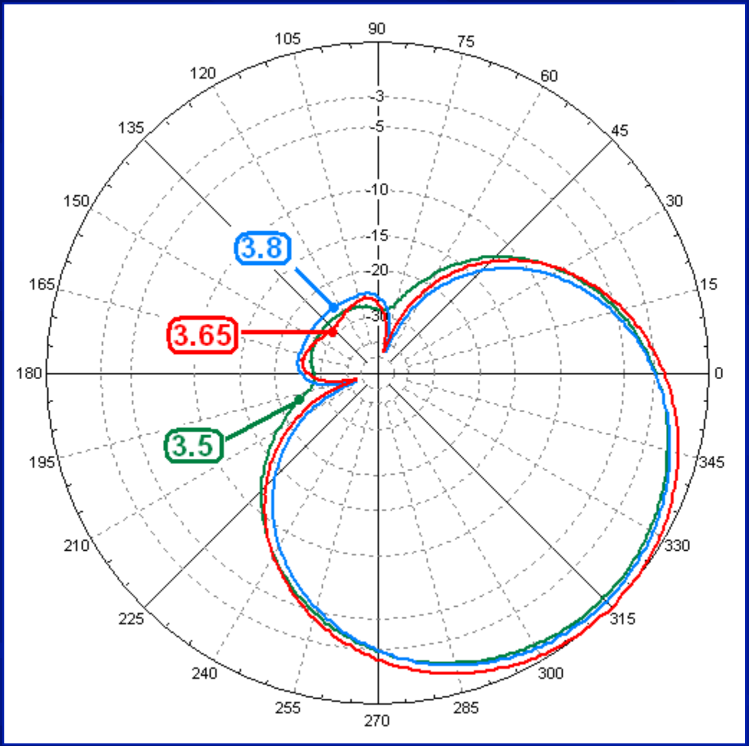


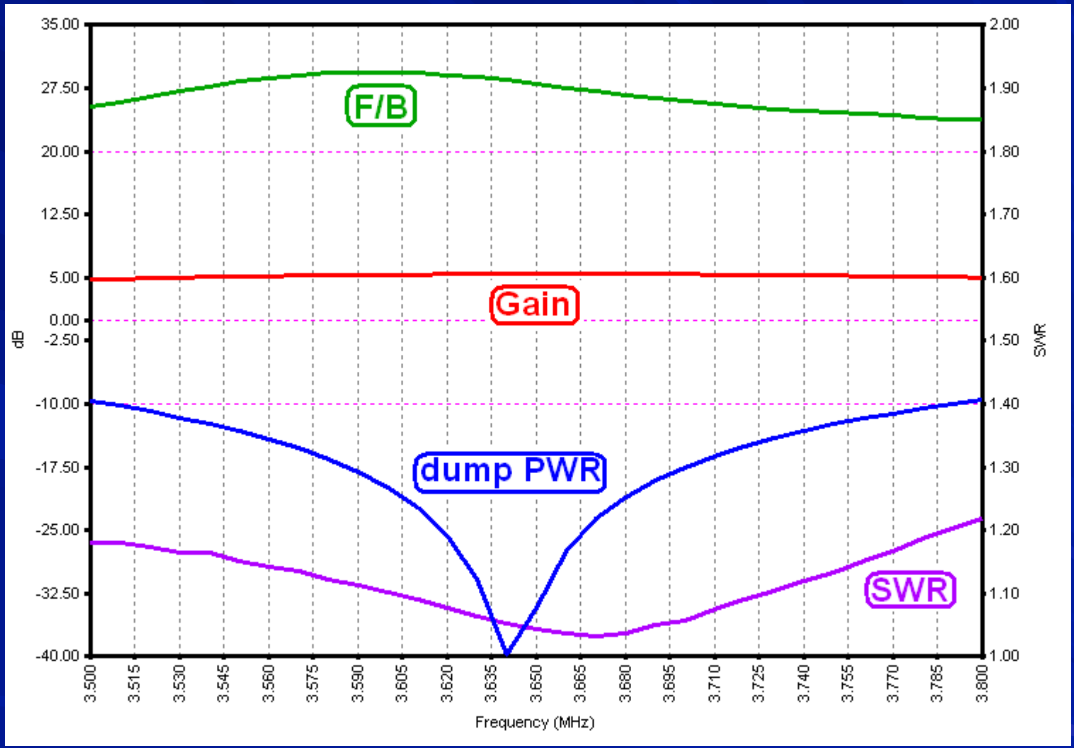
COMPARE WITH

SLIDE 10

Demystifying the hybrid coupler

W8WWV's double network system

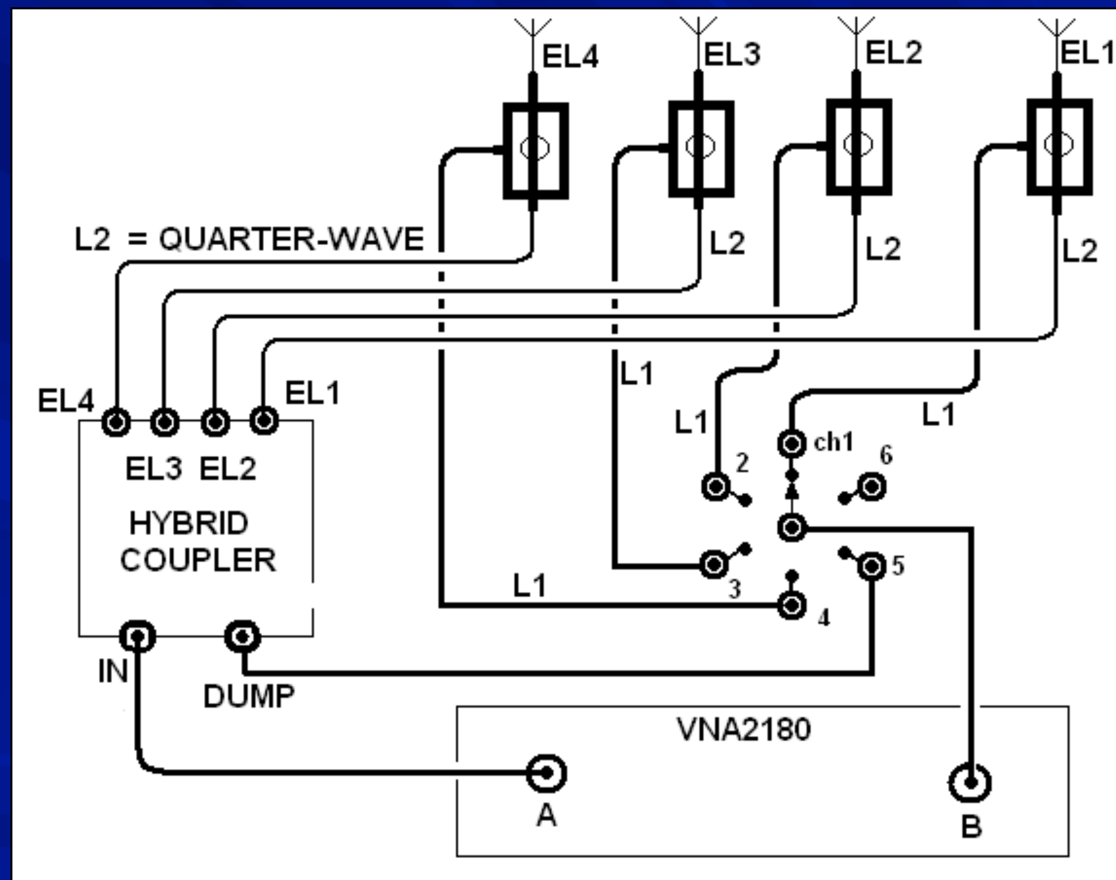




Graphs / Plots made with **LBDXView** by W8WWV

Demystifying the hybrid coupler

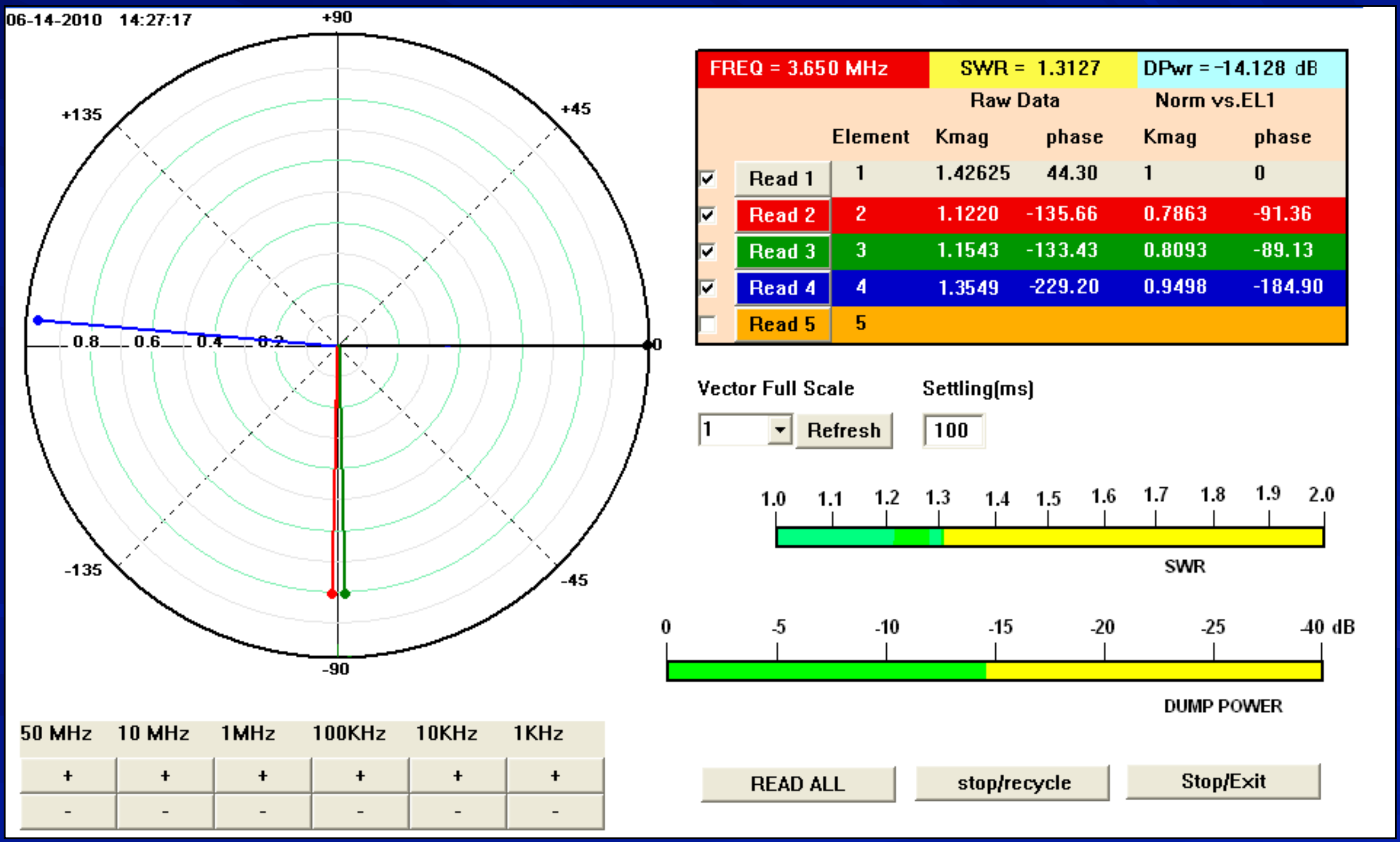
Measuring / testing



VNA + MUX + PROBES

Demystifying the hybrid coupler

RVM (Relative Vector Meter) setup

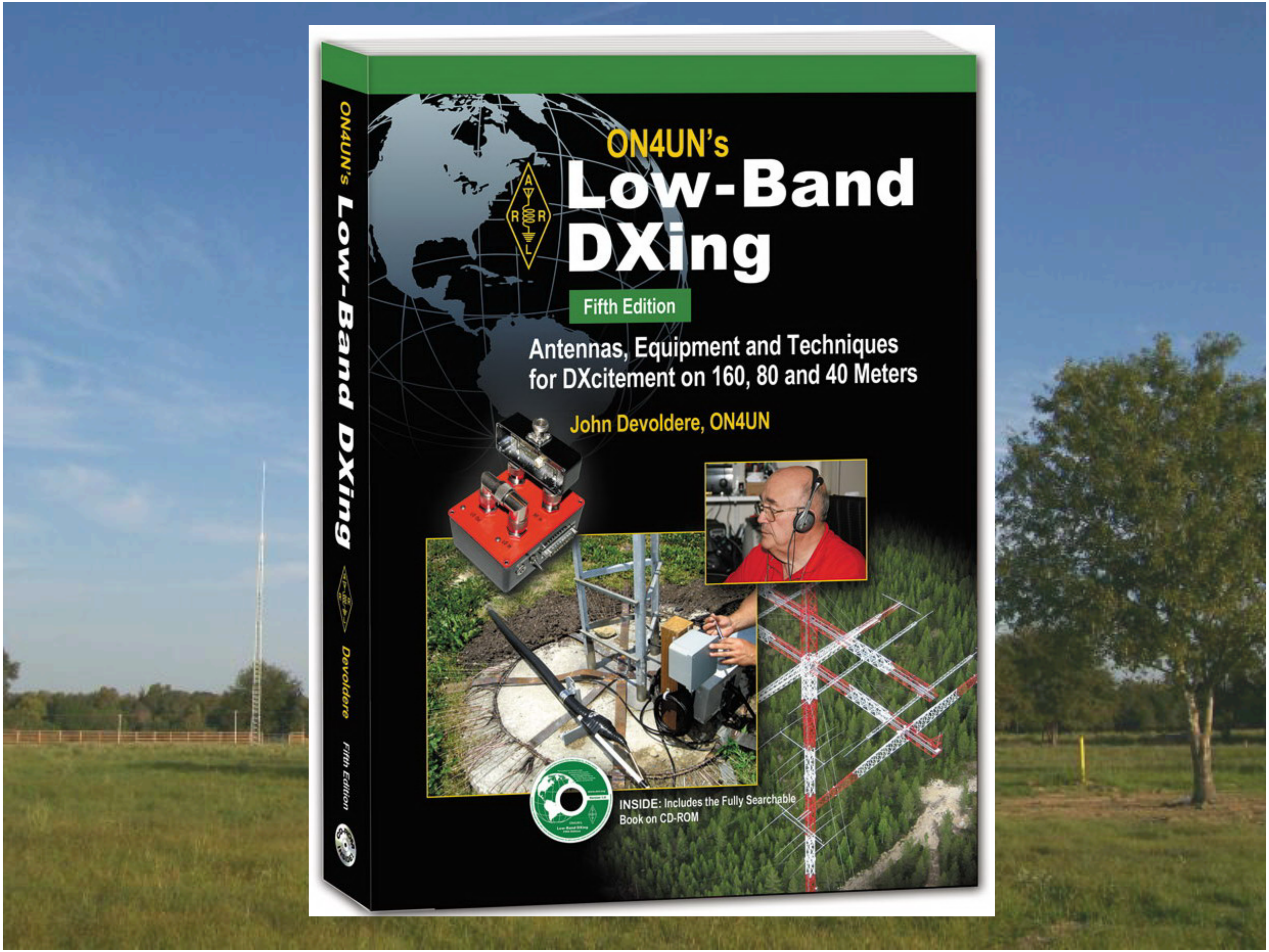


Real Time (single frequency)

Demystifying the hybrid coupler

Conclusion

- No more mysterious properties for a hybrid
- For the first time a complete and simple hybrid model
- A hybrid can be modeled in EZNEC
- Operational BW: L-netw. 4-sq: 75 kHz, hybrid: 300 kHz
- The new 2-port black box Z2 – Z3 approach
- Ways to measure / calculate Z2 and Z3
- Three optimization methods turning the hybrid coupler fed array into a very high performance wideband (300 kHz on 80m) antenna system
- Modeling software for each method
- Very handy LBDXView program from W8WWV
- VNA + MUX for final verification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4-squares at NR5M
Thank you
for listening !