4SQ's with 90 degrees couplers

80m 4SQ at 5A7A directly on the Mediterranean shore

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For a few years I have been working with this form of antenna feeding. In this presentation I have compiled my experience regarding this subject. I will only consider the solution with 90 degrees couplers. Other solutions can be found in ON4UN's book.

Contents

- Thoughts roundup by DF6QV
- General aspects regarding to antennas, arrays and propagation
- Several 90 degrees couplers,
  theory and simulation
- Total conception

Contents

All points depicted in the roundup have been worked on more or less extensively.

Phased array theory, theory of various 90 degree couplers, simulation of some of the couplers,

Hardware: control box, phase- and amplitude network, transformation feed lines, current balun;

Antenna elements, propagation, first array,

impedance plan, experiences.

Working principle of antennas

Antennas provide the coupling between transmitter output and ether. The current, or rather the current elements in the antenna elements, produce fields, the superposition of which provide the radiation diagram of the antenna.

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EZNEC and MMANA, two antenna simulation programs work according to this principle. Antennas can be planned on the computer before they are realized in practice.

Working principle of antennas

Antenna gain is a measure of energy bundling. Reference is a spherical radiator (isotropic reference radiator), indicated with dBi, and the halfwave dipole, indicated with dBd.

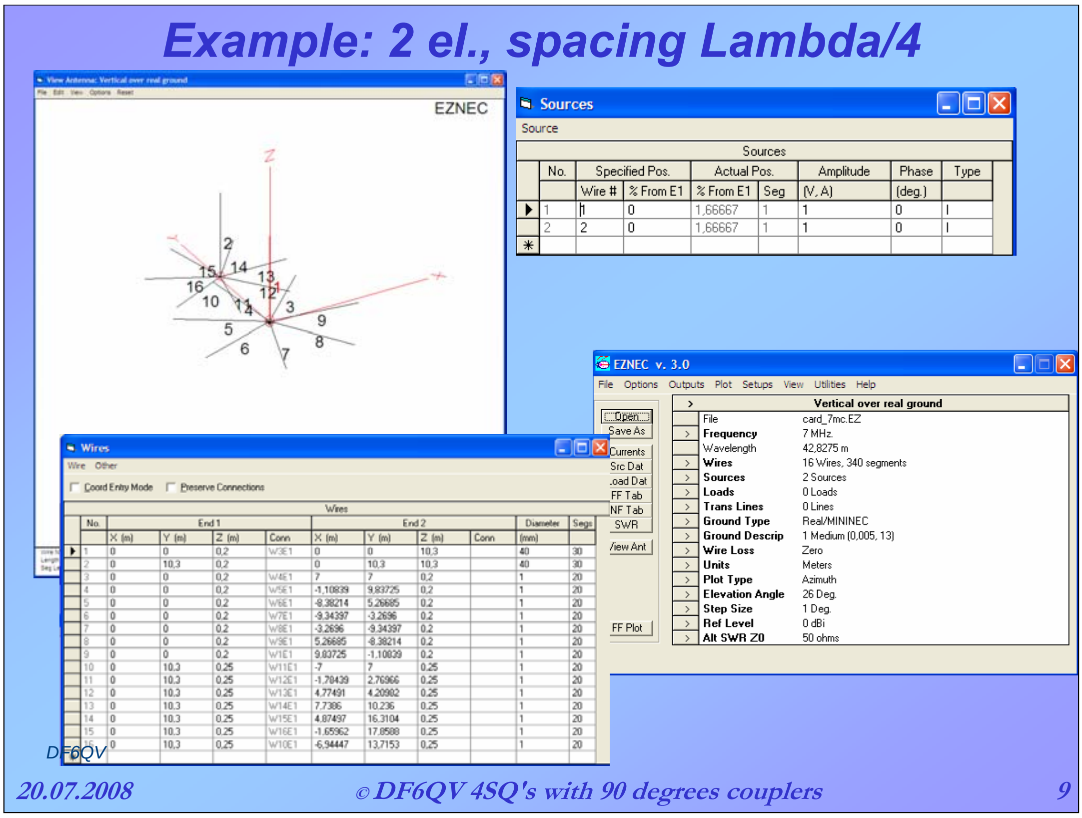
Working principle of antennas

All gain figures should refer to these normative antennas.

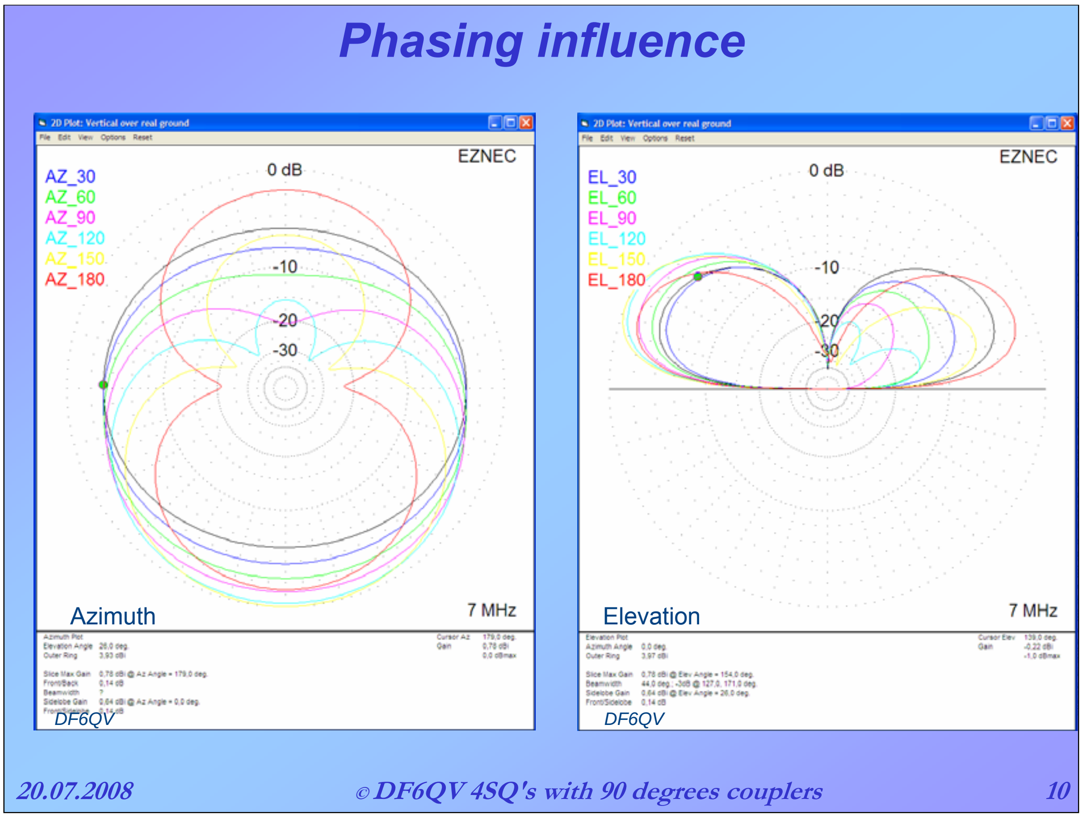
Some companies use their own „proprietory“ correction factors to boost the sales of their antennas....

What is an array?

An array is an antenna system in which each single array element is being fed. Array elements can be e.g. yagis, dipoles etc. In the simplest case the array element is just a single radiator. The gain and direction of radiation is produced by adjusting the phase and amplitude of the elements.



For example,here the elevation and azimuth lobes of a 2-element array with a spacing of lambda/4 are simulated as a function of phase.

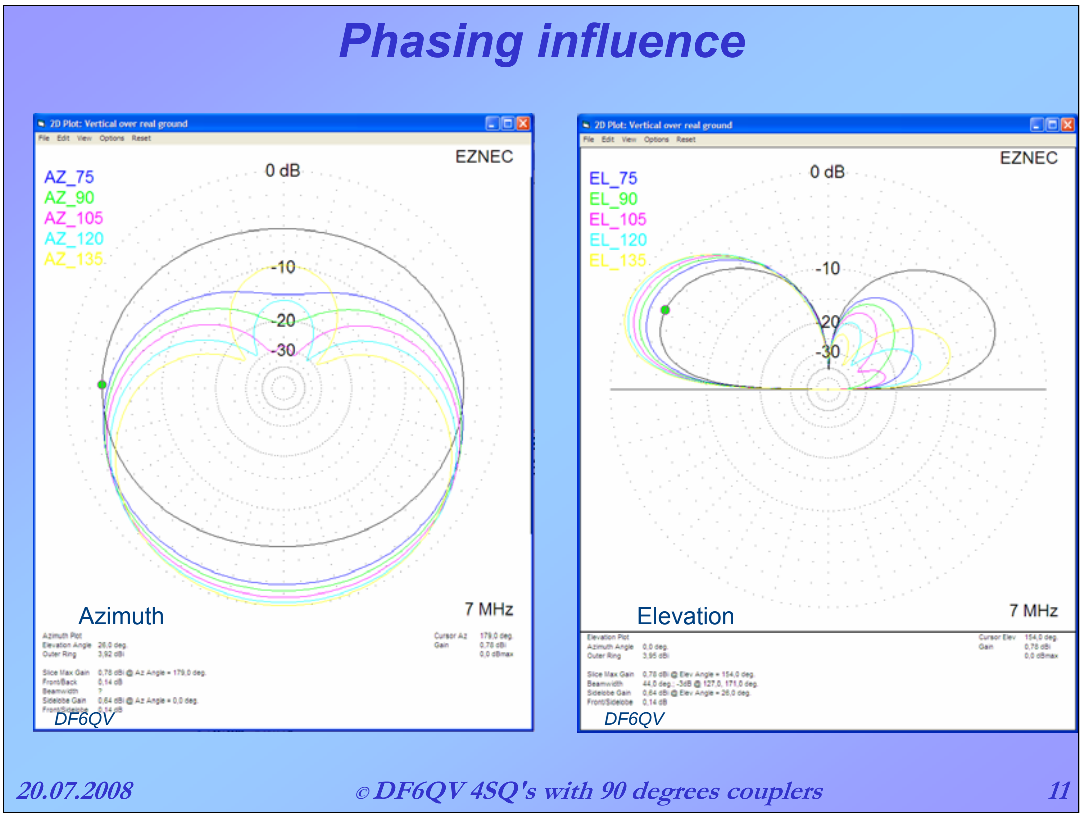


These screen shots show the lobes with different phasing. The black plot shows the lobes with zero degrees phase difference.

AZ30 means 30 degrees

AZ60 menas 60 degrees etc.

The same goes for the elevation plots.



Here the lobes are shown every 15 degrees in the interesting range of 75-135 degrees.

With an element spacing of lambda/4 and a phase difference between 90 and 120 degrees an

appreciable F/B ratio can be obtained.

Simulation, an interesting playing field

At this point there are no limits with regard to playing instinct or research drive. You should consider, however, that the simulated values must be converted to reality at some point. A further important consideration is the bandwidth of our amateur bands.

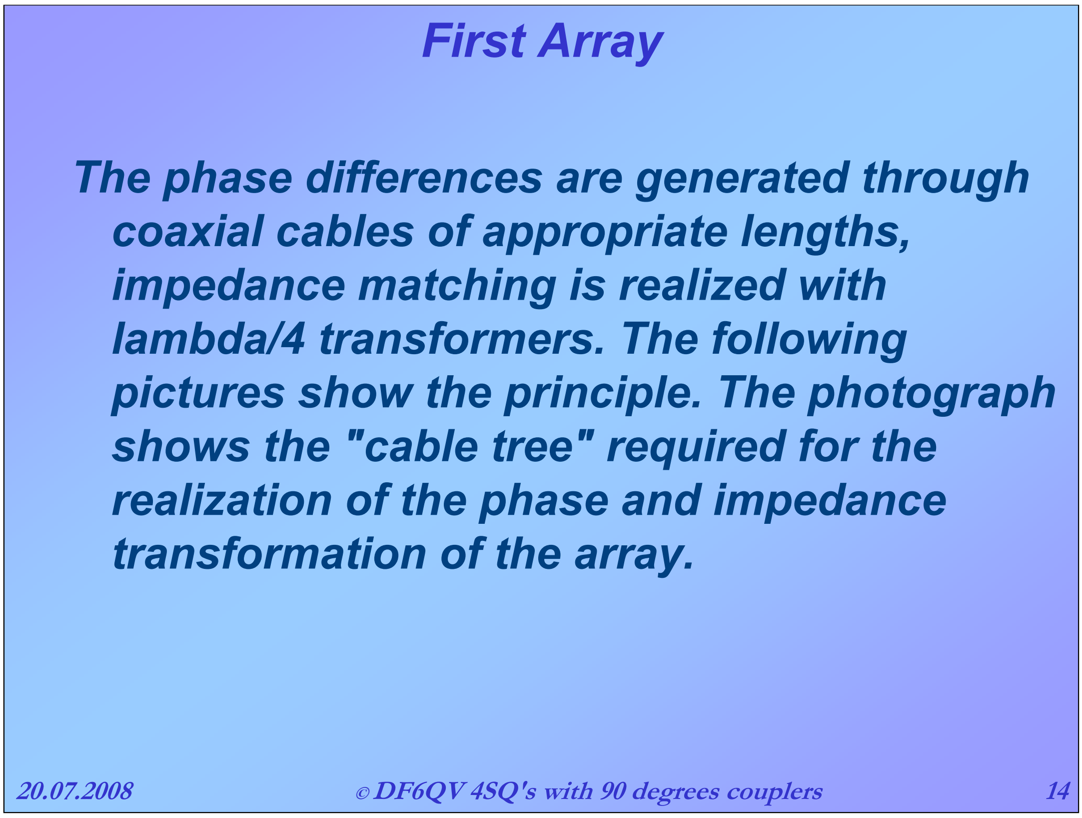
80m has a relative bandwidth of about 8%!

How does the phase network handle this?

Next to EZNEC, MMANA is available as a free simulation program.

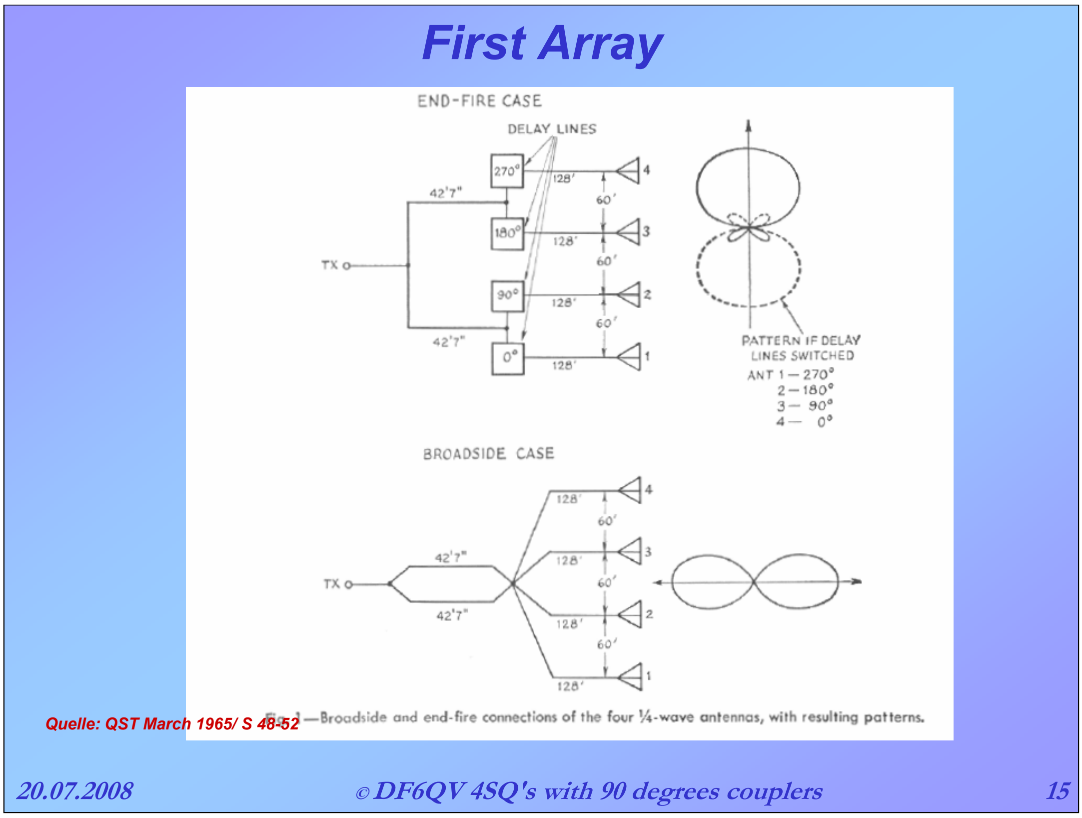
First Array

In QST ,March 1965, an 80m array was described for the first time. The article showed an array with 4 vertical radiators with a mutual spacing of lambda/4. If the radiators are fed with the same phase, the array has broadside characteristics. If the different radiators receive signals phased 0, 90, 180 and 270 degrees, the system works as an end fire array.



W1HKK, A switchable Four-Element 80m Phased Array, QST

March 1965



The top drawing shows the end fire configuration, the broadside configuration is shown at the bottom.

128 ft are about 42.6 meters, equivalent to 3/4 lambda for 80m, when a cable with a velocity factor of 0.66 is used.

42.6 ft are about 14.2 meters, equivalent to 1/4 lambda.

In 1965 PC's and relevant simulation software were not available.

First Array

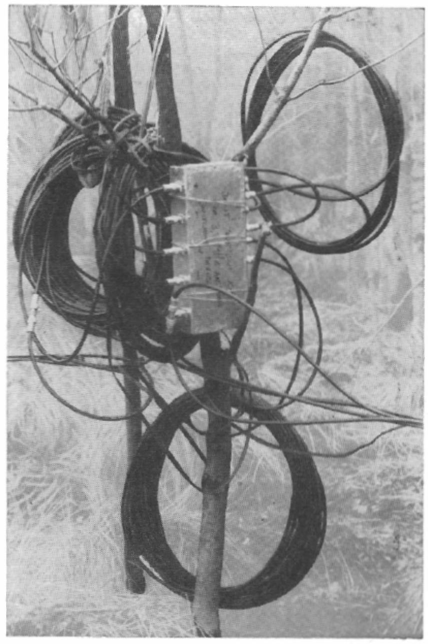


Fig. 5—The relay housing and coiled-up phasing lines.

Quelle: QST March 1965/ S 48-52

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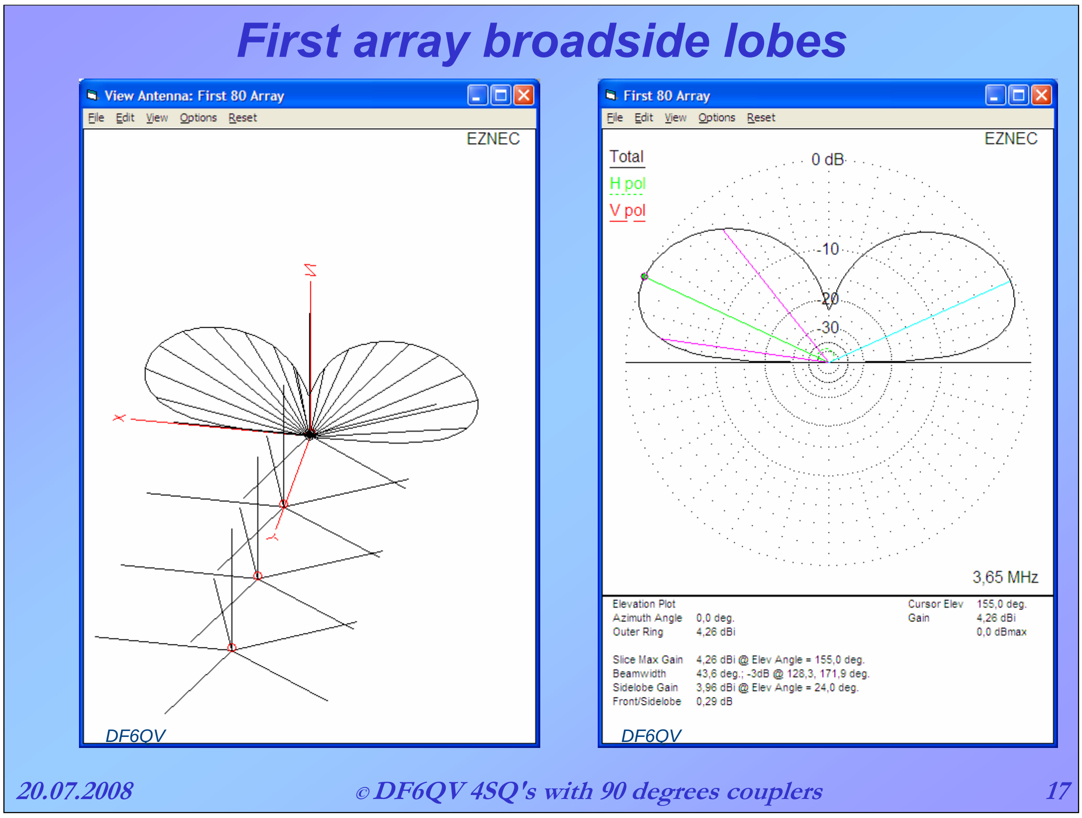
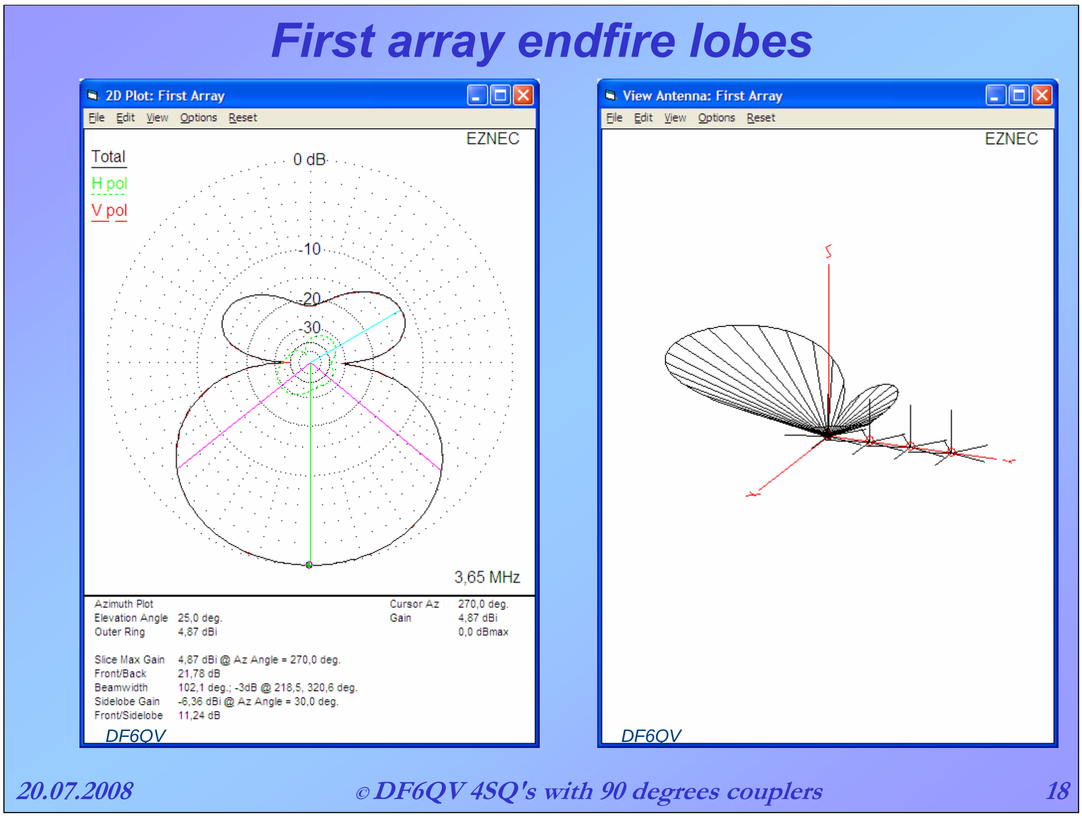
This, for sure, is a lot of cable. There was no switching provision for CW/SSB. When the feeders are cut for the centre of the band, there is an error of 4% at the band edges. Looking at the Smith chart this is an acceptable error for amateur use.

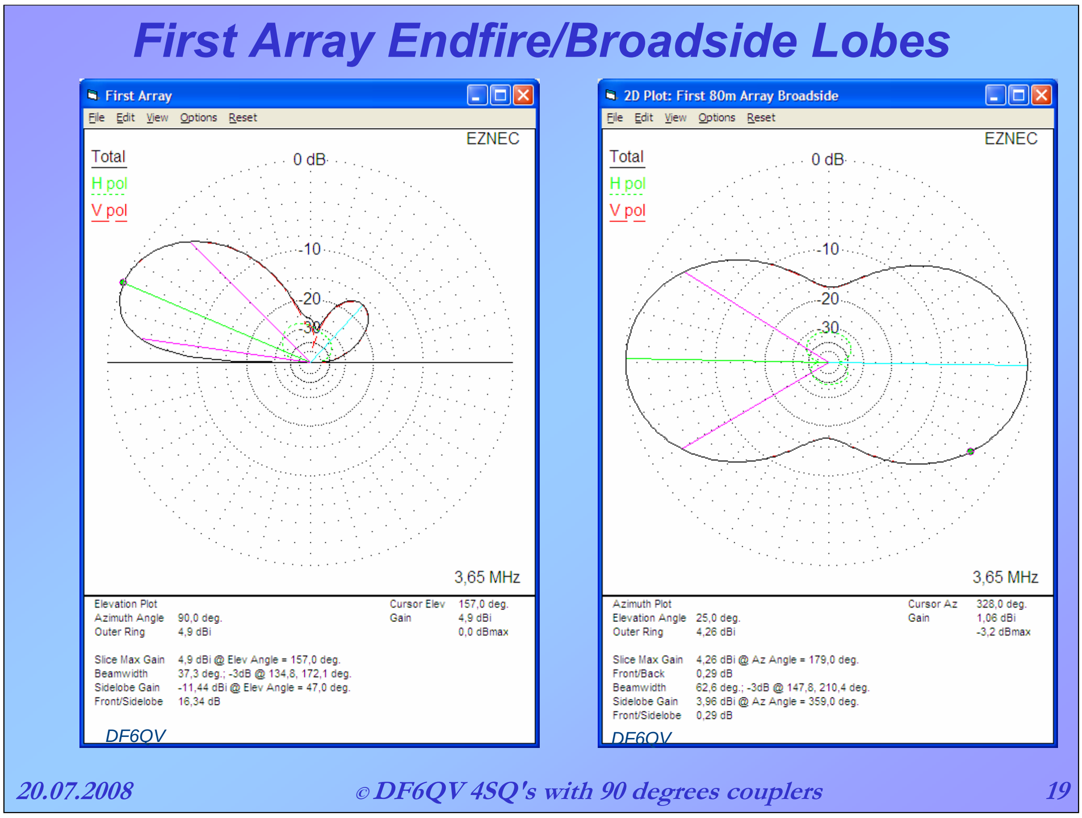


The simulation was done with 5 radials close to ground. The dB values should not be taken for granted. They depend on the choice of ground, and the version of the simulation software.

Here the screen shots of the elevation lobe in broadside mode with 0 degrees phasing for all elements.

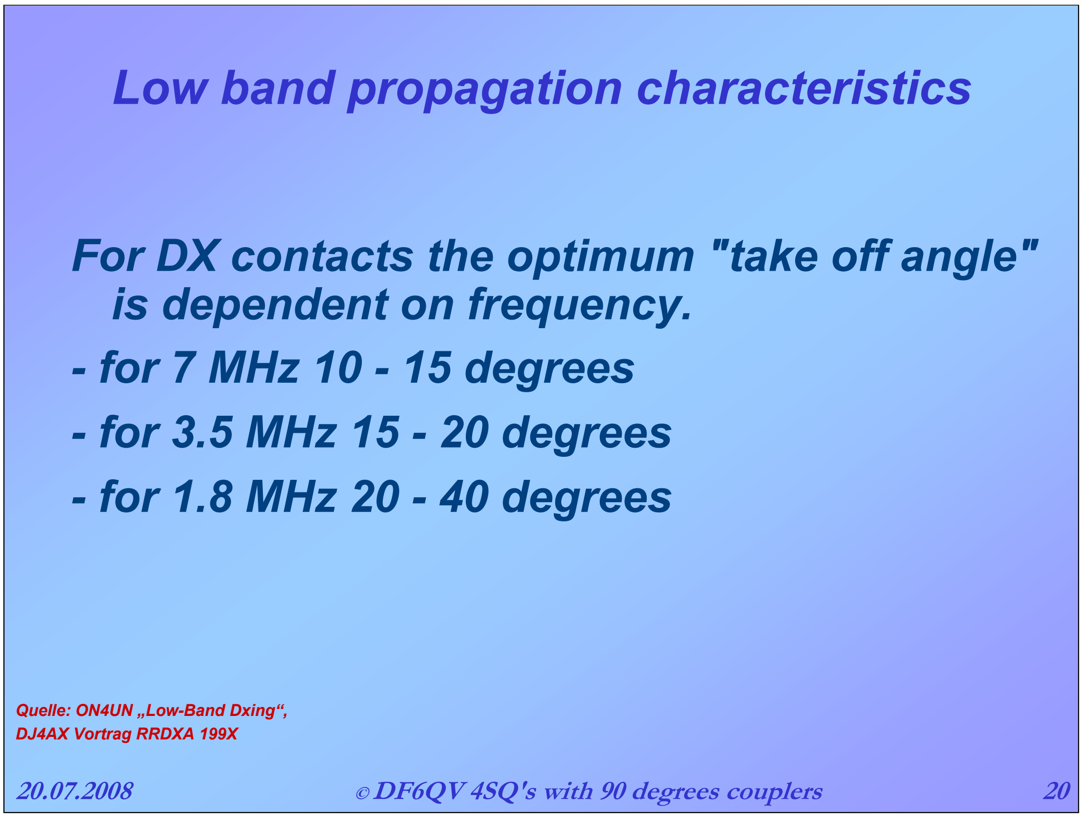


Here the screen shots of the azimuth lobe in end-fire mode with 0, 90, 180 and 270 degrees phasing of the elements.



Here you see the screen shots of the elevation lobe with end-fire phasing and the azimuth lobe in broadside mode.

This antenna design produces reasonable results. The elevation lobes of modern arrays are hardly different from the elevation lobe in end-fire configuration.



The following URLs provide extensive information about propagation on HF:

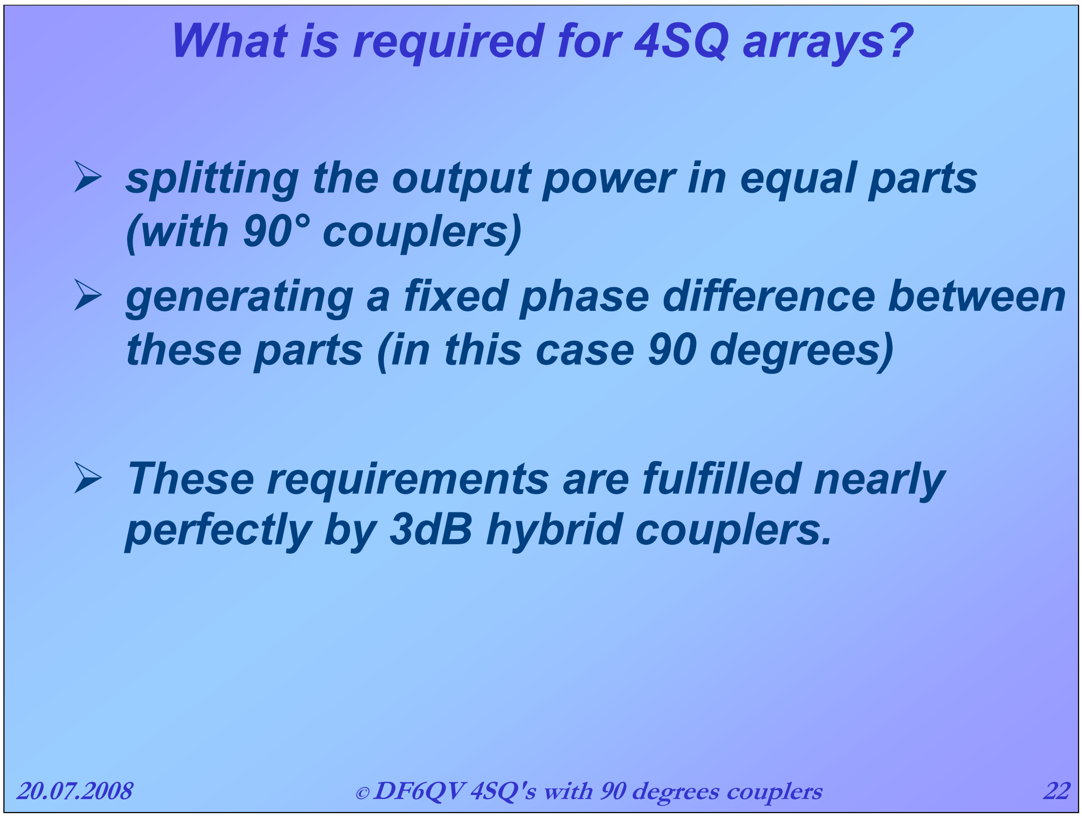
http://www.astrosurf.com/luxorion/qsl-hf-tutorial-nm7m6.htm

http://www.qsl.net/g3yrc/hf%20propagation/hf%20propagation.htm

Low band propagation

Vertical radiators have a radiation minimum at high angles, they are not suitable for local contacts. For DX contacts their flat radiation diagram is well suited. Vertical antennas need a lot of horizontal space, because of the need for a good radial ground system.

ON4UN has described several vertical low band antennas in his book „Low-Band-DXing".



In this presentation I will only consider arrays based on equally split power and a phasing between these parts of 90 or 180 degrees.

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Theoretical considerations

Next we will look at the properties of two kinds of couplers:

1. the 3dB hybrid coupler (also branch-line coupler)

a: realized with feed lines

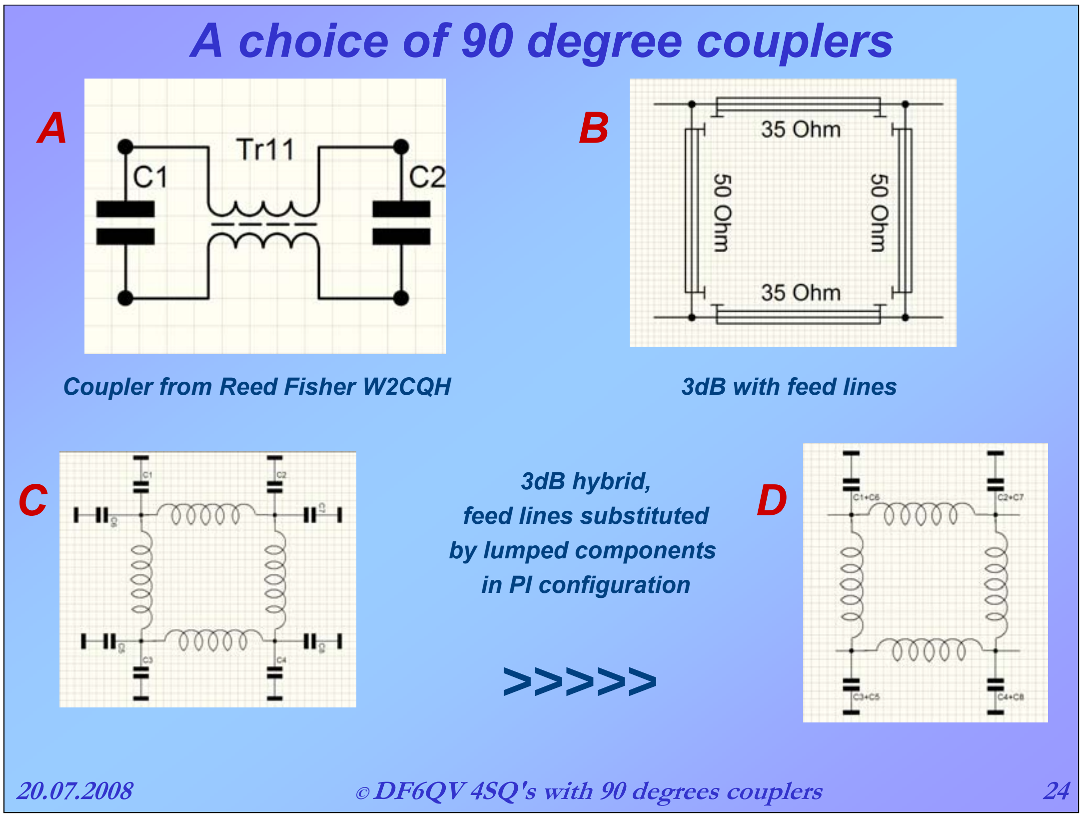
b: feed lines substituted by L/C combinations

2. the Reed Fisher coupler

The simulations were done with SwitcherCad from Linear Technologies at 3.65 MHz

SwitcherCad is a free simulation program:

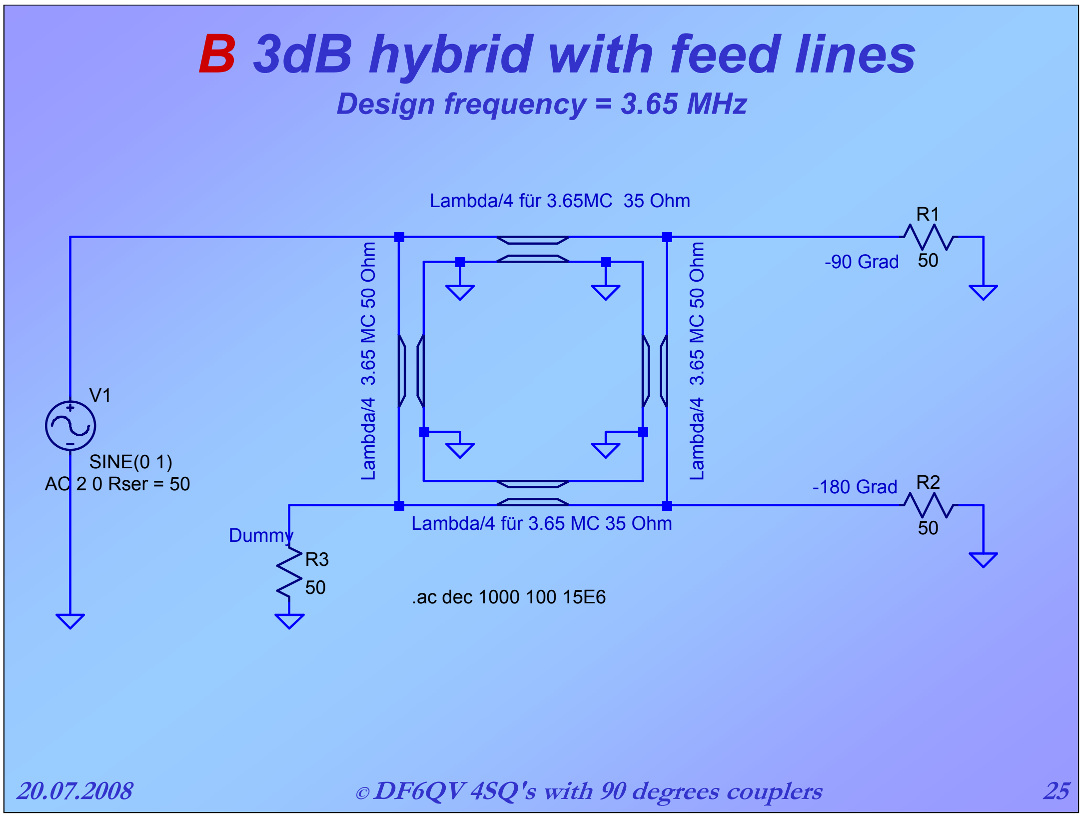
http://www.linear.com/designtools/software/



In hybrid B the feed lines can be substituted by PI circuits with L and C. If the Cs of the corners are combined, diagram D is developed. If you enter “Lumped Element 3 dB Hybrid Coupler” into a search engine you will find a lot of alternative solutions.

The Comtek coupler (Reed Fisher) uses circuit A.

The Reed Fisher coupler is often referred to as Collins coupler.

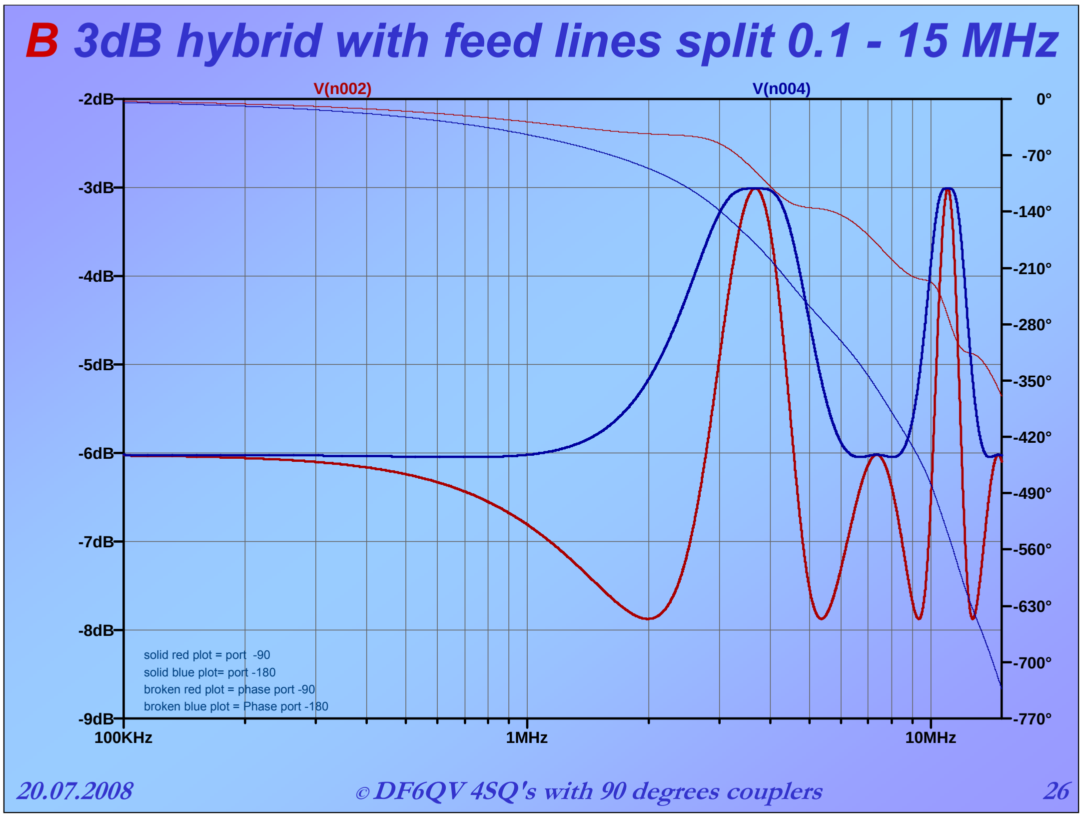


Without the two connections to the dummy (left hand vertical line and bottom horizontal line) you have a simple configuration: a 50 ohm antenna is connected in parallel to a second one via a lambda/4 feeder (right hand vertical line). At this point the impedance is 25 ohms. Via another lambda/4 line (top horizontal line) with 35 ohm impedance the array impedance is transformed back to 50 ohms.

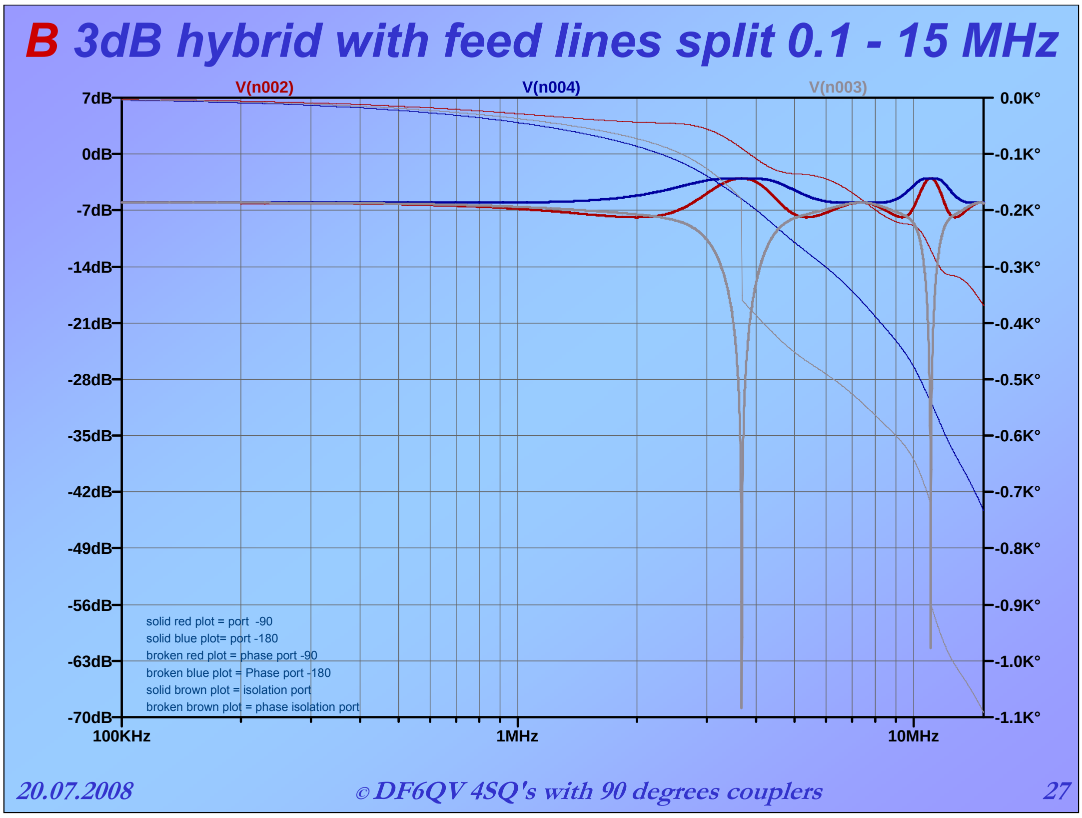
A disadvantage of this configuration is that both antennas are not decoupled, i.e. reflections in one antenna flow into the other and v.v. This influences the radiation diagram. If you add the other feed lines the behavior is changed and both antennas are practically decoupled. However, mutual coupling between the radiators is still present.

This type of coupler was described in detail in:

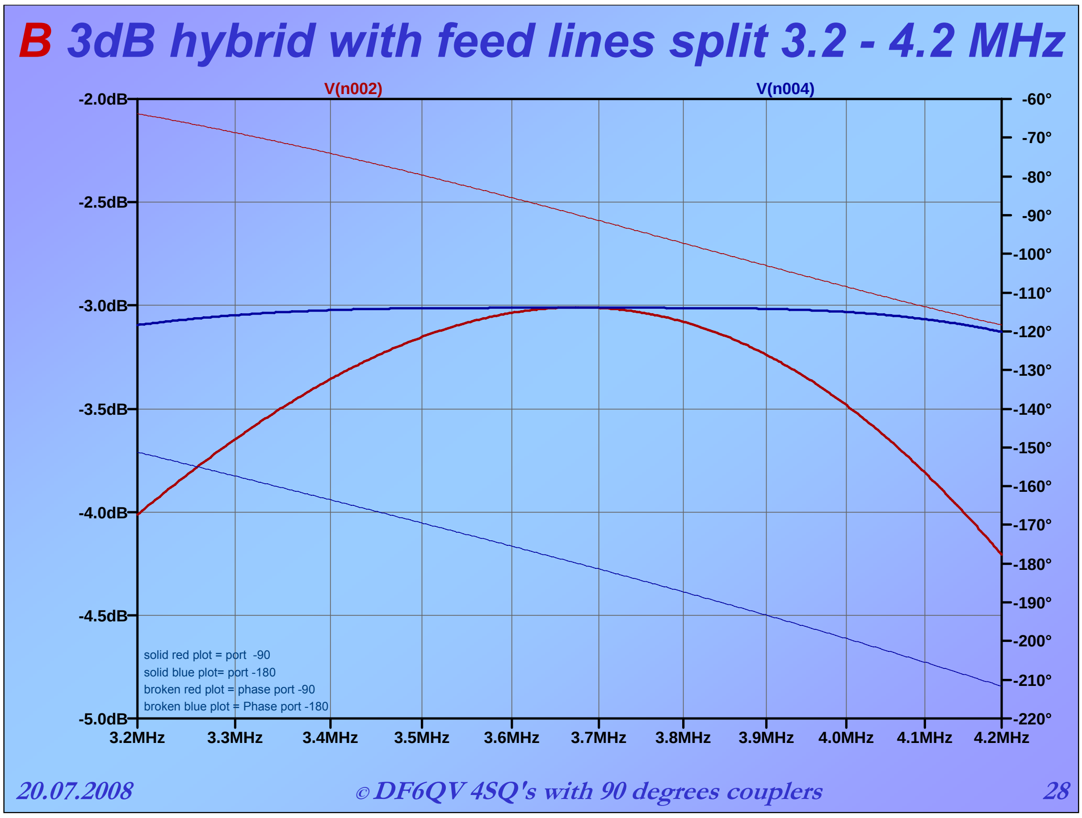
The branchline Hybrid: Part 1/2, Hamradio, April/May1984



Branch line coupler for 3.65 MHz simulation in frequency domain 0.1-15 MHz. At three times the design frequency the same power split is generated at the output ports, now as a result of 270 degrees feed lines.

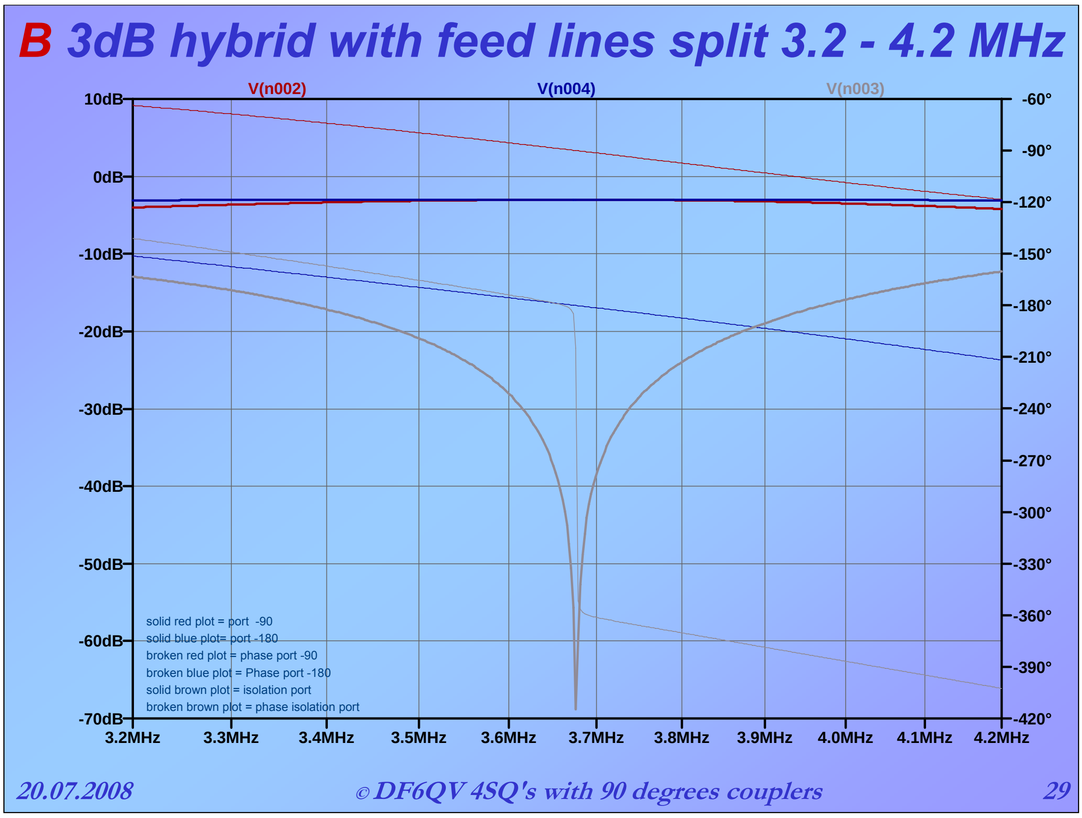


Branch line coupler for 3.65 MHz simulation in frequency domain 0.1-15 MHz. An isolation of >50db is obtained on the design frequency and its third multiple, very useful for our coupler.

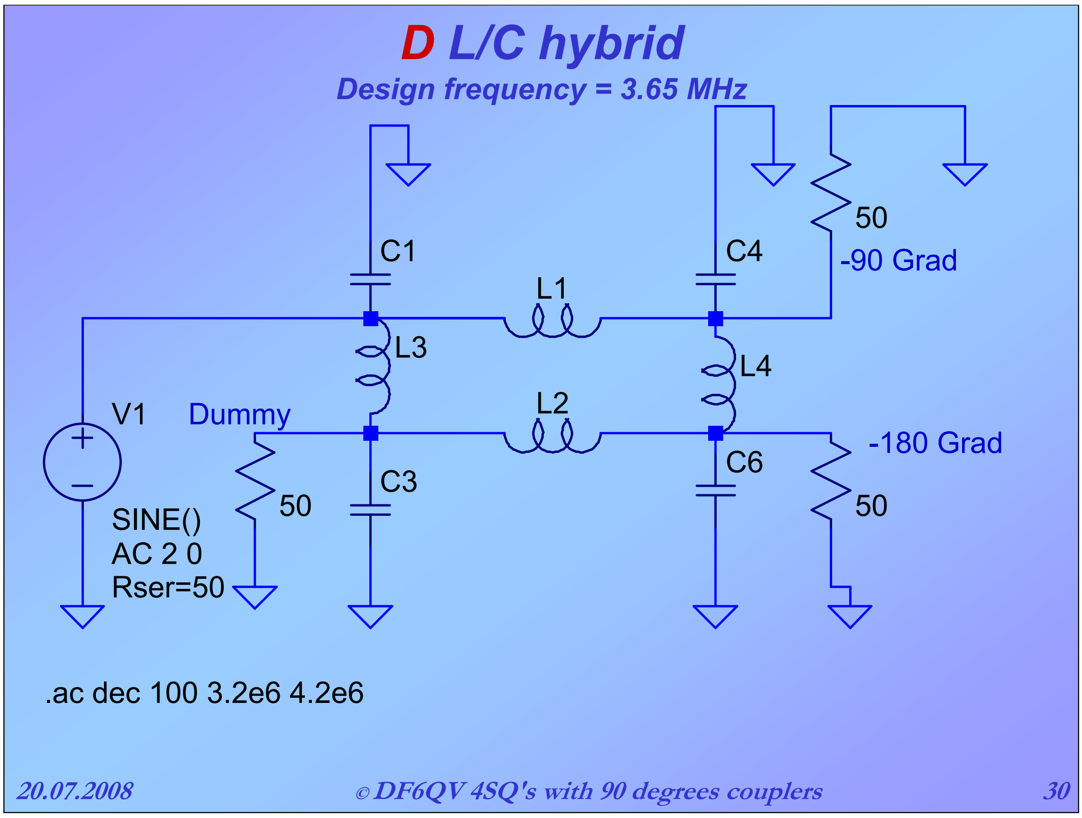


Power split and phase development in the range of 3.2- 4.2 MHz.

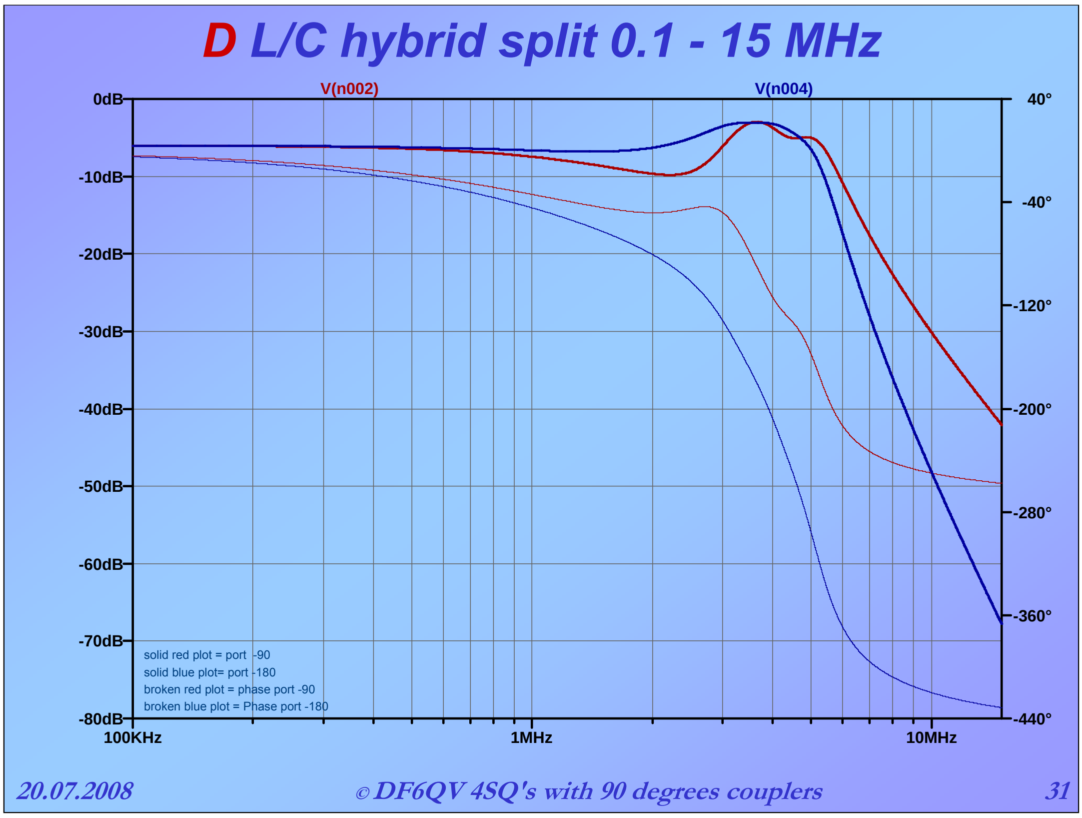
The 3dB hybrid realized with feed lines is good for use at high frequencies like 2m and 70 cm. For 160, 80, 40 and 30 meters the amount of cable required is quite large.



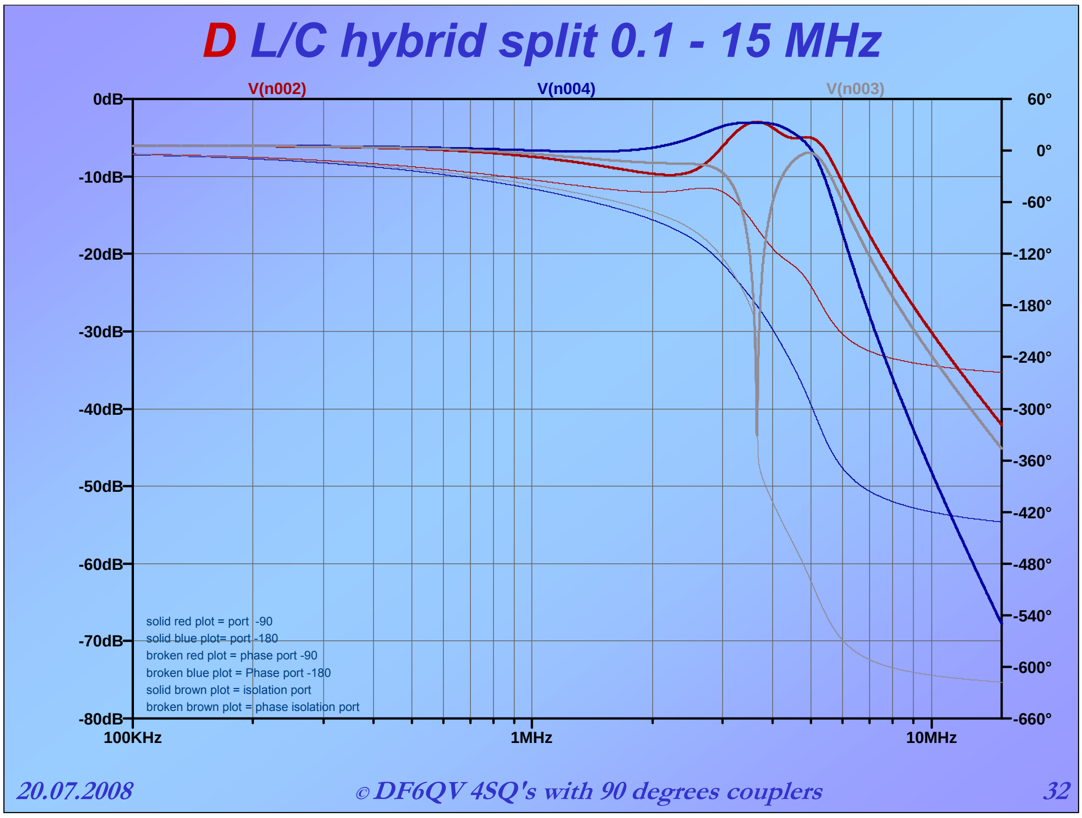
The brown plot shows the isolation to the dummy port. In the range of 3.5 to 3.8 MHz 20dB can be reached.



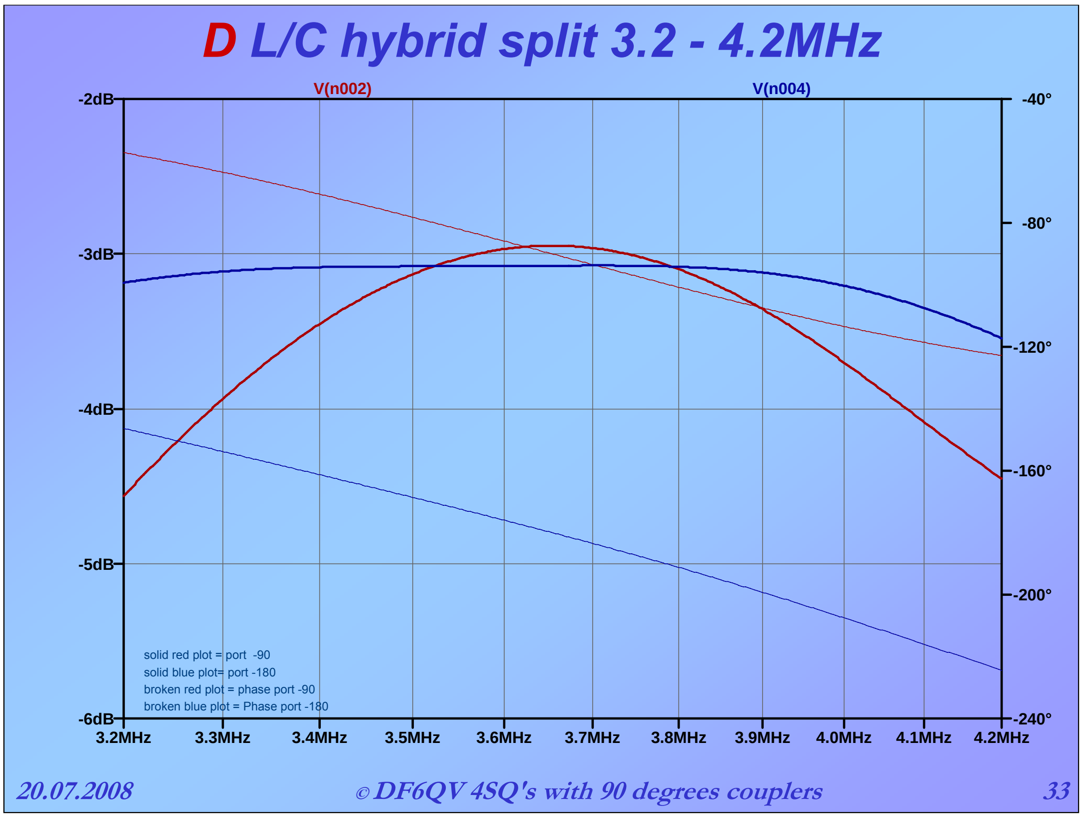
Here the hybrid is realized by substituting the feed lines with PI circuits.



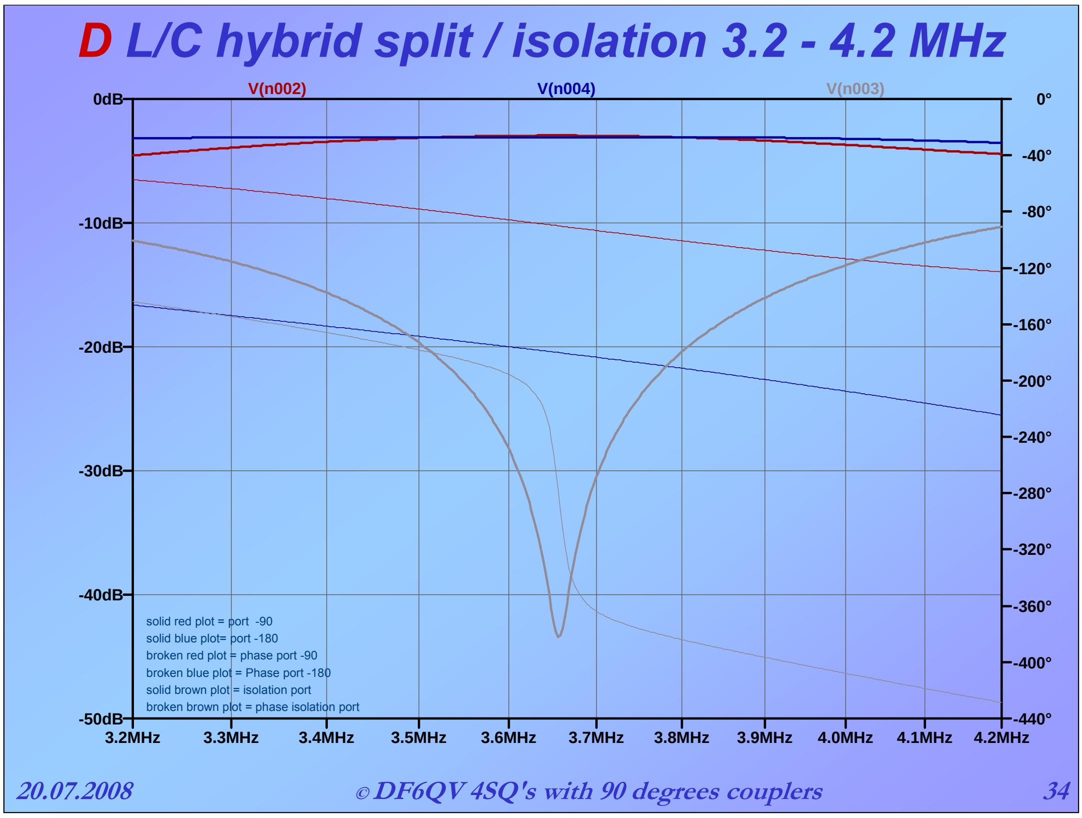
With this hybrid you can build couplers for HF, VHF and UHF frequencies



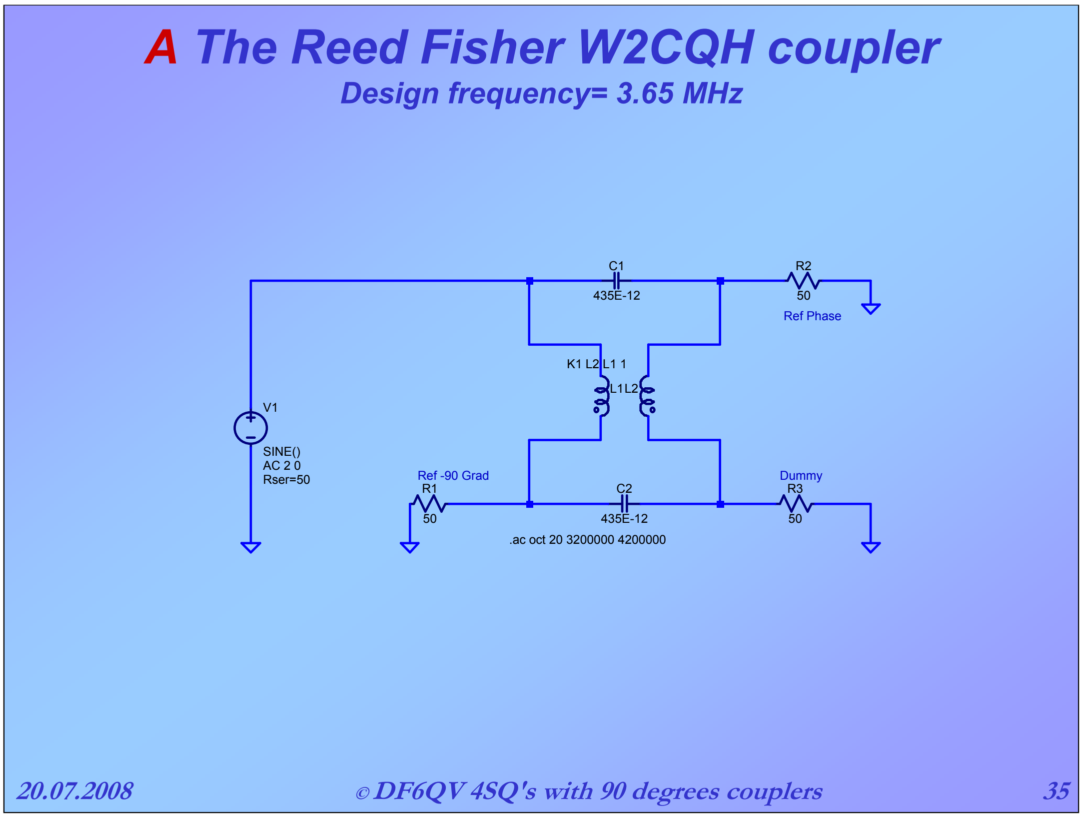
Contrary to the branch line coupler, configuration D can only be used on the design frequency.



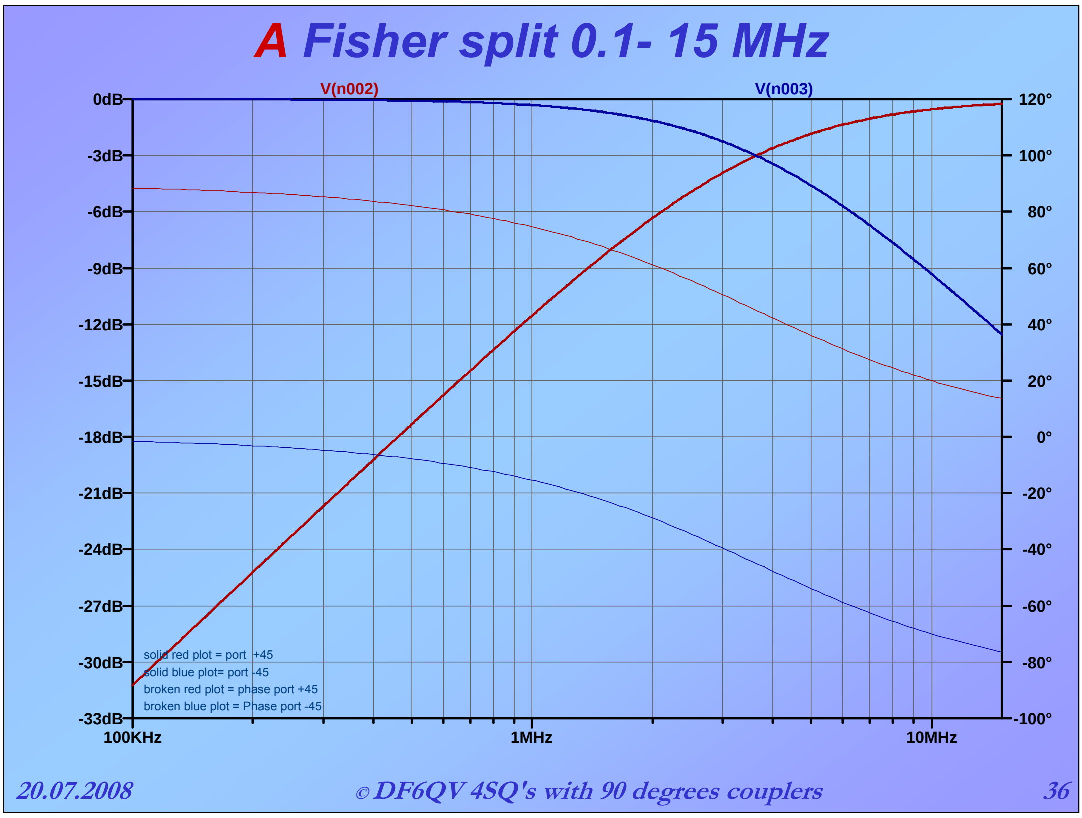
In a limited frequency range a small error in the power split becomes obvious. It is not impossible that the values for capacity and inductivity entered in the simulation model were not precise enough.



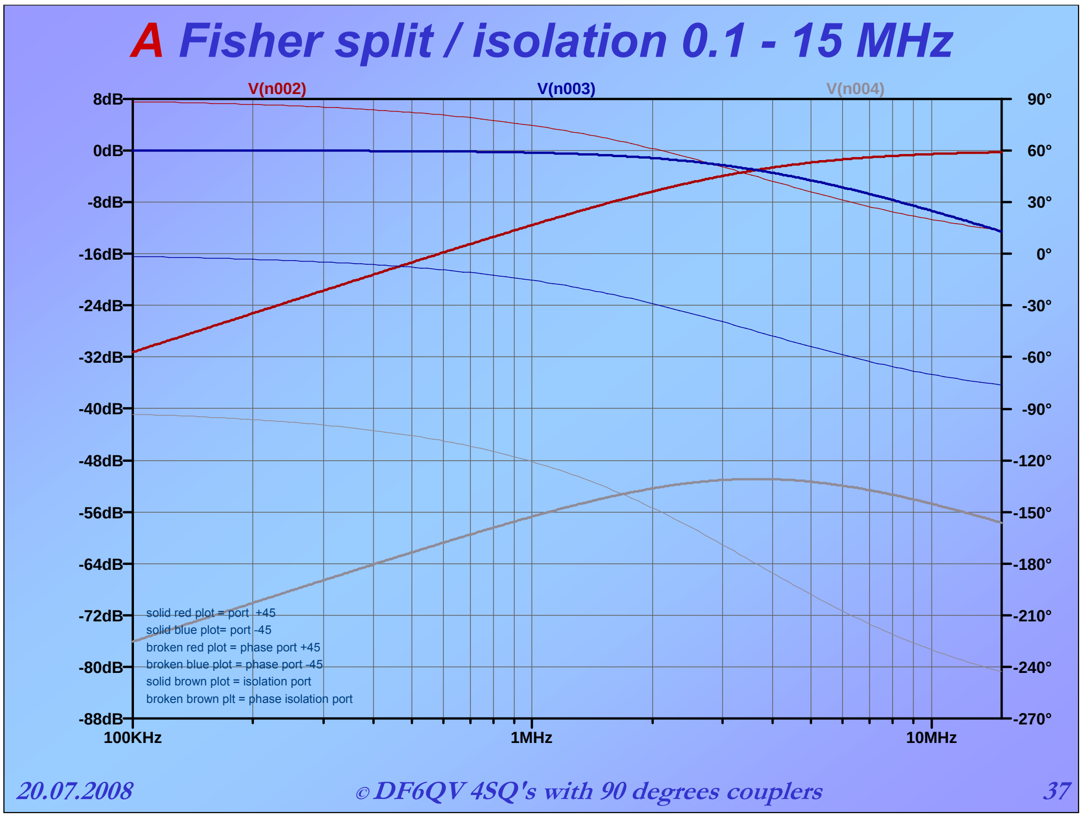
The brown graph shows the isolation to the dummy port. In the area of 3.5 to 3.8MHz 20dB isolation is possible.



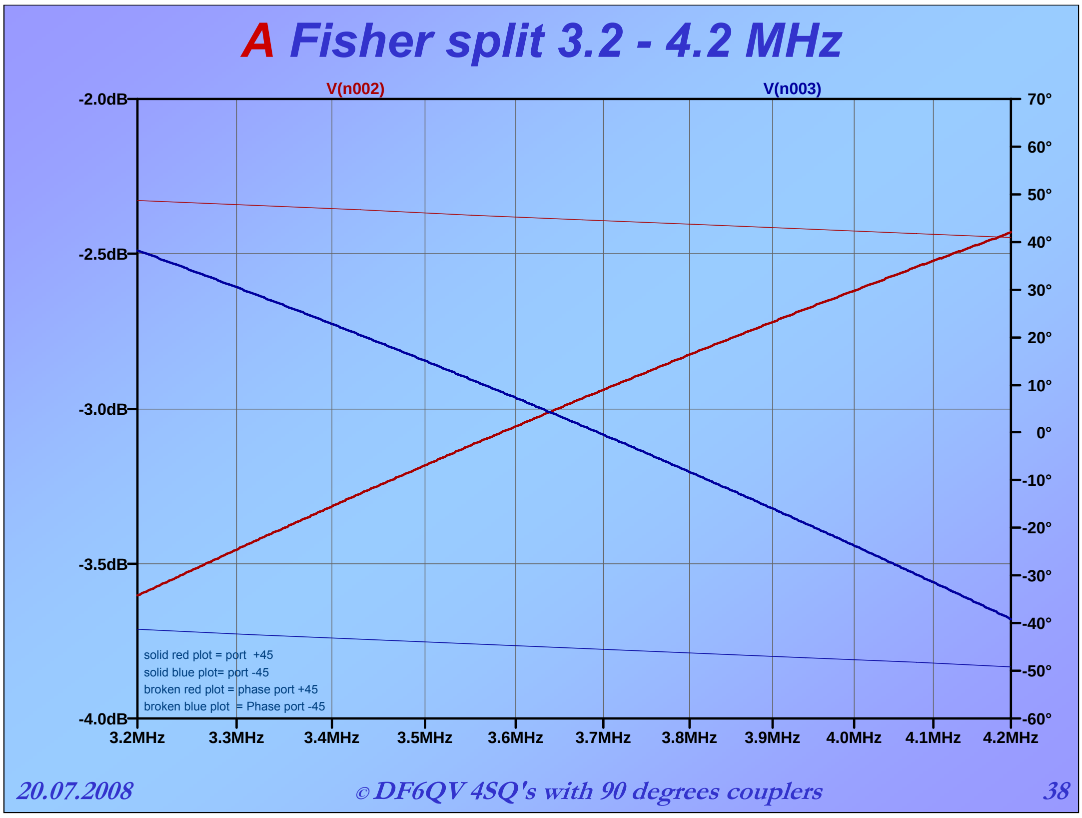
The function of this coupler cannot be compared to the branch line coupler. The power split is frequency dependent. However, for the design frequency the requirements for power split and phase relationship are met: the same power at both output ports with a phase difference of 90 degrees with decoupling of the isolation port.



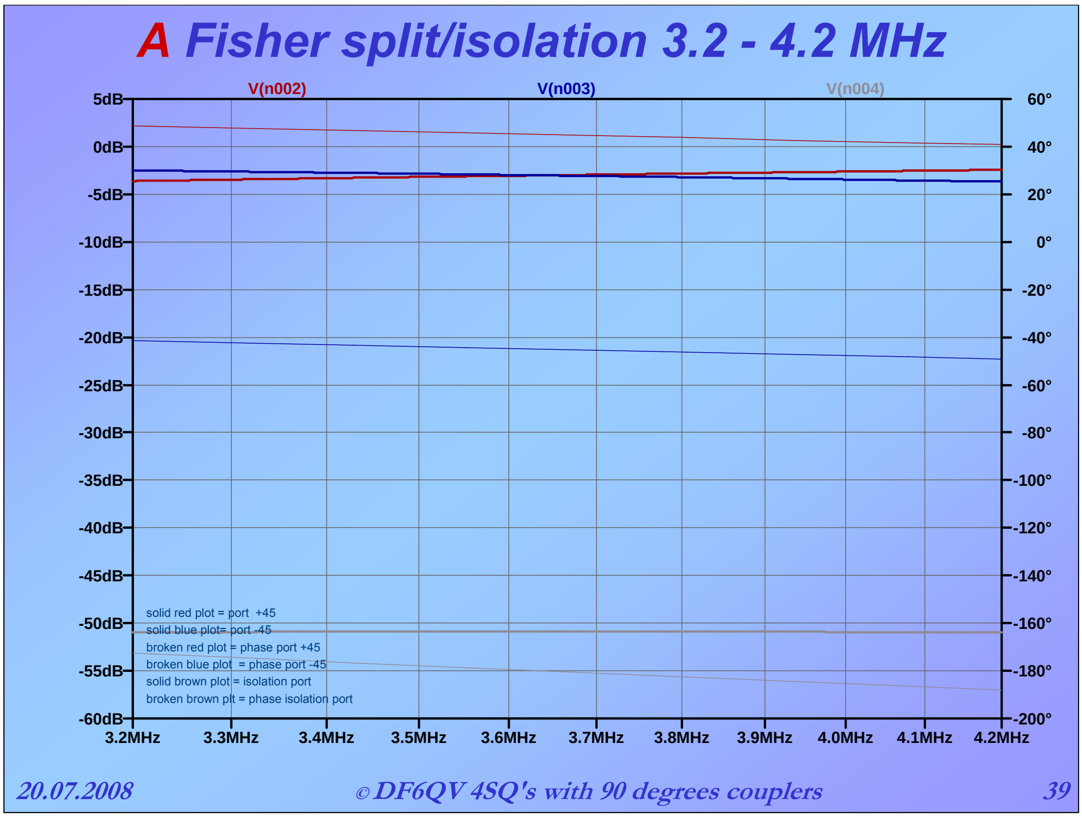
The Reed Fisher coupler seen over a large frequency range. Several different power splits can be realized. The phase difference between the output ports is always 90 degrees.



The dummy isolation is very high over the complete frequency range. This coupler can be designed to realize different power splits.



Power split difference at the band edges is abt. 0.3 dB.
These values are always realized in practice.



Isolation is abt. 50 dB for the whole range. Contrary to the branch line coupler the phase difference is 90 degrees over the whole range.

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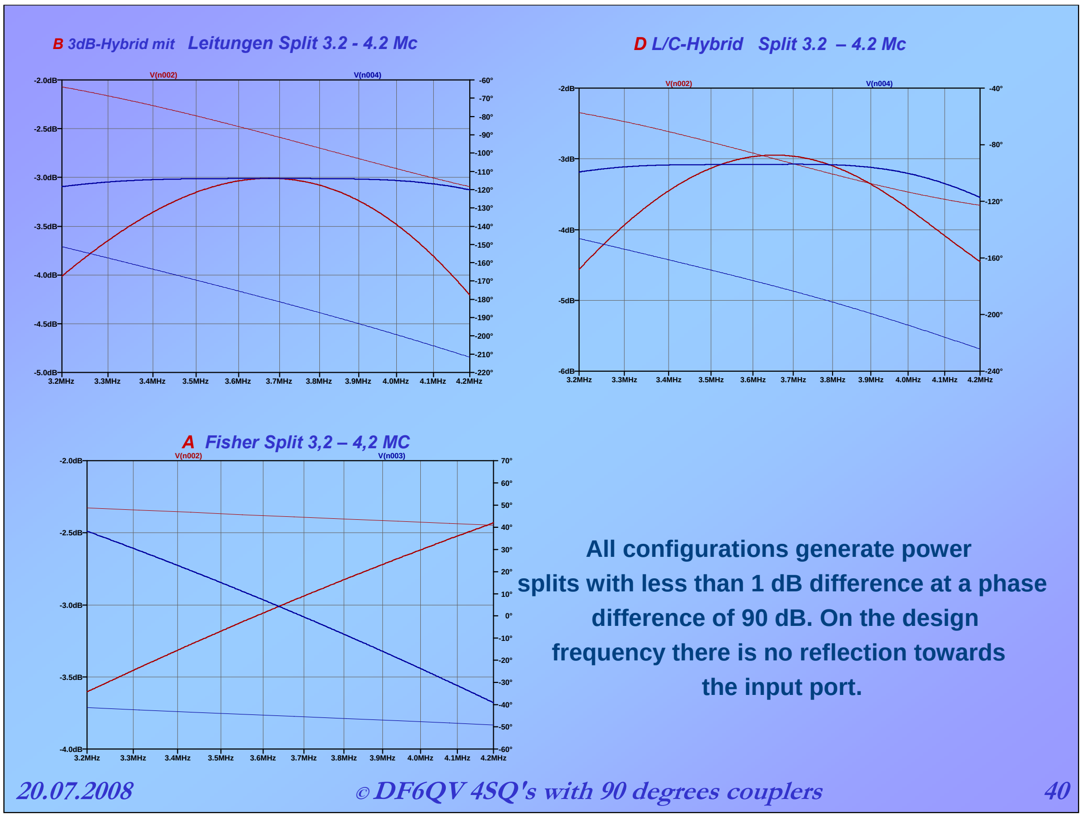


All configurations generate power splits with less than 1 dB difference at a phase difference of 90 dB. On the design frequency there is no reflection towards the input port.

Summary of the results

- ***All variants fulfil the requirements for the design frequency.***
- ***The input power is split into equal parts with a phase difference of 90 degrees.***
- ***The bandwidths are different***
- ***The phase angle of input to output ports is irrelevant (only the output ports matter)***

The Fisher coupler

This coupler shows high isolation to the dummy port over a broad frequency range (theoretically 50 dB, measured 30 dB). You can realize different power splits. The phase difference is 90 degrees over a broad frequency range.

It is hardly believable that there are so many positive properties combined in one circuit design....

Dimensions

The hybrid according to Reed Fisher, W2CQH, described in QST January 1978,

can realize a frequency dependent power split. Equal power is realized when:

- Zo=sqrt (L/C),
- Zo=2*PI*fo*L,
- Zo=1/(2*PI*fo*C).

Dimensions

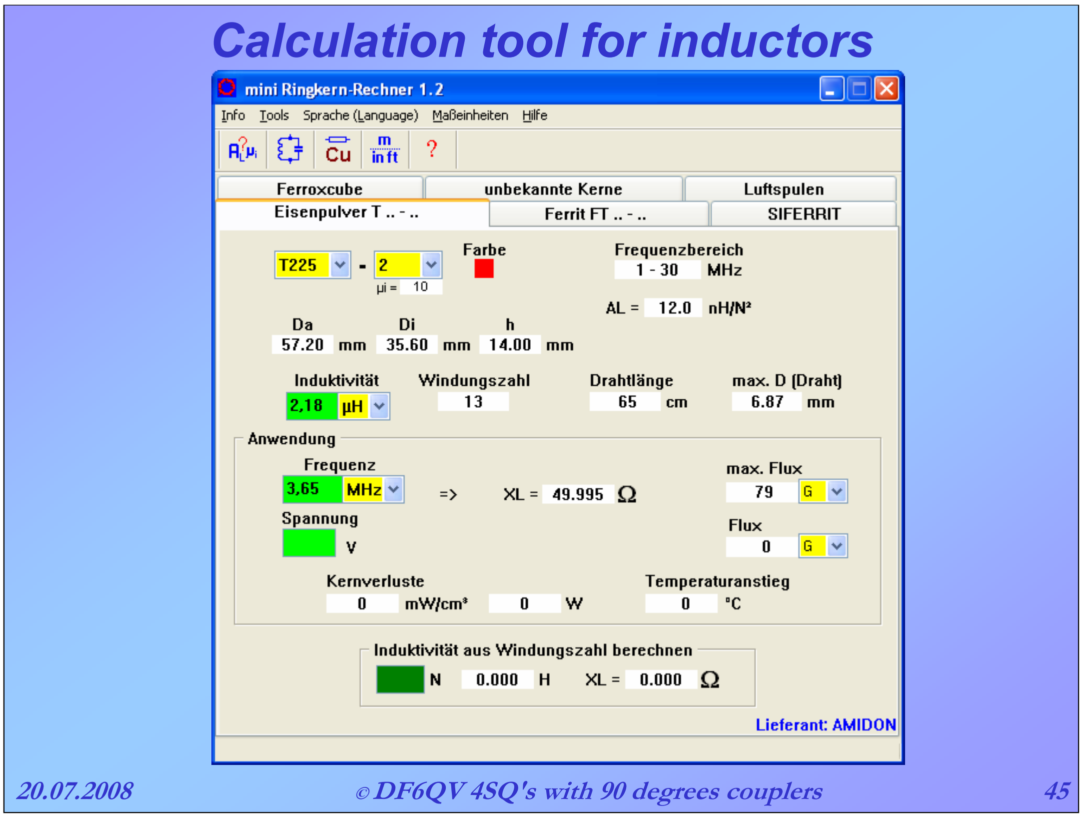
For Zo=50 ohm that means:

Cg = 1/(50*2*PI*fo) for both capacitors inclusive the winding capacitance of the coil

- C = (Cg - stray capacitance) /2

- L = 50/(2*PI*fo)

Das gilt aber für ALLE Zo!!!



http://www.dl5swb.de/html/mini_ringkern-rechner.htm

The software is freeware.

Summary Fisher Hybrid

When both output ports are terminated with the same impedance, no power is reflected to the input! SWR is 1, even if the terminations are not 50 ohms.

The SWR does not provide an indication of the array quality!!!

Several different coupling configurations can be realized, so arrays can be designed with different amplitudes and phasings.

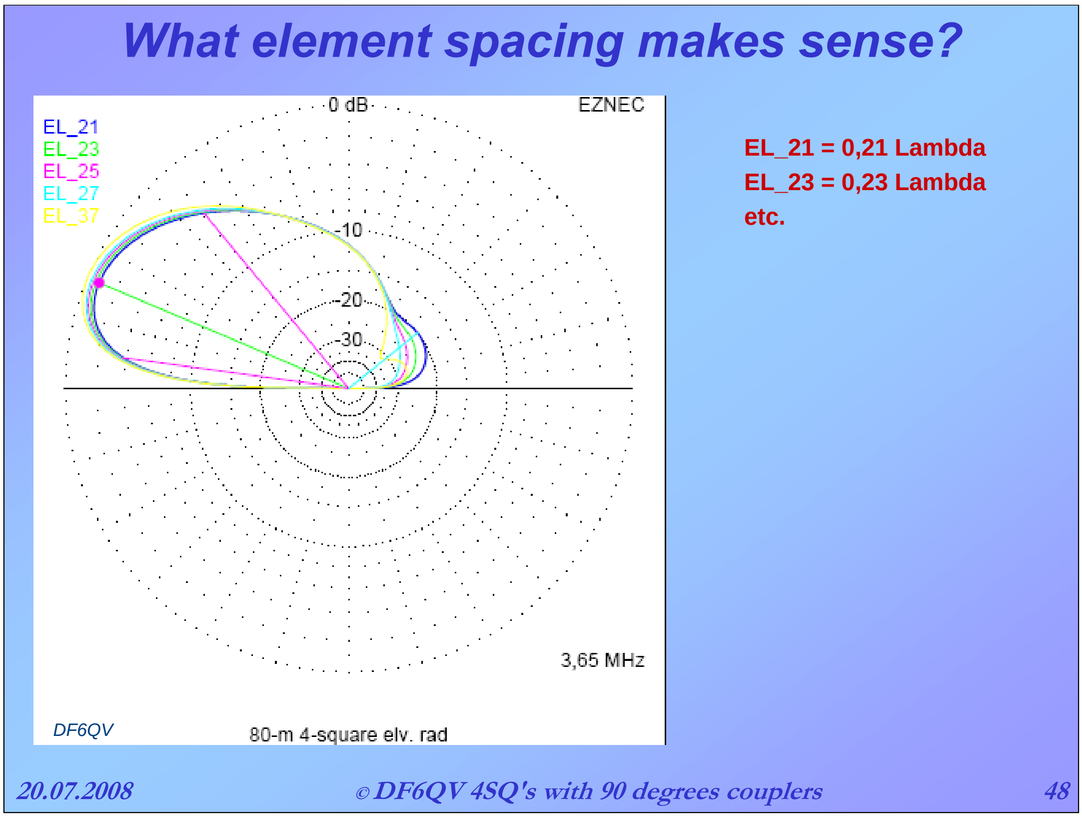
Some more simulations

Radiation diagram vs. element spacing of a 4SQ with one elevated radial (DF6QV 80m 4SQ TS7N) to answer the following questions

Wide spaced arrays?

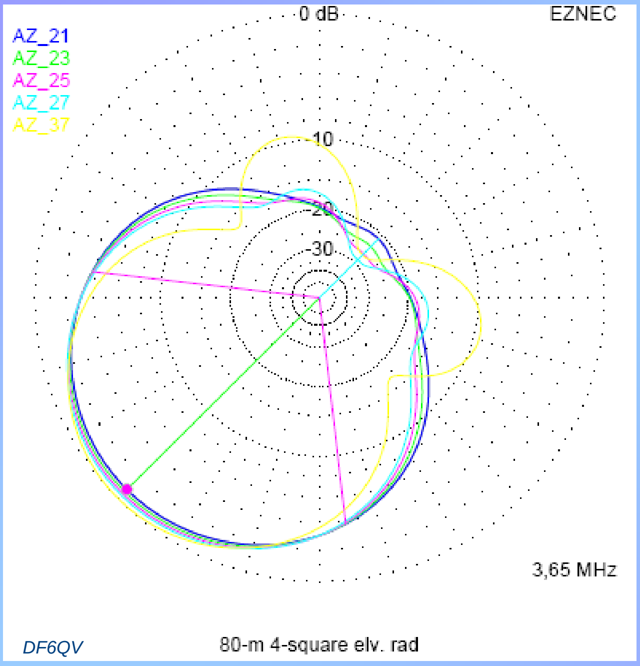
Does it pay?

I have simulated the radiation diagrams for the 4SQ (one radial per radiator) at TS7N for different spacings. Elevation and azimuth diagrams are shown in the next slides.



Elevation plot of an array at different spacings

What element spacing makes sense?



AZ_21 = 0,21 Lambda
AZ_23 = 0,23 Lambda
etc.

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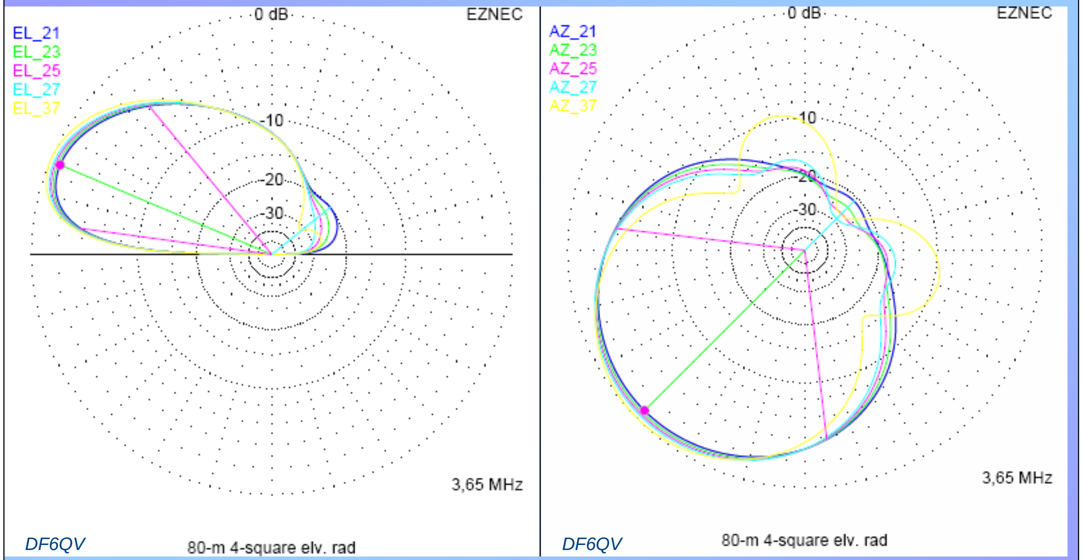
Azimuth plot of an array at different element spacings.

What element spacing makes sense?



Results

Wide spacing results in a small increase in gain, but also in an increase in side lobes.

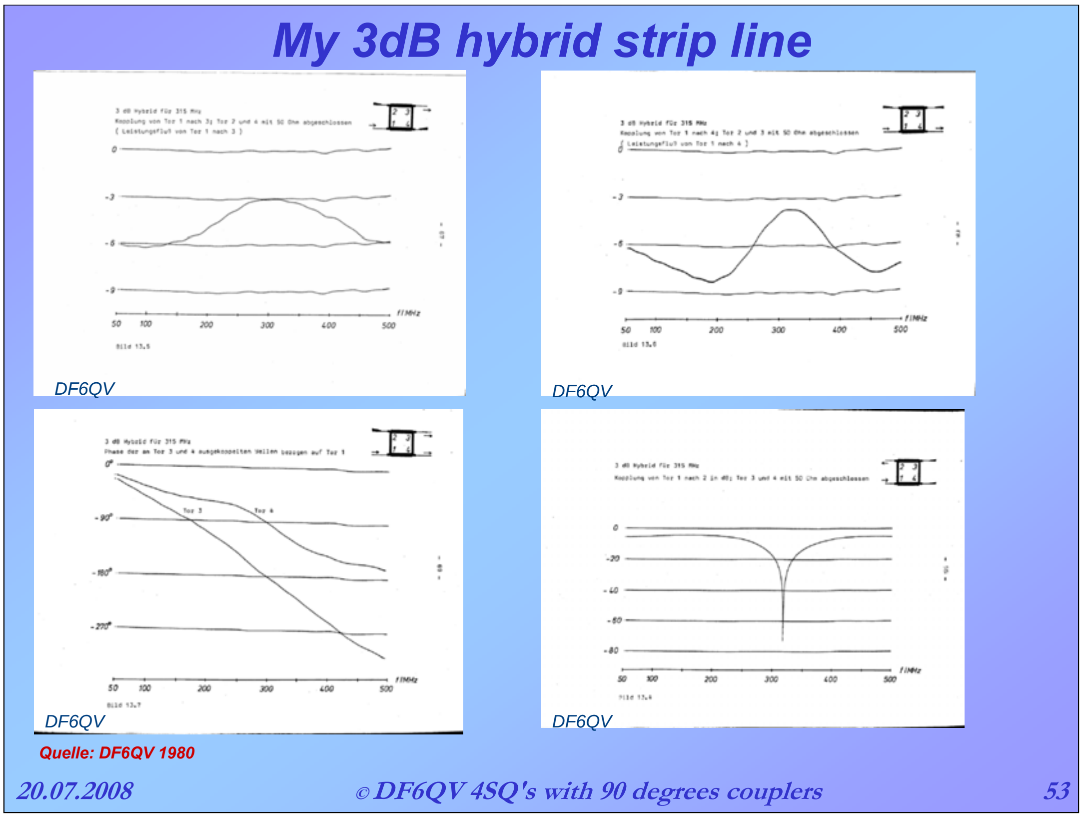
The 3 dB opening angle of the main lobe decreases.

Optimum spacing is between 0.21 and 0.23 wavelengths.

Lambda/4 is not a law!

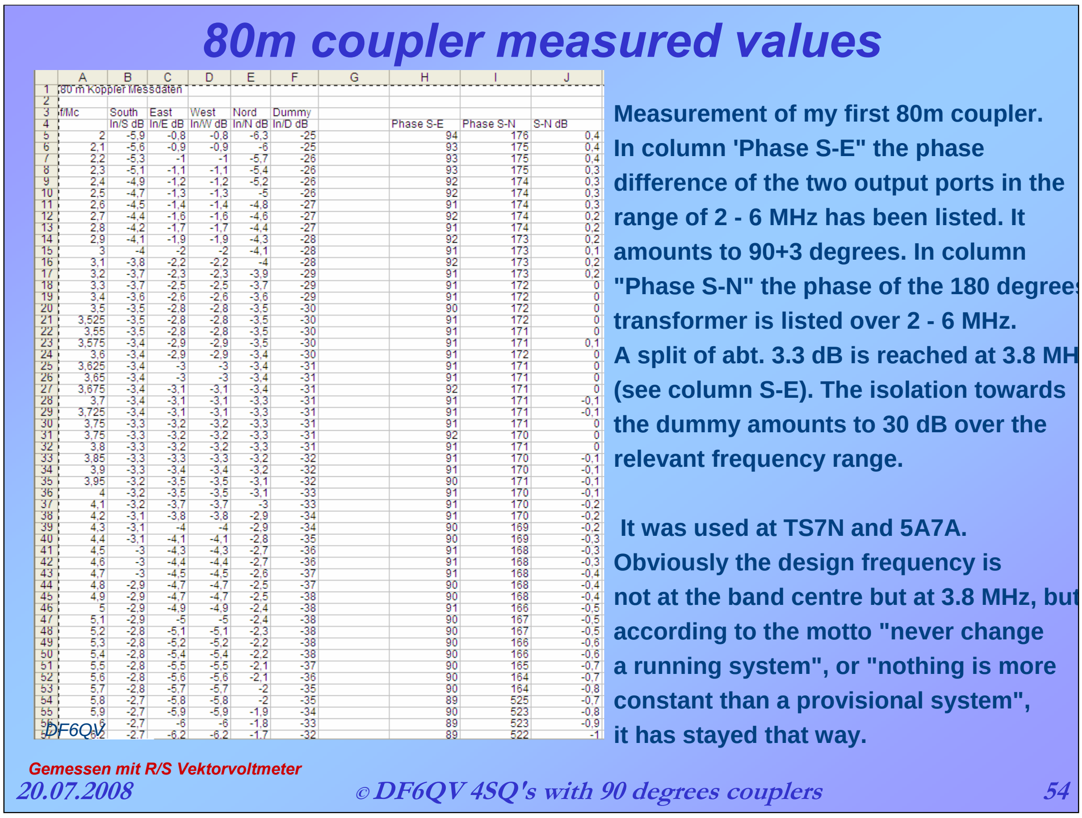
When smaller spacings are used transformer lines with a velocity factor of 0.66 will do. My lines have a velocity factor of 0.66, no foam isolated material. One reason was costs, I still had a lot of 75m ohm spare cable in stock.

From grey theory into the real world!



Here measurements on my 3 dB hybrid for 315 MHz. Couplers with branch lines are used for higher frequencies. One could think of a 4SQ for 2m or 70 cm with collinear elements.

The phase angle is 90 degrees only on the design frequency. It increases with frequency.



	A	B	C	D	E	F	G	H	I	J
1	80 m Koppler Messdaten									
2										
3	f/Mc	South	East	West	Nord	Dummy				
4		In/S dB	In/E dB	In/W dB	In/N dB	In/D dB		Phase S-E	Phase S-N	S-N dB
5	2	-5,9	-0,8	-0,8	-6,3	-25		94	176	0,4
6	2,1	-5,6	-0,9	-0,9	-6	-25		93	175	0,4
7	2,2	-5,3	-1	-1	-5,7	-26		93	175	0,4
8	2,3	-5,1	-1,1	-1,1	-5,4	-26		93	175	0,3
9	2,4	-4,9	-1,2	-1,2	-5,2	-26		92	174	0,3
10	2,5	-4,7	-1,3	-1,3	-5	-26		92	174	0,3
11	2,6	-4,5	-1,4	-1,4	-4,8	-27		91	174	0,3
12	2,7	-4,4	-1,6	-1,6	-4,6	-27		92	174	0,2
13	2,8	-4,2	-1,7	-1,7	-4,4	-27		91	174	0,2
14	2,9	-4,1	-1,9	-1,9	-4,3	-28		92	173	0,2
15	3	-4	-2	-2	-4,1	-28		91	173	0,1
16	3,1	-3,8	-2,2	-2,2	-4	-28		92	173	0,2
17	3,2	-3,7	-2,3	-2,3	-3,9	-29		91	173	0,2
18	3,3	-3,7	-2,5	-2,5	-3,7	-29		91	172	0
19	3,4	-3,6	-2,6	-2,6	-3,6	-29		91	172	0
20	3,5	-3,5	-2,8	-2,8	-3,5	-30		90	172	0
21	3,525	-3,5	-2,8	-2,8	-3,5	-30		91	172	0
22	3,55	-3,5	-2,8	-2,8	-3,5	-30		91	171	0
23	3,575	-3,4	-2,9	-2,9	-3,5	-30		91	171	0,1
24	3,6	-3,4	-2,9	-2,9	-3,4	-30		91	172	0
25	3,625	-3,4	-3	-3	-3,4	-31		91	171	0
26	3,65	-3,4	-3	-3	-3,4	-31		91	171	0
27	3,675	-3,4	-3,1	-3,1	-3,4	-31		92	171	0
28	3,7	-3,4	-3,1	-3,1	-3,3	-31		91	171	-0,1
29	3,725	-3,4	-3,1	-3,1	-3,3	-31		91	171	-0,1
30	3,75	-3,3	-3,2	-3,2	-3,3	-31		91	171	0
31	3,75	-3,3	-3,2	-3,2	-3,3	-31		92	170	0
32	3,8	-3,3	-3,2	-3,2	-3,3	-31		91	171	0
33	3,85	-3,3	-3,3	-3,3	-3,2	-32		91	170	-0,1
34	3,9	-3,3	-3,4	-3,4	-3,2	-32		91	170	-0,1
35	3,95	-3,2	-3,5	-3,5	-3,1	-32		90	171	-0,1
36	4	-3,2	-3,5	-3,5	-3,1	-33		91	170	-0,1
37	4,1	-3,2	-3,7	-3,7	-3	-33		91	170	-0,2
38	4,2	-3,1	-3,8	-3,8	-2,9	-34		91	170	-0,2
39	4,3	-3,1	-4	-4	-2,9	-34		90	169	-0,2
40	4,4	-3,1	-4,1	-4,1	-2,8	-35		90	169	-0,3
41	4,5	-3	-4,3	-4,3	-2,7	-36		91	168	-0,3
42	4,6	-3	-4,4	-4,4	-2,7	-36		91	168	-0,3
43	4,7	-3	-4,5	-4,5	-2,6	-37		91	168	-0,4
44	4,8	-2,9	-4,7	-4,7	-2,5	-37		90	168	-0,4
45	4,9	-2,9	-4,7	-4,7	-2,5	-38		90	168	-0,4
46	5	-2,9	-4,9	-4,9	-2,4	-38		91	166	-0,5
47	5,1	-2,9	-5	-5	-2,4	-38		90	167	-0,5
48	5,2	-2,8	-5,1	-5,1	-2,3	-38		90	167	-0,5
49	5,3	-2,8	-5,2	-5,2	-2,2	-38		90	166	-0,6
50	5,4	-2,8	-5,4	-5,4	-2,2	-38		90	166	-0,6
51	5,5	-2,8	-5,5	-5,5	-2,1	-37		90	165	-0,7
52	5,6	-2,8	-5,6	-5,6	-2,1	-36		90	164	-0,7
53	5,7	-2,8	-5,7	-5,7	-2	-35		90	164	-0,8
54	5,8	-2,7	-5,8	-5,8	-2	-35		89	525	-0,7
55	5,9	-2,7	-5,9	-5,9	-1,9	-34		90	523	-0,8
56	6	-2,7	-6	-6	-1,8	-33		89	523	-0,9
57	6,2	-2,7	-6,2	-6,2	-1,7	-32		89	522	-1

Measurement of my first 80m coupler. In column 'Phase S-E" the phase difference of the two output ports in the range of 2 - 6 MHz has been listed. It amounts to 90+3 degrees. In column "Phase S-N" the phase of the 180 degrees transformer is listed over 2 - 6 MHz. A split of abt. 3.3 dB is reached at 3.8 MHz (see column S-E). The isolation towards the dummy amounts to 30 dB over the relevant frequency range.

It was used at TS7N and 5A7A. Obviously the design frequency is not at the band centre but at 3.8 MHz but according to the motto "never change a running system", or "nothing is more constant than a provisional system", it has stayed that way.

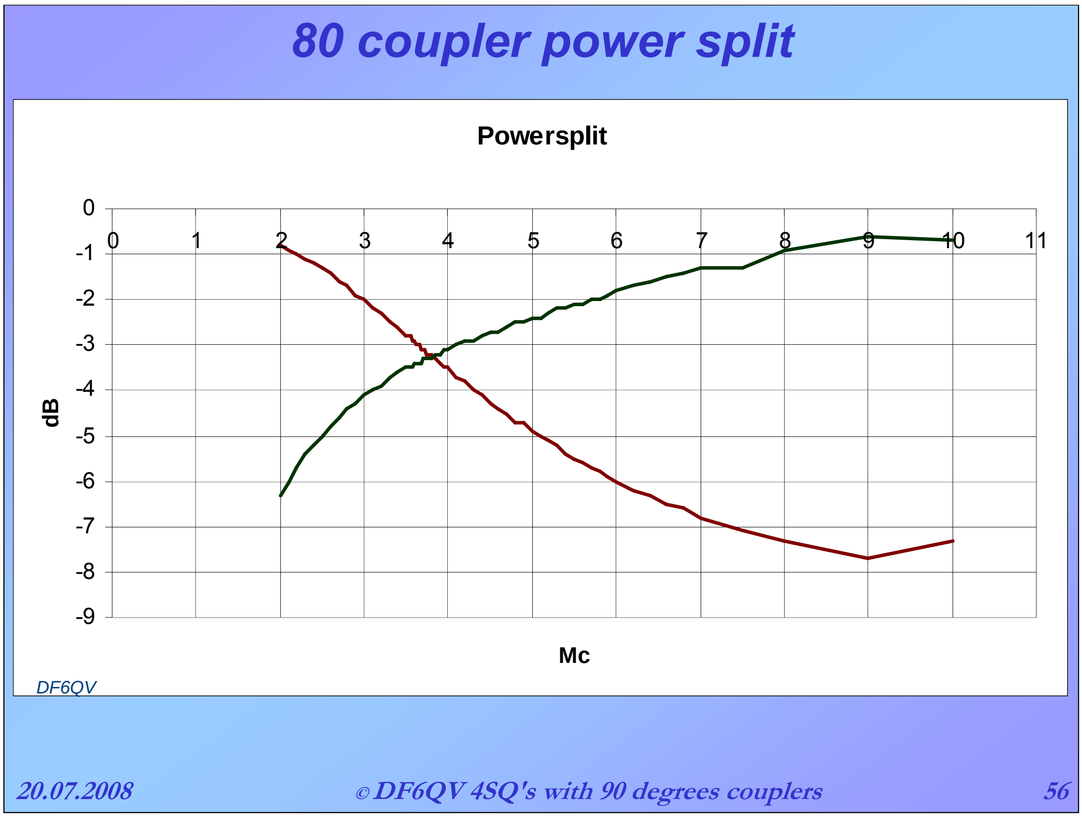
80m coupler measurement (Fisher)

15	80 m Koppler Messdaten								
16									
17	f/Mc	South	East	West	Nord	Dummy			
18		In/S dB	In/E dB	In/W dB	In/N dB	In/D dB	Phase S-E	Phase S-N	S-N dB
19									
20	3	-4	-2	-2	-4,1	-28	91	173	0,1
21	3,1	-3,8	-2,2	-2,2	-4	-28	92	173	0,2
22	3,2	-3,7	-2,3	-2,3	-3,9	-29	91	173	0,2
23	3,3	-3,7	-2,5	-2,5	-3,7	-29	91	172	0
24	3,4	-3,6	-2,6	-2,6	-3,6	-29	91	172	0
25	3,5	-3,5	-2,8	-2,8	-3,5	-30	90	172	0
26	3,525	-3,5	-2,8	-2,8	-3,5	-30	91	172	0
27	3,55	-3,5	-2,8	-2,8	-3,5	-30	91	171	0
28	3,575	-3,4	-2,9	-2,9	-3,5	-30	91	171	0,1
29	3,6	-3,4	-2,9	-2,9	-3,4	-30	91	172	0
30	3,625	-3,4	-3	-3	-3,4	-31	91	171	0
31	3,65	-3,4	-3	-3	-3,4	-31	91	171	0
32	3,675	-3,4	-3,1	-3,1	-3,4	-31	92	171	0
33	3,7	-3,4	-3,1	-3,1	-3,3	-31	91	171	-0,1
34	3,725	-3,4	-3,1	-3,1	-3,3	-31	91	171	-0,1
35	3,75	-3,3	-3,2	-3,2	-3,3	-31	91	171	0
36	3,75	-3,3	-3,2	-3,2	-3,3	-31	92	170	0
37	3,8	-3,3	-3,2	-3,2	-3,3	-31	91	171	0
38	3,85	-3,3	-3,3	-3,3	-3,2	-32	91	170	-0,1
39	3,9	-3,3	-3,4	-3,4	-3,2	-32	91	170	-0,1
40	3,95	-3,2	-3,5	-3,5	-3,1	-32	90	171	-0,1
41	4	-3,2	-3,5	-3,5	-3,1	-33	91	170	-0,1
42	4,1	-3,2	-3,7	-3,7	-3	-33	91	170	-0,2
43	4,2	-3,1	-3,8	-3,8	-2,9	-34	91	170	-0,2
44	4,3	-3,1	-4	-4	-2,9	-34	90	169	-0,2

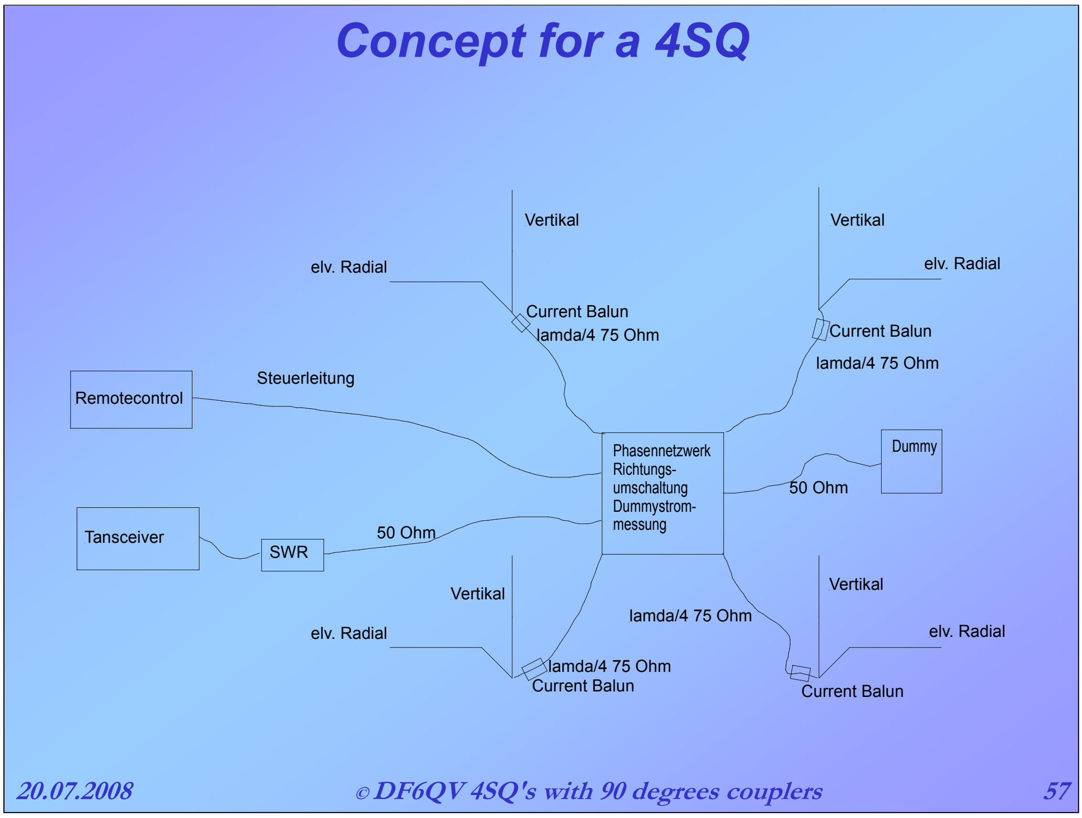
DF6QV

Gemessen mit R/S Vektorvoltmeter

At 3.8 MHz the difference between the output ports is 0 dB, at the lower band end 0.7 dB. The decoupling to the dummy (isolation) is abt. 30 dB. The phase angle is 91 +- 1 degree. The 180 degree transformer (compressed delay line) provides 170 degrees.



The amount of coupling is strongly frequency dependent. However, it can be used across the entire 80m band. If you choose only one mode (CW/SSB), you can tune the coupler to the required design frequency.

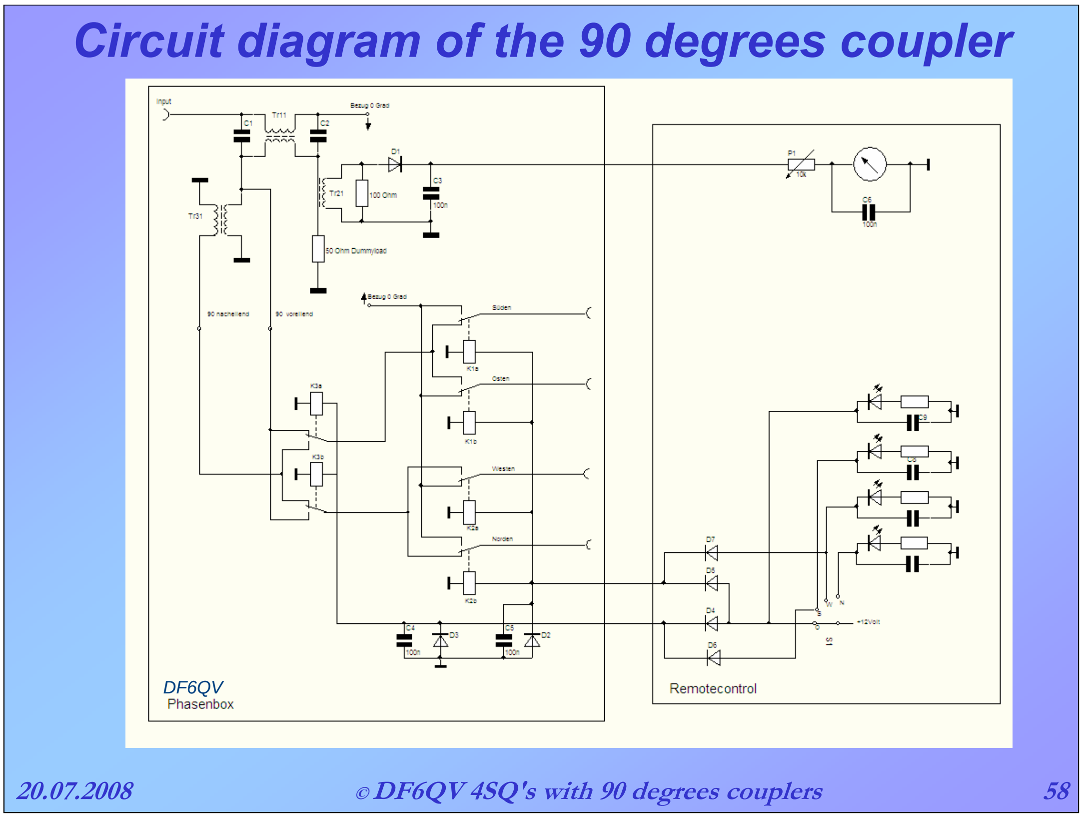


Concept for a 4SQ

The radiator impedance should be as close to 50 ohms as possible. Through the lambda/4 transformers (75 ohm cables) this impedance is transformed to about 100 ohms. In the phasing network 2 of the radiators are switched in parallel, one pair directly having the same 0 degree phase, and the other two separated by the 180 degrees transformer with the same effect on the impedance. The hybrid coupler has been designed for 50 ohm.

If you use ground planes with 36 Ohm impedance, lambda/4 transformers made of 60 Ohm cables transform the impedance exactly to the 100 ohm you need.

One could also imagine a coupler for 25 ohms. In that case you do not need the lambda/4 transformer lines to the radiators. The input impedance of the hybrid will be 25 ohms, which will have to be transformed to the 50 ohms TX output.



Here is the circuit diagram of the coupler.

The power measurement for the power in the dummy has a current transformer of 30:1. Top left you find the hybrid according to Reed Fisher, under it at the left there is the 180 degrees transformer.

The power going into the dummy should not exceed 10% of the input power. This would mean a loss of 1dB already. To calibrate the measuring instrument you take away all 4 antennas. At the four antenna terminals there will be infinite SWR (reflection factor 1), and the complete power goes into the dummy. Then mark the instrument for a 100 Watts reading (10% of 1 kW).

Note: The input SWR will remain 1, the same value as with all antennas connected!

Radiator elements for 4SQs

- -Groundplanes with elevated radials
- -Groundplanes with non-resonant radials on or in the ground
- -vertical dipoles
- -collinear elements etc.

The input impedance of an antenna is

Ze=Zs+Zv

Zs=Radiation resistance

Zv=Loss resistance

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Of course, other elements are possible. The losses should be small compared to the radiation resistance in order to maintain high efficiency. It is not recommendable to warm up the ground with our precious RF...

RDF Receiving-Directory-Factor

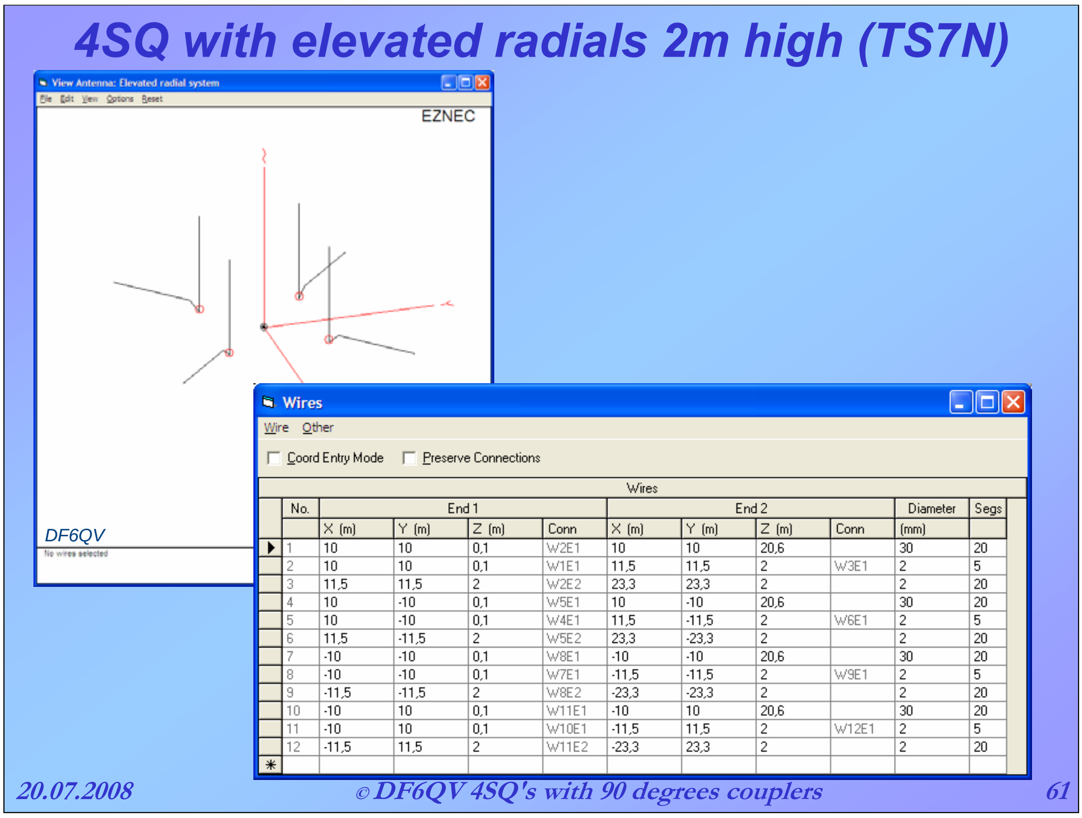
	RDF Summary Table #1				
	RDF (dB)	Max Gain (dBi)	Take-Off Angle (degrees)	Broadband	Description
	5.06	1.41	24	no	130' Vertical (MININEC ground (no loss))
	5.06	-0.09	24	no	130' Vertical (MININEC ground (15 Ohms loss))
	5.06	0.6	24	no	130' Vertical (real ground, 60 radials)
	5.26	-15.9	90	no	small loop (6-sided, 36' perimeter)
	7.52	-15.42	24	yes	Big Flag (40'X50')
	7.54	-24.35	24	yes	K9AY (MININEC ground)
	7.67	-20.31	33	yes	EWE (15' X 45', MININEC ground)
	7.69	-28.75	24	yes	Flag
	8.02	**-21.34**	**24**	**yes**	**2-element Broadside K9AY Array, 0 degree phasing, 100' spacing**
	8.10	7.46	90	no	Inverted VEE (100'/80')
	8.11	**-26.01**	**24**	**yes**	**2-element Broadside Flag Array, 0 degree phasing, 100' spacing**
	8.13	4.55	90	no	Inverted VEE (40'/20')
	8.13	**2.81**	**27**	**no**	**EZNEC demo 2-element End-fire vertical (real ground)**
	8.28	7.34	90	no	Inverted VEE (80'/60')
	8.30	-18.53	66	yes	Benchmark Beverage (250')
	8.33	6.68	90	no	Inverted VEE (60'/40')
	8.52	**-24.48**	**24**	**yes**	**3-element Broadside Flag Array, 0 degree phasing, 100'X100' spacing**
	9.05	-16.94	60	yes	Benchmark Beverage (330')
	9.34	**-19.23**	**60**	**yes**	**W8JI Parallelogram Array (370'X70')**
	10.03	-15.23	48	yes	Benchmark Beverage (470')
>>>	**10.42**	**5.29**	**24**	**no**	**EZNEC demo 4-Square (MININEC ground, 7.15 MHz)**
	11.04	-13.48	39	yes	Benchmark Beverage (660')
	11.12	**-25.28**	**18**	**yes**	**2-element End-fire K9AY Array, 180 degree phasing, 117' spacing**
	11.35	**6.01**	**24**	**no**	**EZNEC demo 4-Square, WA3FET, Jim Breakall phasing**
	11.39	**-31.38**	**18**	**yes**	**2-element End-fire Flag array, 180 degree phasing, 100' spacing**
>>>	**11.73**	**6.3**	**24**	**no**	**EZNEC demo 4-Square, 120 degree phasing**
	12.00	-11.9	30	yes	Benchmark Beverage (890')
	12.47	**7.16**	**21**	**no**	**W8WWV hex array (165 degree phasing, MININEC ground)**
	13.00	-10.51	24	yes	Benchmark Beverage (1160')
	14.00	-9.33	21	yes	Benchmark Beverage (1460')
>>>	14.92	-8.31	18	yes	Benchmark Beverage (1800')

Quelle: http://www.seed-solutions.com/gregordy/Amateur%20Radio/Experimentation/RDFMetric.htm
W8WWV -Greg Ordy

Antennas are often compared to RDF (Receiving Directivity Factor). It is the ratio of Average Gain (shown by EZNEC in the 3D-plot) to the forward gain of the antenna. Compare both 4SQs and the long beverages maked in the sheet...

Normally, you do not need a separate receiving antenna when using a 4SQ.

Verticals receive more noise, but when the noise level is reasonable the 4SQ does the job. At 5A7A only the 4SQ was used for TX and RX on 80 m.



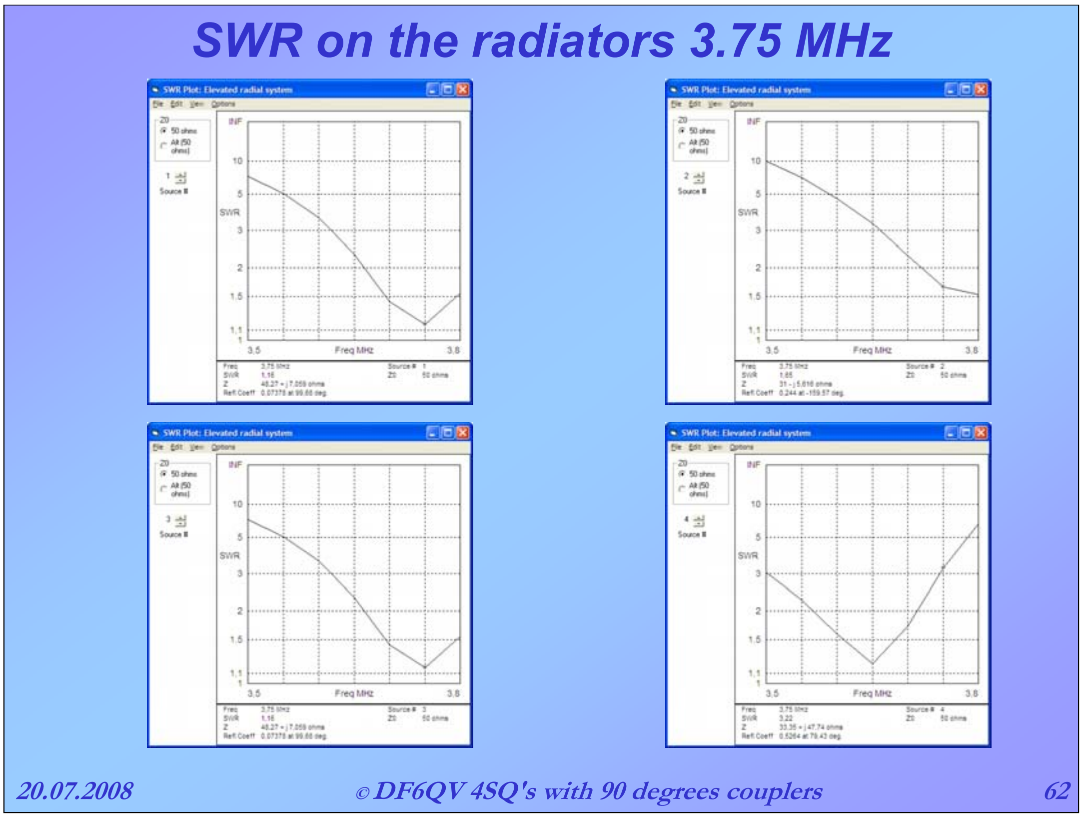
No.	End 1 X (m)	End 1 Y (m)	End 1 Z (m)	End 1 Conn	End 2 X (m)	End 2 Y (m)	End 2 Z (m)	End 2 Conn	Diameter (mm)	Segs
1	10	10	0,1	W2E1	10	10	20,6		30	20
2	10	10	0,1	W1E1	11,5	11,5	2	W3E1	2	5
3	11,5	11,5	2	W2E2	23,3	23,3	2		2	20
4	10	-10	0,1	W5E1	10	-10	20,6		30	20
5	10	-10	0,1	W4E1	11,5	-11,5	2	W6E1	2	5
6	11,5	-11,5	2	W5E2	23,3	-23,3	2		2	20
7	-10	-10	0,1	W8E1	-10	-10	20,6		30	20
8	-10	-10	0,1	W7E1	-11,5	-11,5	2	W9E1	2	5
9	-11,5	-11,5	2	W8E2	-23,3	-23,3	2		2	20
10	-10	10	0,1	W11E1	-10	10	20,6		30	20
11	-10	10	0,1	W10E1	-11,5	11,5	2	W12E1	2	5
12	-11,5	11,5	2	W11E2	-23,3	23,3	2		2	20

Here the modeling of the elements of the 80m 4SQ for TS7N is shown. It consists of 4 radiators with a length of 20.6m, which are operated with one elevated radial each. This runs up at an angle of 45 degrees to a height of 2m and the rest is kept at that height.

Theoretically, the radiator would be enough, the function of the radial is to provide ground. With a lambda/4 radial above ground (the higher the less loss) the open end of the radial transforms into an RF-short at the base of the radiator.

As current flows in the radial it will radiate (high angle radiation). If a second radial is connected symmetrically to the first one, both fields cancel and only the radiation of the radiator will remain.

The resonance of the antenna can be adjusted with the length of the radial(s). For the antenna above radial length is abt. 21 m for CW and abt. 19m for SSB.

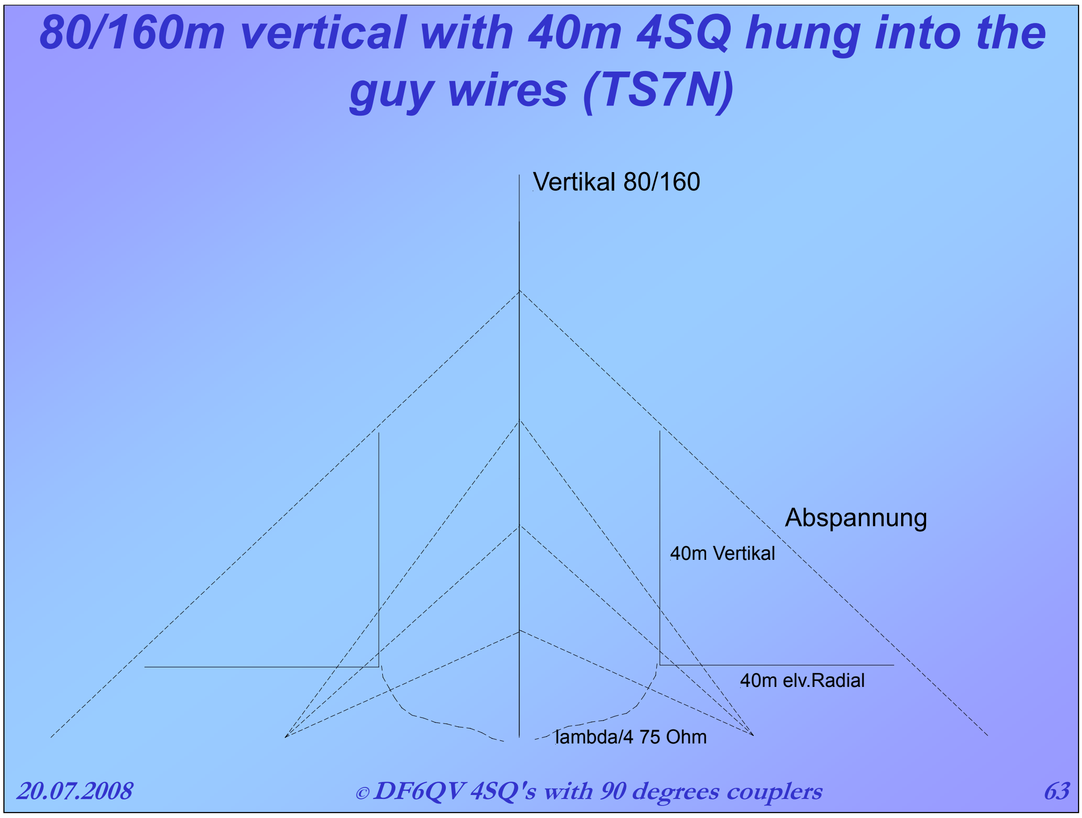


SWR of the radiators on 3.75 MHz

Here the modeled SWR of the 4 elements, which have been separately tuned to 3.75 MHz. Through mutual coupling the input impedances will be influenced and they become different from the targeted 50 ohms.

In practice I have tuned every single element with the length of the radials to the operating frequency (with the 3 other radiators open!), and then connected it to the coupler. The dummy showed a minimum of power, which remained well under 5%.

The 50 ohms input resistance are the sum of 38 ohms radiation resistance, and abt. 12 ohms ground loss.



This picture shows the 40m wire 4SQ. It was hung into the guy wires of a 22m vertical. The vertical was designed to be used on 80/160, but was used on 30m via a match box.

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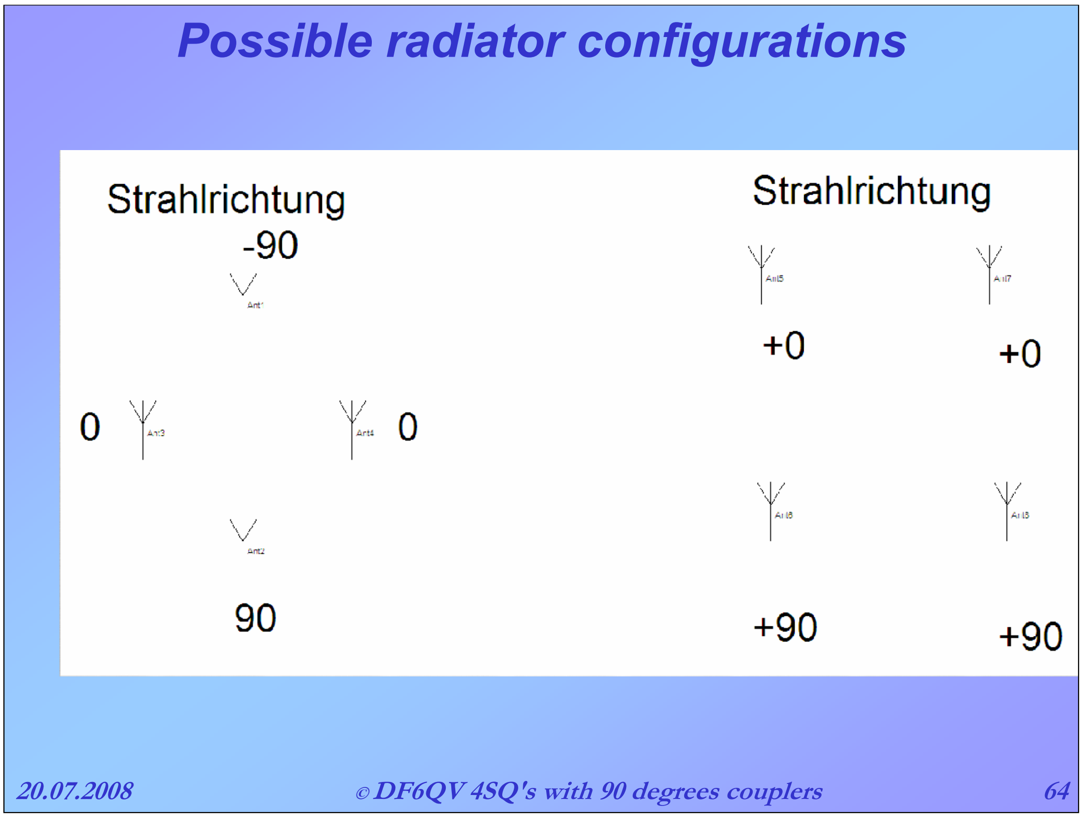


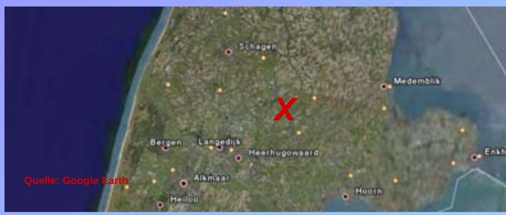
In the sketch 2 possible radiator configurations are shown. For the "simple" solution of a 4SQ in 90 degree technique a diamond structure was chosen. When optimum amplitude and phase angles are chosen, the 3dB lobe width can become so narrow that 45 degree switching becomes necessary.

That could be a combination of both configurations

PA0GMW has realized a 4SQ with 45 degree switching.

Eight direction switching is described by Al Christman, K3LC, in the web:
http://www.ncjweb.com/k3lc4squarea.pdf

http://www.qrz.com/detail/PA0GMW



Have a look to the URL for some more pictures

You cannot find a better location for a 4SQ. Low height over ground water level, 45 degrees switching

The red cross marks the location of the antenna

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The red cross marks the location of the antenna

Make the system portable

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Not all this belongs to the 4SQ, in three of the drain pipes and some suitcases, not shown here, I had 180 kg of baggage for TS7N.

4 x 20,5 m Alu in TS7N

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4 Aluminum verticals 20.5 meter elements for the 80m 4SQ

Does not look very comforting

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Homemade aluminum vertical 20.5 m long.

The diameter at the bottom is 50 mm.

Must go up...

This picture was also published in CQDL

Attaching coax and radial

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You can see the radial going up at a 45 degree angle. To the rear on the ground the 75 ohm lambda/4 transformer line can be seen.

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With 3 guys almost storm-proof

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An 80m element viewed from the ground. The element is guyed in 4 directions at 3 levels. The guys are prepared for the right length before the element is hoisted. Guy wires are 3mm rope.

80m 4SQ / 22m vertical with 40m 4SQ

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To the rear there is the 80m 4SQ. In the front you can see the 22m vertical with the wire 4SQ for 40m.

80m coupler with dummyload

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Home made coupler and dummy provisionally protected from rain

Foot point with current balun (abt 500 ohms)

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The common mode choke has a Z of 500 ohms. You can measure the impedance at the design frequency with an antenna bridge like the RF1. We want the elements to radiate and not the cables! The coil on the right has quite a high impedance and short-circuits the element for statics. It may not be necessary...

By changing the length of the radials by about 2 meters the antenna can be tuned for either CW or SSB. Tuning the array takes about 15 minutes, and was integrated in our operator fitness program...

40m coupler on the wire 4SQ

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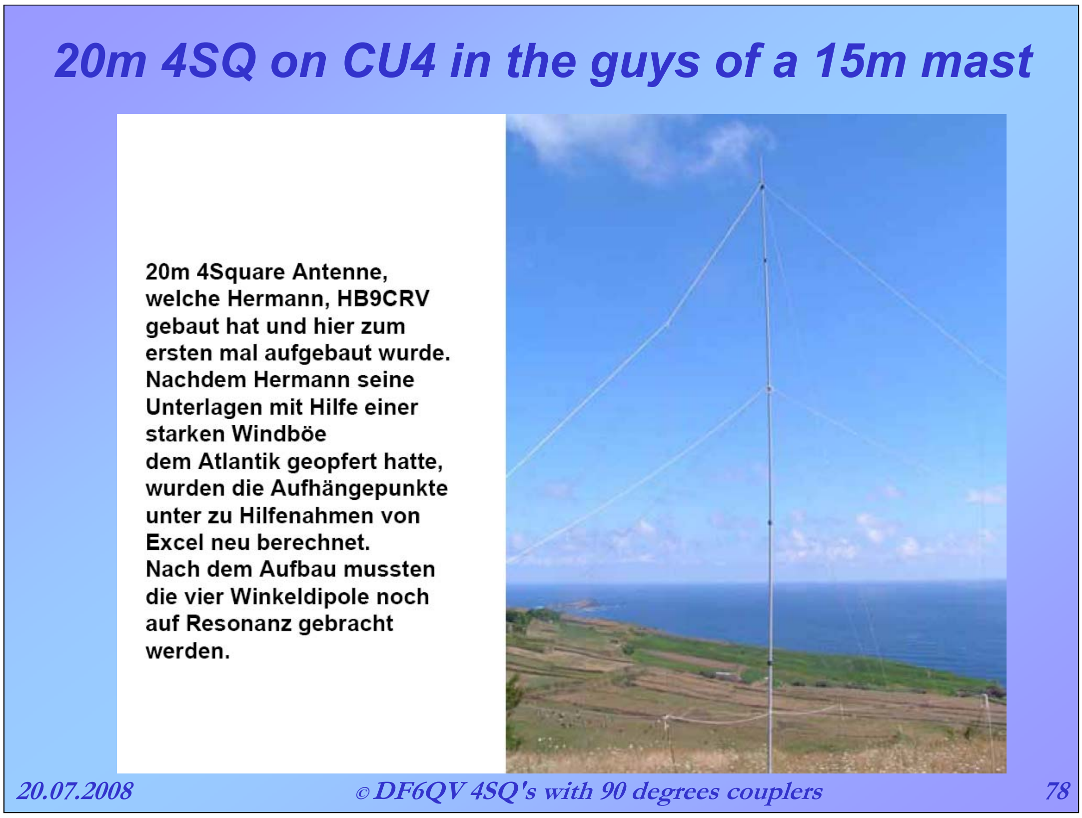
The 22m vertical was originally planned to be used on 80 and 160m with a matching network. This was not tested at home. And then Murphy was present and it did not work. Later the cause was found to be a defective measurement lead. Its length of 22m is not far from 5/8 lambda for 30m. The antenna could be matched with the built-in matching unit of a FET power amp.

We used Dynema kite wire to guy the antenna.

40m element with current balun

Feed point of a 40m wire element with a common mode choke of abt. 500 ohms, which can be easily reached at 7 MHz. In my opinion 500 ohms is sufficient.



Built for the first time, the 20m 4SQ antenna by Hermann HB9CRV.

After Hermann lost the building instructions in a strong wind gust, which blew them into the Atlantic, all connection points had to be recalculated with an excel spreadsheet.

There is always a lot of stuff to be packed. To the right a test model for a 4SQ element. Mechanically everything was o.k., but it should have been tested better electrically. I had tested it with an elevated radial. It was not optimal and to be perfected in 5A. In 5A, 2...3 km from the hotel there was a 1250 kHz transmitter that did not allow us to use the RF1. It always synchronized on 1250 kHz. So the only way was to build it and look how it worked.

Before an expedition there is always a lot of work to be done. Most team members got a job according to their capabilities. It is the job of the team leader to find the right people for the job, and to persuade them to do it responsibly. Andy, DJ7IK, chose me to look after some of the low band antennas.

At the top,there is a test model of an 18m GFK mast lengthened with 2m aluminum tubing. I wanted to make sure we could put it on almost any type of ground. Suitably guyed an element can be erected by 2 persons.

40m 4SQ in 5A7A (K1LZ)

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The 40m 4SQ on the roof of the hotel.

Instead of one elevated radial we connected 4 on-ground radials. Question by the ops: "How's the SWR?". Through the use of the coupler with equal loads (all too long, hi) the SWR was 1 "Oh, great!". In the CW band about 10% of the power of the ACOM 1000 went into the dummy, in the SSB portion about 15%. Nobody wanted to take the radiator down anymore, and from the bottom we could shorten the radiators some 70 cm. In CW it was now only 5% and on SSB still 10%... we could have been 1dB louder.

It is not easy to provide data for such an antenna. I have noticed a F/B of abt. 20dB in TS7N and 5A7A. When the antenna in 5A7A was switched from Italy towards the USA, the Italians were about 30 dB down (on the S-meter of an IC746).

I remember one contact with a N8 station. It had 100 Watts and a dipole. It took about 1 minute before I had the call sign ok.

"Little pistols" also have fun working DX!

18m fibreglass with 2m Aluminum foot.

The aluminum tent pegs needed help from a stone.

Under the black plastic bag the coupler and the dummy are hidden.

Element foot with PVC insulator, an aluminum profile to get hold in sand or any other material one finds, 4 radials, a common mode choke with abt. 500 ohms and a loose screw.

The feed point resistance of a ground mounted GP is dependent on the number of radials. An ideal GP has 36 ohms. That value is reached with some 120 radials. 60 radials already do a good job.

Obviously the number of radials near salt water is not significant.

You can find some info about verticals, radials etc.:
http://www.steppir.com/pdf/radial%20systems%20for%20vertical%20antennas.pdf

Stone washed in by the flood (tent peg)

A strong northerly wind had made the Mediterranean wash away half the beach, so one of the tent pegs came loose. The 4SQ had become a 3SQ.

Electrically this means that 100% of the power in that element were reflected (25% of the total 4SQ power). 50% of this power was reflected into the dummy and 50% into the input terminal of the coupler. The ACOM got 12.5% back and showed an SWR of 2.

Normally we had 850 Watts fwd and only 2 Watts reverse.

Antennas cannot be high enough

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DJ4AX once said: "Antennas cannot be high enough". He meant horizontal antennas like Yagis and dipoles. Here is an attempt involving a vertical...

If you build too close to the water...

then you need flexibility. Krassy and Dima bring a waterproof tent peg.

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Often a high degree of flexibility is necessary.

Picture taken by "US spy" K3LP

Top left: DF6QV walking along an aluminum vertical

Top right: Construction detail aluminum/GFK mast

Bottom: 80m coupler

The boxes have worked well. The antenna could have been adjusted better, but it worked anyway. This antenna construction tolerates small errors.

I would call it a plug-and-play system.

18021 QSOs, a former world record...

until VP6DX worked 300 more....

20.07.2008 *© DF6QV 4SQ's with 90 degrees couplers* *93*

18000 QSOs, how you can get that record?

1. Activate a rare country
2. Have a crew that can manage pileups
3. Build the antenna close to the sea, so you have the best possible ground.

Salt water keeps the front lobe down to 5 degrees. This means an extra gain of 6dB, less hops decrease the reflection losses on the E- and F-layers.

4. Take an antenna that is tried out and tested, and has acceptable gain
5. Take along a propagation specialist
6. Somebody should know the ins and outs of antennas, so they can be repaired, adjusted and whatever is needed to enhance them.
7. If you knew how many small errors were still present in the 5A7A antenna, you would wonder why we could set a world record.

8 Good organization, tnx to Andy, DJ7IK (TS7N, 5A7A)

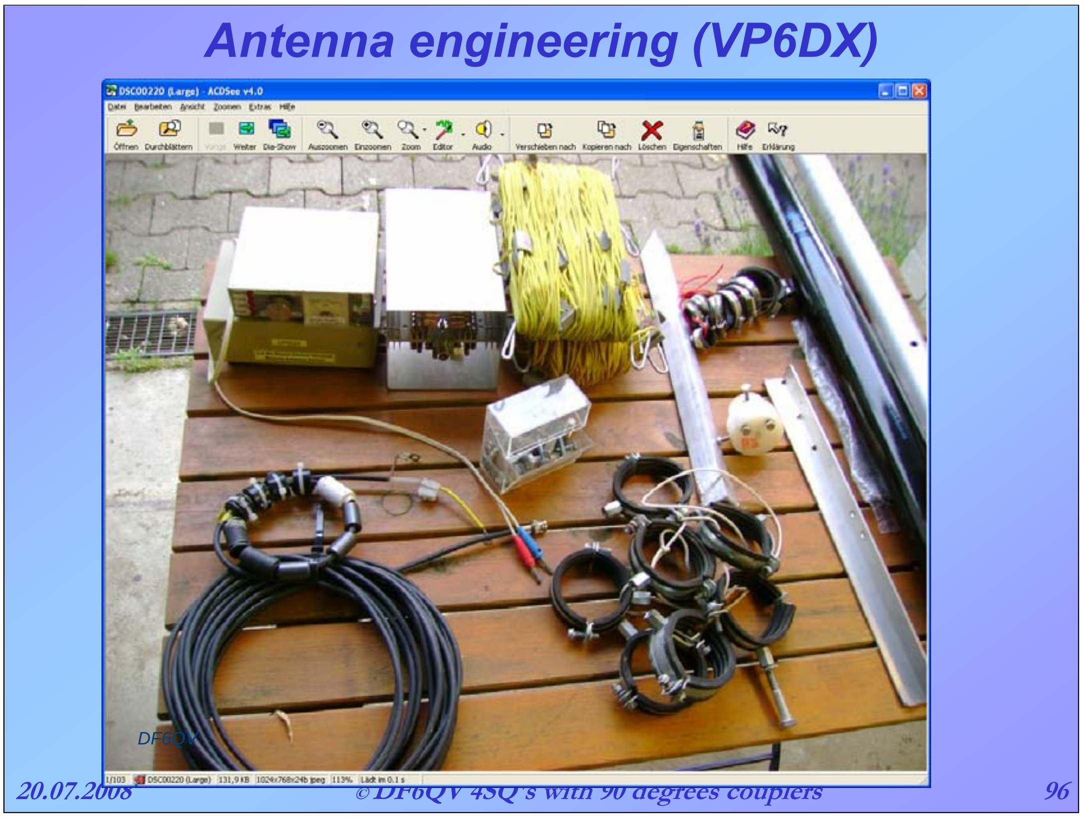
Antenna engineering (VP6DX)

DJ8NK called me and asked if I would like to help the crew of VP6DX with my experience. In Dayton there were rumours 6QV had provided a reasonable 80m 4SQ in 5A7A. After a week I called DL6LAU to say I would help. I was a bit uncomfortable, because for VP6DX it MUST work! First Carsten wanted my 5A7A coupler. After some discussions we decided he would not get this "plug and pray" version, but I would build a new one.

Antenna engineering (VP6DX)

It took some time, but it has really become a plug-and-play version.

I had a strange feeling when I packed the coupler and put it into the mail. I had provided several pictures and other documentation, so they could begin with the antenna construction.



Top left you see the coupler with the control box, next to it the dummy. Then there are the pre-cut guys, an aluminum tent peg, the 18m GFK mast, 2 meters of aluminum pipe to be used as a foot construction to lengthen the mast.

Bottom left there are the 75 ohm transformer line with common mode choke, the mounting clamps for the GFK mast and the aluminum pipe, PVC insulator with an aluminum bracket as antenna foot.

Here another view, you see the partly pre-mounted GFK mast and the foot construction.

Information pics for VP6DX

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A few more informative pictures.

Tent peg details

To the right the phasing and remote control box with control leads.

At the bottom left you can see how the guys were attached to the mast to be easily fastened and loosened with any tools.

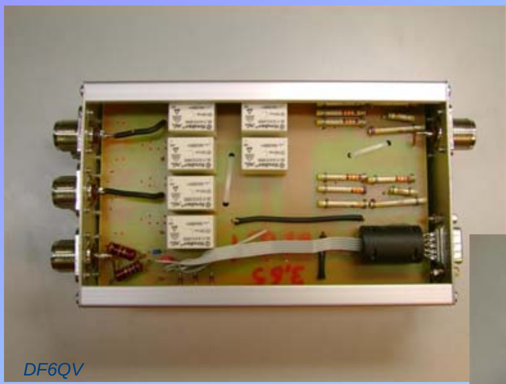
Top left: 1.2 kW out, SWR 1.1

Top right: Coupler with four 100 ohm dummies (antenna substitutes) and a 50 ohm dummy for a quick test (CW dots) for abt. 30 seconds (afterwards you see smoke...).

Bottom: inside view of the couplers, two for 80m, one for 40m and one for 30m

Not in the picture a coupler for 160m, all for VP6DX

Left 80m - right 30m



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The two couplers for 80m and 30m – top and bottom view

Hardware for VP6DX

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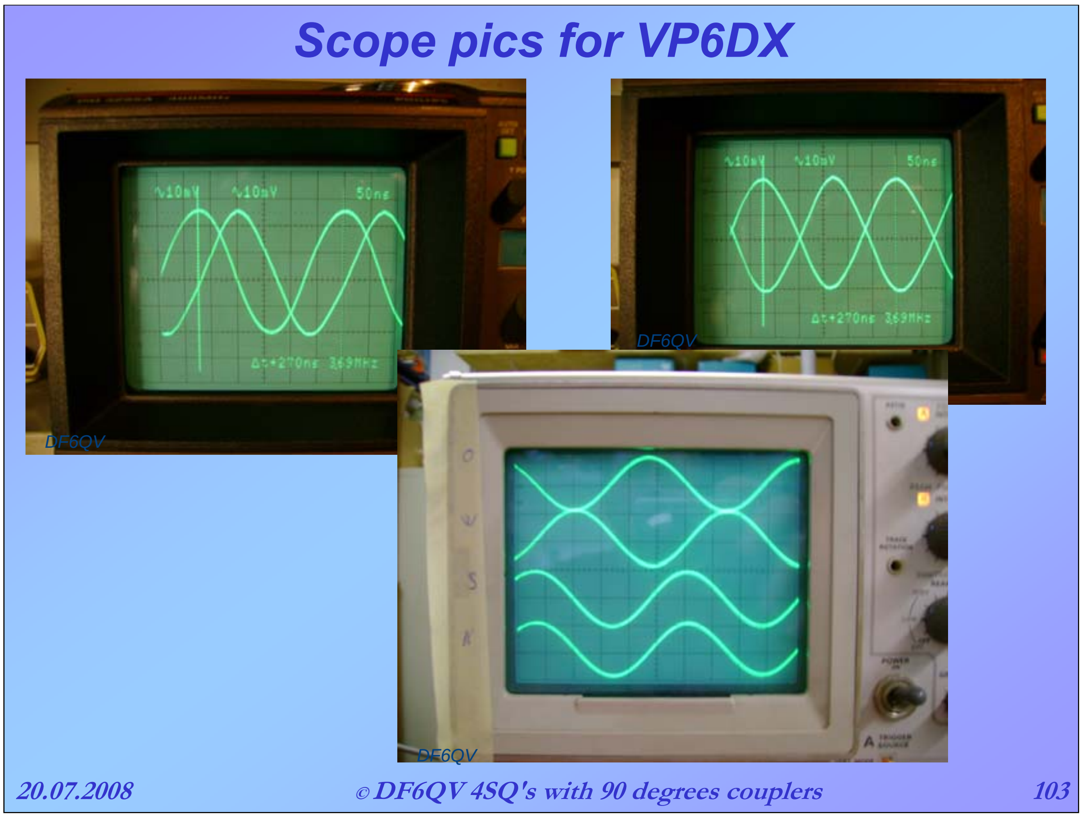
Front and rear view of the the couplers and control boxes



Screen shots of the output signals on the artificial antennas at low power.

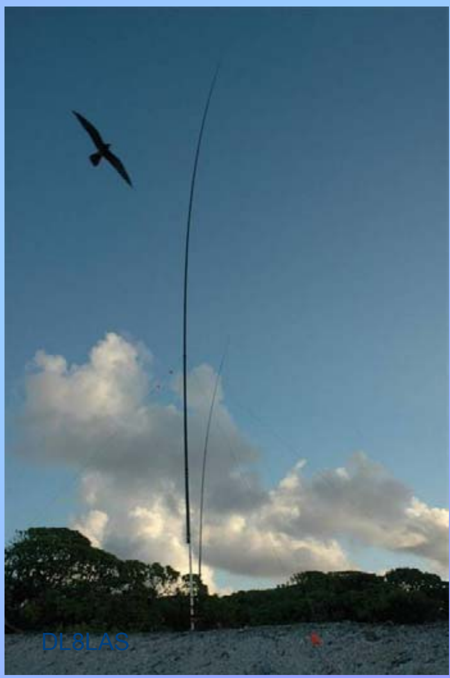
With a lot of advice by mail and phone, the pictures I have sent to DL6LAU, the discussion about possible variants and not in the least by the 5 hybrid couplers with control boxes, the VP6DX team succeeded in building 4squares on Ducie that were real killer antennas.

A great DXpedition in every way!!!

VP6DX 4SQ Pictures

VP6DX 4SQ Pictures

VP6DX 4SQ Pictures



VP6DX 4SQ Pictures

VP6DX 4SQ Pictures

VP6DX 4SQ Pictures

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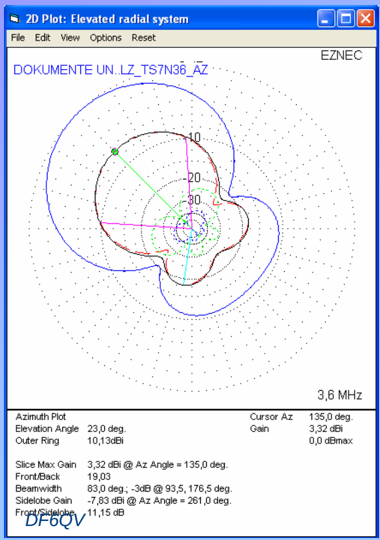
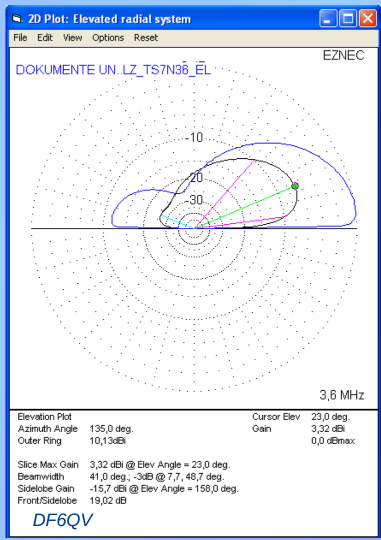
30m setup at VP6DX

What makes the difference?





Simulation of the TS7N 4SQ (one elev. radial). Comparison of various grounds.

Normative ground:0.005/13m vs. salt water 5/80

This looks the same for all vertical antennas.

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Near salt water the flat radiation decreases the number of hops to the DX station. A reflection on salt water suffers negligible attenuation, but every reflection on the ground or at the E- or F-layers causes a lot of loss..

This is why a 4SQ or 2-el vertical beam can become a "killer" antenna.

At VP6DX all this has been done in the right way!

Something else:

A compressed delay line (180 degree transformer) already mentioned in ON4UN's book.

Here a further development:

The variable compressed delay line…

Variable Compressed Delay line

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9. Phasenschieber mit 3 dB Hybridkopplern

Die Koppeleigenschaften sollen an Bild 9.1 und Gleichung 9.1 erläutert werden.

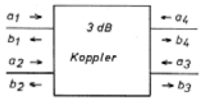

Bild 9.1

$$S = -\frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 & 1 & j \\ 0 & 0 & j & 1 \\ 1 & j & 0 & 0 \\ j & 1 & 0 & 0 \end{pmatrix} \qquad \text{(Gl. 9.1)}$$

Bild 9.1 zeigt einen 3 dB Koppler mit den üblichen Wellengrößen. Gleichung 9.1 ist die Steumatrix des Kopplers. In der Gleichung 9.2 ist die Verknüpfung zwischen des S - Parametern und den Wellengrößen angegeben.

$$\begin{pmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{pmatrix} = S \times \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix} \qquad \text{(Gl. 9.2)}$$

Die an Tor 1 ankommende Leistung wird zu gleichen Teilen auf die Tore 3 und 4 aufgeteilt. Die Wellen unterscheiden sich durch einen Phasenwinkel von 90^0. Werden Tor 3 und 4 durch gleiche Blindelemente abgeschlossen, tritt dort eine Totalreflektion auf. Die reflektierten Leistungen von Tor 3 und 4 werden in Tor 1 und 2 zurückgekoppelt. Die Wellen treten an Tor 2 phasengleich auf und addieren sich. An Tor 1 ist der Phasenunterschied der reflektierten Wellen 180^0 und es kommt

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zur Auslöschung. Durch die Reflektion an Tor 3 und 4 ist eine Transmission von Tor 1 nach 2 entstanden. Die Phase des Transmissionsfaktors ist abhängig von der Phase des Reflektionsfaktors an Tor 3 und 4. In Kap. 9.1 wird ein 3 dB Koppler, in Kap. 9.2 werden gekoppelte 3 dB Hybrid's auf ihre Eignung als Phasenschieber untersucht.

9.1 Phasenschieber mit einem 3 dB Koppler

Im Bild 9.2 ist das Prinzip dargestellt.

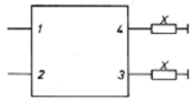

Bild 9.2

Die Tore 1 und 2 sollen reflektionsfrei, die Tore 3 und 4 durch gleiche Blindelemente abgeschlossen sein. Für die Reflektionsfaktoren an den Toren 3 und 4 gilt:

$$r = r_3 = r_4 = \frac{jX - 1}{jX + 1} \qquad \text{(Gl. 9.3)}$$

X = normierte Reaktanz des Blindelementes

Gleichung 9.3 läßt sich umformen zu Gleichung 9.4

$$r = r \; e^{j\varphi} \qquad \text{(Gl. 9.4)}$$

mit $|r| = 1$

$\varphi = \arctan(-X) - \arctan(X)$

Der Betrag des Reflektionsfaktors ist unabhängig von der Größe des Blindelementes gleich 1. Die Blindelemente beeinflussen lediglich die Phase des Reflektionsfaktors. Weiter gilt:

$$r_3 = a_3 / b_3 \qquad r_4 = a_4 / b_4 \qquad \text{(Gl. 9.5)}$$

Quelle: DF6QV 1980

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A little theory, because often it is good to know how things work. This paper shows the S-parameter of a 3dB hybrid with deductions how to use it as a variable phase controller.

How it works

Power arriving at port 1 will be equally split to ports 3 and 4 with a phase difference of 90°. If ports 3 and 4 are terminated with the same reactance, all power will be reflected to port 1 and 2. The waves at port 2 add as they are in phase. Waves arriving at port 1 have a phase difference of 180° and cancel each other.

The reflection at ports 3 and 4 results in a transmission from port 1 to port 2. The phase of the transmission coefficient depends on the phase of the reflection coefficient at ports 3 and 4.

In Chapter 9.1 a 3 db coupler will be analysed for its phase shifting capabilities. In Chapter 9.2 coupled 3 db hybrids will be treated.

Quelle: DF6QV 1980

Power arriving at port1 will be equally split to ports 3 and 4 with a phase difference of 90°. If ports 3 and 4 are terminated by the same reactance, all power will be reflected to port 1 and 2. The waves are in phase at port 2 and thus add. Waves arriving at port 2 have a phase difference of 180° and are cancelled. The reflection at ports 3 and 4 has resulted in a transmission from port 1 to port 2. The phase of the transmission coefficient depends on the reflection coefficient at ports 3 and 4. In Chapter 9.1 a 3 db coupler will be analysed for its phase shifting capabilities. In Chapter 9.2 coupled 3 db hybrids will be treated.

Variable Compressed Delay line

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Mit diesen Voraussetzungen ist die Transmission von Tor 1 nach Tor 2 (b_2 / a_1) zu berechnen. Aus Gleichung 9.1 und 9.2 folgt mit $a_2 = 0$

$$b_1 = -\frac{1}{\sqrt{2}}\,(a_3 + ja_4)$$

$$b_2 = -\frac{1}{\sqrt{2}}\,(ja_3 + a_4)$$

$$b_3 = -\frac{1}{\sqrt{2}}\,a_1$$

$$b_4 = -\frac{1}{\sqrt{2}}\,ja_1 \qquad (\text{Gl. } 9.6)$$

Setzt man Gleichung 9.5 in 9.6 ein, erhält man

$$a_3 = -\frac{1}{\sqrt{2}}\,a_1\,r_3$$

$$a_4 = -\frac{1}{\sqrt{2}}\,ja_1\,r_4 \qquad (\text{Gl. } 9.7)$$

Es folgt weiter

$$b_1 = \frac{1}{2}\,a_1\,(r_3 - r_4)$$

$$b_2 = \frac{1}{2}\,a_1\,(r_3 + r_4) \qquad (\text{Gl. } 9.8)$$

Ist $r_3 = r_4 = r$, sind die Blindelemente an Tor 3 und 4 gleich groß und b_1 wird 0. Damit folgt für den Transmissionsfaktor von Tor 1 nach 2

$$\frac{b_2}{a_1} = \frac{1}{2}\,(r_3 + r_4) = jr = j\,\frac{jX - 1}{jX + 1} \qquad (\text{Gl. } 9.9)$$

Für die Phase des Transmissionfaktors gilt:

$$\phi = \arctan \frac{\mathrm{Im}\left(\frac{b_2}{a_1}\right)}{\mathrm{Re}\left(\frac{b_2}{a_1}\right)} \qquad (\text{Gl. } 9.10)$$

$$\phi = \arctan\left(\frac{1}{X}\right) - \arctan(X) \qquad (\text{Gl. } 9.11)$$

Im Bild 9.3 ist der Verlauf der Phase für positive und negative Reaktanzen dargestellt.

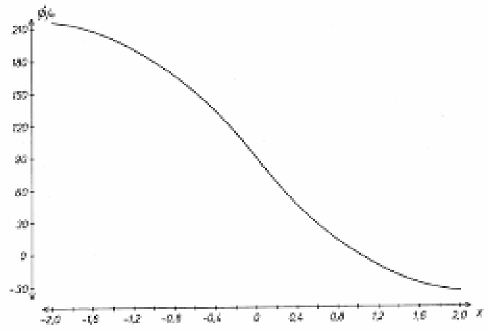
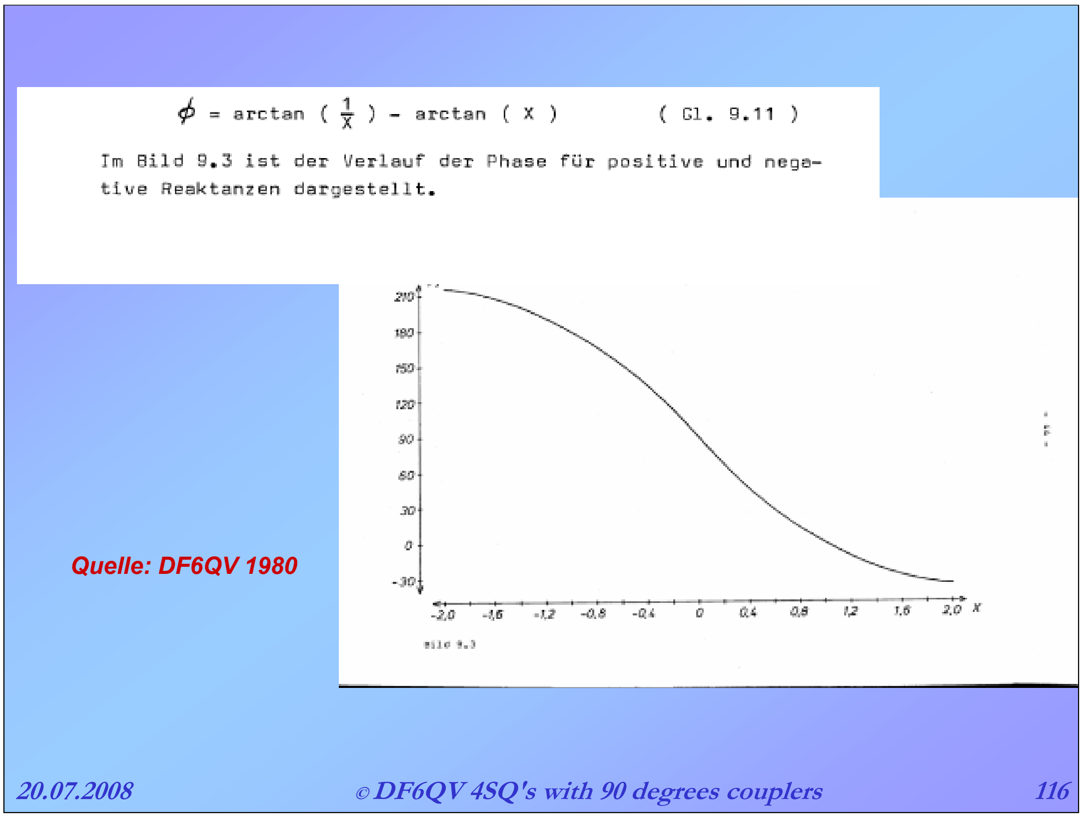


Bild 9.3

Quelle: DF6QV 1980



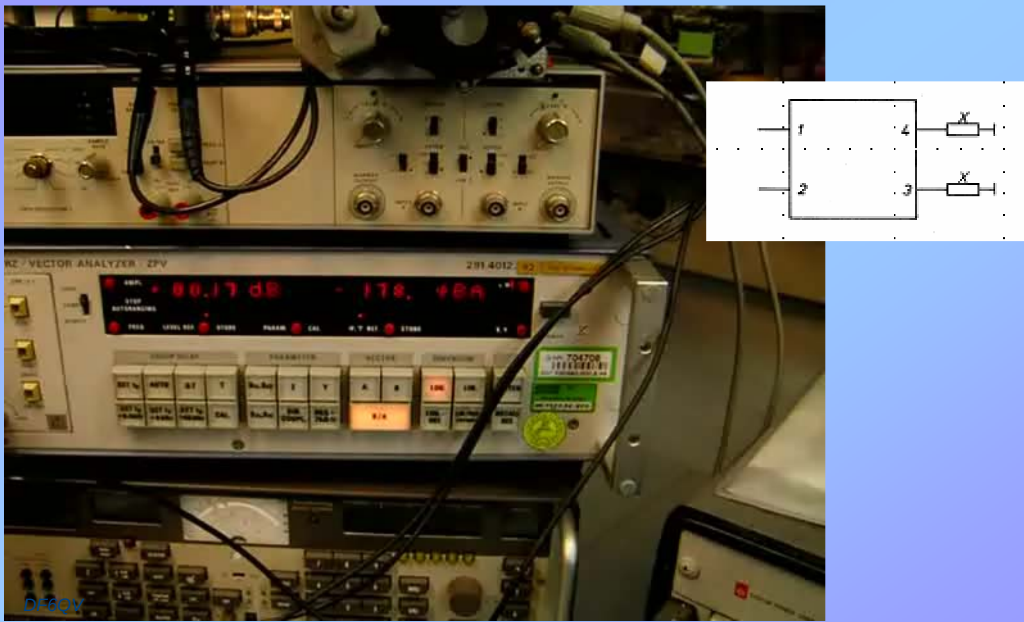
The equation at the top is plotted in the graph showing the phase angle between input and output (isolation) port as a function of normalized reactance. Apart from a phase shift of 45°, the equation is also valid for the coupler according to Reed.

On the design frequency, branch line and Reed couplers differ in phase angle as follows:

Input port to first output port = -90° (λ/4 quarter-wave line) for branch line

Input port to first output port = -45° for the Reed coupler

110 Grad auf 7MC mit 2 x 450 pF



Video: http://de.youtube.com/watch?v=JwTlvFOYzRk

The video „http://de.youtube.com/watch?v=JwTlvFOYzRk“ shows the test environment with my old 7 MHz coupler. The coupler doesn‘t have exactly 50Ω, because the cores available to me didn‘t allow that. The input SWR is about 1.5 The two output ports are loaded with a tandem capacitor with a variation range of about 400pF, and the isolation port is terminated with 50Ω.

The vector analyser shows the transmission attenuation (input, isolation port) on the left, and on the right the phase angle between the two ports is displayed. An RF1 antenna-analyser was used as a signal source.

Summary

With the coupler according to W2CQH, it is quite easy to build 4SQs. We can almost say that it's a „Plug and Play" system.

With this coupler, we can divide the power at a phase difference of 90° not only into equal parts but also according to your needs!

With a variable phase shifter, which, as seen before, reaches 110 degrees with a ΔC of 400pF at 7 MHz and an almost constantly good SWR in a 50Ohm system, there is still a lot of potential progress.

Optimized systems

In 2005,ON4UN presented W1MK's optimized feeding system for 4SQs in Dayton. The system provides better side lobes and a forward gain that exceeds that of other systems by about 1dB.

It is pretty complex and thus difficult to realize. Here I ask myself which amateur is able to buy and adjust it?

PA0GMW has optimized amplitudes and phases in his 80m 4SQ system. At a slightly higher forward gain and smaller side lobes, as well as less beamwidth, he uses 45° (instead of 90°) switching.

Sources

- ON4UN Low Band DXing 3rd Edition
- ON4UN Dayton 2005: A new Feed System for Arrays
  http://www.kkn.net/dayton2005/ON4UN-Dayton-2005.pdf
- W1HKK A switchable Four-Element 80m Phased Array, QST March 1965
- W2CQH Twisted wire Quadrature Hybrid Directional Couplers, QST January 1978
- The branchline Hybrid: Part 1/2, Hamradio, April/May1984
- DJ4AX Vortrag RRDXA 199x (nicht publiziert)
- DF6QV Steuerbare Phasenschieber 1980 (nicht publiziert)
- http://de.youtube.com/watch?v=JwTlvFOYzRk

URLs for more…

- http://force12inc.com/k5kinfo.htm
- http://www.qrz.com/detail/PA0GMW
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- http://ducie2008.dl1mgb.com/
- http://www.ncjweb.com/k3lc4squarea.pdf

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Final remarks

Thanks to everybody who made my experiences with 4SQs possible.

Thanks to Rein, PA0R, and Uli, DJ2YA, for preparing the English version.

Thanks for listening. If you have any questions, don‘t hesitate to ask me.

There‘s a lot to do…let‘s wait and see.

vy 55 + 73 de Franz, DF6QV

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