Yagi Simulation: CAD-Software for Evaluation and Development

(A Case Study and Performance Report)
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(Part IV)

5. Evaluation of Simulation Quality

5.1 Description of Evaluation Procedure

To evaluate the performance of the simulation programs, experimental data are compared with simulation results. Experimental data are horizontal pattern and gain. Horizontal pattern is weighted more than gain, because pattern measurements are easier to perform with good accuracy than gain measuremens. Furthermore patterns are very sensitive to frequency shifts but gain is not.

The comparison between measured and simulated pattern is done by visual inspection. A more scientific approach would be to calculate the cross correlation between the patterns. This requires the availabilty of the pattern as numbers. This is not the case for the cases selected and for amateur purpose the visual comparison method is accurate enough. The match quality is expressed qualitatively in categories (Excellent,Good, Medium, Fair, Poor).

For each test antenna the pattern comparison and the gain comparison are performed for the measuring frequency and for a 'best-match' frequency, which is found by running the simulation at a frequency which gives the best match between the measured and the simulated pattern. This approach proved to be very sensitive, because it easily unveils shortcomings of the simulation method used.

Additionally a judgement for the validity of the simulated input impedance is given, which is based on tknown VSWR behaviour of the practical antennas. This judgement is qualitative only.

After all the following data is shown for each testcase:

1. Measuring Frequency (f_m:)
   - Measured pattern
   - Measured gain
   - Simulated pattern
   - Simulated gain
2. 'Best-Match' Frequency(f_{opt})
   - Simulated Pattern

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1 *Gluecksburger Str. 20, D-2000 Hamburg 50*
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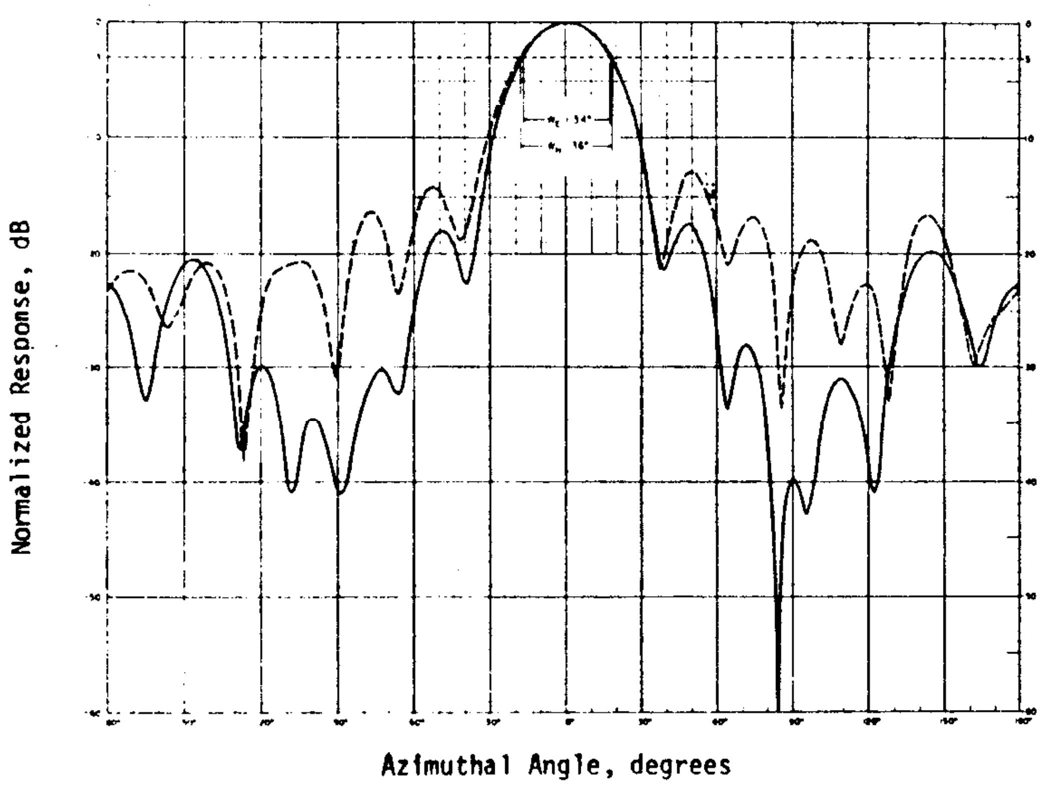


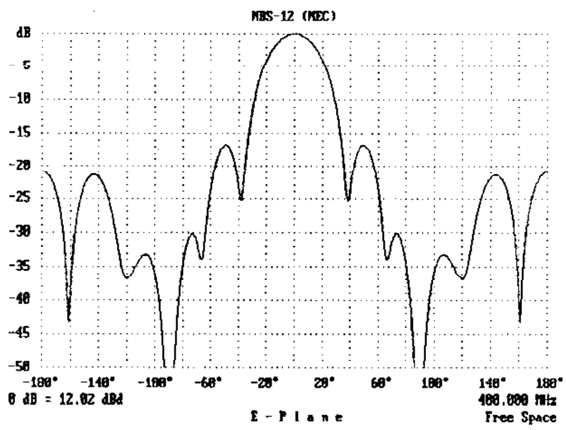
Bild/Figure 1: NBS-12: Measured Pattern

- Simulated Gain
- Simulated Input Impedance

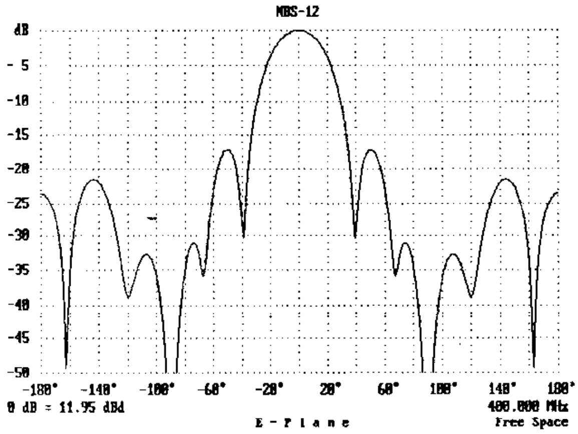
5.2 Programs

The following Programs have been investigated:

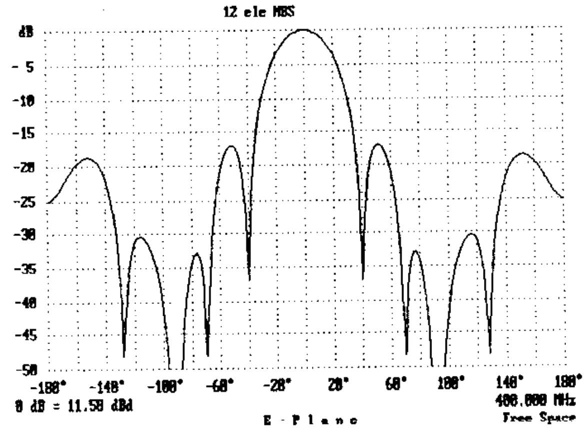
1. NEC-PC Version 1.04
2. YO 4.23 running in the NEC calibration mode
3. MN 3.0
4. YAGIANALYSIS V3.3
5. YAGIMAX V2.15
6. RADICAL V1.12
7. ELNEC V2.08N



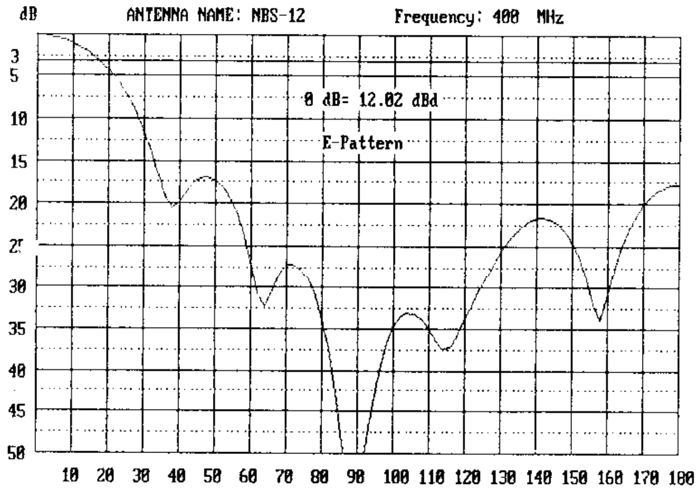
Bild/Figure 2: Simulation by NEC-PC: NBS12



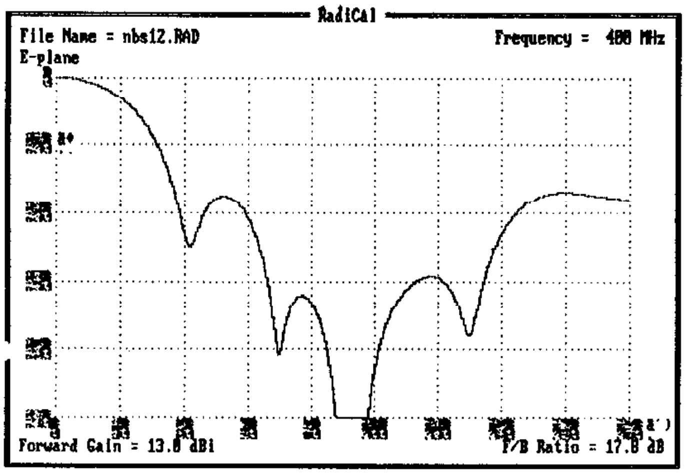
Bild/Figure 3: Simulation by YO: NBS-12



Bild/Figure 5: Simulation by MN: NBS-12



Bild/Figure 4: Simulation by YAGIANA: NBS-12



Bild/Figure 6: Simulation by RADICAL: NBS-12

NEC-PC was selected, because of the simple handling of *.yag files, which are input into YO. The differences to NEC-81 and NEC-II are negligible.

5.3 Selected Cases

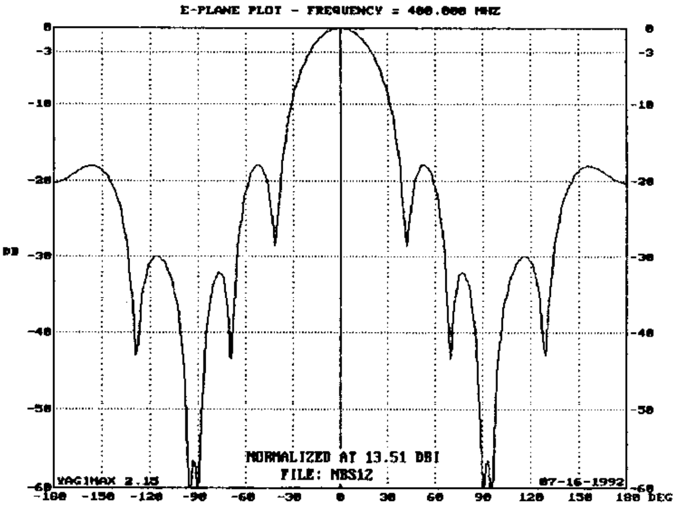
Because of our restrictions in space and in the possible amount of work to be done the comparison cannot be done on all antennas, where experimental data is available. Selecting a group of relevant samples, suited to identify the limitations of the various simulation methods inspected was not an easy task.

After all the following group of test antennas were selected:

- Case 1: 12-El Yagi, NBS-12, for 400 MHz
- Case 2: 6-El Yagi, Lyngby-Design, for 432 MHz
- Case 3: 21-El Yagi, TONNA, for 432 MHz
- Case 4: 23-El Yagi, TONNA, for 1296 MHz
- Case 5: 37-El Yagi, DL6WU Design, for 1296 MHz

The following guidelines served as selection criteria. All test antennas have been measured repeatedly and well established results are available:

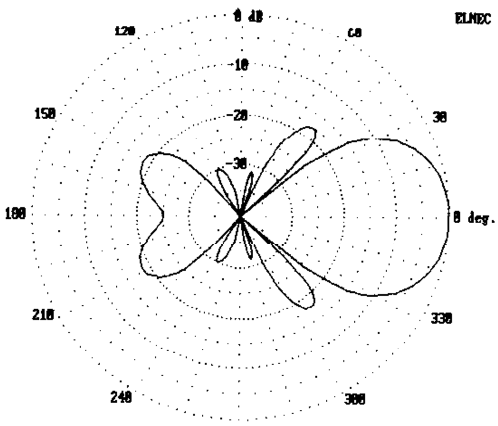
1. Case 1 has normal elements (0.0085wl) and is well known.
2. Case 2 is a very critical design similar to the Chen-Cheng antenna [2] and has been developed in Denmark[1]. It's very narrow band, critically tuned and provides 'super-gain', which is more than an equal length DL6WU Yagi. The critical tuning will easily unveil frequency offset problems.
3. Case 3 has been measured many times on antenna gain contests, has a low input impedance (12.5Ω) and should unveil inaccurate input impedance calculation, which leads to wrong results for gain.
4. Case 4 is a homogenous yagi, has thick elements (0.013λ).



Bild/Figure 7: Simulation by YAGIMAX: NBS-12

Table 1: Case1 (NBS-12)	
Position [mm]	**Half Length [mm]**
0	180.63
150	168.64
300	161.89
450	155.52
600	152.52
750	149.15
900	146.15
1049	146.15
1199	146.15
1349	146.15
1499	149.15
1649	152.52

Environment:	Free Space
Element-Diameter:	6.37mm
Feeder:	Dipole
Measuring Frequency:	400.0MHZ
Measured Gain:	12.2dBD
Measured Pattern:	Figure 1



Bild/Figure 8: Simulation by ELNEC: NBS-12

Case 5 has electrical thick elements (0.017λ) and has the same function as Case 4. Additionally this antenna has electrically short elements[1] because of the element taper. Therefore all programs which assume a sinusoidal current distribution on the element will fail to compute the correct pattern. Short elements have a significant distortion in the current profile and therefore have a different contribution to the overall pattern, which results from the superpositon of all fields of the element currents.

1 *The shortest element has a length of only 0.33wl which implies a significant distortion in the current profile compared with a sinusoidal distribution.*

5.4. Case 1: 12 el-Yagi

5.4.1 Dimensions

Table 1 shows the mechanical parameters.

5.4.2 Results

NEC-PC:
Pattern Match is good on f_m . Gain difference is -0.2dB. Frequency offset for best pattern match is -0.1%. At f_{opt} pattern match is excellent.

YO:
Pattern Match is good on f_m . Gain difference is -0.25dB. Frequency offset for best pattern match is +0.13%. At f_{opt} pattern match is excellent.

MN:
Pattern Match is poor on f_m . Gain difference is -0.55dB. Frequency offset for best pattern match is +1.4%. At f_{opt} pattern match is good.

YAGIANALYSIS:
Pattern Match is poor on f_m . Gain difference is -0.18dB. Frequency offset for best pattern match is -0.5%. At f_{opt} pattern match is good.

CASE 1: NBS-12 YAGI on 400 MHz
Pattern: Figure 1
Data: Table 1

Program	Simulation @ f_m =400MHz			Simulation @ f_{opt}			
	Pattern-Match	Gain[dBD]	Z	f_{opt} ,[MHz]	Pattern-Match	Gain[dBD]	Z
NEC-PC	Fig. 2: Good	12.02	19.9+j*3.6	399.6	Good	12.0	20+j*2.3
YO	Fig. 3:Good	11.95	18.8+j*1.4	400.5	Good	11.98	18.6+j*2.7
MN	Fig. 5: Poor	11.58	22-j*11	406.0	Good	12.0	N/A
YAGIANALYSIS	Fig. 4:poor	12.02		398.0	Good	12.01	
YAGIMAX	Fig.7: Fair	11.37	24.4-j*15.3	401.5	Good	11.5	23.7-j*12.6
RADICAL	Fig. 6:Poor	10.85	N/A	410	Fair	11.65	N/A
ELNEC	Fig. 8:Poor	11.65	24-j*14.5	405.5	Good	12.0	22.4+j*0

YAGIMAX
Pattern Match is fair on f_m . Gain difference is -0.83dB. Frequency offset for best pattern match is +0.4%. At f_{opt} pattern match is good.

RADICAL

Pattern Match is poor on f_m . Gain difference is -1.4dB. Frequency offset for best pattern match is +2.5%. At f_{opt} pattern match is fair.

ELNEC

Pattern Match is poor on f_m . Gain difference is -0.55dB. Frequency offset for best pattern match is +1.4%. At f_{opt} pattern match is good.

5.5 Case 2: Lyngby Yagi

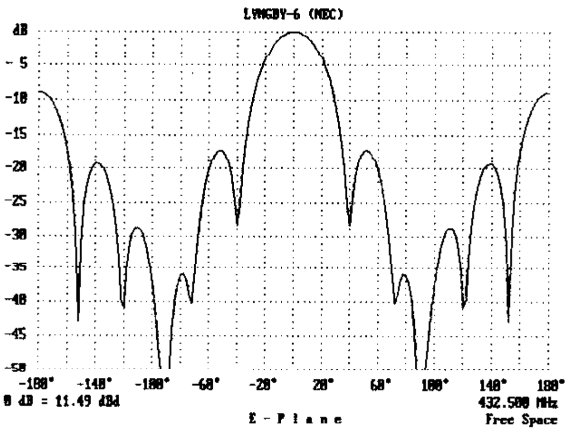
The 6El Lyngby Yagi has been developed at the University of Lyngby, Denmark, to demonstrate the facilities of optimizing antenna software. It's characteristic is similar to the Chen-Cheng Yagi. They feature extremely low input impedance (< 10 Ohms), critical narrow band tuning and controlled current profile.

DATA: Case2 (Lyngby Yagi)

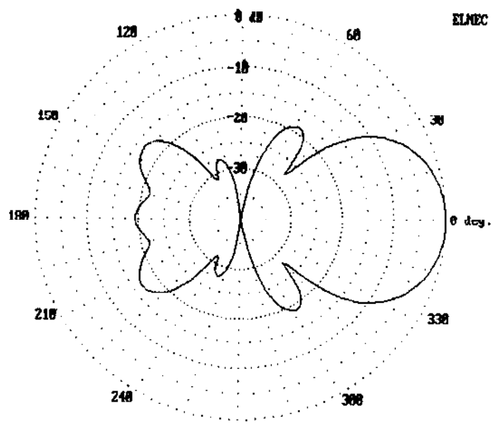
Position [mm]	Half Length [mm]
0	164
173	157
339	150
617	146
902	145
1166	147

Environment:	Free Space
Element-Diameter:	5.2mm
Feeder:	Dipole
Measuring Frequency:	432.5MHZ
Measured Gain:	10.5dBD*
Measured Pattern:	Figure 9

* Because of mismatch problems during the measurement measured gain is too low



Bild/Figure 9: Simulation by NEC-PC: LYNGBY-6

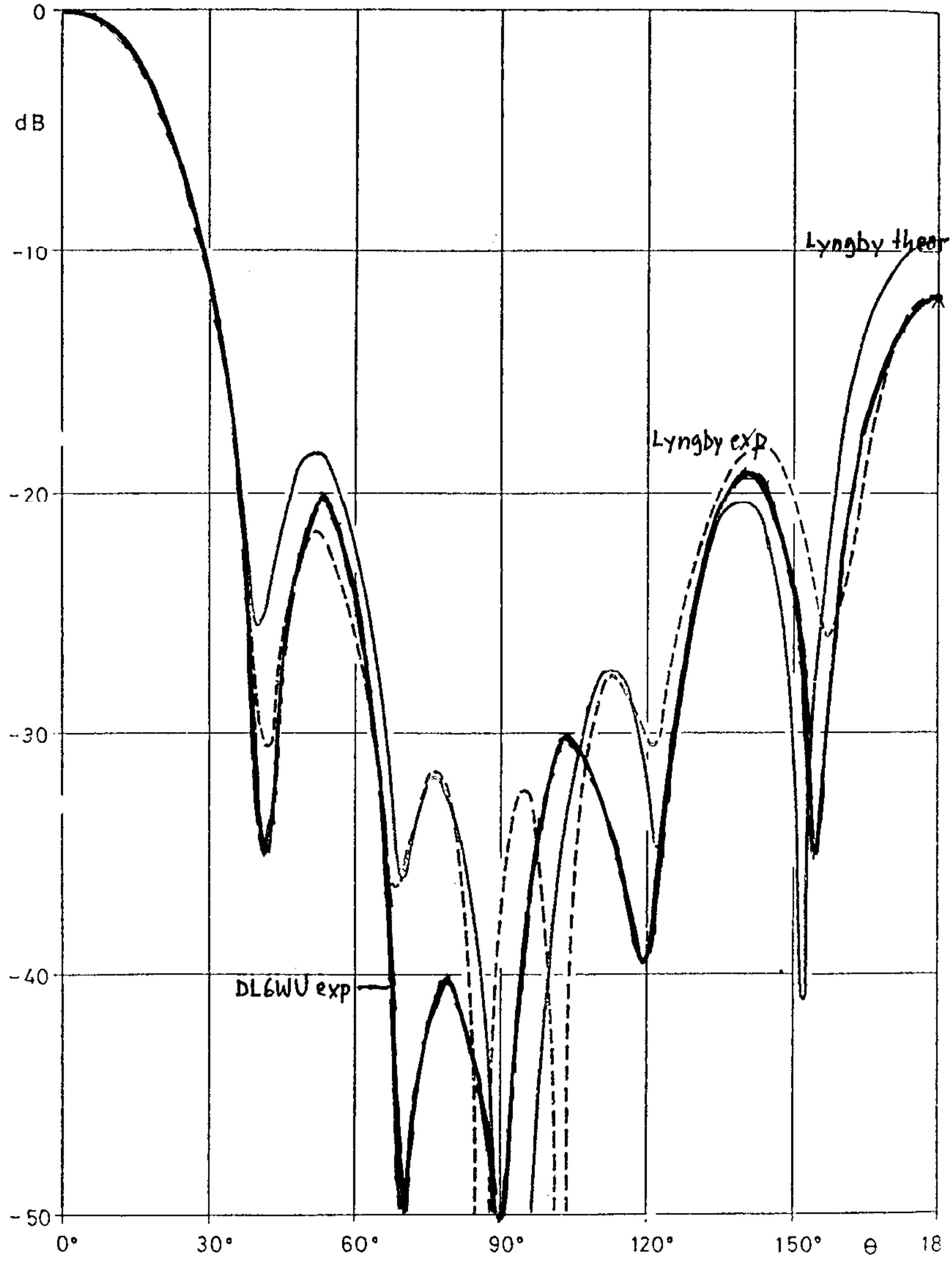


Bild/Figure 10: Simulation by ELNEC: LYNGBY-6

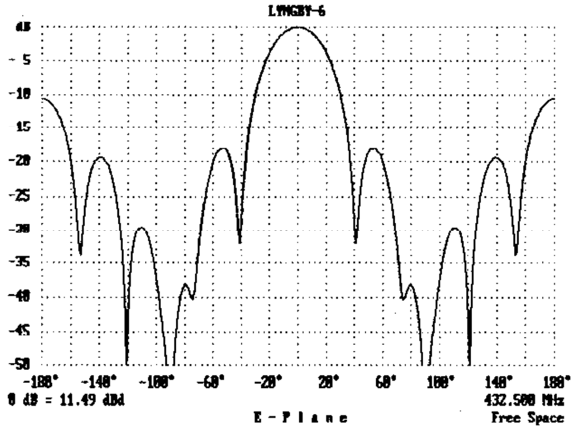
The gain is about 11.25 dBD, which is higher than for normal Yagis with the same length.

5.5.1 Dimensions

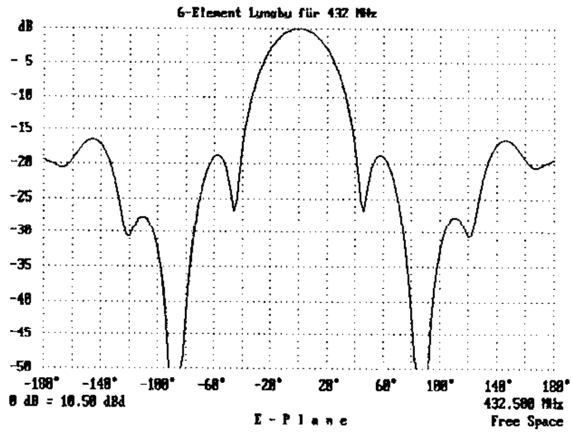
The following table display the mechanical parameters:



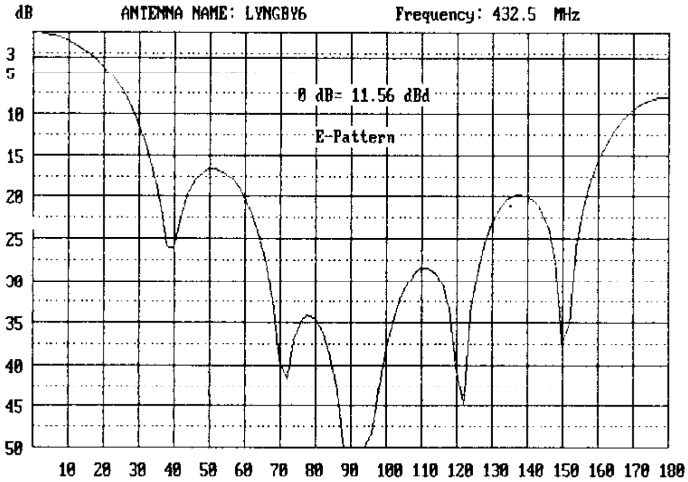
Bild/Figure 11: LYNGBY-6: Measured Pattern



Bild/Figure 12: Simulation by YO: LYNGBY-6



Bild/Figure 13: Simulation by MN: LYNGBY-6



Bild/Figure 14: Simulation by YAGIANA: LYNGBY-6

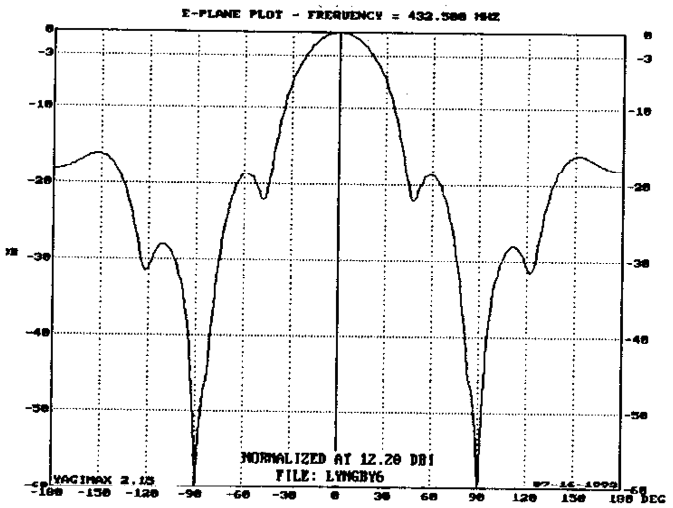
5.5.2 Results

NEC-PC

Pattern Match is fair on f_m . Gain difference is +0.24dB. Frequency offset for best pattern match is -0.35%. At f_{opt} pattern match is good.

YO

Pattern Match is fair on f_m . Gain difference is +0.24dB. Frequency offset for best pattern match is -0.18%. At f_{opt} pattern match is good.



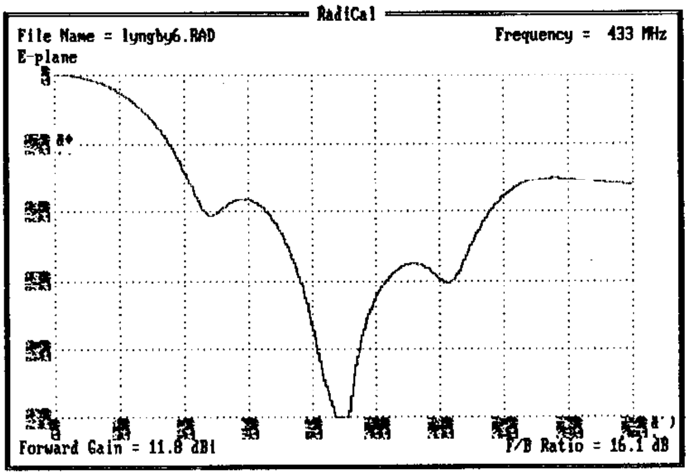
Bild/Figure 15: Simulation by YAGIMAX: LYNGBY-6

MN

Pattern Match is poor on f_m . Gain difference is -0.75dB. Frequency offset for best pattern match is +1.3%. At f_{opt} pattern match is good. Impedance on f_m is not plausible.

YAGIANALYSIS

Pattern Match is fair on f_m . Gain difference is +0.3dB. Frequency offset for best pattern match is -0.6%. At f_{opt} pattern match is good.



Bild/Figure 16: Simulation by RADICAL: LYNGBY-6

YAGIMAX

Pattern Match is poor on f_m. Gain difference is -1.25dB. Frequency offset for best pattern match is +1.7%. At f_{opt} pattern match is good. Impedance on f_m is not plausible.

RADICAL

Pattern Match is poor on f_m. Gain difference is -1.7dB. Frequency offset for best pattern match is +2.4%. At f_{opt} pattern match is good.

ELNEC

Pattern Match is poor on f_m. Gain difference is -0.76dB. Frequency offset for best pattern match is +1%. At f_{opt} pattern match is good. Impedance on f_m is not plausible.

CASE 2: LYNGBY-6 YAGI on 432.5 MHz
Pattern: Figure 11
Data: Table 2

Program	Simulation @ f_m =432.5MHz			Simulation @ f_{opt}			
	Pattern-Match	Gain[dBD]	Z	f_{opt},[MHz]	Pattern-Match	Gain[dBD]	Z
NEC-PC	Fig. 9: Fair	11.49	7.2+j*9.8	431.0	Good	11.41	8.6+j*3.1
YO	Fig. 12:Fair	11.49	9.5+j*4.6	431.7	Good	11.41	10.3+j*1.7
MN	Fig. 13:Poor	10.5	17.5-j*18.6	438.0	Good	11.37	9.6+j*0.7
YAGIANALYSIS	Fig. 14:Fair	11.55	6.6+j*12.6	430.0	Good	11.42	8.7+j*1.3
YAGIMAX	Fig.15:Poor	10.0	22.9-j*20.4	440	Good	11.39	10.8+j*0
RADICAL	Fig. 16:Poor	9.55	N/A	443	Good	11.45	N/A
ELNEC	Fig. 10:Poor	10.49	16.8-j*15	437	Good	11.25	10.2+j*0

5.6 Case 3: Tonna-21

The TONNA-21 is a standard amateur antenna for 432 MHz, which is on the market since more than 10 years. Pattern and gain were measured very often. Features of this design are low input impedance of 12.5 Ohms, to match directly to a folded dipole with 50 Ohms, high gain and very high F/B. Gain measurements vary from 15.1 to 16dBD with a mean value of 15.6 dBD

5.6.1 Dimensions

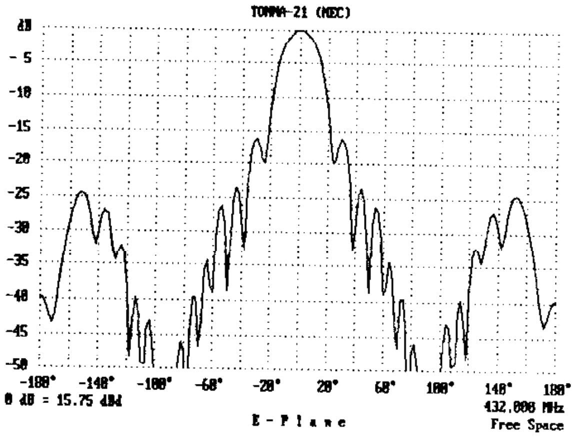
See Table 3.

Table 3*: Case 3 (21El Tonna)

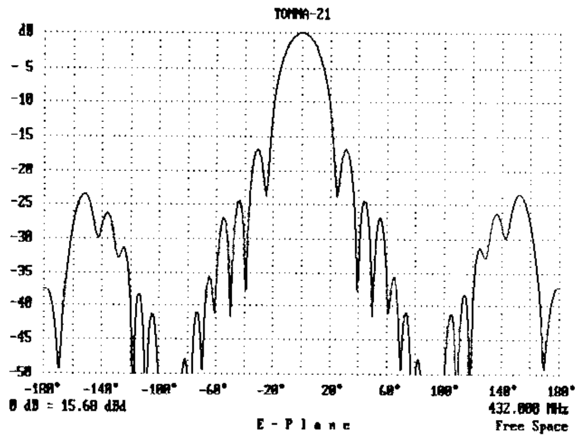
Element	Position [mm]	Half Length [mm]
R	0	176.5
FEED	139	160
D1	187	159
D2	255	154
D3	440	149
D4	623	149
D5	823	146.5
D6	1058	146.5
D7	1328	146.5
D8	1598	141.5
D9	1868	141.5
D10	2138	141.5
D11	2408	141.5
D12	2678	141.5
D13	2948	139
D14	3218	139
D15	3488	139
D16	3758	136.5
D17	4028	136.5
D18	4298	134
D19	4568	134

Environment:	Free Space
Element-Diameter:	4mm
Feeder:	Dipole
Measuring Frequency:	432.0MHZ
Measured Gain:	15.6dBD
Measured Pattern:	Figure 17

* Given are the free space element lengths



Bild/Figure 17: Simulation by NEC-PC: TONNA-21



Bild/Figure 18: Simulation by YO: TONNA-21

5.6.2 Results

NEC-PC

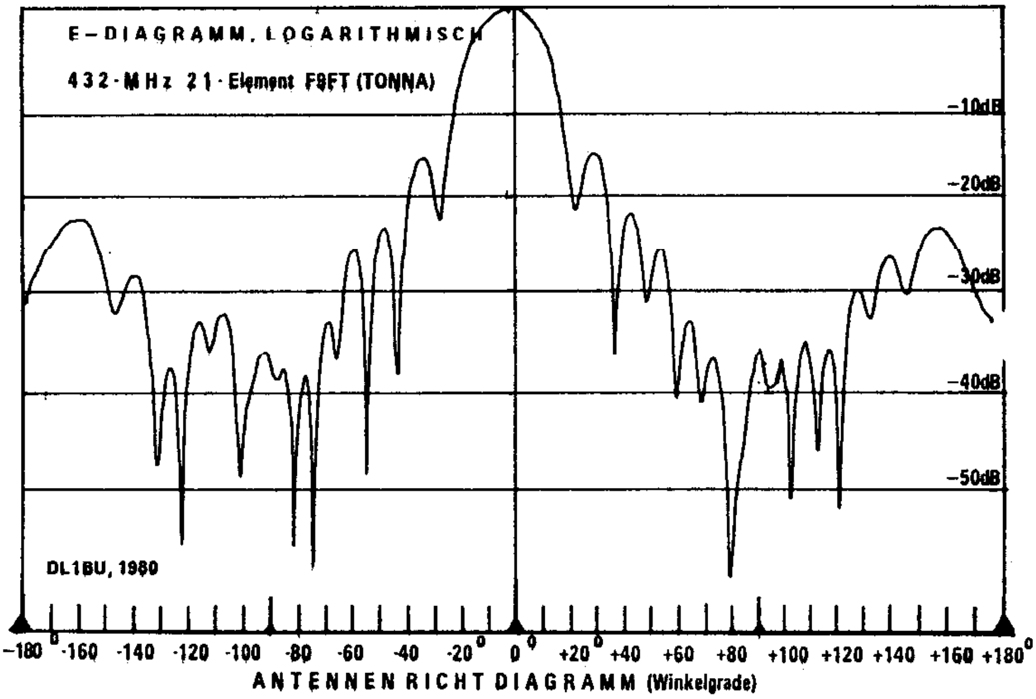
Pattern match is medium on f_m . Gain difference is +.15dB. Frequency offset for best pattern match is -0.12%. At f_{opt} pattern match is medium.

YO

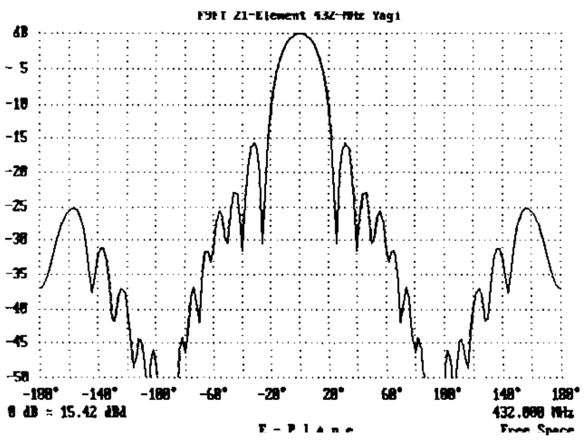
Pattern Match is fair on f_m . Gain difference is +0.08dB. Frequency offset for best pattern match is +0.4%. At f_{opt} pattern match is medium.

MN

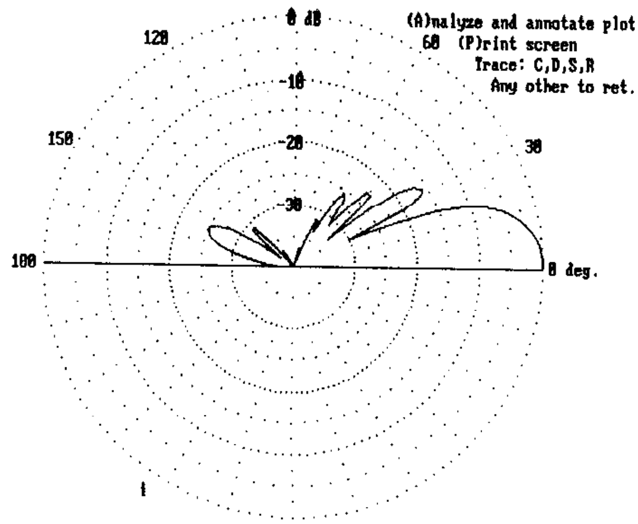
Pattern Match is fair on f_m . Gain difference is +0.18dB. Frequency offset for best pattern match is +1%. At f_{opt} pattern match is medium.



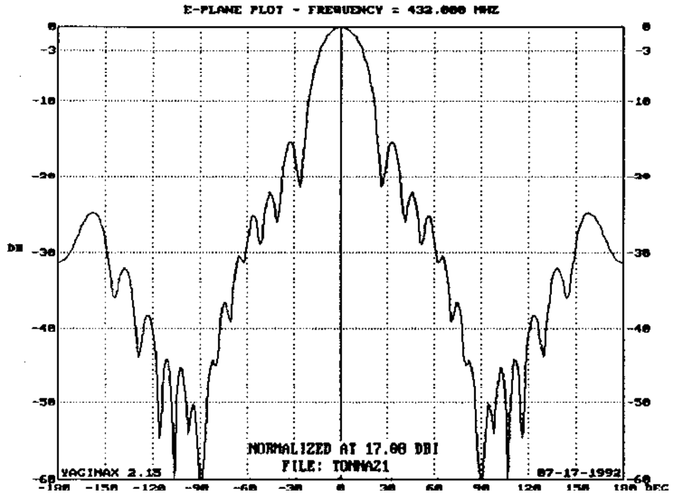
Bild/Figure 19: TONNA-21: Measured Pattern



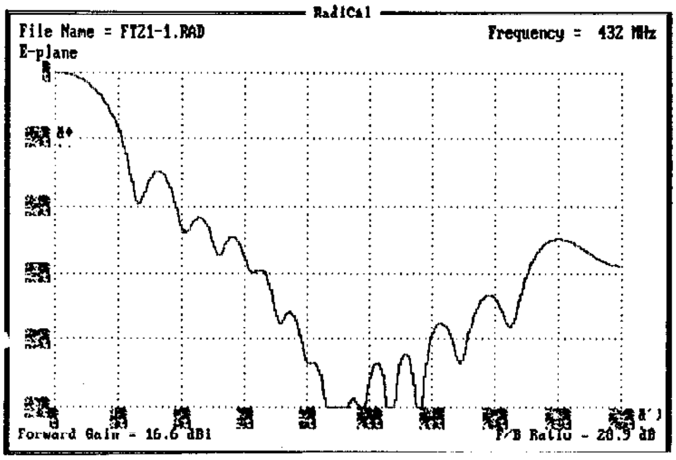
Bild/Figure 20: Simulation by MN: TONNA-21



Bild/Figure 21: Simulation by ELNEC: Tonna-21



Bild/Figure 22: Simulation by YAGIMAX: TONNA-21



Bild/Figure 23: Simulation by RADICAL: TONNA-21

Pattern Match is good on f_m . Gain difference is +.15dB. Frequency offset is +0.23% for best pattern match. On f_{opt} pattern match is excellent

YO

Pattern Match is poor on f_m . Gain difference is +0.16dB. Frequency offset for best pattern match is+0.7%. At f_{opt} pattern match is good.

MN

Pattern Match is poor on f_m . Gain difference is -0.75dB. Frequency offset for best pattern match is 2.5%. At f_{opt} pattern match is medium.

YAGIANALYSIS

Pattern Match is medium on f_m . Gain difference is +.28dB.

YAGIMAX

Pattern Match is fair on f_m . Gain difference is -0.66dB. No better frequency could be found. Impedance on f_m is not plausible.

RADICAL

Pattern Match is poor on f_m . Gain difference is -1.15dB. Frequency offset for best pattern match is +1.8%. At f_{opt} pattern match is good.

ELNEC

Pattern Match is fair on f_m . Gain difference is -0.16dB. Frequency offset for best pattern match is +1.4%. Impedance on f_m is not plausible.

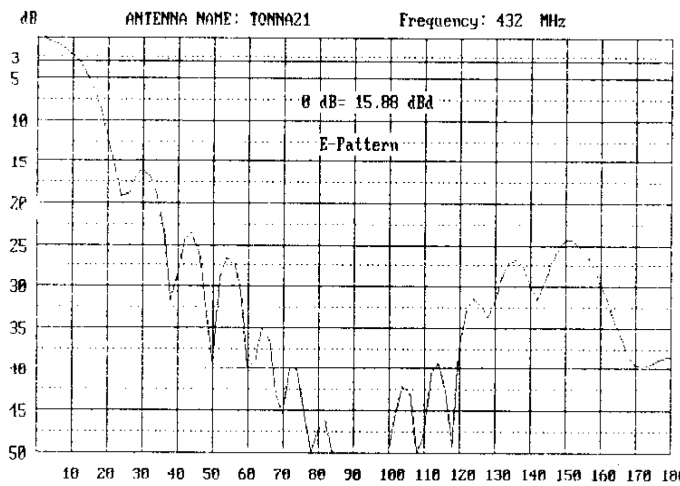
5.7 Case 4: 23El Tonna on 1293MHz

5.7.1 Dimensions

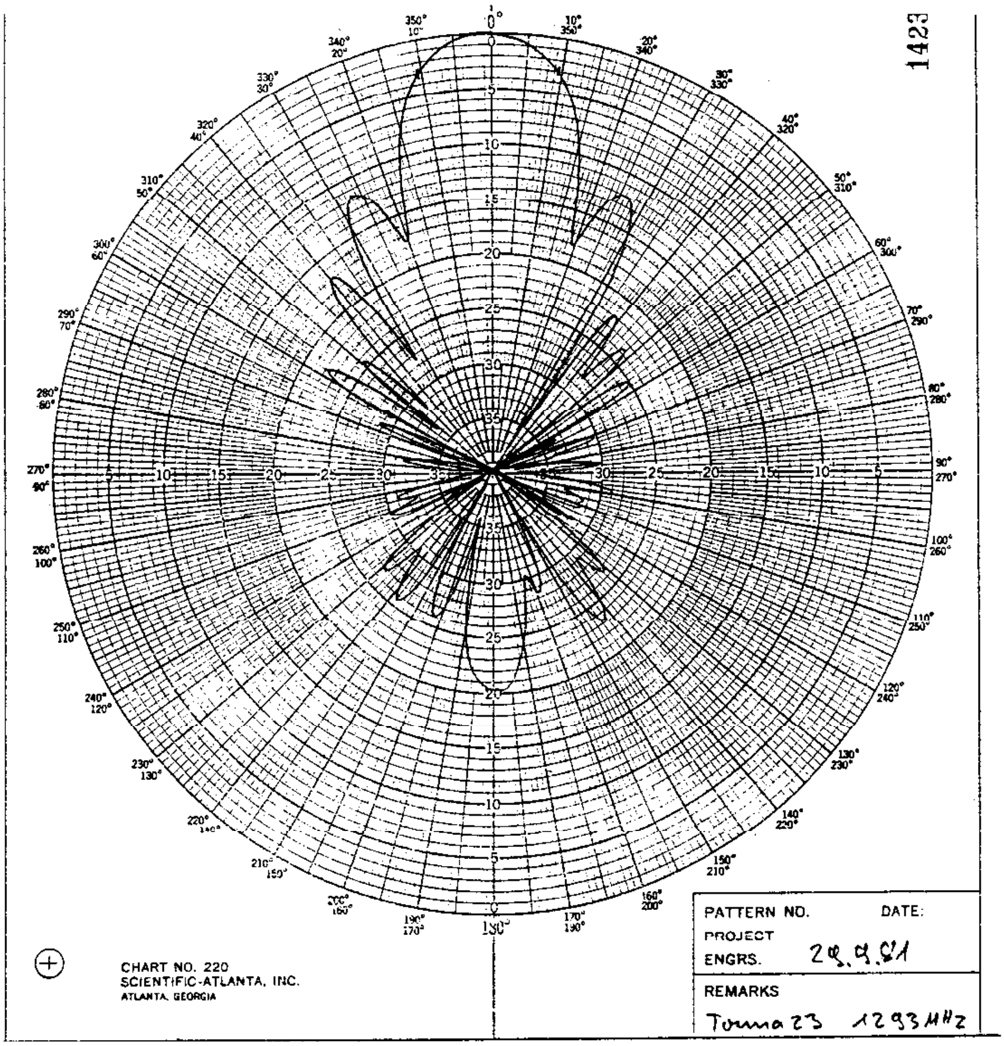
See Table 4.

5.7.2 Results

NEC-PC

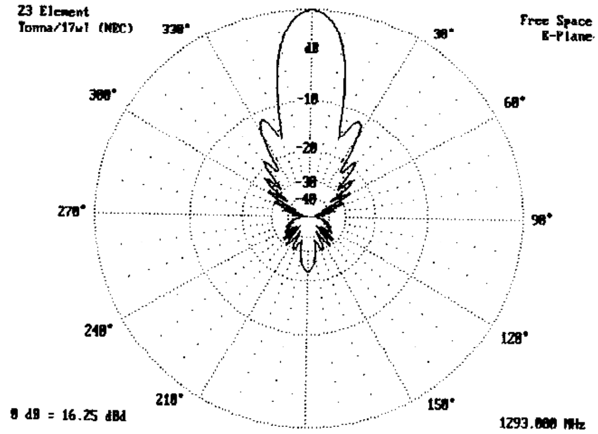


Bild/Figure 24: Simulation by YAGIANA: TONNA-21

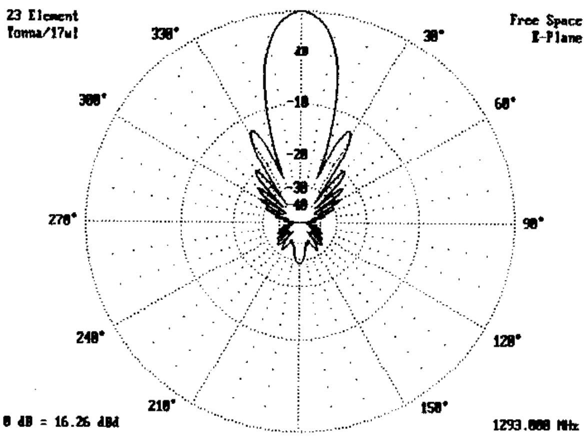


Bild/Figure 25: TONNA-23: Measured Pattern

CASE 3: TONNA-21 YAGI on 432.0MHz Pattern: Figure 19 Data: Table 3							
Program	**Simulation @ f_m =432.0MHz**			**Simulation @ f_{opt}**			
	Pattern-Match	**Gain[dBD]**	**Z**	**f_{opt} ,[MHz]**	**Pattern-Match**	**Gain[dBD]**	**Z**
NEC-PC	Fig. 17: Fair	15.75	11.2-j*19.5	432.5	Medium	15.77	10.6-j*18.3
YO	Fig. 18:Fair	15.6	10.4-j*13	433.5	Medium	15.7	9.3-j*10
MN	Fig. 20:Poor	15.88	N/A	436	Medium	15.78	
YAGIANALYSIS	Fig. 24:Medium	15.88	6.6+j*12.6	436.0	Good	15.78	
YAGIMAX	Fig.22:Fair	14.94	15-j*28	N/A			



Bild/Figure 26: Simulation by NEC-PC: TONNA-23



Bild/Figure 27: Simulation by YO: TONNA-23

Table 4*: Case 4 (23El Tonna)

Element	Position [mm]	Half Length [mm]
R	0	57.5
FEED	34	51
D1	62	49.5
D2	94	48
D3	161	47.5
D4	228	47
D5	295	46.5
D6	375	46
D7	464.5	45.5
D8	554	45
D9	643.5	45
D10	733	45
D11	822.5	45
D12	912	45
D13	1001.5	45
D14	1091	45
D15	1180.5	45
D16	1270	45
D17	1359.5	45
D18	1449	45
D19	1538.5	45
D20	1628	45
D21	1703	45

Environment:	Free Space
Element-Diameter:	3mm
Feeder:	Dipole
Measuring Frequency:	1293MHZ
Measured Gain:	16.1dBD
Measured Pattern:	Figure 17

* Given are the free space element lengths

RADICAL	Fig. 21:Poor	14.45	N/A	440	15.45	fair	N/A
ELNEC	Fair	15.44	15.3-j*28.9	438	15.84	Good	9.5-17.9

CASE 4: TONNA-23 YAGI on 1293MHz
Pattern: Figure 25
Data: Table 4

Program	Simulation @ f_m =1293MHz			Simulation @ f_{opt}			
	Pattern-Match	Gain[dBD]	Z	f_{opt},[MHz]	Pattern-Match	Gain[dBD]	Z
NEC-PC	Fig. 26: Good	16.25	11.9-j*12.3	1296	Good	16.18	12.1-9.9
YO	Fig. 27:Poor	16.26	13.4-j*16.4	1305	Good	16.37	12.2-j*9
MN	Fig. 28:Poor	15.35		1325	Medium		
YAGIANALYSIS	Fig. 29:Medium	15.81	12-j*4.7	1288	Good	16.04	11-j*8.4
YAGIMAX	Fig.30:Poor	15.12	17.3-j*29.6	N/A			
RADICAL	Fig. 31:Poor	14.45	N/A	1345	Fair	16.25	N/A
ELNEC	N/A						

YAGIANALYSIS
Pattern Match is medium on f_m . Gain difference is -0.3dB. Frequency offset for best pattern match is -0.6%. At f_{opt} pattern match is good.

YAGIMAX
Pattern Match is poor on f_m . Gain difference is -1.0dB. No best match frequency could be found. Impedance on f_m is not plausible.

RADICAL
Pattern Match is poor on f_m . Gain difference is -1.65dB. Frequency offset for best pattern match is 4%.

ELNEC
Not available, because antenna is too large for ELNEC.

5.8 Case 5: 37El DL6WU on 1296MHz

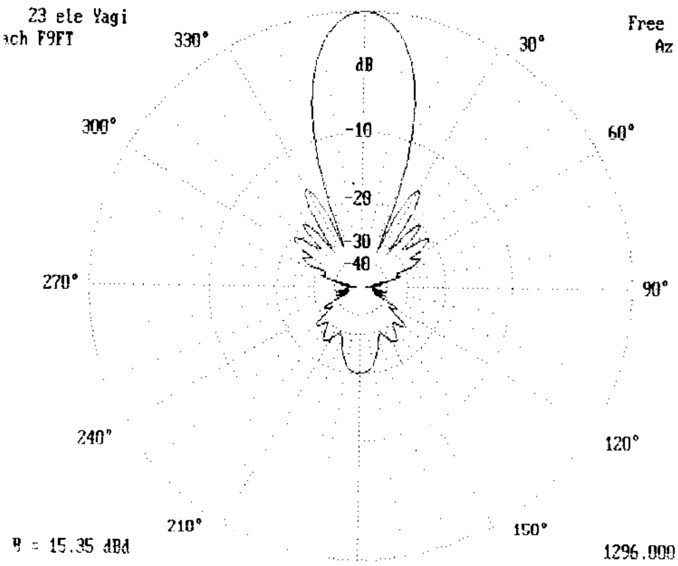
5.8.1 Dimensions

The dimensions are in Table 5.

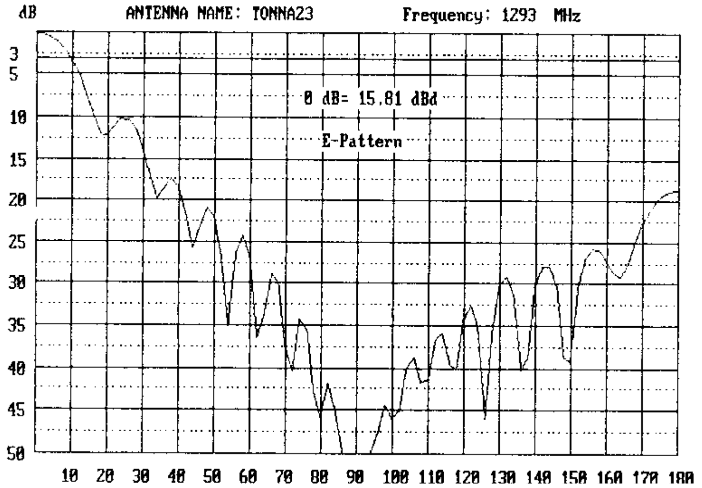
5.8.2 Results

Measurements
Measured Pattern is in Fig. 31.

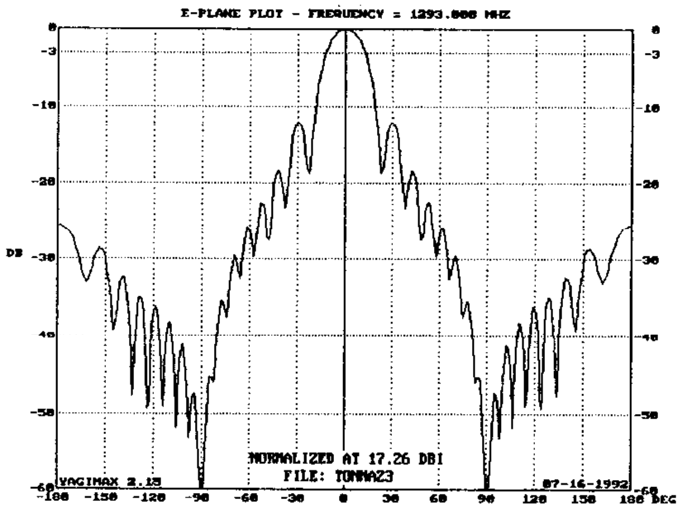
NEC-PC
Pattern Match is good on f_m . Gain difference is -0.2dB. No frequency offset.



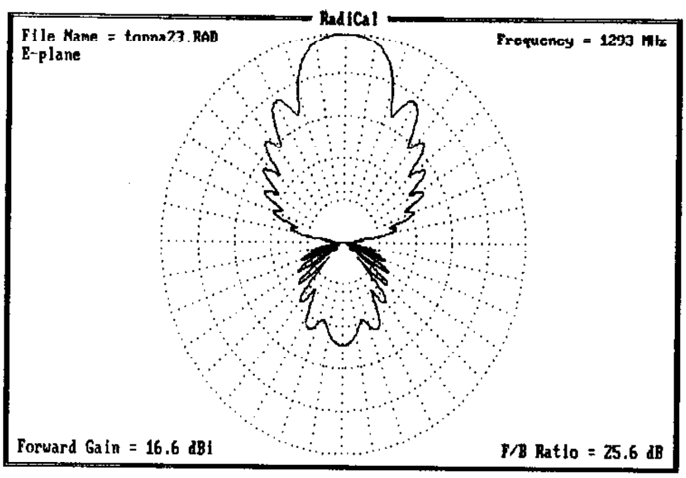
Bild/Figure 28: Simulation by MN: TONNA-23



Bild/Figure 29: Simulation by YAGIANA: TONNA-23



Bild/Figure 30: Simulation by YAGIMAX: TONNA-23



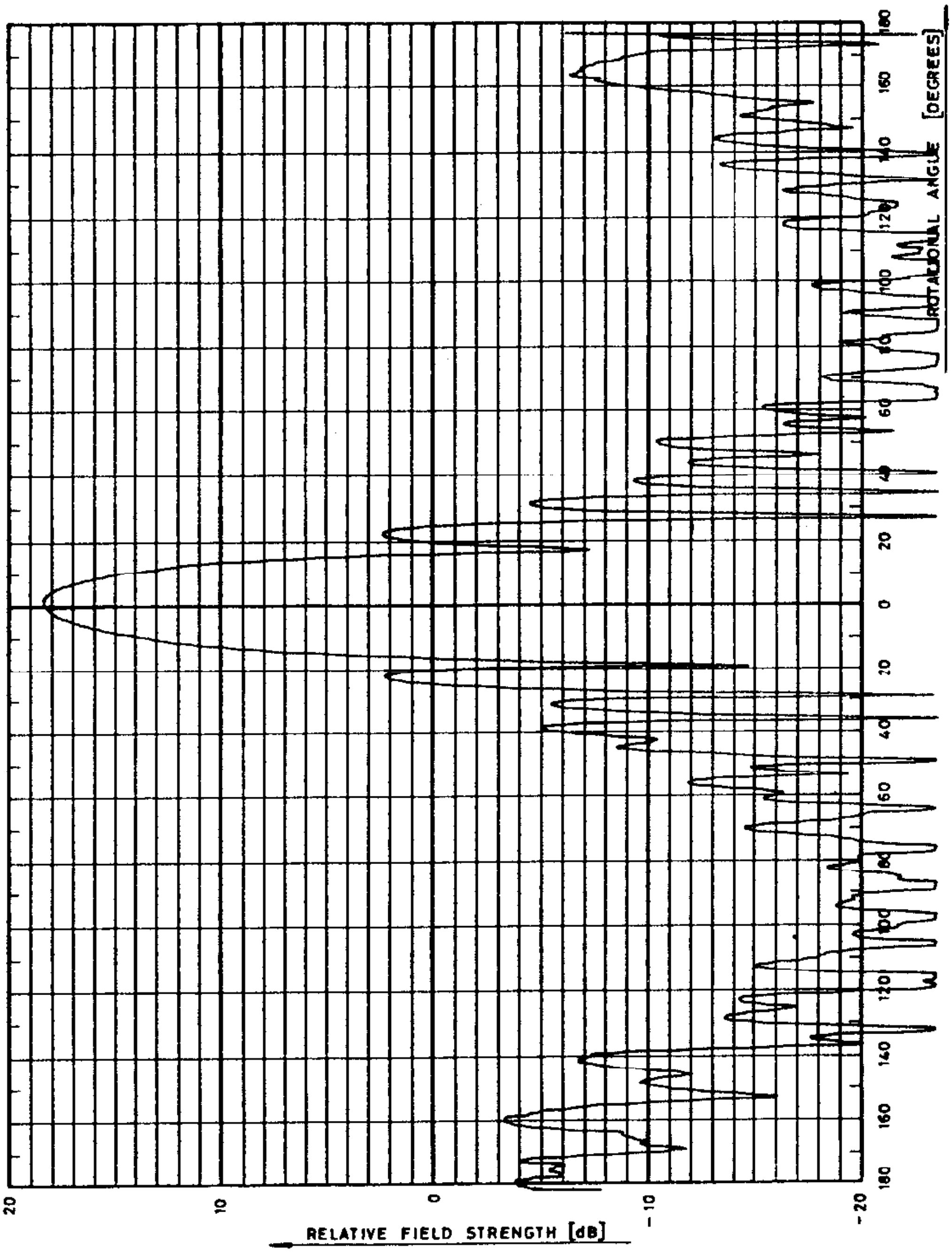
Bild/Figure 31: Simulation by RADICAL: TONNA-23

Table 5*: Case 5 (37EL DL6WU)

Element	Position [mm]	Half Length [mm]
R	0	55
FEED	50	53
D1	68	48
D2	110	47.25
D3	160	46.5
D4	218	45.75
D5	283	45
D6	353	44.5
D7	426	44
D8	502	43.5
D9	582	43
D10	665	43
D11	751	42.5
D12	841	42.5
D13	933	42
D14	1025	42
D15	1117	42
D16	1209	41.5
D17	1301	41.5
D18	1393	41.5
D19	1485	41
D20	1577	41
D21	1669	41
D22	1761	40.5
D23	1853	40.5
D24	1945	40.5
D25	2037	40
D26	2129	40
D27	2221	40
D28	2313	40
D29	2405	39.5
D30	2497	39.5
D31	2589	39.5
D32	2681	39.5
D33	2773	39
D34	2865	39
D35	2957	39

Environment: Free Space
Element-Diameter: 4mm
Feeder: Dipole

RADIATION PATTERN MEASUREMENT			
ANTENNA TYPE : 39 el.	7 60	MEASUREMENT RESULTS	
FREQUENCY :	6 uV	MEASUREMENT PLANE	E
MANUFACTURER :		MEASUREMENT FREQ.	1296
OWNER :	OC 3 XY	GAIN (dBd) :	18,3
STATED SPECIFICATIONS BY MANUFACTURER :		3 dB - BEAMWIDTH :	
GAIN (dBd).	3 dB-BEAMWIDTH:	F/B RATIO :	
F/B RATIO:	MAX. SWR:	SWR AT MEAS. FREQ. :	



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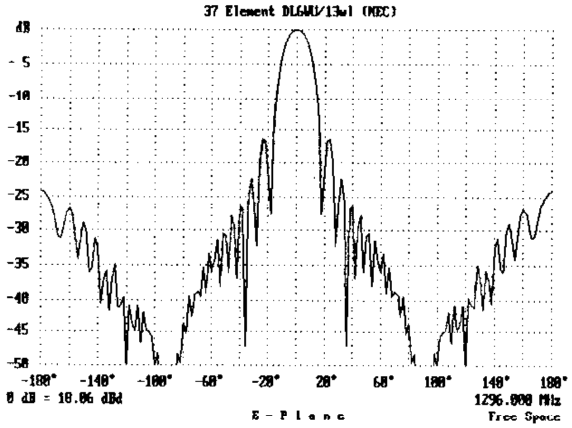
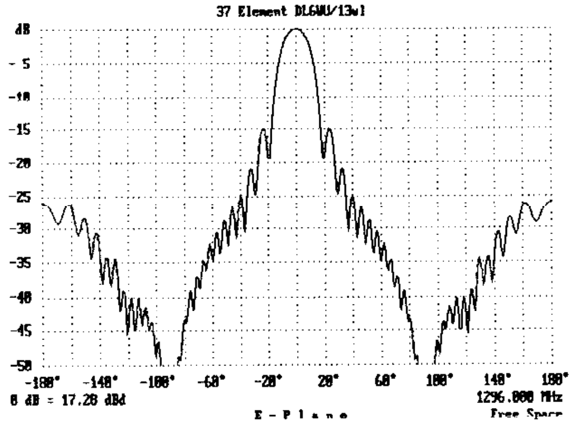
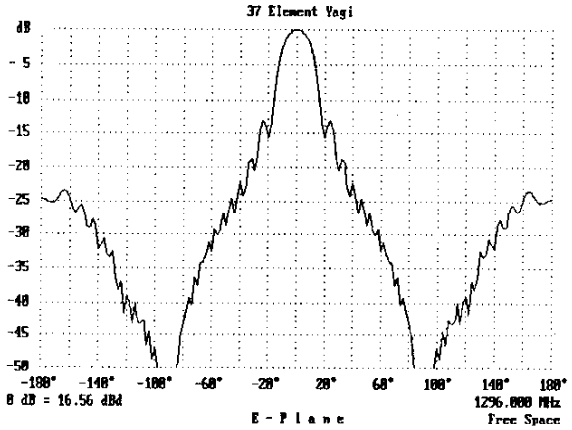
Bild/Figure 32: WU-37: Measured Pattern



Bild/Figure 33: Simulation by NEC-PC: WU-37



Bild/Figure 34: Simulation by YO: WU-37



Bild/Figure 35: Simulation by MNH: WU-37

YO

Pattern Match is poor on f_m . Gain difference is -1.0dB. Frequency offset for best pattern match is +1.1%. At f_{opt} pattern match is good.

MN

Pattern Match is poor on f_m . Gain difference is -1.74dB. No best match frequency could be found.

YAGIANALYSIS

Pattern Match isgood on f_m . Gain difference is +0.1dB. No frequency offset.

YAGIMAX

Pattern Match is poor on f_m . Gain difference is -0.35dB. No best match frequency could be found. Impedance on f_m is not plausible.

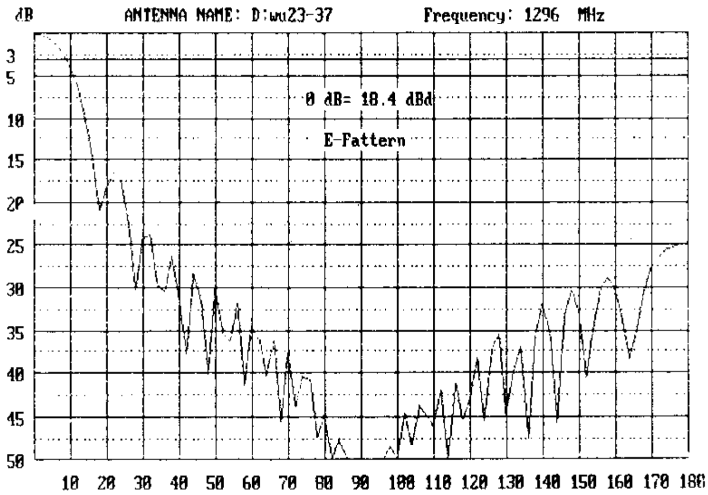
RADICAL

Antenna was not investigated.

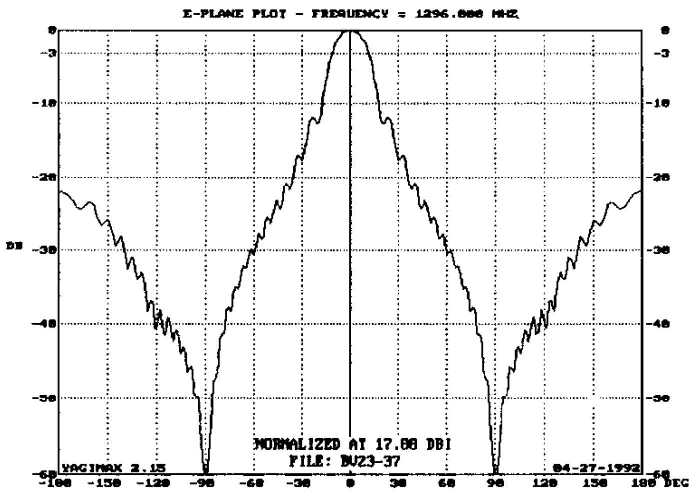
CASE 5: WU-37 YAGI on 1296MHz
Pattern: Figure 32
Data: Table 5

Program	Simulation @ f_m =1296MHz			Simulation @ f_{opt}			
	Pattern-Match	Gain[dBD]	Z	f_{opt} ,[MHz]	Pattern-Match	Gain[dBD]	Z
NEC-PC	Fig. 33: Good	18.06	47.2-j*9.9				8.6+j*3.1

YO	Fig. 34:Poor	17.28	38.9-j*2.7	1310	Good	17.77	37.4-j*0.4
MN	Fig. 35:Poor	16.56	N/A	N/A			
YAGIANALYSIS	Fig. 37:Good	18.4	43.3-j*5.2				
YAGIMAX	Fig.36:Poor	15.74		N/A			
RADICAL	N/A		N/A				N/A
ELNEC	N/A						



Bild/Figure 37: Simulation by YAGIANA: WU-37



Bild/Figure 36: Simulation by YAGIMAX: WU-37

6. Comparison of Results

Table 6: Results

ANT	Measurement			Simulation								
				NEC-PC			YO			MN		
	Gain	Pattern	F	ΔGain	Pattern	Offset%	ΔGain	Pattern	Offset%	ΔGain	Pattern	Offset%
NBS-12	12.2	Fig. 1	400	-0.18	Good	-0.1	-0.25	Good	+0.13	-0.55	Poor	+1.4
LYN-GBY	11.25	Fig. 10	432.5	+0.24	Fair	-0.35	+0.24	Fair	-0.18	-0.75	Poor	+1.3
TON-NA-21	15.6	Fig. 19	432	+0.15	Fair	-0.12	0.0	Fair	+0.4	+0.18	Poor	+1.0
TON-NA-23	16.1	Fig. 24	1293	+0.15	Good	+0.23	+0.16	Poor	+0.7	-0.85	Poor	+4.0
WU-37	18.3	fig. 31	1296	-0.24	Good	0	-1.0	poor	1.1	-1.74	Poor	N/A

ANT	Simulation											
	YAGIANALYSIS			YAGIMAX			RADICAL			ELNEC		
	ΔGain	Pattern	Offset%	ΔGain	Pattern	Offset	ΔGain	Pattern	Offset%	ΔGain	Pattern	Offset%
NBS-12	-0.18	Poor	-0.5	-0.83	Fair	+0.4	-1.35	Poor	+2.5	-0.55	Poor	+1.4
LYN-GBY	+0.3	Fair	-0.6	-0.25	Poor	+1.7	-1.7	Poor	+2.4	-0.76	Poor	+1.04
TON-NA-21	+0.28	Medium	0	-0.86	Fair	N/A	-1.15	Poor	+1.85	-0.16	Fair	+1.4
TON-NA-23	-0.3	Medium	-0.6	-0.98	Poor	N/A	-1.65	Poor	3.8	N/A		
WU-37	+0.1	good	0	-1.0	poor	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 7: Mean Values

Prog	Measurement versus Simulation		
	ΔG	Offset%	Pattern
NEC	0.02	-0.07	good to medium
YO	-0.17	+0.43	Fair
MN	-0.93	2.0	Poor
YA	+0.04	-0.34	Medium to Fair
YM	-0.78	+1.0	Poor
RAD	-1.46	+2.63	Poor
EL	-0.49	+1.28	Fair to Poor

7. Conclusion

7.1 General

The range of computer programs offered to the amateur who seeks support in Yagi design work runs from very simple to highly sophisticated, although the differences are not always visible at first sight.

Presently it appears that only a full-fledged method-of-moments computation applying higher order approximation plus treatment of end effects and resistive loss can lead to results matching the accuracy of good measurements. The only program of this type available to amateurs is NEC in the PC version. Unfortunately, it is slow and the available user surfaces are not very well suited for experimentation and design work. The great value of NEC lies primarily in its function as a standard against which the results of fast design programs can (and must) be checked. The precision of NEC simulations has been treated in the chapter on antenna measurement, the results were fully confirmed by the examples selected for the comparison test. The program will therefore not be further evaluated in this chapter.

7.2 Evaluation of Yagi Software

7.2.1 YO

Only the simulation part of YO is considered here, remarks on the optimizer part are to be found in chapters 4. and 8.

The method of computation is not known but it appears that a full-element (unsegmented) approach is used in combination with carefully chosen correction factors for element diameter and current distribution on short elements. Computation is fast and astonishingly precise for short and medium-length antennas. The somewhat less satisfactory results on long, tapered Yagis show up the limitations of this procedure. The user surface is excellent. YO data files can be automatically converted into NEC input files and NEC output plotted with the YO plot routines. This is perhaps the best feature of the software. The above-mentionned correction factors which match the results closely to NEC can be switched to provide a match to MININEC. The author himself discourages the use of this mode. The findings on MN/MININEC in this test underline his recommendation.

7.2.2 MN/MININEC

Although element segmentation and a method-of-moments algorithm are employed, MININEC and its derivatives are disappointingly inaccurate. Obviously this is caused by the use of faster and less space-consuming approximation procedures and the missing treatment of end effects. A large frequency error, poor pattern fidelity and the low number of permissible segments make the software unacceptable for work on medium-sized or long VHF Yagis. There are applications in the modelling of small irregularly shaped antennas like groundplanes, vees or the like; MN eases the statement of such geometries. By and large, however, this software is obsolete.

7.2.3 YAGI ANALYSIS

Like in the case of YO no information was available on the computation methods. Probably a similar approach is employed. The program is fast and relatively accurate, the surface is user-friendly. Except for the missing bridge to NEC this software is in a class with YO.

7.2.4 YAGIMAX

The simplistic computation based on full elements and sinusoidal current distribution makes this program by far too inaccurate for serious design or simulation work. Especially on long arrays with correspondingly short elements the deficiencies of this approach become obvious, patterns are reproduced so poorly that no best match frequency could be determined. The user surface leaves a lot to be desired.

7.2.5 RADICAL

This is the least accurate software in the test. What has been said about YAGIMAX is true for Radical to an even higher degree. Furthermore no feed impedance is calculated - the program can hardly be termed more than a toy.

7.2.6 ELNEC

Like MN this is basically MININEC in a more user-friendly

package. Results are in the same class though not identical, probably due to a different choice of some parameters.

7.3 Ranking

The results of the comparison test clearly group the software packages into three classes:

1. The assumed position of NEC as precision standard was confirmed.
2. YAGI ANALYSIS and YO show that surprising precision can be obtained with simpler and faster algorithms through appropriate correction factors. From a practical point of view YO is to be preferred because of its link to NEC.
3. Astonishingly enough the MININEC-based programs are not or only slightly more accurate than the simplistic ones based on uncorrected half-wave element calculation. The members of this group can not be recommended for serious work.

7. Schlußbetrachtung

7.1 Allgemeines

Die Reihe der Computerprogramme, die dem Amateur für den Entwurf von Yagis zur Verfügung stehen, reicht von sehr einfachen bis zu hochentwickelten Produkten, wobei die Unterschiede nicht immer auf den ersten Blick zu erkennen sind.

Gegenwärtig scheint es, daß nur der Einsatz der Momentenmethode in Verbindung mit Näherungsverfahren höherer Ordnung sowie der Behandlung von Endeffekten und Widerstandsverlusten zu Ergebnissen führt, die ähnlich genau wie gute Messungen sind. Das einzige für Amateure zugängliche Programm dieses Typs ist NEC in der PC-Version. Leider ist es langsam und die verfügbaren Benutzeroberflächen sind für Versuchs- und Entwurfsarbeit wenig geeignet. Der große Wert dieser Software liegt eher in ihrer Funktion als Normal, mit dem die Ergebnisse schneller Entwurfsprogramme abschließend geprüft werden können (und müssen). Die Genauigkeit von NEC-Simulationen wurde im Kapitel über Antennenmessungen (3.2) behandelt, die für den Test ausgewählten Beispiele bestätigen die dort gemachten Aussagen. Das Programm wird deshalb in diesem Kontext nicht weiter behandelt.

7.2 Bewertung der Yagiprogramme

7.2.1 YO

Nur der Simulationsteil von YO wird hier betrachtet, Bemerkungen zum Optimierer finden sich in Kap. 4 und 8.

Das Rechenverfahren ist nicht bekannt, aber es besteht Grund zur Annahme, daß unsegmentierte Ganzelemente berechnet werden mit sorgfältig gewählten Korrekturen für die Elementdicke und den Strombelag auf kurzen Elementen. Die Berechnung ist schnell und zumindest bei kurzen und mittellangen Antennen erstaunlich genau. Die etwas weniger befriedigenden Ergebnisse bei langen gestuften Yagis zeigen die Grenzen des Verfahrens auf. Die Benutzeroberfläche ist ausgezeichnet. YO-Datenfiles können automatisch in NEC-Eingabefiles gewandelt werden und NEC-Ausgabedaten in das YO-Plotformat. Das ist eins der interessantesten Leistungsmerkmale dieser Software.

Die oben genannten Korrekturfaktoren können so umgeschaltet werden, daß eine Anpassung der Ergebnisse an MININEC erzielt wird. Der Urheber rät jedoch selbst von diesem Mode ab; die Resultate des vorliegenden Tests unterstreichen seine Empfehlung.

7.2.2 MN/MININEC

Obwohl die Momentenmethode und segmentierte Elemente verwendet werden, sind MININEC und seine Abkömmlinge enttäuschend ungenau. Offensichtlich liegen die Gründe in der Anwendung schnellerer und weniger speicheraufwendiger Näherungsverfahren und dem Verzicht auf die Berechnung von Endeffekten. Der große Frequenzfehler, die geringe Wiedergabetreue der Diagramme und die geringe zulässige Gesamtzahl von Segmenten machen diesen Typ Software für den Entwurf mittellanger und langer UKW-Antennen ungeeignet. Sie ist brauchbar für die Modellrechnung an kleinen, unsymmetrischen Antennen, wie Groundplanes und Vs, deren Geometrie sich in MN recht gut formulieren läßt, im großen und ganzen sind aber MININEC-basierte Programme überholt.

7.2.3 YAGI ANALYSIS

Wie im Fall von YO war keine Information über das verwendete Rechenverfahren zu erhalten, wahrscheinlich ist es diesem ähnlich. Das Programm ist schnell und relativ genau, die Benutzeroberfläche ist anwenderfreundlich. Bis auf die fehlende Anbindung an NEC ist es in der gleichen Klasse wie YO.

7.2.4 YAGIMAX

Das einfache Rechenverfahren auf der Basis von Halwellenelementen mit sinusförmigem Strombelag macht dieses Programm viel zu ungenau für ernsthafte Entwurfs- und Simulationsarbeit. Besonders bei langen Arrays mit entsprechend kurzen Elementen treten die Fehler dieses Verfahrens deutlich zu Tage, die Diagramme sind so ungenau, daß die Frequenz der besten Übereinstimmung nicht festgestellt werden konnte. Auch die Bedieneroberfläche läßt viele Wünsche offen.

7.2.5 RADICAL

Was über YAGIMAX gesgt wurde, gilt in noch höherem Maße für RADICAL, es ist das ungenaueste Programm im Test. Außerdem fehlt die Berechnung von Eingangsimpedanzen - das Programm ist kaum mehr als ein Spielzeug.

7.2.6 ELNEC

Wie MN ist dies dem Grunde nach MININEC in einer benutzerfreundlicheren Verpackung. Die Resultate sind ähnlich, aber nicht identisch, offenbar sind manche Parameter anders gewählt.

7.3 Reihung

Die Ergebnisse des Vergleichs gruppieren die Softwarepakete ganz klar in drei Guppen:

1. Die vermutete Position von NEC als Vergleichsmaßstab wurde voll bestätigt.
2. YAGI ANALYSIS und YO zeigen, daß bei entsprechender Korrektur auch mit einfacheren und schnelleren Rechenverfahren erstaunliche Genauigkeit erzielt werden kann. Vom praktischen Standpunkt ist YO vorzuziehen, da es an NEC angebunden werden kann.
3. Die MININEC-basierten Programme sind erstaunlicherweise nicht oder nur wenig genauer als die Simpelverfahren auf der Basis von unkorrigierten Halbwellenelementen. Von der Anwendung der Software dieser Gruppe für ernsthafte Arbeit muß abgeraten werden.

8. Proposals for Software Enhancements

8.1 YO

During the evaluation YO proved to very stable. No crashes or similar problems have been observed.

Functions:

On the functional side there are several deficiencies which make the use of this program somewhat difficult. It's the only software which provides an optimizer. The optimizer is based on a steeppest gradient search algorithm. This method - as all others - is inherently 'shortsighted'. This means it can only find local optima. Without guidance from the user this optimizer, when operating in free run mode, will produce lots of structures which are optimal in a mathematical sense - it maximizes the gain function - but which are 'nonsense' designs from a electrical point of view. These 'non-working' structures' exhibit strange current profiles, low distances between parasitic elements and so on. It's an absolute must to have an opportunity to envolve the electrical know how of the user about practical Yagi design into the design process. This implies facilities for interactive control of the optimizer. This should be:

Interactive Control:

1. Control of input impedance: The current tradeoff menu is insufficient. Required is a specification of a wanted input impedance (or a range) which serves as a constraint for the optimizer.
2. Control of sidelobes: The current tradeoff menu is insufficient. Required is a specification of a wanted sidelobe suppression (or a range) which serves as a constraint for the optimizer.
3. Control of the structure: It should be possible to define elements or group of elements, which are not allowed to change by the optimizer. This would allow to tweak an already good design by adding a few elements or changing only some element dimensions without loosing the good design because the optimizer tries to change everything. This selective approach would be much better than the current 'total' optimisation approach which leads to 'impossible' Yagis.

Output:

An indication of the loss factor (Effciency) would be valuable, because it would allow a judgement about the sensivity of the design[1].

1 *This is based on the fact that overoptimized Yagis have an abnormal loss factor.*

Structure definition:
It should be possible to specify multiple reflectors.

Verification:
The investigation clearly shows that MININEC and all similar programs have an insufficient accuracy for VHF-Yagis. This program is obsolete and even the usefulness for HF-Yagis is in doubt. It should be discarded as a verification tool because YO itself is much better. Only the verification by NEC-PC makes sense. This should be made clear in the documentation.

Apparently this is not clear in the US, as the many articles about MININEC applications show [2,3,4].

8.2 YAGIANALYSIS

Some improvements from Version 3.0 to 3.3 are noticable. No crash problems have occured, except a hangup if you try to output a plot without a plotter. Also the program is much faster.

Some functions are not implemented:

- Change of geometry input to position defintion of elements: Under the menu 'OPTIONS' one can select the submneu 'POSITION' but only a beep happens. This function is not implemented. The input of yagi geometry in terms of distances between directors is rather annoying, because in most cases the position of parasitc elements is specified. This option is therefore very much needed.
- Also the submenu 'Driver Type' is not implemented.
- Also the submenu Result-Graph' under menu 'Results' is not implemented.

Proposal: Either implement the functions or drop the submenu.

We would like the following functional improvements:

- Plot resolution is rather course and should be made user selectable
- As a output medium a HP Laserjet (PCL) should be supported.
- The plot should be printable to a file for further processing
- The geometry should be printable