

### 10-3.3 Yagi-Uda Design Programs

Three DOS command window programs design Yagi-Uda dipole antennas by using gradient search optimizations on one of four cost functions: 1 Maximum Gain, 2 Maximum Front/Back, 3 Maximum Gain for a given Source Impedance, 4 Return Loss:

**YAGIF** Antenna in free space optimized over a frequency band using Kajfez [20] method. The antenna may have a single feed or multiple feeds fed by a crisscross transmission line similar to a log periodic dipole antenna (Section 11-12)

**YAGIFL** Antenna in free space optimized over a frequency band using Kajfez [20] method. This antenna uses a folded dipole (Section 5-12) feed to increase the input impedance. The antenna may have a single feed or multiple feeds fed by a crisscross transmission line similar to a log periodic dipole antenna (Section 11-12)

**YAGMG** Antenna mounted horizontally over ground optimized at a single frequency for a given elevation angle. The antenna maybe tilted with respect to ground. Both antenna height and pointing can be used as optimization variables.

The programs analyze the pattern by using a combination of R. C. Hansen mutual impedance of echelon dipoles [1a] and the Richmond moment method code ASAP (Section 2-5.3) imbedded in the optimization routines and will supply the frequency response or pattern response at a given frequency. The programs can plot results but generates them using the HP Graphics Language (HPGL). While the HPGL format is no longer supported, online conversion sites will convert these to PNG, JPEG, and PDF formats.

The optimization maximizes a cost function. When optimizing over a frequency band, the flatness parameter in Eq. (10-28) only makes sense for gain. Optimizing F/B and return loss should specify this parameter as zero (flatness ignored). The gradient search optimization method converges rapidly but is a local optimum unlike the genetic algorithm or particle swarm methods which give global optimums. Another problem with a gradient search is jumping out of a viable solution space, for example, generating very long dipoles or small spacing between elements. The program allows reentry of dipole length and element spacing before the next search after generating a frequency response, but sometimes the search has to be abandoned. Variables in the optimization can be deactivated, for example, keep spacing between dipoles constant. Below you will see that various cost functions are selected in multiple optimizations to achieve an acceptable design.

Each program generates an output file, for example: YAGIF.OUT. If you want to keep this design, it is necessary to rename this file. The programs operate with dimensions in wavelengths, but will print dimensions when a center frequency is specified. Every call for frequency after this is in the units of the center frequency (kHz, MHz, or GHz). A design can be extracted from an output file and stored in a text file as initial input for the programs. Initial input is given in wavelengths which the programs output before asking for center frequency. The input for a three dipole Yagi-Uda antenna as the form:

```
1 0.55913 -0.02139 0.00600 (element #, dipole length, location, diameter (wavelengths))
2 0.47751 0.10918 0.00600
3 0.41744 0.21061 0.00600
```

## Chapter 10 Traveling-Wave Antennas

[1a] R. C. Hansen, Formulation of Echelon Dipole Mutual Impedance for Computer, *IEEE Transactions on Antennas and Propagation*, vol. AP-20, No. 6, November 1972, pp. 780-781.

### 3 Dipole Yagi-Uda Example

John Kraus (W8JK) designed a three element Yagi-Uda dipole antenna *Antennas*, McGraw-Hill, 1950 with elements spaced  $0.1\lambda$  with a fed dipole  $0.5\lambda$ , a director  $0.45\lambda$ , and a reflector  $0.58\lambda$ . The program YAGIF generates the following analysis of the antenna.

Yagi-Uda Dipole Design with Frequency Band Optimization

Number of Elements: 3  
First Fed Element: 2  
Number of Elements Fed: 1  
Lower Number Elements are Reflectors  
Lower Frequency Opt. Bound: 0.990  
Upper Frequency Opt. Bound: 1.010  
Gaussian Integration Number: 6  
Center Frequency: 1.0000 GHz

Frequency Response of Yagi Antenna units: in.

No.	Length	Position	Diameter
1	6.846	0.000	0.071
2	5.901	1.180	0.071
3	5.311	2.361	0.071

Source Impedance: 50.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR	
0.9000	6.20	5.49	14.16	30.38	-26.48	2.28
0.9100	6.15	5.70	13.99	33.49	-21.32	1.91
0.9200	6.13	5.86	14.00	36.20	-16.73	1.66
0.9300	6.14	5.97	14.21	38.42	-12.69	1.48
0.9400	6.17	6.07	14.63	39.99	-9.16	1.35
0.9500	6.23	6.16	15.33	40.70	-6.04	1.28
0.9600	6.31	6.26	16.40	40.36	-3.14	1.25
0.9700	6.43	6.36	18.01	38.80	-0.17	1.29
0.9800	6.57	6.44	20.59	35.97	3.30	1.40
0.9900	6.74	6.49	25.32	31.99	7.70	1.62
1.0000	6.94	6.41	34.58	27.20	13.43	2.02
1.0100	7.17	6.12	23.90	22.07	20.72	2.73
1.0200	7.42	5.46	17.19	17.13	29.55	4.03
1.0300	7.67	4.34	12.70	12.83	39.70	6.46
1.0400	7.86	2.75	9.17	9.42	50.82	10.89
1.0500	7.88	0.79	6.14	7.00	62.54	18.41
1.0600	7.55	-1.39	3.43	5.52	74.56	29.28
1.0700	6.71	-3.63	0.97	4.87	86.67	41.21
1.0800	5.36	-5.79	-1.23	4.90	98.72	50.10
1.0900	3.77	-7.69	-3.07	5.46	110.64	54.05
1.1000	2.33	-9.16	-4.41	6.45	122.42	54.34

The column labeled “Gain” is the maximum gain with a matching network while “Source Gain” includes mismatch loss. While the “Gain” is about 7 dB, the antenna has a 2:1 VSWR to a  $50\Omega$  system which lowers the gain to 6.41 dB. The antenna has a high F/B (front/back) of 34.6 dB which indicates the only reasonable experimental design technique for adjusting elements is F/B because gain has a broad maximum. The “source gain” and F/B have slowly varying curves below center frequency while dropping quickly in the upper frequency range. Various optimizations are listed below.

Fix position of elements  
Gradient searches 4  
Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 4 Search for 50Ω Match

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Weight on Difference Integral: 0.00  
Optimize reflector length

Input Impedance = 44.31 2.96

No.	Length	Position	Diameter
1	0.58066	0.00000	0.00600
2	0.47955	0.10000	0.00600
3	0.41927	0.20000	0.00600

Relative Gain (max) = 5.96  
Relative Gain Source Match = 5.94  
F/B = 12.91

Gradient searches 4  
Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 2 Search to improve F/B  
Weight on Difference Integral: 0.00  
Optimize reflector length

Input Impedance = 24.33 -8.25

No.	Length	Position	Diameter
1	0.56910	0.00000	0.00600
2	0.48200	0.10000	0.00600
3	0.44880	0.20000	0.00600

Relative Gain (max) = 6.95  
Relative Gain Source Match = 6.35  
F/B = 34.23

Gradient searches 4  
Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 4 Search for 50Ω Match  
Weight on Difference Integral: 0.00  
Optimize reflector length

Input Impedance = 44.04 3.04

No.	Length	Position	Diameter
1	0.56982	0.00000	0.00600
2	0.47963	0.10000	0.00600
3	0.42057	0.20000	0.00600

Relative Gain (max) = 6.05  
Relative Gain Source Match = 6.03  
F/B = 13.58

Center Frequency: 1.0000 GHz

Frequency Response of Yagi Antenna units: in.

No.	Length	Position	Diameter
1	6.725	0.000	0.071
2	5.661	1.180	0.071
3	4.964	2.361	0.071

Source Impedance: 50.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR
0.9000	6.24	3.89	13.91	21.83	-48.46
0.9100	6.12	4.41	13.36	24.82	-41.83
0.9200	6.02	4.82	12.89	27.68	-35.56
0.9300	5.96	5.14	12.54	30.42	-29.61
0.9400	5.91	5.38	12.32	33.03	-23.97

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0.9500	5.89	5.56	12.22	35.49	-18.64	1.74
0.9600	5.89	5.70	12.23	37.78	-13.62	1.52
0.9700	5.90	5.80	12.37	39.86	-8.94	1.35
0.9800	5.93	5.89	12.63	41.66	-4.60	1.23
0.9900	5.98	5.96	13.02	43.09	-0.62	1.16
1.0000	6.05	6.03	13.58	44.04	3.04	1.15
1.0100	6.13	6.10	14.33	44.36	6.42	1.20
1.0200	6.23	6.17	15.35	43.91	9.65	1.27
1.0300	6.36	6.24	16.76	42.56	12.90	1.38
1.0400	6.50	6.31	18.77	40.22	16.45	1.53
1.0500	6.66	6.33	21.82	36.91	20.60	1.75
1.0600	6.85	6.26	26.44	32.77	25.69	2.11
1.0700	7.06	6.03	26.44	28.08	31.97	2.70
1.0800	7.29	5.55	20.23	23.21	39.59	3.70
1.0900	7.53	4.74	15.48	18.55	48.53	5.42
1.1000	7.75	3.56	11.83	14.44	58.63	8.39

Gradient searches 4

Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 3 Search to improve gain

Weight on Difference Integral: 0.00

Optimize reflector length

Input Impedance = 31.59 4.18

No. Length Position Diameter

1	0.55813	-0.01750	0.00600
2	0.48550	0.09679	0.00600
3	0.43940	0.21871	0.00600

Relative Gain (max) = 6.99

Relative Gain Source Match = 6.75

F/B = 24.54

Center Frequency: 1.0000 GHz

Frequency Response of Yagi Antenna units: cm.

No.	Length	Position	Diameter
1	16.732	-0.525	0.180
2	14.555	2.902	0.180
3	13.173	6.557	0.180

Source Impedance: 50.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR	
0.9000	6.80	4.99	15.04	23.76	-42.12	3.81
0.9100	6.68	5.43	15.97	27.30	-35.99	2.99
0.9200	6.59	5.74	16.42	30.42	-30.51	2.46
0.9300	6.53	5.95	16.68	33.04	-25.56	2.09
0.9400	6.51	6.12	16.96	35.11	-21.04	1.83
0.9500	6.52	6.25	17.40	36.54	-16.85	1.65
0.9600	6.55	6.37	18.11	37.24	-12.89	1.52
0.9700	6.62	6.48	19.17	37.15	-9.01	1.44
0.9800	6.71	6.58	20.71	36.18	-5.04	1.41
0.9900	6.84	6.68	22.78	34.31	-0.73	1.46
1.0000	6.99	6.75	24.54	31.59	4.18	1.60
1.0100	7.17	6.75	23.15	28.15	9.96	1.88
1.0200	7.38	6.61	19.31	24.23	16.82	2.36
1.0300	7.61	6.23	15.54	20.17	24.89	3.18
1.0400	7.84	5.52	12.28	16.31	34.16	4.61
1.0500	8.02	4.41	9.42	12.94	44.50	7.04
1.0600	8.08	2.93	6.86	10.30	55.70	11.00
1.0700	7.90	1.18	4.51	8.49	67.49	16.73
1.0800	7.35	-0.72	2.35	7.53	79.64	23.58
1.0900	6.38	-2.63	0.39	7.37	91.94	29.82
1.1000	5.11	-4.43	-1.35	7.91	104.25	33.91

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Gradient searches 4

Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 4 Search for 50Ω Match

Weight on Difference Integral: 0.00

Optimize reflector length

Input Impedance = 49.74 0.38

No. Length Position Diameter

1	0.55913	-0.02139	0.00600
2	0.47751	0.10918	0.00600
3	0.41744	0.21061	0.00600

Relative Gain (max) = 6.16

Relative Gain Source Match = 6.16

F/B = 14.35

Center Frequency: 1.0000 GHz

Frequency Response of Yagi Antenna units: cm.

No. Length Position Diameter

1	16.762	-0.641	0.180
2	14.315	3.273	0.180
3	12.514	6.314	0.180

Source Impedance: 50.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR
0.9000	6.61	4.61	13.65	25.52	-48.78
0.9100	6.46	5.06	14.00	29.15	-42.20
0.9200	6.33	5.37	13.96	32.57	-36.12
0.9300	6.24	5.60	13.78	35.74	-30.44
0.9400	6.16	5.76	13.58	38.67	-25.12
0.9500	6.12	5.87	13.44	41.34	-20.13
0.9600	6.09	5.95	13.39	43.75	-15.44
0.9700	6.08	6.01	13.44	45.85	-11.06
0.9800	6.09	6.06	13.61	47.60	-6.98
0.9900	6.12	6.11	13.90	48.93	-3.18
1.0000	6.16	6.16	14.35	49.74	0.38
1.0100	6.23	6.22	14.97	49.94	3.75
1.0200	6.31	6.29	15.84	49.40	7.03
1.0300	6.41	6.36	17.03	48.04	10.38
1.0400	6.53	6.43	18.69	45.78	14.01
1.0500	6.68	6.49	21.11	42.62	18.16
1.0600	6.85	6.49	24.61	38.64	23.12
1.0700	7.04	6.39	26.93	34.02	29.14
1.0800	7.26	6.11	22.60	29.04	36.41
1.0900	7.50	5.57	17.71	24.04	45.02
1.1000	7.75	4.69	13.87	19.36	54.91

~13% Bandwidth

Frequency: 1.000 GHz

Theta	E Plane Pattern		H Plane Pattern	
	Ampl(dB)	Phase	Ampl(dB)	Phase
0.0	6.16	123.4	6.16	123.4
2.0	6.15	123.4	6.16	123.4
4.0	6.12	123.3	6.15	123.3
6.0	6.07	123.2	6.14	123.2
8.0	6.01	123.0	6.13	123.0
10.0	5.92	122.8	6.11	122.8
12.0	5.81	122.5	6.08	122.6
14.0	5.68	122.1	6.05	122.3
16.0	5.53	121.7	6.02	121.9
18.0	5.37	121.3	5.98	121.5

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20.0	5.18	120.8	5.94	121.1
22.0	4.97	120.2	5.89	120.6
24.0	4.74	119.6	5.84	120.0
26.0	4.49	119.0	5.78	119.4
28.0	4.23	118.2	5.72	118.8
30.0	3.93	117.5	5.65	118.2
32.0	3.62	116.7	5.58	117.4
34.0	3.29	115.8	5.50	116.7
36.0	2.93	114.9	5.41	115.9
38.0	2.55	114.0	5.32	115.1
40.0	2.15	113.0	5.23	114.2

The last design has a flatter and more symmetrical response with a 2:1 VSWR bandwidth of about 14%. Other criteria could be used for a “better” design, but these will do. The H-plane (vertical for a horizontally mounted antenna) pattern response shows that the pattern is falls off slowly to 20°.

## 3 Element Yagi-Uda over Ground Spaced for Elevation Beam = 20°

We use YAGMG to assess the response of this antenna when mounted over ground and perform optimizations to improve the design. A horizontally mounted antenna has a null along the horizon. The difference of reflection between a metal ground plane and soil is small (Figure 1-9) for horizontal polarization near zero grazing angles and we can assume a metal ground plane in the analysis. For an elevation angle of 20° of the horizontally mounted antenna, we compute a height by using Eq. (10-20). The exact value is one of the optimization variables. The following output of YAGMG illustrates the optimization steps.

```
Horizontal Yagi-Uda over ground plane
Number of elements:          3
Elevation of optimum:       20.00
First fed Element:          2
Number of feed points:      1
Feed line impedance:        0.00
Additional feeder length:    0.000
Dielectric constant:        0.00
Element diameters:
Forward firing
Antenna height:             0.7285   Eq. (10-20) to Estimate Height (wavelengths)
Pointing angle:             0.00
Source impedance:          50.00    0.00
Center Frequency:         1.0000 GHz
```

Frequency Response of Yagi Antenna units: in.

No.	Length	Position	Diameter
1	6.599	-0.252	0.071
2	5.636	1.289	0.071
3	4.927	2.486	0.071

Source Impedance: 50.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR	
0.9000	12.44	10.03	10.97	22.20	-50.25	4.76
0.9100	12.32	10.57	10.60	25.02	-43.02	3.71
0.9200	12.21	11.00	10.30	27.83	-36.01	2.95
0.9300	12.12	11.33	10.10	30.68	-29.21	2.38
0.9400	12.06	11.58	10.01	33.59	-22.67	1.95
0.9500	12.01	11.75	10.03	36.60	-16.42	1.63
0.9600	11.97	11.85	10.15	39.70	-10.56	1.39
0.9700	11.95	11.91	10.38	42.84	-5.16	1.21
0.9800	11.95	11.94	10.72	45.94	-0.34	1.09
0.9900	11.96	11.95	11.19	48.87	3.81	1.08
1.0000	11.98	11.96	11.81	51.40	7.20	1.16
1.0100	12.03	11.98	12.61	53.26	9.84	1.22
1.0200	12.08	12.02	13.65	54.09	11.82	1.27

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1.0300	12.16	12.08	15.03	53.56	13.44	1.31
1.0400	12.26	12.16	16.95	51.41	15.16	1.35
1.0500	12.38	12.24	19.79	47.63	17.58	1.44
1.0600	12.52	12.26	24.55	42.45	21.30	1.63
1.0700	12.68	12.17	30.56	36.39	26.76	1.99
1.0800	12.86	11.86	23.06	30.08	34.11	2.66
1.0900	13.05	11.22	17.22	24.13	43.23	3.84
1.1000	13.24	10.19	13.24	18.93	53.80	5.91

Source impedance: 50.00 0.00  
 Antenna height: 0.7300  
 Pointing angle: 0.00  
 Gradient searches -1  
 Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 3 Search to improve gain  
 Normalized frequency of optimization: 1.0000  
 Optimize reflector length  
 Optimize height

Input Impedance = 30.65 3.52

No.	Length	Position	Diameter
1	0.5483	-0.0302	0.0060
2	0.4820	0.0970	0.0060
3	0.4411	0.2303	0.0060

Relative Gain (max) = 13.07  
 Relative Gain Source Match = 12.80  
 F/B = 33.78

Antenna height: 0.7253  
 Pointing angle: 0.00  
 Gradient searches 4  
 Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 4 Search to improve return loss  
 Normalized frequency of optimization: 1.0000  
 Optimize reflector length  
 Optimize height

Input Impedance = 48.23 -0.53

No.	Length	Position	Diameter
1	0.5498	-0.0337	0.0060
2	0.4722	0.1091	0.0060
3	0.4183	0.2223	0.0060

Relative Gain (max) = 12.19  
 Relative Gain Source Match = 12.19  
 F/B = 13.04

Antenna height: 0.7259  
 Pointing angle: 0.00  
 Gradient searches 3  
 Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 4 Search to improve return loss  
 Source impedance: 50.00 0.00  
 Center Frequency: 1.0000 GHz

Frequency Response of Yagi Antenna units: in.

No.	Length	Position	Diameter
1	6.489	-0.398	0.071
2	5.573	1.288	0.071
3	4.937	2.624	0.071

Source Impedance: 50.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR
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0.9000	12.69	9.78	11.03	21.40	-57.11	5.64
0.9100	12.56	10.40	11.14	24.42	-49.84	4.34
0.9200	12.44	10.89	11.03	27.35	-42.91	3.43
0.9300	12.34	11.26	10.90	30.22	-36.26	2.77
0.9400	12.27	11.55	10.84	33.07	-29.89	2.27
0.9500	12.21	11.77	10.87	35.91	-23.84	1.90
0.9600	12.17	11.92	11.02	38.74	-18.16	1.62
0.9700	12.15	12.03	11.29	41.51	-12.92	1.40
0.9800	12.15	12.10	11.70	44.12	-8.21	1.24
0.9900	12.16	12.15	12.27	46.43	-4.07	1.12
1.0000	12.19	12.19	13.04	48.23	-0.53	1.04
1.0100	12.25	12.24	14.06	49.28	2.47	1.05
1.0200	12.32	12.31	15.46	49.29	5.09	1.11
1.0300	12.41	12.38	17.45	48.04	7.64	1.17
1.0400	12.53	12.47	20.50	45.39	10.57	1.27
1.0500	12.67	12.53	26.23	41.43	14.38	1.44
1.0600	12.83	12.51	40.14	36.48	19.53	1.73
1.0700	13.02	12.34	23.62	31.01	26.31	2.23
1.0800	13.21	11.90	17.39	25.56	34.75	3.09
1.0900	13.40	11.11	13.37	20.59	44.69	4.56
1.1000	13.54	9.94	10.29	16.44	55.83	7.02

Source impedance: 50.00 0.00  
Antenna height: 0.7253  
Pointing angle: 0.00  
Gradient searches -1  
Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 2 Search to improve F/B  
Normalized frequency of optimization: 1.0000  
Optimize reflector length  
Optimize height

Input Impedance = 27.78 -11.56

No.	Length	Position	Diameter
1	0.5464	-0.0339	0.0060
2	0.4706	0.1003	0.0060
3	0.4416	0.2350	0.0060

Relative Gain (max) = 13.14  
Relative Gain Source Match = 12.67  
F/B = 64.91

Antenna height: 0.7301  
Pointing angle: 0.00  
Gradient searches 3  
Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 4 Search to improve return loss  
Source impedance: 50.00 0.00  
Center Frequency: 1.0000 GHz

Frequency Response of Yagi Antenna units: cm.

No.	Length	Position	Diameter
1	16.379	-1.015	0.180
2	14.108	3.005	0.180
3	13.240	7.045	0.180

Source Impedance: 50.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR	
0.9000	12.91	9.39	11.31	19.24	-62.07	6.84
0.9100	12.82	10.13	12.18	22.23	-55.18	5.24
0.9200	12.74	10.69	12.70	25.01	-48.85	4.17
0.9300	12.69	11.14	13.14	27.54	-43.02	3.42
0.9400	12.66	11.50	13.67	29.77	-37.69	2.88
0.9500	12.66	11.78	14.43	31.58	-32.85	2.50
0.9600	12.70	12.02	15.56	32.79	-28.48	2.23



## Chapter 10 Traveling-Wave Antennas

0.9700	12.76	12.22	17.26	33.19	-24.48	2.04
0.9800	12.85	12.39	19.99	32.55	-20.59	1.93
0.9900	12.98	12.55	25.24	30.73	-16.45	1.89
1.0000	13.14	12.67	64.91	27.78	-11.56	1.93
1.0100	13.32	12.72	23.63	23.99	-5.48	2.12
1.0200	13.52	12.62	16.84	19.86	2.06	2.52
1.0300	13.69	12.22	12.54	15.93	11.03	3.31
1.0400	13.79	11.41	9.27	12.64	21.21	4.71
1.0500	13.74	10.15	6.57	10.22	32.23	6.99
1.0600	13.42	8.53	4.26	8.71	43.75	10.21
1.0700	12.76	6.74	2.26	8.06	55.50	13.94
1.0800	11.81	4.94	0.55	8.14	67.32	17.39
1.0900	10.69	3.28	-0.89	8.82	79.11	19.99
1.1000	9.56	1.83	-2.02	9.99	90.82	21.67

Source impedance: 50.00 0.00  
 Antenna height: 0.7253  
 Pointing angle: 0.00  
 Gradient searches -1  
 Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 4 Search to improve return loss  
 Normalized frequency of optimization: 1.0000  
 Optimize reflector length  
 Optimize height

Input Impedance = 49.60 1.35

No.	Length	Position	Diameter
1	0.5481	-0.0387	0.0060
2	0.4733	0.1126	0.0060
3	0.4173	0.2280	0.0060

Relative Gain (max) = 12.21  
 Relative Gain Source Match = 12.21  
 F/B = 13.08

Antenna height: 0.7264  
 Pointing angle: 0.00  
 Gradient searches 3  
 Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 3  
 Source impedance: 50.00 0.00  
 Center Frequency: 1.0000 GHz

Frequency Response of Yagi Antenna units: cm.

No.	Length	Position	Diameter
1	16.432	-1.161	0.180
2	14.190	3.374	0.180
3	12.510	6.835	0.180

Source Impedance: 50.00 0.00

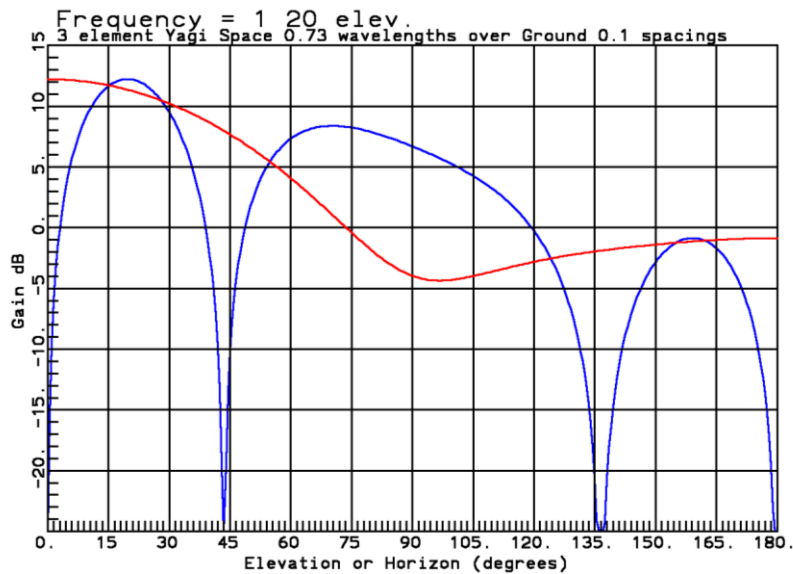
Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR	
0.9000	12.71	10.07	10.78	22.65	-55.26	5.16
0.9100	12.59	10.65	11.03	25.76	-48.00	4.00
0.9200	12.47	11.10	11.00	28.75	-41.09	3.17
0.9300	12.37	11.43	10.92	31.67	-34.46	2.57
0.9400	12.29	11.69	10.88	34.55	-28.12	2.13
0.9500	12.23	11.87	10.92	37.41	-22.08	1.79
0.9600	12.19	12.00	11.07	40.24	-16.42	1.53
0.9700	12.17	12.08	11.34	42.99	-11.19	1.33
0.9800	12.17	12.14	11.75	45.56	-6.45	1.18
0.9900	12.18	12.17	12.32	47.83	-2.27	1.07
1.0000	12.21	12.21	13.08	49.60	1.35	1.03
1.0100	12.26	12.25	14.10	50.63	4.45	1.09
1.0200	12.33	12.31	15.49	50.66	7.21	1.15
1.0300	12.43	12.38	17.44	49.46	9.90	1.22

Bandwidth similar to Free Space

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1.0400	12.54	12.46	20.44	46.92	12.94	1.31
1.0500	12.68	12.52	26.04	43.10	16.80	1.48
1.0600	12.85	12.51	50.62	38.26	21.95	1.75
1.0700	13.03	12.35	24.28	32.85	28.66	2.23
1.0800	13.23	11.94	17.80	27.37	37.04	3.05
1.0900	13.42	11.20	13.72	22.31	46.96	4.44
1.1000	13.57	10.10	10.63	17.99	58.15	6.75

The final design has about 6 dB more gain than the antenna in free space. Figure 5-7 of a single dipole mounted horizontally dipole has an increased gain of about 6 dB (over the 2 dB directivity of a dipole) for a dipole  $0.73\lambda$  above ground.



**Figure 1** 3 element Yagi-Uda Dipole Spaced  $0.73\lambda$  over Ground Elevation pattern (Blue), Horizon pattern @  $20^\circ$  (Red)

### 3 Element Yagi-Uda over Ground Spaced for Elevation Beam = $10^\circ$

Below is a copy of the inputs to YAGMG when the elevation beam peak is  $10^\circ$  including the optimization steps tried.

```

Yagi Dipole over Ground Design with Multiple Feeder
Enter Number of Elements 3
Enter Elevation Angle of Desired Optimum 10
Enter Element Number Fed (Lower Numbers Reflectors) 2
Enter Number of Feed Points 1
Enter Manipulation after Freq. Response
(1) None, (2) Element Lengths, (3) Lengths & Spacings 3
Enter initial design & frequency response? y
Input from file? y
Enter file name yagif310a.txt
Enter #, Length, Location, Diameter in Wavelengths' for Elements
Enter Number, Length, Location, Dia. 1 0.5591 -0.0214 0.0060
Enter Number, Length, Location, Dia. 2 0.4775 0.1092 0.0060
Enter Number, Length, Location, Dia. 3 0.4174 0.2106 0.0060
Enter Antenna Height, Pointing Angle 1.44,0
Enter Source Impedance: real, imag. 50,0
Enter center frequency, scale: 1 kHz, 2 MHz, 3 GHz 1,3
Enter units: 1 in, 2 ft, 3 mm, 4 cm, 5 m 1

Enter Frequency Start,Stop,Step .9,1.1,.01

Frequency Response of Yagi Antenna units: in.

No.    Length    Position    Diameter
1      6.599     -0.252     0.071
2      5.636      1.289     0.071
3      4.927      2.486     0.071

Frequency    Gain    Source Gain    F/B    Input Impedance    USWR
0.9000      12.38    10.40          12.26    24.85    -47.30    4.06
0.9100      12.25    10.92          13.03    28.93    -40.28    3.11
0.9200      12.14    11.28          13.60    33.01    -33.93    2.47
0.9300      12.06    11.52          14.03    36.96    -28.26    2.03
0.9400      12.00    11.68          14.38    40.68    -23.26    1.73
0.9500      11.96    11.77          14.68    44.02    -18.89    1.52
0.9600      11.95    11.84          14.96    46.84    -15.07    1.37
0.9700      11.96    11.90          15.22    49.03    -11.70    1.27
0.9800      11.98    11.95          15.48    50.49    -8.63     1.19
0.9900      12.03    12.01          15.74    51.16    -5.69     1.12
1.0000      12.09    12.08          16.04    51.02    -2.71     1.06
1.0100      12.16    12.16          16.39    50.12     0.48     1.01
1.0200      12.25    12.25          16.82    48.52     4.02     1.09
1.0300      12.36    12.33          17.38    46.29     8.01     1.20
1.0400      12.49    12.39          18.12    43.51    12.54     1.35
1.0500      12.63    12.42          19.10    40.26    17.67     1.56
1.0600      12.79    12.38          20.30    36.59    23.49     1.86
1.0700      12.97    12.24          21.32    32.58    30.07     2.31
1.0800      13.17    11.93          20.96    28.30    37.53     2.99
1.0900      13.39    11.39          18.47    23.90    45.99     4.10
1.1000      13.61    10.54          15.07    19.57    55.53     5.93

Plots?

```

Again, the peak gain increased by about 6 dB for a beam at 10°.

## Chapter 10 Traveling-Wave Antennas

```

Pattern Listing? n
Do you want Frequency Response? n
To Change Spacing Enter Number (-1 terminates)
Enter Number 0
Fix Position of Elements? n
Fix Length of Far-out Directors? n
To Change Element Length Enter Number (-1 terminates)
Enter Number 0
Enter Source Impedance: real, imag. 50,0
Enter Antenna Height, Pointing Angle 1.44,0
Enter Optimization Type:
    1 Max Gain, 2 Max F/B, 3 Max Gain Given Source, 4 Rtn Ls 3
Enter Number of Gradients (.LE.0 Freq. Resp., ' 0 No Return) 4
Enter Normalized Frequency of Optimization 1
Reflector Length Opt? y
Fix Feeder 1 Length? n
Optimize Height? y
Optimize Pointing? n

```

Input Impedance = 31.00 3.97

No.	Length	Position	Diameter
1	0.5422	-0.0345	0.0060
2	0.4827	0.0974	0.0060
3	0.4371	0.2336	0.0060

Relative Gain (max) = 13.15  
 Relative Gain Source Match = 12.89  
 F/B = 21.30

Antenna height: 1.4412  
 Pointing angle: 0.00

```

Enter Optimization Type:
    1 Max Gain, 2 Max F/B, 3 Max Gain Given Source, 4 Rtn Ls 4
Enter Number of Gradients (.LE.0 Freq. Resp., ' 0 No Return) 4
Enter Normalized Frequency of Optimization 1
Reflector Length Opt? y
Fix Feeder 1 Length? n
Optimize Height? y
Optimize Pointing? n

```

Input Impedance = 50.31 -0.61

No.	Length	Position	Diameter
1	0.5437	-0.0378	0.0060
2	0.4757	0.1079	0.0060
3	0.4128	0.2264	0.0060

Relative Gain (max) = 12.32  
 Relative Gain Source Match = 12.32  
 F/B = 17.95

Optimizations on peak gain and return loss produce a design with better gain and impedance match.

## Chapter 10 Traveling-Wave Antennas

```

Antenna height:          1.4408
Pointing angle:          0.00
Enter Optimization Type:
  1 Max Gain, 2 Max F/B, 3 Max Gain Given Source, 4 Rtn Ls 2
Enter Number of Gradients (.LE.0 Freq. Resp., ' 0 No Return) 2
Enter Normalized Frequency of Optimization 1
Reflector Length Opt? y
Fix Feeder 1 Length? n
Optimize Height? y
Optimize Pointing? n

```

Input Impedance = 37.01 -8.83

No.	Length	Position	Diameter
1	0.5299	-0.0393	0.0060
2	0.4748	0.1065	0.0060
3	0.4321	0.2295	0.0060

Relative Gain (max) = 12.94  
 Relative Gain Source Match = 12.80  
 F/B = 30.60

```

Antenna height:          1.4384
Pointing angle:          0.00
Enter Optimization Type:
  1 Max Gain, 2 Max F/B, 3 Max Gain Given Source, 4 Rtn Ls 3
Enter Number of Gradients (.LE.0 Freq. Resp., ' 0 No Return) -1
Do you want Frequency Response? y
Enter Source Impedance: real, imag. 50.0
Enter center frequency, scale: 1 kHz, 2 MHz, 3 GHz 1,3
Enter units: 1 in, 2 ft, 3 mm, 4 cm, 5 m 1

```

Enter Frequency Start,Stop,Step .9,1.1,.01

Frequency Response of Yagi Antenna units: in.

No.	Length	Position	Diameter
1	6.255	-0.464	0.071
2	5.603	1.257	0.071
3	5.100	2.709	0.071

Frequency	Gain	Source Gain	F/B	Input Impedance	USWR	
0.9000	12.86	9.25	4.99	16.98	-57.58	7.05
0.9100	12.99	10.56	7.24	21.23	-48.49	4.79
0.9200	12.97	11.41	9.37	25.96	-40.78	3.44
0.9300	12.90	11.92	11.43	30.66	-34.51	2.64
0.9400	12.84	12.20	13.50	34.88	-29.57	2.17
0.9500	12.78	12.35	15.66	38.21	-25.68	1.89
0.9600	12.76	12.45	18.02	40.38	-22.49	1.71
0.9700	12.76	12.52	20.78	41.27	-19.59	1.60
0.9800	12.79	12.60	24.22	40.90	-16.56	1.51
0.9900	12.85	12.70	28.55	39.41	-13.06	1.46
1.0000	12.94	12.80	30.60	37.01	-8.83	1.44
1.0100	13.06	12.89	26.59	33.95	-3.72	1.49
1.0200	13.20	12.94	22.45	30.46	2.34	1.65
1.0300	13.38	12.90	19.14	26.76	9.39	1.96
1.0400	13.57	12.70	16.34	23.02	17.42	2.50
1.0500	13.78	12.26	13.79	19.39	26.41	3.39
1.0600	13.99	11.50	11.37	16.04	36.33	4.88
1.0700	14.13	10.39	9.01	13.13	47.16	7.32
1.0800	14.13	8.94	6.67	10.85	58.81	11.11
1.0900	13.82	7.21	4.36	9.36	71.15	16.29
1.1000	13.07	5.31	2.13	8.80	83.96	21.83

Plots? n

Pattern Listing? y

Enter Elevation Start,Stop,Step 0,180,1

Although the gain increases somewhat, the gain still increases around 6 dB from the free space case. Examination of Figure 5-7 shows similar variation between changes in ground plane height.

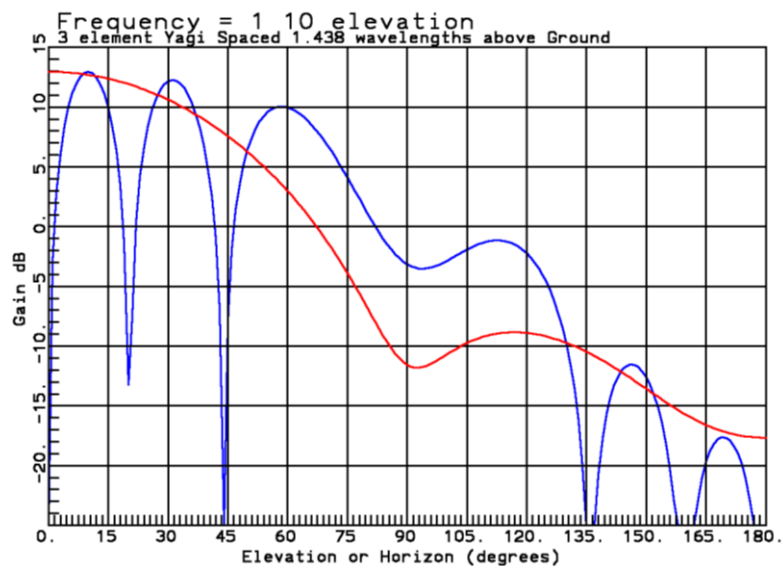
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## Chapter 10 Traveling-Wave Antennas

Enter Frequency 1

Frequency: 1.000 GHz

Angle	Elevation Pattern	Horizon Pattern
0.0	-97.96	12.94
1.0	-3.06	12.94
2.0	2.84	12.93
3.0	6.18	12.92
4.0	8.41	12.90
5.0	10.00	12.87
6.0	11.16	12.85
7.0	11.98	12.81
8.0	12.53	12.78
9.0	12.85	12.73
10.0	12.94	12.68
11.0	12.82	12.63
12.0	12.49	12.57
13.0	11.92	12.51
14.0	11.10	12.44
15.0	9.98	12.36
16.0	8.46	12.28
17.0	6.40	12.20
18.0	3.44	12.11
19.0	-1.33	12.01
20.0	-13.24	11.91
21.0	-7.57	11.80
22.0	0.31	11.69
23.0	4.21	11.58
24.0	6.72	11.45
25.0	8.48	11.33
26.0	9.78	11.19
27.0	10.73	11.06
28.0	11.42	10.91
29.0	11.88	10.76
30.0	12.15	10.61
31.0	12.26	10.45
32.0	12.19	10.28
33.0	11.97	10.11
34.0	11.60	9.93
35.0	11.05	9.74



**Figure 2** 3 element Yagi-Uda Dipole Spaced  $1.438\lambda$  over Ground Elevation pattern (Blue), Horizon pattern @  $10^\circ$  (Red)

## Chapter 10 Traveling-Wave Antennas

The optimization is used to change input impedance to  $50\Omega$ .

```
Pattern Listing? n
Do you want Frequency Response? n
To Change Spacing Enter Number (-1 terminates)
Enter Number 0
Fix Position of Elements? n
Fix Length of Far-out Directors? n
To Change Element Length Enter Number (-1 terminates)
Enter Number 0
Enter Source Impedance: real, imag. 50,0
Enter Antenna Height, Pointing Angle 1.4384,0
Enter Optimization Type:
    1 Max Gain, 2 Max F/B, 3 Max Gain Given Source, 4 Rtn Ls 4
Enter Number of Gradients (.LE.0 Freq. Resp., ' 0 No Return) 2
Enter Normalized Frequency of Optimization 1
Reflector Length Opt? y
Fix Feeder 1 Length? n
Optimize Height? y
Optimize Pointing? n

Input Impedance =    47.37    -1.84

No.   Length   Position   Diameter
  1    0.5304   -0.0406    0.0060
  2    0.4781    0.1106    0.0060
  3    0.4224    0.2270    0.0060

Relative Gain (max) =   12.62
Relative Gain Source Match =   12.62
F/B =   22.47

Antenna height:           1.4381
Pointing angle:           0.00
Enter Optimization Type:
    1 Max Gain, 2 Max F/B, 3 Max Gain Given Source, 4 Rtn Ls 3
Enter Number of Gradients (.LE.0 Freq. Resp., ' 0 No Return) -1
Do you want Frequency Response? y
Enter Source Impedance: real, imag. 50,0_
```

---

Continuing the steps:

## Chapter 10 Traveling-Wave Antennas

Enter center frequency, scale: 1 kHz, 2 MHz, 3 GHz 1,3  
Enter units: 1 in, 2 ft, 3 mm, 4 cm, 5 m 1

Enter Frequency Start,Stop,Step .9,1.1,.01

Frequency Response of Yagi Antenna units: in.

No.	Length	Position	Diameter
1	6.260	-0.479	0.071
2	5.643	1.306	0.071
3	4.985	2.679	0.071

Frequency	Gain	Source Gain	F/B	Input Impedance	USWR	
0.9000	12.83	9.80	5.04	18.14	-51.55	5.88
0.9100	12.93	10.99	7.15	22.52	-42.14	4.00
0.9200	12.89	11.74	9.12	27.44	-34.01	2.86
0.9300	12.80	12.16	10.98	32.49	-27.19	2.19
0.9400	12.72	12.36	12.76	37.29	-21.63	1.77
0.9500	12.64	12.45	14.50	41.50	-17.17	1.52
0.9600	12.59	12.49	16.22	44.84	-13.58	1.36
0.9700	12.56	12.50	17.93	47.14	-10.57	1.25
0.9800	12.55	12.53	19.60	48.31	-7.81	1.18
0.9900	12.58	12.56	21.16	48.35	-4.99	1.11
1.0000	12.62	12.62	22.47	47.37	-1.84	1.07
1.0100	12.69	12.68	23.33	45.50	1.85	1.11
1.0200	12.78	12.74	23.54	42.93	6.22	1.23
1.0300	12.90	12.78	23.05	39.81	11.37	1.41
1.0400	13.04	12.76	21.91	36.29	17.35	1.67
1.0500	13.21	12.65	20.26	32.50	24.19	2.06
1.0600	13.40	12.40	18.21	28.55	31.93	2.66
1.0700	13.61	11.94	15.89	24.55	40.62	3.59
1.0800	13.82	11.22	13.43	20.66	50.31	5.09
1.0900	14.02	10.19	10.92	17.05	61.05	7.51
1.1000	14.12	8.86	8.41	13.96	72.81	11.37

Plots? n

Pattern Listing? n

Do you want Frequency Response? n

To Change Spacing Enter Number (-1 terminates)

Enter Number 0

Fix Position of Elements? n

Fix Length of Far-out Directors? n

To Change Element Length Enter Number (-1 terminates)

Enter Number 0

Enter Source Impedance: real, imag. 50.0

Enter Antenna Height, Pointing Angle 1.4381,0

Enter Optimization Type:

1 Max Gain, 2 Max F/B, 3 Max Gain Given Source, 4 Rtn Ls 3

Enter Number of Gradients (.LE.0 Freq. Resp., 0 No Return) 0

Do you want Frequency Response? n

Changing the design reduces gain by 0.18 dB compared to the one match to about  $37\Omega$ .

### 3 Element Yagi-Uda over Ground with 5° Elevation

The 3 element Yagi-Uda dipole antenna was spaced to produce a beam at 5° and produced similar results.

Horizontal Yagi-Uda over ground plane

Number of elements: 3

Elevation of optimum: 5.00 Elevation

First fed Element: 2

Number of feed points: 1

Feed line impedance: 0.00

Additional feeder length: 0.000

Dielectric constant: 0.00

Element diameters:

Forward firing

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## Chapter 10 Traveling-Wave Antennas

Antenna height: 2.8680 Computed by Eq. (10-20) wavelengths  
 Pointing angle: 0.00  
 Source impedance: 50.00 0.00  
 Center Frequency: 1.0000 GHz

Frequency Response of Yagi Antenna units: in.

No.	Length	Position	Diameter
1	6.599	-0.252	0.071
2	5.636	1.289	0.071
3	4.927	2.486	0.071

Source Impedance: 50.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR	
0.9000	12.56	10.52	14.19	25.58	-49.63	4.15
0.9100	12.42	10.95	13.83	28.71	-43.12	3.31
0.9200	12.31	11.28	13.26	31.61	-36.78	2.70
0.9300	12.22	11.54	12.81	34.46	-30.57	2.24
0.9400	12.15	11.73	12.59	37.38	-24.59	1.88
0.9500	12.10	11.86	12.60	40.40	-18.98	1.60
0.9600	12.06	11.94	12.82	43.44	-13.90	1.39
0.9700	12.05	12.00	13.22	46.33	-9.50	1.24
0.9800	12.05	12.04	13.78	48.80	-5.80	1.13
0.9900	12.08	12.08	14.46	50.56	-2.71	1.06
1.0000	12.13	12.13	15.24	51.39	-0.01	1.03
1.0100	12.20	12.19	16.07	51.15	2.62	1.06
1.0200	12.29	12.27	16.96	49.87	5.51	1.12
1.0300	12.40	12.36	17.90	47.69	8.93	1.21
1.0400	12.52	12.43	18.98	44.82	13.03	1.34
1.0500	12.67	12.47	20.34	41.43	17.87	1.54
1.0600	12.84	12.45	22.14	37.63	23.46	1.83
1.0700	13.02	12.32	23.97	33.47	29.83	2.25
1.0800	13.22	12.04	23.05	28.98	37.09	2.91
1.0900	13.44	11.51	18.93	24.28	45.44	3.99
1.1000	13.66	10.64	14.71	19.65	55.04	5.85

Source impedance: 50.00 0.00  
 Antenna height: 2.8680  
 Pointing angle: 0.00  
 Gradient searches -1  
 Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 3 Search for higher gain  
 Normalized frequency of optimization: 1.0000  
 Optimize reflector length  
 Optimize height

Input Impedance = 30.54 3.87

No.	Length	Position	Diameter
1	0.5448	-0.0325	0.0060
2	0.4825	0.0969	0.0060
3	0.4386	0.2324	0.0060

Relative Gain (max) = 13.24  
 Relative Gain Source Match = 12.97  
 F/B = 23.59

Antenna height: 2.8678  
 Pointing angle: 0.00  
 Gradient searches 4  
 Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 2  
 Normalized frequency of optimization: 1.0000  
 Optimize reflector length  
 Optimize height

## Chapter 10 Traveling-Wave Antennas

Input Impedance = 34.33 -0.95

No.	Length	Position	Diameter
1	0.5342	-0.0327	0.0060
2	0.4831	0.1061	0.0060
3	0.4394	0.2229	0.0060

Relative Gain (max) = 13.08  
 Relative Gain Source Match = 12.93  
 F/B = 45.55

Antenna height: 2.8667  
 Pointing angle: 0.00  
 Gradient searches 4  
 Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 4 Search for better Return Loss  
 Normalized frequency of optimization: 1.0000  
 Optimize reflector length  
 Optimize height

Input Impedance = 50.00 0.06

No.	Length	Position	Diameter
1	0.5349	-0.0345	0.0060
2	0.4809	0.1130	0.0060
3	0.4253	0.2179	0.0060

Relative Gain (max) = 12.55  
 Relative Gain Source Match = 12.55  
 F/B = 19.11

Antenna height: 2.8666  
 Pointing angle: 0.00  
 Gradient searches 3  
 Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 4 Search for better Return Loss  
 Source impedance: 50.00 0.00  
 Center Frequency: 1.0000 GHz

Frequency Response of Yagi Antenna units: in.

No.	Length	Position	Diameter
1	6.313	-0.407	0.071
2	5.676	1.334	0.071
3	5.020	2.572	0.071

Source Impedance: 50.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR	
0.9000	13.11	10.59	7.42	20.01	-47.38	4.94
0.9100	13.08	11.49	9.66	24.54	-39.04	3.48
0.9200	12.96	11.99	11.37	29.04	-31.81	2.62
0.9300	12.83	12.27	12.49	33.31	-25.42	2.07
0.9400	12.71	12.41	13.21	37.36	-19.70	1.71
0.9500	12.62	12.47	13.78	41.20	-14.68	1.45
0.9600	12.55	12.48	14.39	44.71	-10.43	1.28
0.9700	12.51	12.48	15.18	47.66	-7.01	1.16
0.9800	12.49	12.48	16.20	49.71	-4.32	1.09
0.9900	12.51	12.50	17.49	50.55	-2.11	1.04
1.0000	12.55	12.55	19.11	50.00	0.06	1.00
1.0100	12.62	12.61	21.11	48.09	2.66	1.07
1.0200	12.72	12.69	23.51	45.06	6.08	1.18
1.0300	12.84	12.74	26.06	41.23	10.55	1.35
1.0400	12.99	12.74	27.23	36.92	16.15	1.61
1.0500	13.17	12.64	25.09	32.37	22.86	2.02
1.0600	13.37	12.37	21.39	27.74	30.64	2.66

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1.0700	13.60	11.86	17.65	23.15	39.49	3.70
1.0800	13.83	11.02	14.17	18.77	49.47	5.46
1.0900	14.04	9.81	10.97	14.85	60.57	8.49
1.1000	14.15	8.25	8.07	11.67	72.68	13.49

Frequency: 1.000 GHz

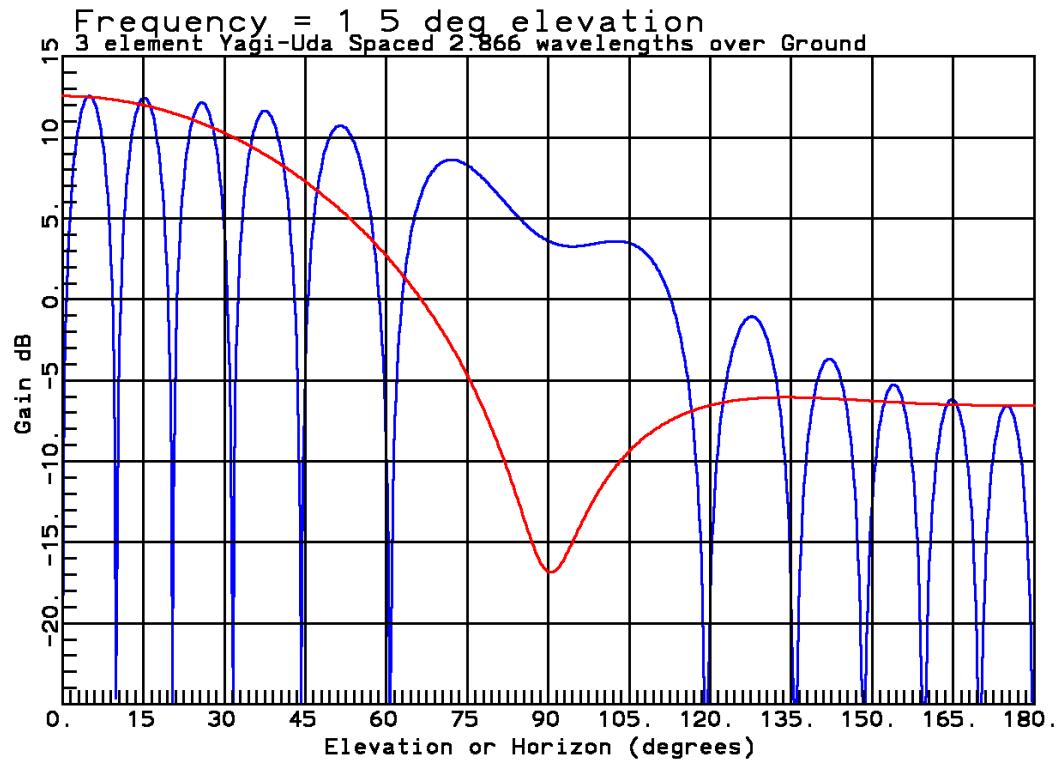
Angle Elevation Pattern Horizon Pattern

0.0	-92.42	12.55
0.2	-11.47	12.55
0.4	-5.47	12.55
0.6	-1.98	12.55
0.8	0.48	12.55
1.0	2.37	12.55
1.2	3.89	12.54
1.4	5.15	12.54
1.6	6.22	12.54
1.8	7.15	12.54
2.0	7.95	12.54
2.2	8.65	12.54
2.4	9.27	12.53
2.6	9.82	12.53
2.8	10.30	12.53
3.0	10.72	12.53
3.2	11.09	12.52
3.4	11.41	12.52
3.6	11.69	12.52
3.8	11.92	12.51
4.0	12.12	12.51
4.2	12.27	12.50
4.4	12.40	12.50
4.6	12.48	12.50
4.8	12.53	12.49
5.0	12.55	12.49
5.2	12.53	12.48
5.4	12.48	12.48
5.6	12.39	12.47
5.8	12.27	12.46
6.0	12.11	12.46
6.2	11.92	12.45
6.4	11.68	12.45
6.6	11.41	12.44
6.8	11.08	12.43
7.0	10.72	12.43
7.2	10.30	12.42
7.4	9.82	12.41
7.6	9.29	12.40
7.8	8.68	12.40
8.0	7.99	12.39
8.2	7.20	12.38
8.4	6.30	12.37
8.6	5.25	12.36
8.8	4.03	12.35
9.0	2.57	12.35
9.2	0.77	12.34
9.4	-1.53	12.33
9.6	-4.73	12.32
9.8	-9.90	12.31
10.0	-24.60	12.30
10.2	-13.89	12.29
10.4	-6.71	12.28
10.6	-2.86	12.27
10.8	-0.23	12.26
11.0	1.76	12.25
11.2	3.35	12.23
11.4	4.66	12.22

Peak at 5° Elevation ~6 dB increase from Free Space

11.6	5.77	12.21
11.8	6.72	12.20
12.0	7.55	12.19
12.2	8.27	12.18
12.4	8.91	12.16
12.6	9.47	12.15
12.8	9.97	12.14
13.0	10.40	12.12
13.2	10.79	12.11
13.4	11.13	12.10
13.6	11.42	12.08
13.8	11.67	12.07
14.0	11.88	12.06
14.2	12.05	12.04
14.4	12.19	12.03
14.6	12.30	12.01
14.8	12.37	12.00
15.0	12.41	11.98
15.2	12.42	11.97
15.4	12.39	11.95
15.6	12.33	11.94
15.8	12.24	11.92
16.0	12.12	11.91
16.2	11.97	11.89
16.4	11.77	11.87
16.6	11.55	11.86
16.8	11.28	11.84
17.0	10.97	11.82

Second peak in Elevation pattern

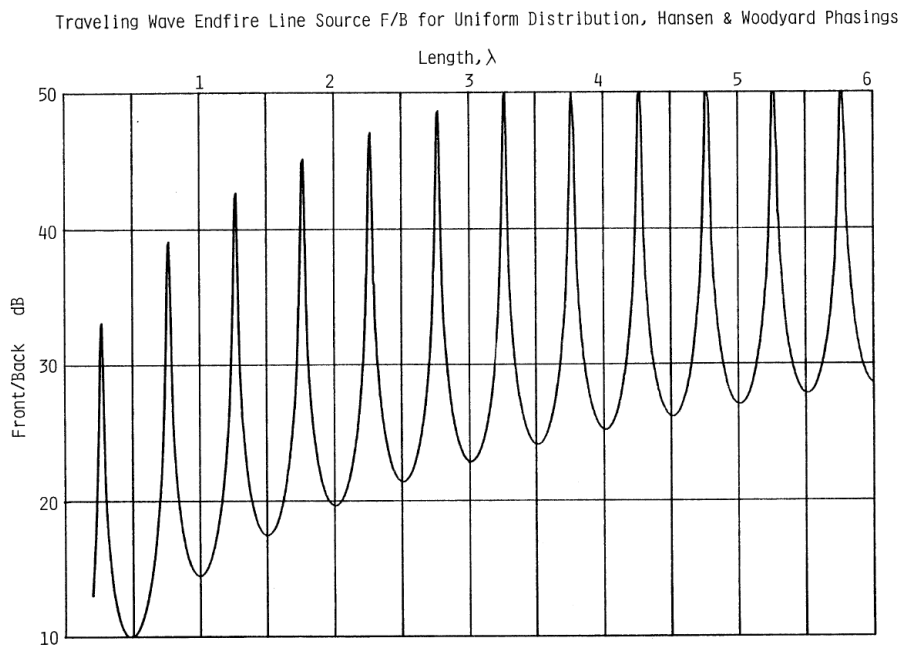


**Figure 3** 3 element Yagi-Uda Dipole Spaced  $2.866\lambda$  over Ground Elevation pattern (Blue), Horizon pattern @  $5^\circ$  (Red)

### Effects of Length of Antenna

Figure 10-2 plotting the directivity of a uniform distribution traveling wave antenna predicts gain will increase as the length of the Yagi-Uda dipole boom increases. This trend is less clear for antennas with a few elements. Think of the series of dipoles as a transmission line spreading the input power along the dipoles. A uniform distribution produces the highest directivity (Figure 10-2) after achieving the Hansen and Woodyard phasing criterion and a general Yagi-Uda dipole array will fail these requirements depending on spacing and dipole lengths. Hence, we need to try various optimizations if our quest is maximum gain. Another goal could be maximum F/B which might not be compatible with maximum gain. Figure 4 plots F/B for a traveling wave rod radiating from a uniform distribution satisfying the Hansen and Woodyard phasing criterion. This says we should avoid lengths multiples of  $\lambda/2$ . However, we may not achieve either a uniform distribution or the phasing for maximum gain and still generate useful designs.

Consider a longer 3 element Yagi-Uda antenna. Increasing the dipole spacings from  $0.1\lambda$  to  $0.2\lambda$  give the potential for higher gain when the design optimization YAGIF is run. The following design was obtained. The center frequency gain has increased by about 2 dB to 8.1 dB from the one designed with  $0.1\lambda$  dipole spacing. While Figure 4 predicts F/B of only ~13 dB, the antenna achieved 18.8 dB and failed to follow the curve. The gain does approximate the value predicted by Figure 10-2. The 2:1 VSWR bandwidth does drop from 13% to about 6%. The higher coupling between dipoles when closely spaced has increased bandwidth due to an easier excitation of the reflector and director elements.



**Figure 4** F/B of uniform distribution traveling wave antenna

### 3 element Yagi-Uda antenna with $0.2\lambda$ dipole separations

Input Impedance = 30.53 0.86

No.	Length	Position	Diameter
1	0.49761	0.00000	0.00600
2	0.46631	0.20000	0.00600
3	0.42592	0.40000	0.00600

## Chapter 10 Traveling-Wave Antennas

Relative Gain (max) = 8.11  
 Relative Gain Source Match = 7.85  
 F/B = 18.81

Source Impedance: 30.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR
0.9500	7.56	6.16	8.44	25.87	-34.07
0.9550	7.65	6.55	9.59	26.85	-30.29
0.9600	7.73	6.88	10.78	27.76	-26.64
0.9650	7.79	7.15	12.00	28.57	-23.11
0.9700	7.83	7.38	13.26	29.26	-19.66
0.9750	7.88	7.57	14.55	29.83	-16.27
0.9800	7.92	7.72	15.82	30.25	-12.91
0.9850	7.96	7.86	17.02	30.53	-9.54
0.9900	8.01	7.96	18.02	30.66	-6.14
0.9950	8.06	8.05	18.67	30.66	-2.68
1.0000	8.11	8.11	18.81	30.53	0.86
1.0050	8.17	8.15	18.45	30.28	4.51
1.0100	8.24	8.16	17.70	29.91	8.28
1.0150	8.31	8.13	16.74	29.45	12.19
1.0200	8.39	8.06	15.69	28.90	16.27
1.0250	8.46	7.95	14.63	28.29	20.53
1.0300	8.54	7.79	13.59	27.62	24.99
1.0350	8.62	7.56	12.58	26.94	29.68
1.0400	8.69	7.27	11.62	26.25	34.59
1.0450	8.74	6.92	10.70	25.59	39.75
1.0500	8.78	6.51	9.81	24.98	45.16

## 6 element Yagi-Uda Antenna

### Case 1: Matched to 50Ω

Input Impedance = 47.57 -1.08

No.	Length	Position	Diameter
1	0.48664	0.00513	0.00600
2	0.45912	0.28126	0.00600
3	0.43034	0.54949	0.00600
4	0.44371	0.83368	0.00600
5	0.44256	1.12461	0.00600
6	0.42072	1.40396	0.00600

Relative Gain (max) = 11.42  
 Relative Gain Source Match = 11.41  
 F/B = 15.38

Source Impedance: 50.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR
0.9000	6.97	3.46	2.00	27.75	-79.98
0.9100	7.69	4.74	2.91	28.44	-71.29
0.9200	8.41	6.02	4.00	29.56	-62.47
0.9300	9.06	7.24	5.26	31.16	-53.69
0.9400	9.63	8.32	6.71	33.22	-45.17
0.9500	10.09	9.22	8.33	35.56	-37.09
0.9600	10.47	9.93	10.12	37.91	-29.47
0.9700	10.80	10.49	12.03	40.07	-22.16
0.9800	11.07	10.93	13.82	42.08	-14.87
0.9900	11.30	11.25	15.03	44.37	-7.57
1.0000	11.42	11.41	15.38	47.57	-1.08
1.0100	11.39	11.38	15.70	51.15	1.84

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## Chapter 10 Traveling-Wave Antennas

1.0200	11.20	11.19	18.66	47.80	-1.64	1.06
1.0300	10.78	10.37	21.33	27.07	3.74	1.86
1.0400	7.94	5.00	2.87	12.94	33.69	5.70
1.0500	1.14	-2.61	-6.10	19.21	65.88	7.37
1.0600	-0.30	-3.65	-6.75	35.48	89.59	6.49
1.0700	-0.49	-3.51	-6.08	54.85	105.00	5.86
1.0800	-0.85	-3.67	-5.72	73.88	113.76	5.48
1.0900	-1.28	-3.97	-5.54	90.75	117.78	5.23
1.1000	-1.71	-4.31	-5.44	104.74	118.87	5.07

### Case 2: Matched to 38Ω

Input Impedance = 37.16 4.91

No.	Length	Position	Diameter
1	0.48047	0.00972	0.00600
2	0.45791	0.29515	0.00600
3	0.43841	0.55996	0.00600
4	0.43647	0.86472	0.00600
5	0.43911	1.16651	0.00600
6	0.42917	1.45056	0.00600

Relative Gain (max) = 12.01  
 Relative Gain Source Match = 11.91  
 F/B = 11.74

Source Impedance: 38.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR	
0.9000	6.80	2.62	2.37	28.52	-83.34	8.37
0.9100	7.46	3.83	3.23	28.94	-75.28	7.09
0.9200	8.14	5.08	4.28	29.51	-67.13	5.91
0.9300	8.81	6.33	5.55	30.24	-58.97	4.87
0.9400	9.44	7.51	7.04	31.04	-50.87	3.98
0.9500	10.02	8.60	8.76	31.77	-42.82	3.24
0.9600	10.55	9.58	10.62	32.27	-34.65	2.62
0.9700	11.04	10.46	12.32	32.52	-26.02	2.09
0.9800	11.48	11.23	13.19	32.83	-16.54	1.63
0.9900	11.83	11.79	12.79	33.95	-6.03	1.22
1.0000	12.01	12.00	11.74	37.16	4.91	1.14
1.0100	11.99	11.86	11.05	43.61	13.42	1.43
1.0200	11.93	11.78	11.98	48.84	12.31	1.46
1.0300	12.11	11.96	22.13	30.44	10.41	1.46
1.0400	8.50	5.19	4.81	14.72	44.88	6.42
1.0500	-1.91	-5.72	-7.68	28.83	77.91	7.49
1.0600	-2.75	-6.23	-7.88	50.63	96.40	6.77
1.0700	-2.18	-5.45	-6.63	71.53	105.31	6.34
1.0800	-2.14	-5.28	-6.00	89.22	108.50	6.08
1.0900	-2.31	-5.38	-5.66	103.22	108.65	5.93
1.1000	-2.56	-5.57	-5.45	113.88	107.54	5.83

Both 6 element Yagi-Uda antennas have an average boom length of about  $1.42\lambda$ . The gain of both antennas follows the curve of Figure 10-2. The second antenna generates higher gain because the distribution along the 6 elements is more nearly uniform. Requiring the antenna to be matched to  $50\Omega$  altered the distribution and lowered gain. The antenna matched to  $50\Omega$  has a slightly wider 2:1 VSWR bandwidth, but both are about 6%.

### 16 element Yagi-Uda Antenna

## Chapter 10 Traveling-Wave Antennas

The example of a 16 element Yagi-Uda antenna given in Tables 10-5 and 10-6 was repeated. This optimization asked for an impedance match to  $50\Omega$  with a similar boom length. In both cases most of the directors were made the same length and equally spaced.

Input Impedance = 51.52 -6.61

No.	Length	Position	Diameter
1	0.48800	-0.02991	0.00600
2	0.46545	0.26795	0.00600
3	0.44656	0.44885	0.00600
4	0.44218	0.65839	0.00600
5	0.41918	0.94447	0.00600
.			
.			
.			
16	0.41918	4.44792	0.00600

Relative Gain (max) = 15.72  
 Relative Gain Source Match = 15.70  
 F/B = 14.25

Source Impedance: 50.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR
0.9000	10.23	7.09	6.40	27.57 -73.27	6.09
0.9100	11.01	8.42	7.12	28.43 -64.64	5.07
0.9200	11.78	9.76	7.95	29.83 -55.97	4.13
0.9300	12.50	11.01	9.04	31.82 -47.61	3.33
0.9400	13.15	12.11	10.59	34.07 -39.96	2.72
0.9500	13.74	13.03	12.90	35.89 -32.91	2.28
0.9600	14.30	13.84	16.12	36.97 -25.60	1.93
0.9700	14.83	14.59	18.50	38.31 -17.06	1.60
0.9800	15.25	15.19	16.65	42.13 -8.02	1.28
0.9900	15.51	15.51	14.42	49.31 -2.99	1.06
1.0000	15.72	15.70	14.25	51.52 -6.61	1.14
1.0100	16.07	16.01	17.67	40.17 -4.94	1.28
1.0200	16.18	15.94	23.69	33.93 11.67	1.61
1.0300	15.61	15.49	14.90	45.57 15.50	1.40
1.0400	14.82	13.06	16.75	15.65 19.61	3.73
1.0500	10.01	6.72	11.12	17.49 53.84	6.37
1.0600	2.74	-1.29	-2.17	19.30 70.38	7.98
1.0700	-14.88	-18.60	-19.35	31.23 90.13	7.29
1.0800	-7.46	-11.03	-11.26	43.65 105.28	6.95
1.0900	-7.21	-10.65	-10.71	56.09 116.12	6.67
1.1000	-7.06	-10.42	-10.32	67.77 124.45	6.51

Both 16 element Yagi-Uda antennas with a boom length of  $4.4\lambda$  follow the curve of Figure 10-2 for gain which shows the transmission line of coupled dipoles can reasonably sustain an approximately uniform distribution and Hansen and Woodyard phasing over 16 elements.

The usual mounting of this antenna is over a ground plane. While short boom length antenna maybe mounted close to the ground plane and produce high elevation ( $>20^\circ$ ) beam, the pattern of this higher gain drops off too fast to generate a nearly equal reflected beam required to produce these beams. Consider the pattern.

Frequency: 1.000 GHz

Theta	E Plane Pattern		H Plane Pattern	
	Ampl(dB)	Phase	Ampl(dB)	Phase
0.0	15.72	86.2	15.72	86.2
0.5	15.72	86.2	15.72	86.2

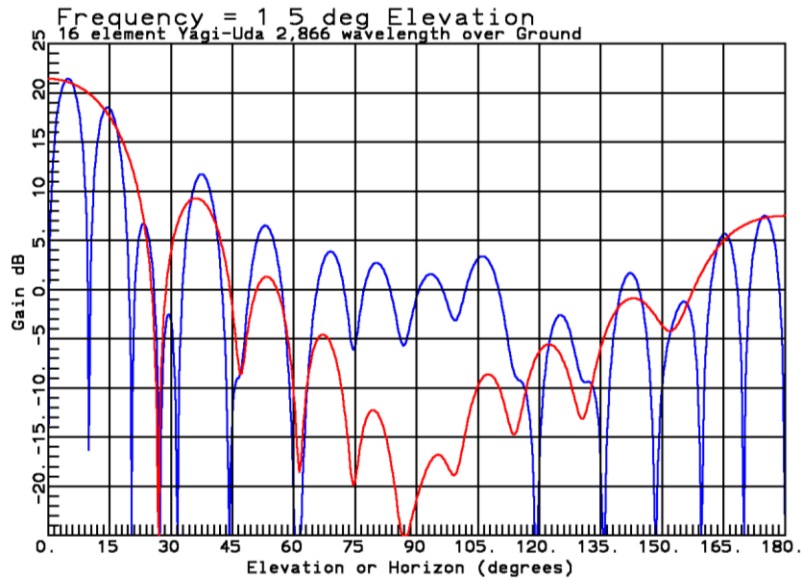
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1.0	15.71	86.1	15.71	86.1
1.5	15.69	85.9	15.70	85.9
2.0	15.67	85.8	15.68	85.8
2.5	15.64	85.5	15.65	85.5
3.0	15.60	85.2	15.62	85.2
3.5	15.56	84.8	15.58	84.9
4.0	15.51	84.4	15.54	84.4
4.5	15.45	84.0	15.48	84.0
5.0	15.38	83.5	15.43	83.5
5.5	15.31	82.9	15.36	82.9
6.0	15.23	82.2	15.29	82.3
6.5	15.14	81.6	15.22	81.6
7.0	15.05	80.8	15.13	80.8
7.5	14.94	80.0	15.04	80.0
8.0	14.83	79.2	14.94	79.2
8.5	14.70	78.3	14.83	78.3
9.0	14.57	77.3	14.71	77.3
9.5	14.43	76.3	14.58	76.3
10.0	14.27	75.2	14.45	75.2
10.5	14.11	74.1	14.30	74.1
11.0	13.93	72.9	14.14	72.9
11.5	13.75	71.7	13.98	71.7
12.0	13.55	70.4	13.80	70.4
12.5	13.33	69.0	13.60	69.1
13.0	13.11	67.6	13.40	67.7
13.5	12.86	66.2	13.18	66.2
14.0	12.61	64.6	12.95	64.7
14.5	12.33	63.1	12.69	63.1
15.0	12.04	61.4	12.43	61.5
15.5	11.73	59.7	12.14	59.9
16.0	11.39	58.0	11.84	58.1
16.5	11.04	56.2	11.51	56.3
17.0	10.66	54.4	11.16	54.5
17.5	10.25	52.4	10.78	52.6
18.0	9.82	50.5	10.38	50.6
18.5	9.36	48.4	9.94	48.6
19.0	8.86	46.4	9.48	46.5
19.5	8.32	44.2	8.97	44.4
20.0	7.75	42.0	8.43	42.2

At 20° the reflected beam has dropped more than 7 dB and the combination of the two beams fail to produce a good beam at 20° but would droop to a lower elevation angle. Spacing the antenna height to produce a 10° elevation beam would work better with a -1.3 dB lower second beam. The design from YAGIF was reanalyzed in YAGMG with the antenna spaced over ground to produce a beam elevated at 5° as shown in Figure 5.



**Figure 5** 16 element Yagi-Uda antenna spaced over ground to produce elevated beam of  $5^\circ$

Spacing the antenna  $2.86\lambda$  over ground has little effect on its impedance when the coupling to the image antenna is included in the YAGMG analysis. The gain increases by 5.7 dB from the free space analysis, a value predicted in Figure 5-7 of a horizontal dipole spaced over ground.

### 30 element Yagi-Uda Antenna

By using YAGIF and optimizing on gain using equal space and length directors for the far elements, a suitable design is easily found starting with  $0.25\lambda$  element spaces which the program increased to  $0.2659\lambda$  for the equally spaced elements.

Input Impedance = 31.02 -1.84

No.	Length	Position	Diameter
1	0.48757	0.00242	0.00200
2	0.46945	0.22960	0.00200
3	0.45350	0.45993	0.00200
4	0.44228	0.68676	0.00200
5	0.42402	0.90355	0.00200
6	0.42402	1.16943	0.00200
.			
.			
.			
30	0.42402	7.55060	0.00200

Relative Gain (max) = 17.78  
 Relative Gain Source Match = 17.53  
 F/B = 22.31

Source Impedance: 35.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR
0.9500	13.87	11.37	9.21	26.06 -52.51	4.91
0.9550	14.49	12.42	10.67	26.44 -46.82	4.21
0.9600	15.07	13.40	12.44	26.79 -41.11	3.60

0.9650	15.60	14.32	14.32	27.16	-35.24	3.04
0.9700	16.07	15.17	15.75	27.75	-29.12	2.53
0.9750	16.50	15.93	16.07	28.89	-22.90	2.07
0.9800	16.85	16.54	15.62	30.76	-17.08	1.70
0.9850	17.12	16.97	15.30	33.02	-12.43	1.45
0.9900	17.34	17.27	15.78	34.44	-9.30	1.31
0.9950	17.56	17.52	17.65	33.63	-6.51	1.21
1.0000	17.78	17.76	22.31	31.02	-1.84	1.14
1.0050	17.94	17.87	46.67	28.95	5.51	1.29
1.0100	17.93	17.70	22.79	29.65	14.03	1.59
1.0150	17.75	17.39	17.39	33.42	19.97	1.78
1.0200	17.51	17.16	16.01	34.57	20.00	1.76
1.0250	17.20	16.56	18.49	26.63	22.82	2.17
1.0300	16.32	14.48	39.26	20.13	35.52	3.84
1.0350	14.71	11.96	15.82	21.81	50.26	5.35
1.0400	13.30	10.70	10.05	29.06	57.45	5.08
1.0450	11.24	7.86	7.99	23.41	61.08	6.57
1.0500	7.13	2.37	4.66	22.47	78.07	9.85

The antenna with a boom length of  $7.5\lambda$  continues to follow the curves of Figure 10-2 for the directivity of a traveling wave antenna with a uniform distribution phased by the Hansen and Woodyard criterion. Even over 30 dipoles a transmission line excitation characteristic is maintained.

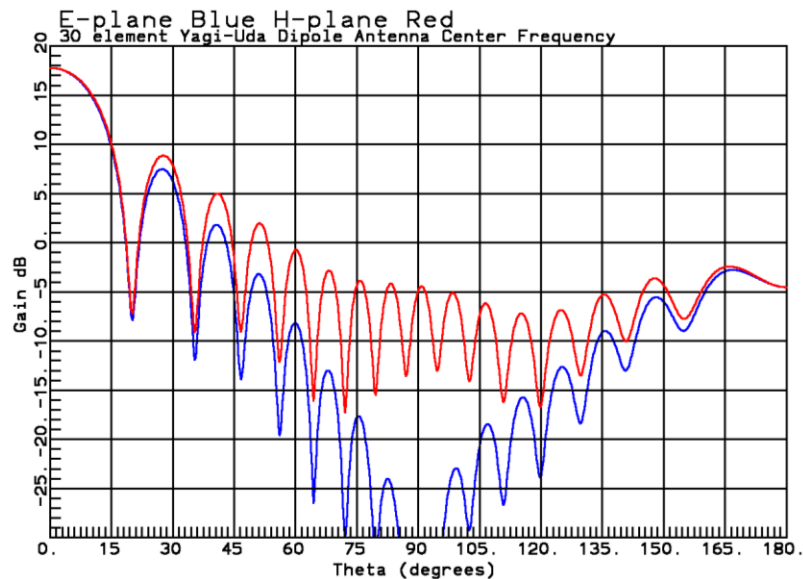


Figure 6 30 element Yagi-Uda Dipole antenna pattern

## 40 element Yagi-Uda Antenna

No.	Length	Position	Diameter
1	0.49103	0.00106	0.00600
2	0.46249	0.25230	0.00600
3	0.44345	0.49617	0.00600
4	0.43925	0.74984	0.00600
5	0.40284	0.99511	0.00600
6	0.40284	1.25532	0.00600
.			
.			
.			
40	0.40284	10.10256	0.00600

Relative Gain (max) = 18.65

Relative Gain Source Match = 18.46

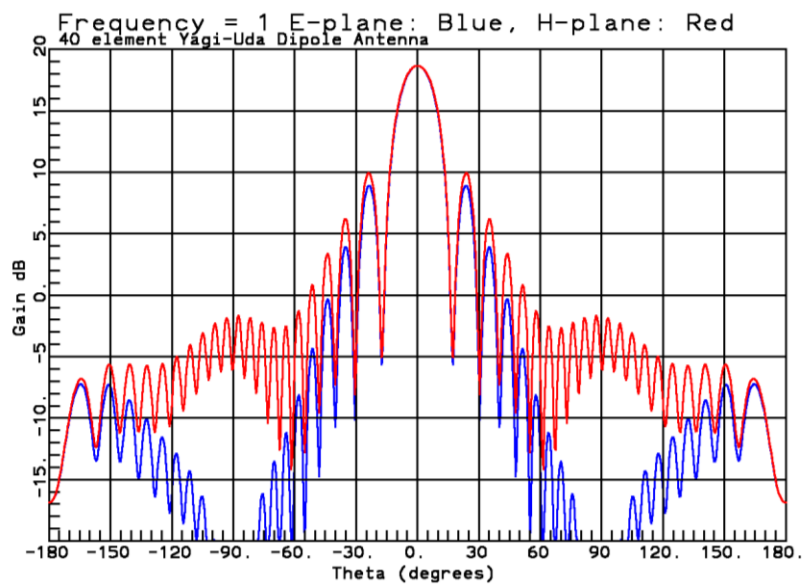
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## Chapter 10 Traveling-Wave Antennas

F/B = 35.50

Source Impedance: 35.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR	
0.9600	16.76	16.18	16.46	34.04	-26.05	2.09
0.9625	16.91	16.41	17.72	34.30	-24.34	1.99
0.9650	17.07	16.63	19.15	34.52	-22.50	1.89
0.9675	17.21	16.85	20.52	34.78	-20.55	1.79
0.9700	17.36	17.07	21.42	35.15	-18.51	1.69
0.9725	17.49	17.27	21.47	35.69	-16.46	1.59
0.9750	17.62	17.44	20.79	36.43	-14.51	1.50
0.9775	17.73	17.59	19.86	37.32	-12.78	1.43
0.9800	17.83	17.72	19.05	38.26	-11.40	1.38
0.9825	17.92	17.82	18.53	39.05	-10.43	1.35
0.9850	18.01	17.92	18.38	39.48	-9.81	1.34
0.9875	18.11	18.02	18.66	39.34	-9.35	1.32
0.9900	18.21	18.14	19.44	38.57	-8.76	1.29
0.9925	18.32	18.27	20.88	37.27	-7.75	1.25
0.9950	18.44	18.41	23.27	35.70	-6.09	1.19
0.9975	18.55	18.54	27.38	34.21	-3.77	1.12
1.0000	18.65	18.64	35.50	33.09	-0.91	1.06
1.0025	18.72	18.71	32.68	32.56	2.20	1.10
1.0050	18.75	18.72	25.90	32.67	5.20	1.18
1.0075	18.76	18.70	22.39	33.26	7.66	1.26
1.0100	18.74	18.66	20.44	33.90	9.24	1.31
1.0125	18.72	18.63	19.54	33.86	9.93	1.34
1.0150	18.71	18.61	19.60	32.42	10.32	1.37
1.0175	18.71	18.54	20.78	29.50	11.52	1.48
1.0200	18.67	18.34	23.78	25.89	14.37	1.75
1.0225	18.55	17.90	32.03	22.67	18.96	2.19
1.0250	18.29	17.21	31.51	20.62	24.69	2.77
1.0275	17.88	16.36	21.34	19.98	30.81	3.38
1.0300	17.35	15.49	16.57	20.66	36.62	3.88
1.0325	16.78	14.73	13.60	22.28	41.50	4.18
1.0350	16.22	14.07	11.67	23.98	44.97	4.32
1.0375	15.60	13.32	10.44	24.41	47.44	4.55
1.0400	14.73	12.08	9.69	23.09	50.69	5.16



**Figure 7** 40 element Yagi-Uda Dipole antenna pattern

### 50 element Yagi-Uda Antenna

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## Chapter 10 Traveling-Wave Antennas

No. Length Position Diameter

1 0.49030 0.00187 0.00400  
 2 0.46286 0.25227 0.00400  
 3 0.44914 0.49377 0.00400  
 4 0.44832 0.75129 0.00400  
 5 0.43730 1.00039 0.00400  
 6 0.40338 1.24933 0.00400

.  
 .  
 .

50 0.40338 12.27884 0.00400

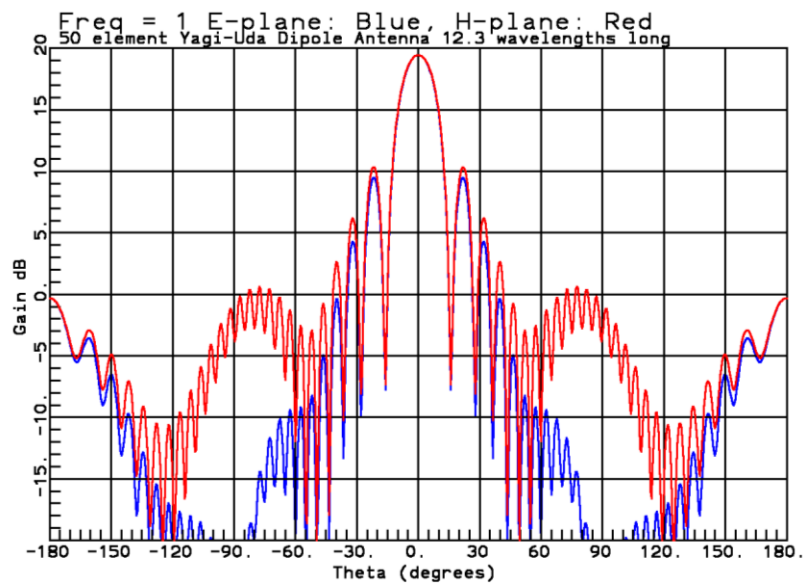
Relative Gain (max) = 19.43

Relative Gain Source Match = 19.34

F/B = 19.74

Source Impedance: 40.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR	
0.9500	16.51	14.90	14.19	28.47	-43.75	3.51
0.9550	16.95	15.63	16.03	29.03	-39.21	3.11
0.9600	17.37	16.31	18.19	29.47	-34.42	2.73
0.9650	17.75	16.97	19.18	30.18	-29.29	2.37
0.9700	18.09	17.56	18.43	31.50	-24.25	2.03
0.9750	18.38	18.03	17.80	33.16	-19.98	1.77
0.9800	18.65	18.42	18.52	34.20	-16.55	1.60
0.9850	18.93	18.77	21.41	34.02	-12.86	1.47
0.9900	19.18	19.10	26.84	33.69	-7.76	1.31
0.9950	19.36	19.33	24.06	34.97	-1.96	1.16
1.0000	19.43	19.42	19.74	37.94	1.93	1.08
1.0050	19.48	19.48	18.74	39.02	2.53	1.07
1.0100	19.56	19.53	21.33	35.47	4.35	1.18
1.0150	19.52	19.37	34.60	32.18	10.74	1.44
1.0200	19.27	19.01	24.05	32.85	16.60	1.64
1.0250	18.96	18.62	18.76	30.08	17.37	1.77
1.0300	18.18	16.96	19.53	20.28	25.63	2.95
1.0350	16.04	13.52	19.22	17.35	40.88	4.94
1.0400	13.19	10.04	10.00	19.49	53.86	6.10
1.0450	8.21	4.51	2.81	22.01	66.37	7.23
1.0500	1.45	-2.40	-3.31	27.84	78.79	7.58



**Figure 7** 40 element Yagi-Uda Dipole antenna pattern

The antennas with 40 and 50 dipole elements produce gains that follow Figure 10-2 for boom lengths of  $10.1\lambda$  and  $12.2\lambda$ . While antennas with 30 to 50 dipole elements are impractical, it is interesting that they continue to follow the predicted gain curve for a traveling wave rod antenna. The transmission line, consisting of a coupled dipole string, transmits power between the many members to produce a nearly uniform distribution and with proper phasing. Of course, it takes an optimization routine, such as, YAGIF to compute the necessary lengths and spacing of dipoles to make this happen. All three antennas have a 2:1 VSWR bandwidth of about 5% which shows it is independent of length and the number of elements.

### Bandwidth Effect of Number and Spacing of Elements

Antennas with few elements (3 – 5) can have larger than normal bandwidth, the average bandwidth for the higher gain antennas is 5- to 6%. The length of the boom determines the gain for an optimized design. A group of Yagi-Uda antennas were designed with a length of  $1.5\lambda$ .

Elements	Spacing	Gain	Impedance	2:1 Bandwidth
31	$0.05\lambda$	12.29	18	5.4%
25	$0.0625$	12.26	25	6.2
21	$0.075$	12.27	30	6.3
16	$0.1$	12.18	37	6.9
13	$0.125$	12.54	34	6.1
11	$0.15$	12.5	35	6.0
9	$0.187$	12.61	32	5.2
7	$0.25$	12.22	40	6.0
6	$0.30$	11.80	42	4.4

The element type determines the bandwidth and not the boom length or the number of elements. For closely spaced or widely spaced elements the antennas fail to work well. At  $0.3\lambda$  the coupling between dipoles falls off and fails to excite a transmission line structure.

### 10 Dipole Yagi-Uda Antenna with Crisscross Feeder

The crisscross feeder uses a portion of a log periodic antenna (usually 2 elements) to broaden the bandwidth of the response. The routine YAGIF optimizes a multiple feed Yagi-Uda dipole antenna with a crisscross transmission line between feed dipoles. The length of the first feed dipole is optimized while the second feed dipole located behind the first feeder towards the reflector dipole has its length controlled by the Tau factor of a LP (Section 11-12) specified in the initial input.

#### Yagi-Uda Dipole Design with Frequency Band Optimization

```

Number of Elements:           10
First Fed Element:            3
Number of Elements Fed:       2
Lower Number Elements are Reflectors
Feed Line Impedance:          100.00
Additional Line between Elements:  0.000 Wavelengths
Criss-cross Feeder Line
Multiple criss-cross feeder elements scaled by Tau = 0.9500
Forward Firing
Lower Frequency Opt. Bound:    0.940
Upper Frequency Opt. Bound:    1.060
Gaussian Integration Number:   16
Equate lengths of far elements starting:  6
Equate lengths of far elements starting:  6
Gradient searches  5  ...

```

## Chapter 10 Traveling-Wave Antennas

Gradient searches 4  
 Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 4  
 Weight on Difference Integral: 0.00  
 Optimize reflector length

Input Impedance = 49.99 0.83

No.	Length	Position	Diameter
1	0.50740	-0.00094	0.00400
2	0.45813	0.14853	0.00400
3	0.43523	0.33638	0.00400
4	0.42989	0.45611	0.00400
5	0.42781	0.63523	0.00400
6	0.41266	0.75217	0.00400
7	0.41266	1.01179	0.00400
8	0.41266	1.27141	0.00400
9	0.41266	1.53103	0.00400
10	0.41266	1.79066	0.00400

Relative Gain (max) = 11.86  
 Relative Gain Source Match = 11.86  
 F/B = 22.33

Source Impedance: 50.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR	
0.9000	6.48	4.23	1.02	14.03	24.90	4.51
0.9100	8.26	6.60	3.40	20.75	32.67	3.57
0.9200	9.55	8.53	5.84	33.31	38.54	2.69
0.9300	10.33	9.80	8.15	49.79	35.69	2.02
0.9400	10.74	10.52	10.25	59.82	23.28	1.58
0.9500	10.97	10.89	12.13	59.85	11.51	1.32
0.9600	11.13	11.10	13.85	56.10	5.18	1.16
0.9700	11.27	11.26	15.54	52.73	2.70	1.08
0.9800	11.43	11.43	17.34	50.74	1.97	1.04
0.9900	11.63	11.63	19.49	50.01	1.62	1.03
1.0000	11.86	11.86	22.33	49.99	0.83	1.02
1.0100	12.12	12.12	26.65	49.78	-0.74	1.02
1.0200	12.40	12.40	35.68	48.36	-2.52	1.06
1.0300	12.67	12.66	35.70	45.64	-2.92	1.12
1.0400	12.89	12.87	26.71	43.52	-0.44	1.15
1.0500	13.05	13.03	22.37	46.20	4.38	1.13
1.0600	13.13	13.08	19.33	61.18	2.88	1.23
1.0700	13.15	12.62	16.57	59.26	-38.22	2.03
1.0800	12.95	10.43	13.50	14.01	-30.05	4.94
1.0900	11.76	6.49	10.10	4.48	-7.12	11.39
1.1000	9.90	4.18	7.40	4.00	8.70	12.87

The 2:1 VSWR bandwidth has increased to 14% remarkable for a  $1.8\lambda$  long Yagi-Uda dipole antenna, but the gain increases by 3 dB over this band. The crisscross feeder line increases F/B over the band, but not sufficiently to completely cover the 2:1 VSWR bandwidth. The average gain of this antenna matches Figure 10-2, but the frequency slope of the gain curve may be undesirable.

### 10 Dipole Yagi-Uda Antenna with Folder Feeder

YAGIFL uses a folded dipole where the coupled line pair shorted at the ends is added to the model. The folded dipole increases the impedance of the antenna. Unfortunately, the feed element is usually shorter than a  $\lambda/2$  which adds a capacitive reactance to the feed impedance.

Yagi-Uda Dipole Design with Frequency Band Optimization

Number of Elements: 10

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## Chapter 10 Traveling-Wave Antennas

```

First Fed Element:          2
Number of Elements Fed:     1
Folded Dipole spacing (wavelengths): 0.0120
Lower Number Elements are Reflectors
Lower Frequency Opt. Bound: 0.970
Upper Frequency Opt. Bound: 1.030
Gaussian Integration Number: 8
Equate lengths of far elements starting: 6
Equate lengths of far elements starting: 6
Gradient searches 4
Type: 1 Max gain, 2 Max F/B, 3 Max Gain w/ source 4 Rtn Ls: 3
Weight on Difference Integral: 0.00
Optimize reflector length

```

...

...

...

Input Impedance = 98.03 -8.27

No.	Length	Position	Diameter
1	0.50073	0.00526	0.00600
2	0.46569	0.15369	0.00600
3	0.44202	0.32124	0.00600
4	0.43481	0.47089	0.00600
5	0.41378	0.64089	0.00600
6	0.41818	0.79275	0.00600
7	0.42065	0.96974	0.00600
8	0.42065	1.16442	0.00600
9	0.42065	1.34430	0.00600
10	0.42065	1.53519	0.00600

Relative Gain (max) = 12.79  
Relative Gain Source Match = 12.78  
F/B = 18.39

Source Impedance: 100.00 0.00

Frequency	Gain	Source Gain	F/B	Input Impedance	VSWR
0.9500	11.66	8.45	10.95	54.79 -148.11	6.22
0.9550	11.93	9.43	11.90	58.84 -128.97	4.91
0.9600	12.14	10.29	12.66	63.69 -110.42	3.86
0.9650	12.29	11.01	13.24	69.30 -92.69	3.05
0.9700	12.41	11.58	13.69	75.55 -76.07	2.43
0.9750	12.50	12.00	14.08	82.18 -60.92	1.99
0.9800	12.57	12.28	14.50	88.72 -47.52	1.67
0.9850	12.63	12.48	15.02	94.44 -36.05	1.45
0.9900	12.68	12.61	15.75	98.42 -26.27	1.30
0.9950	12.74	12.70	16.81	99.78 -17.44	1.19
1.0000	12.79	12.78	18.39	98.03 -8.27	1.09
1.0050	12.85	12.84	20.89	93.43 2.74	1.08
1.0100	12.90	12.84	25.44	87.01 16.83	1.26
1.0150	12.92	12.71	40.14	80.24 34.60	1.55
1.0200	12.89	12.37	27.89	74.64 56.01	2.01
1.0250	12.79	11.80	20.36	71.53 80.61	2.64
1.0300	12.61	11.06	16.18	72.20 107.81	3.43
1.0350	12.34	10.27	13.37	78.36 136.94	4.22
1.0400	12.04	9.62	11.42	93.27 166.63	4.77
1.0450	11.76	9.32	10.19	123.62 191.41	4.80
1.0500	11.57	9.60	9.72	175.70 186.53	4.06