Example Design of a Yagi-Uda Antenna

Problem: Design a Yagi-Uda antenna with a gain of at least 10 dBi to receive television channel 43 (UHF) for a cable-ready television.

Design Steps:

1. Select or specify design parameters:
   a. Desired directivity- select **5 element Yagi-Uda antenna** from Table 10.6 which has a directivity of 9.2 dBd = 9.2 + 2.15 = **11.35 dBi**. [Note: For a Yagi-Uda antenna, gain ≈ directivity.]
   b. Design Frequency- Channel 43 644-650 MHz , so ***f* = 647 MHz**.
   c. Desired input impedance- **R_0 = 75 Ω.**
2. Select diameter d of elements and diameter D of metallic supporting boom (optional, only necessary if a metallic boom is to be used) based on mechanical considerations (e.g., strength, rigidity) and parts availability (refer to Table 1).

   Element diameter- ***d* = 1/4" = 0.635 cm** (use brass pipe)

   Boom diameter- ***D* = 5/8" = 1.5875 cm** (use 1/2" I.D. copper pipe)
3. Calculate design wavelength λ. Use λ to calculate s_{12} (reflector-driven element spacing) and s_{ij} [driven-director & director-director spacing(s)] using Table 10.6 values.

$$\lambda = \frac{c}{f} = \frac{3*10^8}{647*10^6} = 0.4637\text{ m} = \underline{46.3679\text{ cm}}$$

   Per Table 10.6, $s_{12} = s_{ij} = 0.2\lambda$ = **9.274 cm**

Table 10.6 OPTIMIZED UNCOMPENSATED LENGTHS OF PARASITIC ELEMENTS FOR YAGI-UDA ANTENNAS OF SIX DIFFERENT LENGTHS

$d/\lambda = 0.0085$		LENGTH OF YAGI-UDA (IN WAVELENGTHS)					
s_{12} **= 0.2λ**		0.4	**0.8**	1.20	2.2	3.2	4.2
LENGTH OF REFLECTOR (l_1/λ)		0.482	**0.482**	0.482	0.482	0.482	0.475
LENGTH OF DIRECTORS, λ	l_3	0.442	**0.428**	0.428	0.432	0.428	0.424
	l_4		**0.424**	0.420	0.415	0.420	0.424
	l_5		**0.428**	0.420	0.407	0.407	0.420
	l_6			0.428	0.398	0.398	0.407
	l_7				0.390	0.394	0.403
	l_8				0.390	0.390	0.398
	l_9				0.390	0.386	0.394
	l_{10}				0.390	0.386	0.390
	l_{11}				0.398	0.386	0.390
	l_{12}				0.407	0.386	0.390
	l_{13}					0.386	0.390
	l_{14}					0.386	0.390
	l_{15}					0.386	0.390
	l_{16}					0.386	
	l_{17}					0.386	
SPACING BETWEEN DIRECTORS (s_{ij}/λ)		0.20	**0.20**	0.25	0.20	0.20	0.308
DIRECTIVITY RELATIVE TO HALF-WAVE DIPOLE (dB)		7.1	**9.2**	10.2	12.25	13.4	14.2
DESIGN CURVE (SEE FIGURE 10.25)		(*A*)	**(*B*)**	(*B*)	(*C*)	(*B*)	(*D*)

SOURCE: Peter P. Viezbicke, *Yagi Antenna Design*, NBS Technical Note 688, December 1976.

Table 1 Available tubing/pipe/rod sizes

Nominal Diameter		Outer Diameter*	
(inches)	(cm)	(inches)	(cm)
3/32	0.238125	3/32	0.238125
1/8	0.3175	1/8	0.3175
5/32	0.397	5/32	0.397
3/16	0.476	3/16	0.476
7/32	0.556	7/32	0.556
1/4	**0.635**	**1/4**	**0.635**
9/32	0.714	9/32	0.714
5/16	0.794	5/16	0.794
11/32	0.873	11/32	0.873
3/8	0.9525	3/8	0.9525
13/32	1.032	13/32	1.032
7/16	1.111	7/16	1.111
1/2	1.27	1/2	1.27
1/2	1.27	9/16	1.429
1/2	**1.27**	**5/8**	**1.5875**
3/4	1.905	7/8	2.223

* For brass tubing/pipe/rods, the nominal and outer diameters are the same (i.e., wall thickness is negligible). For copper pipes, the wall thickness is substantial and should be measured as it varies between manufacturers.

4. Calculate d / λ. Is $0.001 \le d / \lambda \le 0.04$? If not, go to step 2 and reconsider selection of d.

   $d/\lambda = 0.635/46.3679 = \underline{\mathbf{0.0137}}$ $\Rightarrow$ Within $0.001 \le d/\lambda \le 0.04$ range.

5. If a metal boom is used, calculate D/λ. Is $0.001 \le D/\lambda \le 0.04$? If not, go to step 2 and reconsider selection of D.

   $D/\lambda = 1.5875/46.3679 = \underline{\mathbf{0.0342}}$ $\Rightarrow$ Within $0.001 \le D/\lambda \le 0.04$ range.

6. If $d/\lambda = 0.0085$, go to step 11 (no element diameter length corrections required). If $d/\lambda \ne 0.0085$, the elements lengths must be corrected. Plot the lengths of the reflector (element 1) and first director (element 3) from Table 10.6 on the appropriate design curves on Figure 10.25 (should fall on or near vertical line drawn from $d/\lambda = 0.0085$). Label these points l_1'' and l_3'' respectively.

   On Design curves B at $d/\lambda = 0.0085$, plot-

   $\underline{\boldsymbol{l_1'' = 0.482\lambda}}$

   $\underline{\boldsymbol{l_3'' = 0.428\lambda}}$

7. Draw a vertical line from $\boldsymbol{d/\lambda = 0.0137}$ through reflector and director design curves ***B***, where this line intersects the curves is the corrected lengths of the reflector l_1' and first director l_3'. The length l_3' should be used for any other directors that are the same original length as l_3.

   Label and read the corrected (for element diameter) lengths-

   $\underline{\boldsymbol{l_1' = 0.48\lambda}}$

   $\underline{\boldsymbol{l_3' = l_5' = 0.419\lambda}}$

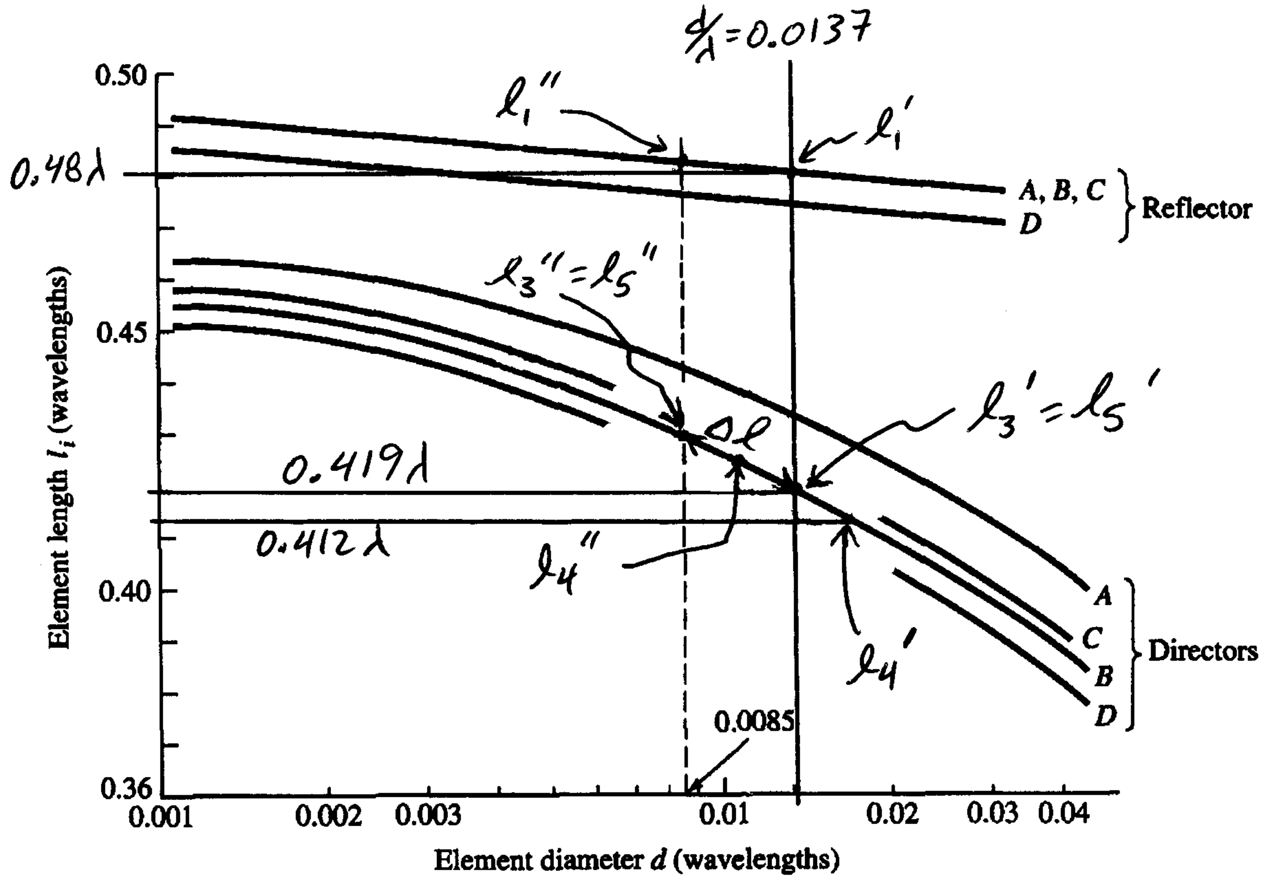


Figure 10.25 Design curves to determine element lengths of Yagi-Uda arrays. (SOURCE: P. P. Viezbicke, "Yagi Antenna Design," NBS Technical Note 688, U.S. Department of Commerce/National Bureau of Standards, December 1976)

8. Measure and label the arc length Δl between l_3'' and l_3' along the design curve.

   Using ruler, **Δl = 1.45 cm**.

9. Plot the remaining original optimized director lengths from Table 10.6 on the appropriate director design curve on Figure 10.25 and label l_i''

   On director design curve B, plot length of fourth director-

   l_4'' = 0.424λ

10. To find the corrected (for element diameter) length(s) for the remaining directors, move Δl from l_i'' (same direction as between l_3'' and l_3') to the corrected length l_i'.

    Move **Δl = 1.45 cm** from **l_4'' = 0.424λ**, and read ⇒ **l_4' = 0.412λ**

11. If a metal boom is used (else, skip to next step), the element lengths must be lengthened to compensate for it. On Figure 10.26, draw a vertical line from ***D*/λ = 0.0342** through the curve. Draw a horizontal line from the intersection to the left axis of the figure and read the compensation length. The final lengths of the elements (label l_i) are found by adding this length to the original (Table 10.6) or the corrected (for element diameter) element lengths.

    From Figure 10.26, read ⇒ **compensation length = 0.0254λ**

    $l_1 = l_1' + 0.0254\lambda = 0.48\lambda + 0.0254\lambda = 0.5054\lambda$ = 23.434 cm

    $l_3 = l_5 = l_3' + 0.0254\lambda = 0.419\lambda + 0.0254\lambda = 0.4444\lambda$ = 20.606 cm

    $l_4 = l_4' + 0.0254\lambda = 0.412\lambda + 0.0254\lambda = 0.4374\lambda$ = 20.281 cm

12. Design matching network (e.g., Gamma match, …) to connect the antenna to the selected transmission line. The length of the driven element is empirically adjusted to achieve a match at the design frequency. Typically, it has a length between that of the reflector and the first director.

$$l_1 = 23.434 \text{ cm} < l_2 < l_3 = 20.606 \text{ cm}$$

For drawing, use simple average ⇒ **l_2 = 22.02 cm**

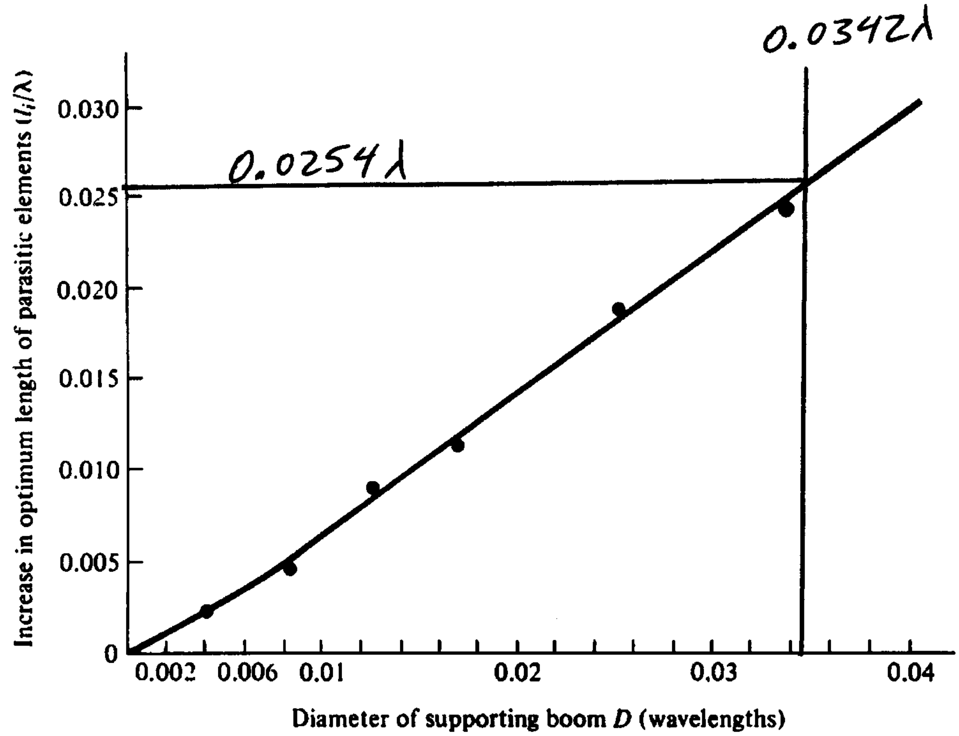
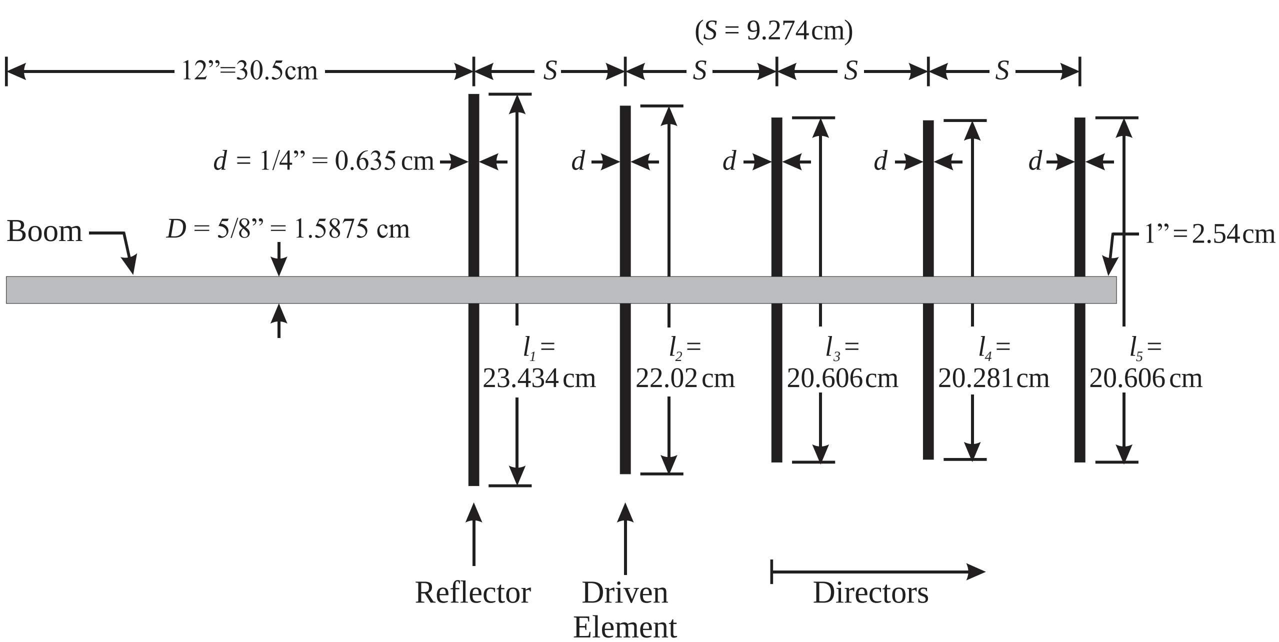


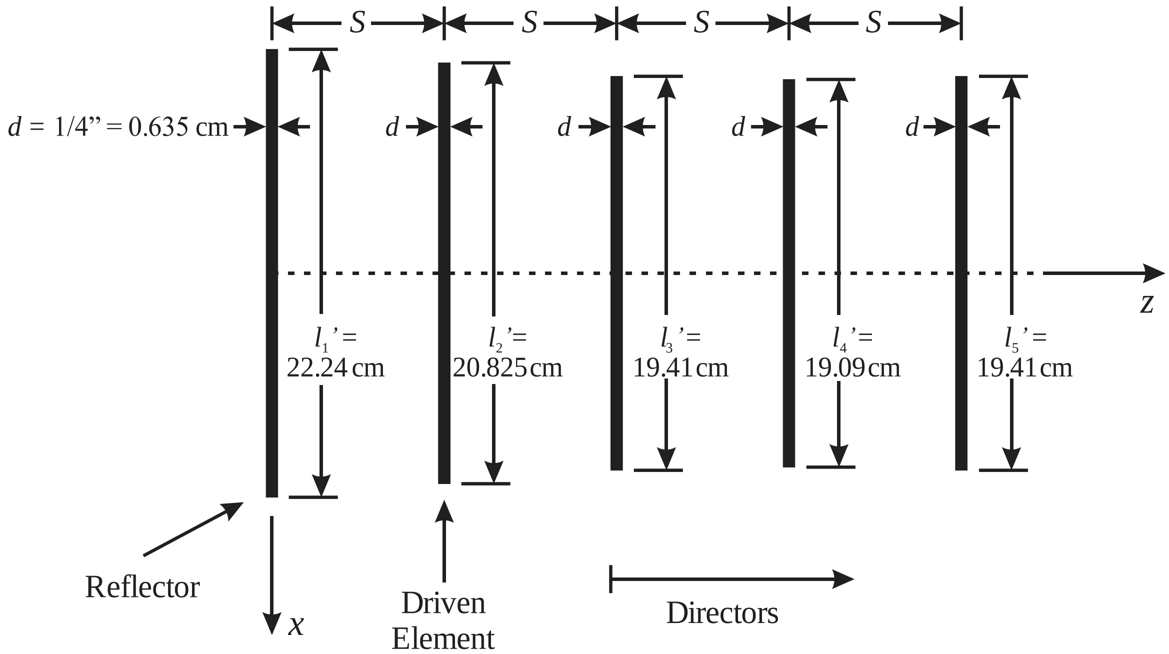
Figure 10.26 Increase in optimum length of parasitic elements as a function of metal boom diameter. (SOURCE: P. P. Viezbicke, " Yagi Antenna Design," NBS Technical Note 688, U.S. Department of Commerce/National Bureau of Standards, December 1976)

5 element, channel 43 Yagi-Uda antenna w/ boom



5 element, channel 43 Yagi-Uda antenna (No Boom)

(element spacing S = 3.651" = 9.274cm)



NEC-2 Input file

```
CM Yagi-Uda Antenna for UHF channel 43 (NO BOOM)
CM THIS FILE IS USED TO DETERMINE INPUT IMPEDANCE OF THE DRIVEN
CM ELEMENT OF A 5 ELEMENT ANTENNA. CENTER FREQUENCY IS 647 MHz
CM W/ WAVELENGTH OF 0.4634 m.
CM THE DIMENSIONS ARE:
CM element diameters d=0.635cm=0.25in, radius a=d/2=0.3175cm=0.125in,
CM l1=0.48 l=0.2224m, l3=l5=0.419 l=0.1941m, l4=0.412 l=0.1909m,
CM driven element l2=(l1+l3)/2=0.45 l= 0.2085m
CM ELEMENT SPACINGS Sij=0.2 l=0.09267m
CM SELECT SEGMENT LENGTH OF APPROX. 1.25cm=0.025 l
CE THE DRIVEN SEGMENT IS #9 on l2 Tag 2.
GW 1 17 -0.1112  0.0 0.0      0.1112  0.0 0.0     0.003175 !Reflector
GW 2 17 -0.10425 0.0 0.09267  0.10425 0.0 0.09267 0.003175 !Driven
GW 3 15 -0.09705 0.0 0.18534  0.09705 0.0 0.18534 0.003175 !Director 1
GW 4 15 -0.09545 0.0 0.27801  0.09545 0.0 0.27801 0.003175 !Director 2
GW 5 15 -0.09705 0.0 0.37068  0.09705 0.0 0.37068 0.003175 !Director 3
GE 0 0
EK 0
FR 0 1 0 0 647 0
EX 0 2 9 0 1.0 0.0
RP 0 2 2 0000 0.0 0.0 180.0 90.0
PT -1
XQ 0
EN
```

NEC-2 Output file

```
<snip>
- - - STRUCTURE SPECIFICATION - - -
<snip>
  WIRE
NO. OF    FIRST  LAST     TAG
NO.  X1       Y1  Z1         X2      Y2  Z2       RADIUS  SEG. SEG. SEG. NO.
1   -0.11120 0.0 0.00000  0.11120 0.0 0.00000 0.00317 17     1    17   1
2   -0.10425 0.0 0.09267  0.10425 0.0 0.09267 0.00317 17    18    34   2
3   -0.09705 0.0 0.18534  0.09705 0.0 0.18534 0.00317 15    35    49   3
4   -0.09545 0.0 0.27801  0.09545 0.0 0.27801 0.00317 15    50    64   4
5   -0.09705 0.0 0.37068  0.09705 0.0 0.37068 0.00317 15    65    79   5

   TOTAL SEGMENTS USED=   79 <snip>

 - - - - - - FREQUENCY - - - - - -
FREQUENCY= 6.4700E+02 MHZ
WAVELENGTH= 4.6337E-01 METERS
<snip>

- - - ANTENNA INPUT PARAMETERS - - -

TAG SEG. VOLTAGE (V) CURRENT (A)  IMPEDANCE (OHMS) ADMITTANCE (S) <snip>
NO. NO.  REAL IMAG.  REAL  IMAG.    REAL   IMAG    REAL    IMAG.   <snip>
 2  26   1.0  0.0 2.5E-02-2.9E-02 1.73564E+01 1.95524E+01 2.5E-2-2.9E-2

<snip>

- - - RADIATION PATTERNS - - -

- - ANGLES - -     - POWER GAINS - <snip>
- - - E(THETA) - - - <snip>
THETA      PHI         MAJOR   <snip>
DEGREES  DEGREES        DB     <snip>
  0.00      0.00       11.26  <snip>
180.00      0.00       -0.73  <snip>

<snip>
```