Match the channel 10 six-element Yagi-Uda antenna from the previous assignment with the boom omitted to a **100 Ω** twin-lead transmission line using a **T-match** so that the VSWR is less than 1.1 at the center frequency. At each step, discuss and justify design changes/choices. Accurately sketch final design. In a table, summarize the original (unmatched) and final Yagi-Uda input impedance, input reflection coefficient (polar format), VSWR, gain (dBi), and front-to-back ratio (dB). Comment on how the final design compares with the original.

- Use NEC-2 to find the antenna-mode input impedance(s). Include the input file(s) and relevant excerpts of the output file(s). Assume $c = 2.998 \times 10^8$ m/s.

****

Design a six-element Yagi-Uda antenna for VHF television channel 13 using ~~a copper-pipe boom~~ <snip> ~~and~~ brass elements with an outer diameter of 3/8 inch. <snip>

Design Summary:

Directivity of a six-element Yagi-Uda antenna is 10.2 dBd = 10.2 + 2.15 ⇒ **12.35 dBi**

(Note: For a Yagi-Uda antenna, gain ≈ directivity.)

Design Frequency- Channel 10 (192-198 MHz) ⇒ f_c **= 195 MHz**.

Desired input impedance for T-match ⇒ R_0 **= 100 Ω**

Element diameter (use brass pipe $\sigma_{brass} = 1.1\times10^8$ S/m) ⇒ $d = 2a$ **= 3/8" = 0.9525 cm**

Design wavelength λ, s_{12} (reflector-driven element spacing) & s_{ij} [driven-director & director-director spacing(s)] using Table 10.6 values.

$$\lambda = \frac{c}{f} = \frac{2.998\times10^8}{195\times10^6} = 1.5374359 \text{ m} \quad \Rightarrow \quad \lambda = 153.7436 \text{ cm}$$

reflector-driven element spacing $s_{12} = 0.2\lambda = 30.7487$ cm

driven-director & director-director spacing(s) $s_{ij} = 0.25\lambda = 38.4359$ cm

Corrected (only for element diameter) lengths-

reflector $l_1' = 0.484\lambda$ ⇒ $l_1' = 74.4119$ cm

directors $l_3' = l_6' = 0.436\lambda$ ⇒ $l_3' = l_6' = 67.0322$ cm

directors $l_4' = l_5' = 0.427\lambda$ ⇒ $l_4' = l_5' = 65.6485$ cm

Choose **driven element** $l_2' \approx (l_1' + l_3')/2 = 0.46\lambda$ ⇒ $l_2' = 70.722$ cm

****

No Match

Input NEC File

```
CM yagi_6element_ch10.txt
CM THIS PROGRAM ASSUMES THAT THERE IS NO BOOM.
CM
CM Determine the antenna mode input impedance of the driven element.
CM Center frequency is 195 MHz W/ wavelength of 153.7436 cm.
CM
CM Brass 6-element Yagi-Uda antenna dimensions:
CM element diameters d = 3/8” = 0.9525 cm = 0.375in, radius a = 0.47625 cm
CM Reflector l1' = 74.4119 cm & Driven element l2' = 70.722 cm
CM Directors l3' = l6' = 67.0322 cm  & l4' = l5' = 65.6485 cm
CM Reflector-Driven spacing S12 = 30.7487 cm
CM other element spacings Sij = 38.4359 cm
CM Place antenna on the y-z plane.
CM Choose segment length approx. delta ~ 3.8 cm = 8a
CE
GW 1 21 0.0 -0.37206   0.0       0.0 0.37206   0.0      0.0047625 ! Reflector l1
GW 2 19 0.0 -0.35361   0.307487  0.0 0.35361   0.307487 0.0047625 ! Driven l2
GW 3 17 0.0 -0.335161  0.691846  0.0 0.335161  0.691846 0.0047625 ! Director l3
GW 4 17 0.0 -0.3282425 1.076205  0.0 0.3282425 1.076205 0.0047625 ! Director l4
GW 5 17 0.0 -0.3282425 1.460564  0.0 0.3282425 1.460564 0.0047625 ! Director l5
GW 6 17 0.0 -0.335161  1.844923  0.0 0.335161  1.844923 0.0047625 ! Director l6
GE 0 0
PT -1 ! suppress current outputs
EK 0  ! Use extended kernel to be safe
LD 5 0 0 0 1.1e7  ! Set conductivity of brass elements
FR 0 1 0 0 195.0 0
EX 0 2 10 0 1.0 0.0 ! Excite middle segment of driven element
RP 0 2 2 0000 0.0 0.0 180.0 90.0
EN
```

No Match NEC results

$Z_a = 15.8053 + j17.2159\ \Omega \quad \Rightarrow \quad \Gamma_{in} = 0.734\angle 160° \ \&\ \text{VSWR} = 6.52$ (wrt 100 Ω)

$G_{max} = 12.40$ dBi

$G_{back} = -1.98$ dBi

F/B ratio = 14.38 dB

Note: Z_a is resistive-inductive, will want to shorten l_2’ to make it more resistive-capacitive.

Try 1: T-Match Design choices

Shorten driven element length from l_2' = 70.722 cm to **l_2' = 69.0 cm**

Select a T-Match diameter smaller than elements (3/8"): $2a$' = 1/4" = **0.635 cm**

Select a T-Match length roughly a bit less than l_2'/3: **l' = 20 cm**

Select a T-Match spacing so that $Z_{0,\text{t-match}} < 300\ \Omega$: **$s$ = 3 cm**

From MathCad, the effective radius of T-Match section is **a_e = 1.07974 cm**.

Input NEC File- Try 1

```
CM yagi_6element_ch13_tmatch_try1.txt
CM THIS PROGRAM ASSUMES THAT THERE IS NO BOOM.
CM
CM Determine the antenna mode input impedance of the driven element.
CM Center frequency is 195 MHz W/ wavelength of 153.7436 cm.
CM
CM Brass 6-element Yagi-Uda antenna dimensions:
CM element diameters: d=0.9525 cm = 0.375in, radius a = 0.47625 cm
CM equiv. radius T-Match portion of driven element ae = 1.07974 cm
CM T-match has a length of l'= 20 cm
CM Reflector l1' = 74.4119 cm & Driven element l2' = 69 cm (new)
CM Directors l3' = l6' = 67.0322 cm  & l4' = l5' = 65.6485 cm
CM Reflector-Driven spacing S12 = 30.7487 cm
CM other element spacings Sij = 38.4359 cm
CM Place antenna on the y-z plane.
CM Segment length approx. delta ~ 3.8 cm = 8a
CE
GW 1 21 0.0 -0.37206   0.0       0.0  0.37206   0.0      0.0047625 ! Reflector l1
GW 2  6 0.0 -0.345     0.307487  0.0 -0.1       0.307487 0.0047625 ! Driven end 1 l2
GW 3  7 0.0 -0.1       0.307487  0.0  0.1       0.307487 0.0107974 ! Driven middle l2
GW 4  6 0.0  0.1       0.307487  0.0  0.345     0.307487 0.0047625 ! Driven end 2 l2
GW 5 17 0.0 -0.335161  0.691846  0.0  0.335161  0.691846 0.0047625 ! Director l3
GW 6 17 0.0 -0.3282425 1.076205  0.0  0.3282425 1.076205 0.0047625 ! Director l4
GW 7 17 0.0 -0.3282425 1.460564  0.0  0.3282425 1.460564 0.0047625 ! Director l5
GW 8 17 0.0 -0.335161  1.844923  0.0  0.335161  1.844923 0.0047625 ! Director l6
GE 0 0
PT -1 ! suppress current outputs
EK 0  ! Use extended kernel to be safe
LD 5 0 0 0 1.1e7    ! Set conductivity of brass elements
FR 0 1 0 0 195.0 0
EX 0 3 4 0 1.0 0.0  ! Drive middle element of tag #3
RP 0 2 2 0000 0.0 0.0 180.0 90.0
EN
```

Try 1 NEC results- Z_a = 12.688 - j2.00747 Ω, G_{max} = 12.96 dBi, & G_{back} = -1.36 dBi

From MathCad- Z_{in} = 62.434 + j9.05 Ω, |Γ| = 0.238, & VSWR = 1.623 (too high)

Comments: On second try, make l_2' shorter (more capacitive) & l' longer (per suggestion) to make Z_{in} have less inductive reactance.

MatchCad spreadsheet:

T-Match equations- Try 1

$c := 2.998\cdot10^{8}$ m/s $fc := 195\cdot10^{6}$ Hz $\lambda := \frac{c}{fc}$ $\lambda = 1.53744$ m

$k := \frac{2\cdot\pi}{\lambda}$ $k = 4.08679$ rad/m Zdesired := 100 Ω

$d := 0.9525\cdot10^{-2}$ $a := d\cdot0.5$ $a = 0.0047625$ m

$dprime := 0.635\cdot10^{-2}$ $aprime := dprime\cdot0.5$ $aprime = 0.003175$ m

$s := 3\cdot10^{-2}$ m $lprime := 20.0\cdot10^{-2}$ m

$$Z0 := \frac{376.73}{2\cdot\pi}\cdot\operatorname{acosh}\left[\frac{\left(s^2 - a^2 - aprime^2\right)}{2\cdot a\cdot aprime}\right] \qquad Z0 = 242.767 \ \Omega$$

$u := \frac{a}{aprime}$ $u = 1.5$ $v := \frac{s}{aprime}$ $v = 9.44882$

$$\alpha := \frac{\operatorname{acosh}\left[\frac{\left(v^2 - u^2 + 1\right)}{2\cdot v}\right]}{\operatorname{acosh}\left[\frac{\left(v^2 + u^2 - 1\right)}{2\cdot v\cdot u}\right]} \qquad ae := aprime\cdot e^{\frac{1}{(1+u)^2}\cdot\left(u^2\cdot\ln(u)+2\cdot u\cdot\ln(v)\right)}$$

$\alpha = 1.2139$ $ae = 0.0107974$ m

$$Zt := j\cdot Z0\cdot\tan\left(\frac{k\cdot lprime}{2}\right) \qquad Zt = 105.1334i \ \Omega$$

$Yt := \frac{1}{Zt}$ $Yt = -9.512i\times10^{-3}$ S $\frac{Yt}{2} = -4.756i\times10^{-3}$ S

Za from NEC (a MoM program)- Try 1

$Za := 12.688 - j\cdot2.00747$ Ω $Ya := \frac{1}{Za}$ $Ya = 0.07689 + 0.01217i$ S

$$Yin := \frac{Yt}{2} + \frac{Ya}{(1+\alpha)^2} \qquad Yin = 0.016 - 2.274i\times10^{-3} \ S$$

$Zin := \frac{1}{Yin}$ $Zin = 62.434 + 9.05i$ Ω Zdesired = 100 Ω

$\Gamma := \frac{(Zin - Zdesired)}{Zin + Zdesired}$ $|\Gamma| = 0.238$ $VSWR := \frac{(1 + |\Gamma|)}{1 - |\Gamma|}$ $VSWR = 1.623$

$$lsuggested := \frac{2}{k}\cdot\operatorname{atan}\left[\frac{1}{2\cdot Z0\cdot Im\left[\frac{Ya}{(1+\alpha)^2}\right]}\right]$$

$lsuggested = 0.33897$ m

$lsuggested\cdot0.5 = 0.169$ m

Try 2: T-Match Design choices

Shorten driven element length from $l_2' = 69.0$ to **$l_2' = 68.8$ cm**

Keep T-Match diameter: $2a' = 1/4" = 0.635$ cm (no change)

Lengthen T-Match length from $l' = 20$ cm to **$l' = 24$ cm**

Keep T-Match spacing: $s = 3$ cm (no change)

From MathCad, the effective radius of T-Match section remains $a_e = 1.07974$ cm.

Input NEC File- Try 2

```
CM yagi_6element_ch13_tmatch_try2.txt
CM THIS PROGRAM ASSUMES THAT THERE IS NO BOOM.
CM
CM Determine the antenna mode input impedance of the driven element.
CM Center frequency is 195 MHz W/ wavelength of 153.7436 cm.
CM
CM Brass 6-element Yagi-Uda antenna dimensions:
CM element diameters: d=0.9525 cm = 0.375in, radius a = 0.47625 cm
CM equiv. radius T-Match portion of driven element ae = 1.07974 cm
CM T-match has a length of l'= 24 cm (longer)
CM Reflector l1' = 74.4119 cm & Driven element l2' = 68.8 cm (shorter)
CM Directors l3' = l6' = 67.0322 cm  & l4' = l5' = 65.6485 cm
CM Reflector-Driven spacing S12 = 30.7487 cm
CM other element spacings Sij = 38.4359 cm
CM Place antenna on the y-z plane.
CM Segment length approx. delta ~ 3.8 cm = 8a
CE
GW 1 21 0.0 -0.37206   0.0       0.0  0.37206   0.0      0.0047625 ! Reflector l1
GW 2  6 0.0 -0.3440    0.307487  0.0 -0.12      0.307487 0.0047625 ! Driven end 1 l2
GW 3  7 0.0 -0.12      0.307487  0.0  0.12      0.307487 0.0107974 ! Driven middle l2
GW 4  6 0.0  0.12      0.307487  0.0  0.3440    0.307487 0.0047625 ! Driven end 2 l2
GW 5 17 0.0 -0.335161  0.691846  0.0  0.335161  0.691846 0.0047625 ! Director l3
GW 6 17 0.0 -0.3282425 1.076205  0.0  0.3282425 1.076205 0.0047625 ! Director l4
GW 7 17 0.0 -0.3282425 1.460564  0.0  0.3282425 1.460564 0.0047625 ! Director l5
GW 8 17 0.0 -0.335161  1.844923  0.0  0.335161  1.844923 0.0047625 ! Director l6
GE 0 0
PT -1 ! suppress current outputs
EK 0  ! Use extended kernel to be safe
LD 5 0 0 0 1.1e7    ! Set conductivity of brass elements
FR 0 1 0 0 195.0 0
EX 0 3 4 0 1.0 0.0  ! Drive middle element of tag #3
RP 0 2 2 0000 0.0 0.0 180.0 90.0
EN
```

Try 2 NEC results- $Z_a = 12.8283 - j3.99679\ \Omega$, $G_{max} = 12.85$ dBi, & $G_{back} = -1.45$ dBi

From MathCad- $Z_{in} = 68.837 - j3.13\ \Omega$, $|\Gamma| = 0.185$, & VSWR = 1.455 (too high)

Comments: Z_{in} is still too small & a bit capacitive. On third try, decrease $2a'$ and s to make α bigger.

MatchCad spreadsheet:

T-Match equations- Try 2

$c := 2.998 \cdot 10^{8}$ m/s $\quad fc := 195 \cdot 10^{6}$ Hz $\quad \lambda := \frac{c}{fc}$ $\lambda = 1.53744$ m

$k := \frac{2 \cdot \pi}{\lambda}$ $\quad k = 4.08679$ rad/m $\quad Zdesired := 100$ Ω

$d := 0.9525 \cdot 10^{-2}$ $\quad a := d \cdot 0.5$ $\quad a = 0.0047625$ m

$dprime := 0.635 \cdot 10^{-2}$ $\quad aprime := dprime \cdot 0.5$ $\quad aprime = 0.003175$ m

$s := 3 \cdot 10^{-2}$ m $\quad lprime := 24 \cdot 10^{-2}$ m

$$Z0 := \frac{376.73}{2 \cdot \pi} \cdot \operatorname{acosh}\left[\frac{\left(s^2 - a^2 - aprime^2\right)}{2 \cdot a \cdot aprime}\right] \qquad Z0 = 242.767 \ \Omega$$

$u := \frac{a}{aprime}$ $\quad u = 1.5$ $\quad v := \frac{s}{aprime}$ $\quad v = 9.44882$

$$\alpha := \frac{\operatorname{acosh}\left[\frac{\left(v^2 - u^2 + 1\right)}{2 \cdot v}\right]}{\operatorname{acosh}\left[\frac{\left(v^2 + u^2 - 1\right)}{2 \cdot v \cdot u}\right]} \qquad ae := aprime \cdot e^{\frac{1}{(1+u)^2} \cdot \left(u^2 \cdot \ln(u) + 2 \cdot u \cdot \ln(v)\right)}$$

$\alpha = 1.2139$ $\quad ae = 0.0107974$ m

$$Zt := j \cdot Z0 \cdot \tan\left(\frac{k \cdot lprime}{2}\right) \qquad Zt = 129.61885i \ \Omega$$

$Yt := \frac{1}{Zt}$ $\quad Yt = -7.715i \times 10^{-3}$ S $\quad \frac{Yt}{2} = -3.857i \times 10^{-3}$ S

Za from NEC (a MoM program)- Try 2

$Za := 12.8283 - j \cdot 3.99679$ Ω $\quad Ya := \frac{1}{Za}$ $\quad Ya = 0.07106 + 0.02214i$ S

$$Yin := \frac{Yt}{2} + \frac{Ya}{(1 + \alpha)^2} \qquad Yin = 0.014 + 6.592i \times 10^{-4} \ S$$

$Zin := \frac{1}{Yin}$ $\quad Zin = 68.837 - 3.13i$ Ω $\quad Zdesired = 100$ Ω

$\Gamma := \frac{(Zin - Zdesired)}{Zin + Zdesired}$ $\quad |\Gamma| = 0.185$ $\quad VSWR := \frac{(1 + |\Gamma|)}{1 - |\Gamma|}$ $\quad VSWR = 1.455$

$$lsuggested := \frac{2}{k} \cdot \operatorname{atan}\left[\frac{1}{2 \cdot Z0 \cdot Im\left[\frac{Ya}{(1 + \alpha)^2}\right]}\right]$$

$lsuggested = 0.20937$ m

$lsuggested \cdot 0.5 = 0.105$ m

Try 3: T-Match Design choices

Keep driven element length $l_2' = 68.8$ cm (no change)

Shrink T-Match diameter from $2a' = 1/4" = 0.635$ cm to **$2a' = 3/16" = 0.47625$ cm**

Keep T-Match length: $l' = 24$ cm (no change)

Shrink T-Match spacing from $s = 3$ cm to **$s = 2$ cm**

From MathCad- the effective radius of T-Match section is now **$a_e = 0.83438$ cm**.

Input NEC File- Try 3

```
CM yagi_6element_ch13_tmatch_try3.txt
CM THIS PROGRAM ASSUMES THAT THERE IS NO BOOM.
CM
CM Determine the antenna mode input impedance of the driven element.
CM Center frequency is 195 MHz W/ wavelength of 153.7436 cm.
CM
CM Brass 6-element Yagi-Uda antenna dimensions:
CM element diameters: d=0.9525 cm = 0.375in, radius a = 0.47625 cm
CM equiv. radius T-Match portion of driven element ae = 0.83438 cm (new)
CM T-match has a length of l'= 24 cm
CM Reflector l1' = 74.4119 cm & Driven element l2' = 68.8 cm
CM Directors l3' = l6' = 67.0322 cm  & l4' = l5' = 65.6485 cm
CM Reflector-Driven spacing S12 = 30.7487 cm
CM other element spacings Sij = 38.4359 cm
CM Place antenna on the y-z plane.
CM Segment length approx. delta ~ 3.8 cm = 8a
CE
GW 1 21 0.0 -0.37206   0.0       0.0  0.37206   0.0      0.0047625 ! Reflector l1
GW 2  6 0.0 -0.3440    0.307487  0.0 -0.12      0.307487 0.0047625 ! Driven end 1 l2
GW 3  7 0.0 -0.12      0.307487  0.0  0.12      0.307487 0.0083438 ! Driven middle l2
GW 4  6 0.0  0.12      0.307487  0.0  0.3440    0.307487 0.0047625 ! Driven end 2 l2
GW 5 17 0.0 -0.335161  0.691846  0.0  0.335161  0.691846 0.0047625 ! Director l3
GW 6 17 0.0 -0.3282425 1.076205  0.0  0.3282425 1.076205 0.0047625 ! Director l4
GW 7 17 0.0 -0.3282425 1.460564  0.0  0.3282425 1.460564 0.0047625 ! Director l5
GW 8 17 0.0 -0.335161  1.844923  0.0  0.335161  1.844923 0.0047625 ! Director l6
GE 0 0
PT -1 ! suppress current outputs
EK 0  ! Use extended kernel to be safe
LD 5 0 0 0 1.1e7    ! Set conductivity of brass elements
FR 0 1 0 0 195.0 0
EX 0 3 4 0 1.0 0.0  ! Drive middle element of tag #3
RP 0 2 2 0000 0.0 0.0 180.0 90.0
EN
```

Try 3 NEC results- $Z_a = 13.3119 - j4.41455\ \Omega$, $G_{max} = 12.7$ dBi, & $G_{back} = -1.60$ dBi

From MathCad- $Z_{in} = 88.8 + j6.017\ \Omega$, $|\Gamma| = 0.067$, & VSWR = 1.144 (too high)

Comments: Z_{in} is better, but still a bit inductive and small. On fourth try, make l_2' a tiny bit shorter, l' a bit longer, and decrease s a tiny bit.

MatchCad spreadsheet:

T-Match equations- Try 3

$c := 2.998\cdot10^{8}$ m/s $fc := 195\cdot10^{6}$ Hz $\lambda := \frac{c}{fc}$ $\lambda = 1.53744$ m

$k := \frac{2\cdot\pi}{\lambda}$ $k = 4.08679$ rad/m Zdesired := 100 Ω

$d := 0.9525\cdot10^{-2}$ $a := d\cdot0.5$ $a = 0.0047625$ m

$dprime := 0.47625\cdot10^{-2}$ $aprime := dprime\cdot0.5$ $aprime = 0.0023813$ m

$s := 2\cdot10^{-2}$ m $lprime := 24\cdot10^{-2}$ m

$$Z0 := \frac{376.73}{2\cdot\pi}\cdot\operatorname{acosh}\left[\frac{\left(s^2 - a^2 - aprime^2\right)}{2\cdot a\cdot aprime}\right] \qquad Z0 = 209.172 \ \Omega$$

$u := \frac{a}{aprime}$ $u = 2$ $v := \frac{s}{aprime}$ $v = 8.39895$

$$\alpha := \frac{\operatorname{acosh}\left[\frac{\left(v^2 - u^2 + 1\right)}{2\cdot v}\right]}{\operatorname{acosh}\left[\frac{\left(v^2 + u^2 - 1\right)}{2\cdot v\cdot u}\right]} \qquad ae := aprime\cdot e^{\frac{1}{(1+u)^2}\cdot\left(u^2\cdot\ln(u)+2\cdot u\cdot\ln(v)\right)}$$

$\alpha = 1.45711$ $ae = 0.0083438$ m

$$Zt := j\cdot Z0\cdot\tan\left(\frac{k\cdot lprime}{2}\right) \qquad Zt = 111.68152i \ \Omega$$

$Yt := \frac{1}{Zt}$ $Yt = -8.954i\times10^{-3}$ S $\frac{Yt}{2} = -4.477i\times10^{-3}$ S

Za from NEC (a MoM program)- Try 3

$Za := 13.3119 - j\cdot4.41455$ Ω $Ya := \frac{1}{Za}$ $Ya = 0.06768 + 0.02244i$ S

$$Yin := \frac{Yt}{2} + \frac{Ya}{(1+\alpha)^2} \qquad Yin = 0.011 - 7.596i\times10^{-4} \ S$$

$Zin := \frac{1}{Yin}$ $Zin = 88.8 + 6.017i$ Ω Zdesired = 100 Ω

$\Gamma := \frac{(Zin - Zdesired)}{Zin + Zdesired}$ $|\Gamma| = 0.067$ $VSWR := \frac{(1 + |\Gamma|)}{1 - |\Gamma|}$ $VSWR = 1.144$

$$lsuggested := \frac{2}{k}\cdot\operatorname{atan}\left[\frac{1}{2\cdot Z0\cdot Im\left[\frac{Ya}{(1+\alpha)^2}\right]}\right]$$

$lsuggested = 0.27966$ m

$lsuggested\cdot0.5 = 0.14$ m

Try 4: T-Match Design choices

Shorten driven element from l_2' = 68.8 cm to **l_2' = 68.7 cm**

Keep T-Match diameter: $2a$' = 3/16" = 0.47625 cm (no change)

Lengthen T-Match: from l' = 24 cm to **l' = 26 cm**

Shrink T-Match spacing from s = 2 cm to **s = 1.9 cm**

From MathCad, the effective radius of T-Match section is now **a_e = 0.81557 cm.**

Input NEC File- Try 4

```
CM yagi_6element_ch13_tmatch_try4.txt
CM THIS PROGRAM ASSUMES THAT THERE IS NO BOOM.
CM
CM Determine the antenna mode input impedance of the driven element.
CM Center frequency is 195 MHz W/ wavelength of 153.7436 cm.
CM
CM Brass 6-element Yagi-Uda antenna dimensions:
CM element diameters: d=0.9525 cm = 0.375in, radius a = 0.47625 cm
CM equiv. radius T-Match portion of driven element ae = 0.81557 cm (new)
CM T-match has a length of l'= 26 cm (new)
CM Reflector l1' = 74.4119 cm & Driven element l2' = 68.7 cm (new)
CM Directors l3' = l6' = 67.0322 cm  & l4' = l5' = 65.6485 cm
CM Reflector-Driven spacing S12 = 30.7487 cm
CM other element spacings Sij = 38.4359 cm
CM Place antenna on the y-z plane.
CM Segment length approx. delta ~ 3.8 cm = 8a
CE
GW 1 21 0.0 -0.37206   0.0       0.0  0.37206   0.0      0.0047625 ! Reflector l1
GW 2  6 0.0 -0.3435    0.307487  0.0 -0.13      0.307487 0.0047625 ! Driven end 1 l2
GW 3  7 0.0 -0.13      0.307487  0.0  0.13      0.307487 0.0081557 ! Driven middle l2
GW 4  6 0.0  0.13      0.307487  0.0  0.3435    0.307487 0.0047625 ! Driven end 2 l2
GW 5 17 0.0 -0.335161  0.691846  0.0  0.335161  0.691846 0.0047625 ! Director l3
GW 6 17 0.0 -0.3282425 1.076205  0.0  0.3282425 1.076205 0.0047625 ! Director l4
GW 7 17 0.0 -0.3282425 1.460564  0.0  0.3282425 1.460564 0.0047625 ! Director l5
GW 8 17 0.0 -0.335161  1.844923  0.0  0.335161  1.844923 0.0047625 ! Director l6
GE 0 0
PT -1 ! suppress current outputs
EK 0  ! Use extended kernel to be safe
LD 5 0 0 0 1.1e7    ! Set conductivity of brass elements
FR 0 1 0 0 195.0 0
EX 0 3 4 0 1.0 0.0  ! Drive middle element of tag #3
RP 0 2 2 0000 0.0 0.0 180.0 90.0
EN
```

Try 4 NEC results-

Z_a = 13.3703 - j5.37718 Ω, G_{max} = 12.66 dBi, G_{back} = -1.63 dBi, & F/B ratio = 14.29 dB

From MathCad- **Z_{in} = 94.857 - j0.344 Ω, |Γ| = 0.0265, & VSWR = 1.054 < 1.1 (DONE)**

MatchCad spreadsheet:

T-Match equations- Try 4

$c := 2.998\cdot10^{8}$ m/s $fc := 195\cdot10^{6}$ Hz $\lambda := \frac{c}{fc}$ $\lambda = 1.53744$ m

$k := \frac{2\cdot\pi}{\lambda}$ $k = 4.08679$ rad/m Zdesired := 100 Ω

$d := 0.9525\cdot10^{-2}$ $a := d\cdot0.5$ $a = 0.0047625$ m

$dprime := 0.47625\cdot10^{-2}$ $aprime := dprime\cdot0.5$ $aprime = 0.0023813$ m

$s := 1.9\cdot10^{-2}$ m $lprime := 26\cdot10^{-2}$ m

$$Z0 := \frac{376.73}{2\cdot\pi}\cdot\operatorname{acosh}\left[\frac{\left(s^2 - a^2 - aprime^2\right)}{2\cdot a\cdot aprime}\right] \qquad Z0 = 202.511 \ \Omega$$

$u := \frac{a}{aprime}$ $u = 2$ $v := \frac{s}{aprime}$ $v = 7.979$

$$\alpha := \frac{\operatorname{acosh}\left[\frac{\left(v^2 - u^2 + 1\right)}{2\cdot v}\right]}{\operatorname{acosh}\left[\frac{\left(v^2 + u^2 - 1\right)}{2\cdot v\cdot u}\right]} \qquad ae := aprime\cdot e^{\frac{1}{(1+u)^2}\cdot\left(u^2\cdot\ln(u)+2\cdot u\cdot\ln(v)\right)}$$

$\alpha = 1.47122$ $ae = 0.0081557$ m

$$Zt := j\cdot Z0\cdot\tan\left(\frac{k\cdot lprime}{2}\right) \qquad Zt = 119.00402i \ \Omega$$

$Yt := \frac{1}{Zt}$ $Yt = -8.403i\times10^{-3}$ S $\frac{Yt}{2} = -4.202i\times10^{-3}$ S

Za from NEC (a MoM program)- Try 4

$Za := 13.3703 - j\cdot5.37718$ Ω $Ya := \frac{1}{Za}$ $Ya = 0.06438 + 0.02589i$ S

$$Yin := \frac{Yt}{2} + \frac{Ya}{(1+\alpha)^2} \qquad Yin = 0.011 + 3.821i\times10^{-5} \ S$$

$Zin := \frac{1}{Yin}$ $Zin = 94.857 - 0.344i$ Ω Zdesired = 100 Ω

$\Gamma := \frac{(Zin - Zdesired)}{Zin + Zdesired}$ $|\Gamma| = 0.0265$ $VSWR := \frac{(1 + |\Gamma|)}{1 - |\Gamma|}$ $VSWR = 1.054$

$$lsuggested := \frac{2}{k}\cdot\operatorname{atan}\left[\frac{1}{2\cdot Z0\cdot Im\left[\frac{Ya}{(1+\alpha)^2}\right]}\right]$$

$lsuggested = 0.25807$ m

$lsuggested\cdot0.5 = 0.129$ m

Parameter	Original/unmatched	w/ T-Match
Z_{in}	15.8053 + j17.2159 Ω	94.857 - j0.344 Ω
Γ_{in}	0.734∠160°	0.0265∠-176°
VSWR	6.52	1.054
Gain (dBi)	12.40	12.66
F/B ratio (dB)	14.38	14.29

Comments: The T-Match resulted in a dramatic improvement in matching while giving a small 0.26 dB increase in gain and incurring a slight 0.09 dB decrease in front-to-back ratio. A gain of 12.35 dBi was expected for the 6-element design.

6 element, channel 10 Yagi-Uda antenna with T-match and without boom

Dimensions: $s_{12} = 0.2\lambda = 30.7487$ cm, $s_{ij} = 0.25\lambda = 38.4359$ cm, $d = 3/8" = 0.9525$ cm,
T-Match- $2a' = 3/16" = 0.47625$ cm, $s = 1.9$ cm, and $l' = 26$ cm