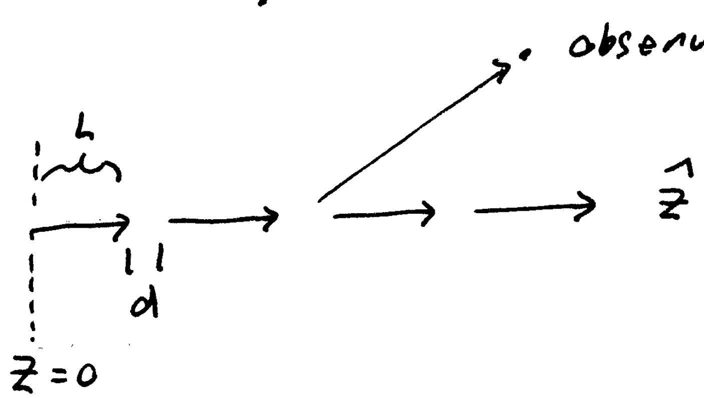
EE533-15

Array antennas: (chapter 6.1-6.3 intro)

Consider a co-linear arrangemet or "linear" array of dipoles. (special case)



⇒ find the vector potential for the array

1st element: $A_z = \frac{e^{-jkr}}{4\pi r} L I_o$

using super position.

$$A_z = \frac{e^{-jkr} L}{4\pi r}\left[I_o + I_1 e^{jkd\cos\theta} + I_2 e^{j2kd\cos\theta} + \cdots\right]$$

$$A_z = \frac{e^{-jkr}}{4\pi r} L \sum_{n=0}^{N-1} I_n e^{jknd\cos\theta}$$

N is the total number of Array elements.

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$A_r \cong 0 \;,\; A_\phi = 0 \;,\; A_\theta = -\sin\theta\, A_z$

$$E_\theta \cong -jk\eta A_\theta = \frac{jk\eta\, e^{-jkr}}{4\pi r} L \sum_{n=0}^{N-1} I_n e^{jknd\cos\theta}$$

So the normalized pattern can be written as:

$$F(\theta,\phi) = \underbrace{g_a(\theta,\phi)}_{\text{element factor}}\ \underbrace{f(\theta,\phi)}_{\text{Array Factor.}}$$

$$F(\theta,\phi) = \sin\theta\, \underbrace{\sum_{n=0}^{N-1} I_n e^{jknd\cos\theta}}_{\text{(with proper normalization)}}$$

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we can feed each element with different phase and magnitude.

$I_n = I_0 e^{j\alpha n}$ $\quad$ α is the phase progression.

$$\xrightarrow[n=0]{0} \quad \xrightarrow[n=1]{\alpha} \quad \xrightarrow[n=2]{2\alpha} \quad \hat{z}$$

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$$\sum_{n=0}^{N-1} I_n e^{jknd\cos\theta} = I_o \sum_{n=0}^{N-1} e^{jn\psi}$$

where $\psi = kd\cos\theta + \alpha$

(note: our text uses $\psi = kd\cos\theta + \beta$)

(see eq 6-7 text)

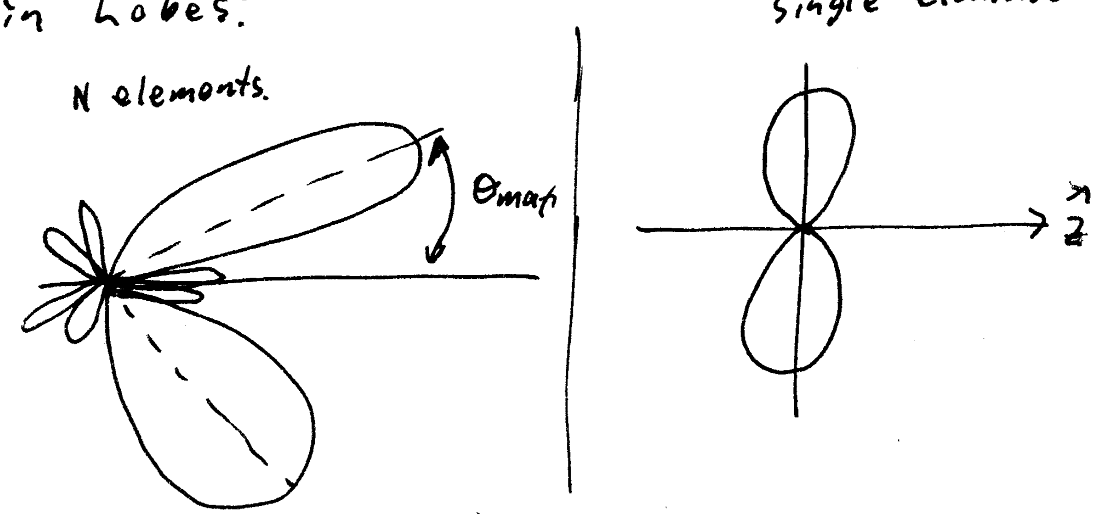
$$F(\theta,\phi) = g_a(\theta,\phi)\, f(\theta,\phi)$$

$$f(\theta,\phi) = f(\theta) = \frac{\sin\left(\frac{N}{2}\psi\right)}{\sin\left(\frac{\psi}{2}\right)}$$

→ uniform spacing on z axis.

d is typically $\frac{\lambda}{2}$

for Large N side lobes appear with the main lobes:



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Direction of the peak value occurs

when $\psi = 0 \Rightarrow kd\cos\theta_{max} + \alpha = 0$

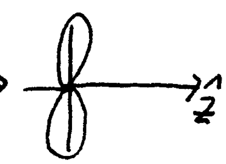
$$k = \frac{2\pi}{\lambda} \Rightarrow \theta_{max} = \cos^{-1}\left[\frac{-\alpha}{2\pi d/\lambda}\right]$$

Summary

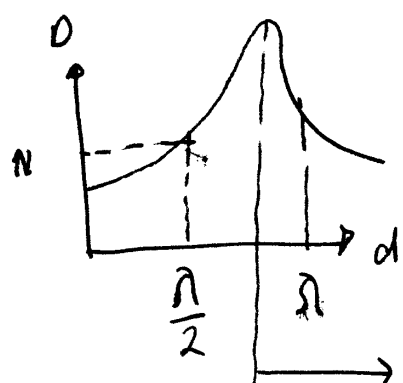
① when N increases, directivity goes up.

② " " " , side lobe level goes down $\left(\propto \frac{1}{N}\right)$

③ as d increases, the directivity increases up to a certain point

$\alpha = 0$ is a "broad side pattern" $\Rightarrow$ 

(see section 6.31)



(see fig 6.6, 6.7)

additional side lobes appear.

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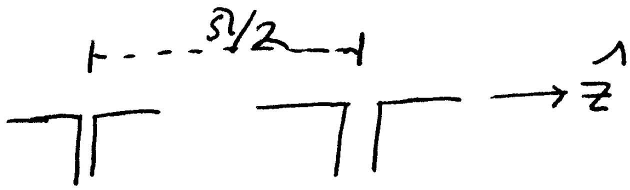
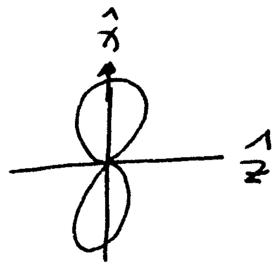
Orientation of the array elements has to be considered.

Example: Consider 2-element array:



for the above:

Element factor

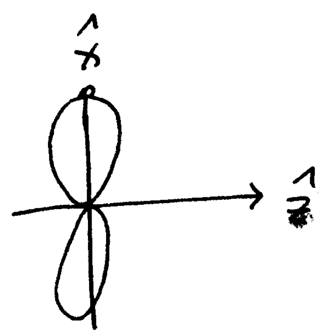


Array factor

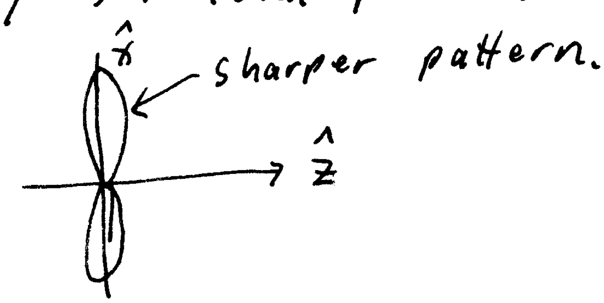
$N = 2 \quad d = \frac{\lambda}{2}$

$$kd = \frac{2\pi}{\lambda} d = \pi$$

$$f(\theta) = \frac{\sin(\pi \cos\theta)}{\sin\left(\frac{\pi}{2}\cos\theta\right)}$$



multiply for total pattern.



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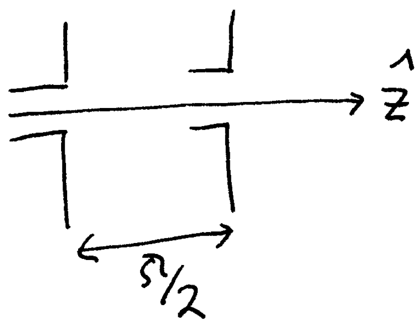
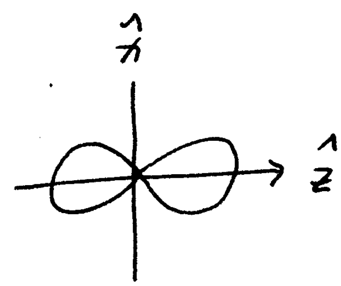
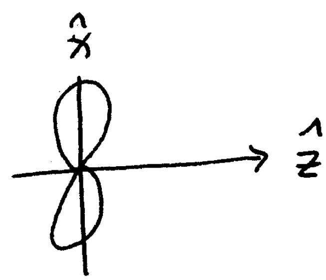
now turn the 2 elements



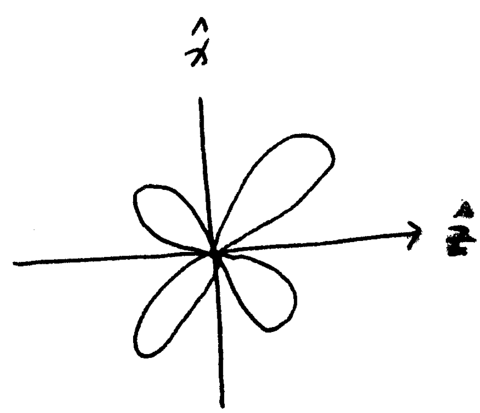
the element $g(\theta) \Rightarrow$



the array factor is the same.



So the total pattern is now $F(\theta) = g(\theta) f(\theta)$



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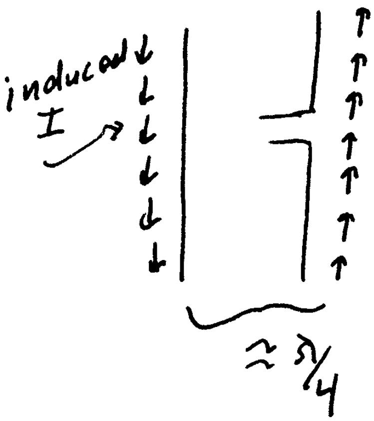
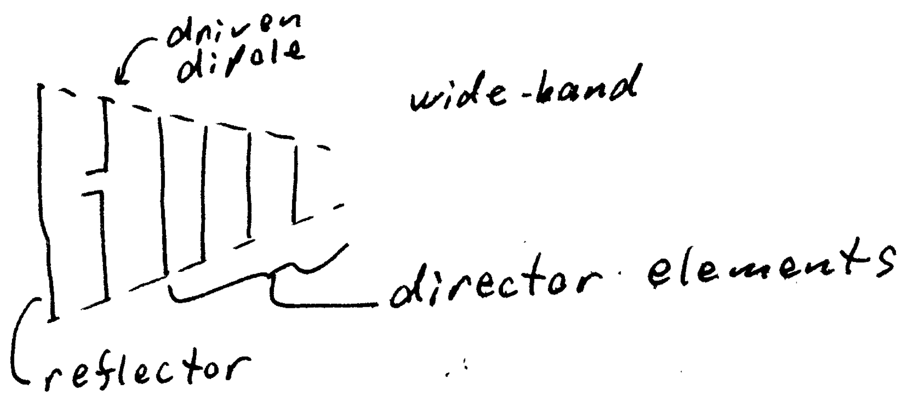
variations on the dipole (origional work done in the 1920's!)



reflected current in phase with driven current adds constructivly to increase D

⇌ path length ≈ λ/2 so induced current adds to I_0



wide-band

called Yagi-Uda Antenna (see text)

Directivity > 10dB

Uda did the work - student, but Yagi was his teacher → Japan custom to credit the teacher!

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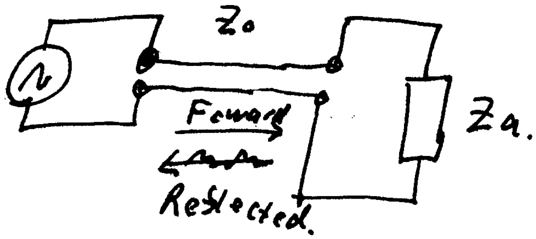
Antenna matching and Feed Lines.



To connect a transmitter or Receiver to the antenna we use a transmission Line. Small Antennas may use microstip Line on the pcb → but we still have a transmission Line.

The Reflection coef. is.

$$\Gamma = \frac{Z_a - Z_0}{Z_a + Z_0}$$

$0 \leq |\Gamma| \leq 1 \leftarrow$ all power reflected → non radiated.

↑ ideal - no reflection loss

~~Antennas are spec.~~

Antenna match is usually specified by Return loss: $RL = -20 \log |\Gamma|$ or VSWR:

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|}$$

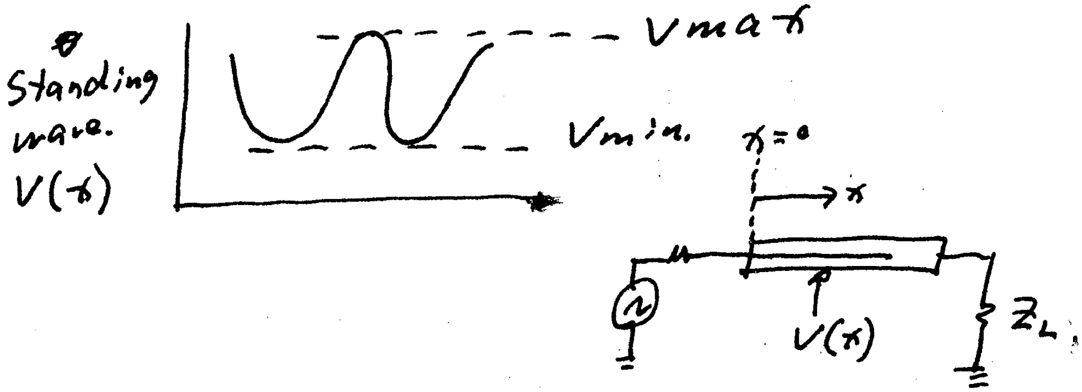
$1 \leq VSWR \leq \infty$ ← total Reflection.

1 ← ideal

Transmitter antennas, $VSWR < 1.5$

Receive antennas $VSWR < 2.0$.

VSWR ⇒ "Voltage standing wave Ratio" on the line.



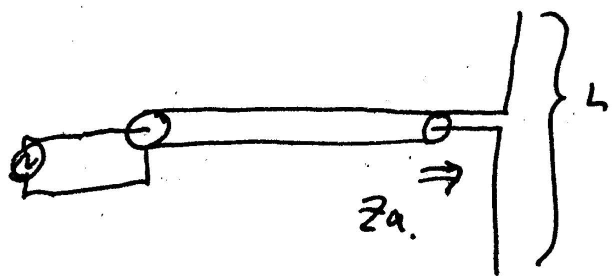
$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \Rightarrow \frac{V_{max}}{V_{min}}$$

$$|\Gamma| = \frac{VSWR-1}{VSWR+1}$$

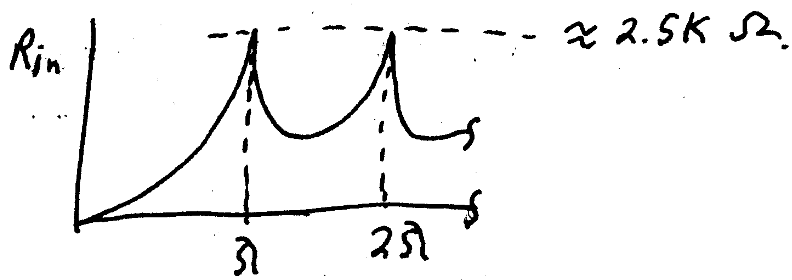
$|\Gamma|^2$ is the fraction of incident power reflected from the input of the Antenna ⇒ wasted power!

VSWR $= 2 \Rightarrow \Gamma = \frac{1}{3} \Rightarrow$ 11% of power is not radiated → it is reflected back down the transmission Line.

example - real dipole. - see plots in text.



$Z_a = R + jX.$



similar plot for X

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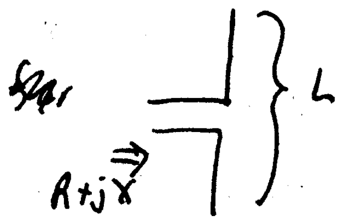
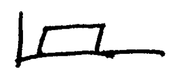
for dipoles: (see 8.62 in text)

Emperical Expression for R.

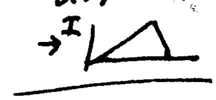


for

$0 \le L < \frac{\lambda}{4}$ $R = 20\pi^2\left(\frac{L}{\lambda}\right)^2$ - uniform current infinitesimal dipole.



$\frac{\lambda}{4} \le L < \frac{\lambda}{2}$ $R = 24.7\left(\frac{\pi L}{\lambda}\right)^{2.4}$ Short dipole.



$\frac{\lambda}{2} \le L \le 0.637\lambda$ $R = 11.14\left(\frac{\pi L}{\lambda}\right)^{4.17}$

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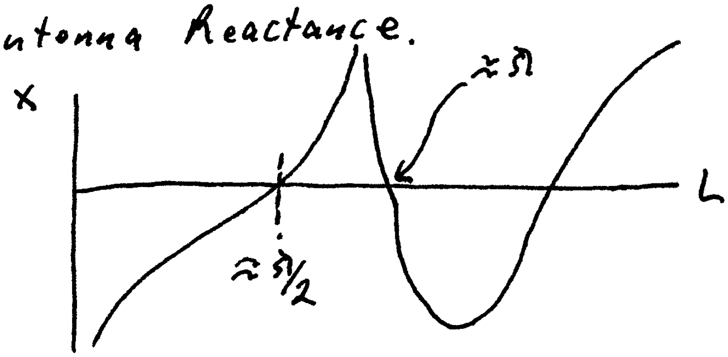
antenna Reactance.



Element diameter effects the Length where $X = 0$

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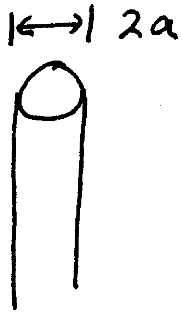

Lengths for $jX = 0$;

very thin $\Rightarrow \dfrac{L}{2a} = 5000 \Rightarrow L = 0.49\,\lambda$.

Thick: $\dfrac{L}{2a} = 10 \Rightarrow L = 0.455\,\lambda$.

Thin: $\dfrac{L}{2a} = 50 \Rightarrow L = 0.475\,\lambda$.

see the text for the formal treatment of input Z ----

"wire" antennas are often made from tubing → (check out a TV Antenna)

→ light weight + Larger "a" ⇒ wider BW

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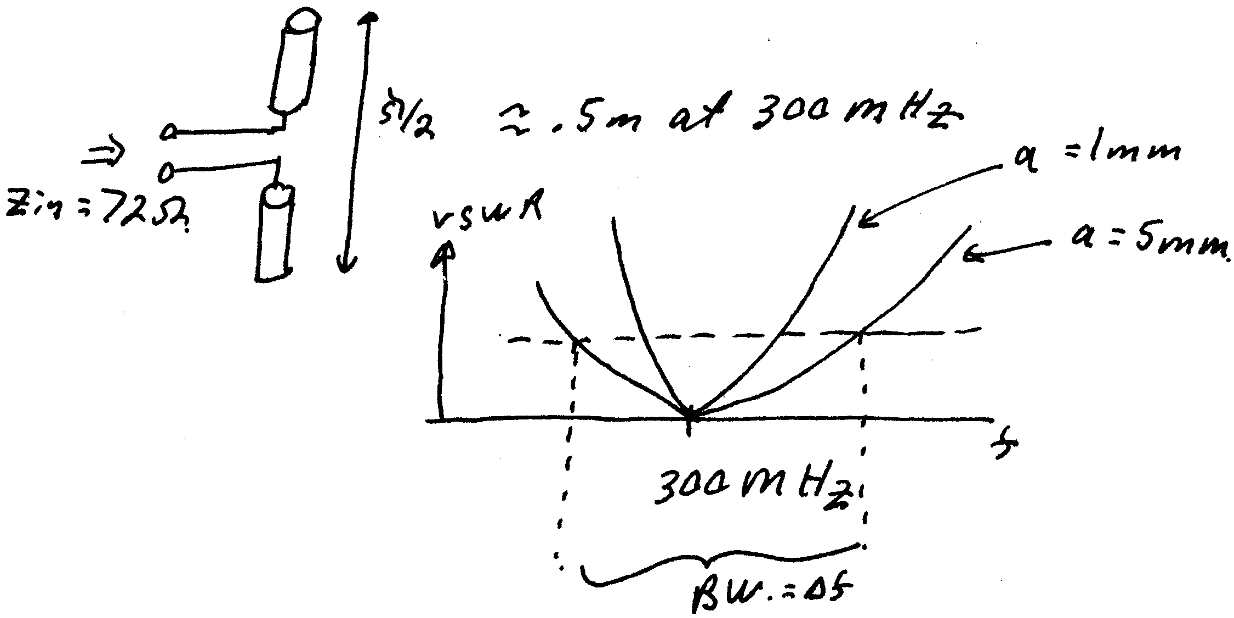
Bandwidth $\Rightarrow$ thick rods give wider BW.

BW $\triangleq$ frequency range ~~over~~ such that VSWR < 2:1, i.e. $|\Gamma|^2 < 11\%$ power Loss.

example $\rightarrow$ dipole.



$$a = 0.005 \rightarrow \frac{L}{2a} = 50 \rightarrow \Delta f = 48 \text{ mHz}.$$

$$\text{Bandwidth} = \frac{\Delta f}{f_0} = \frac{48}{300} = \underline{16\%}$$

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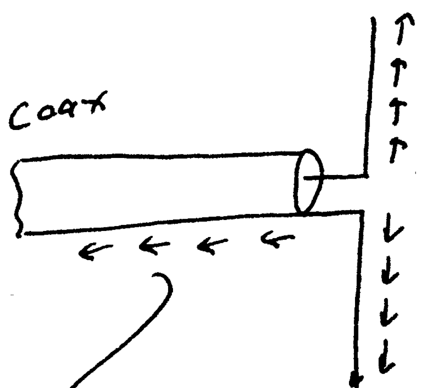
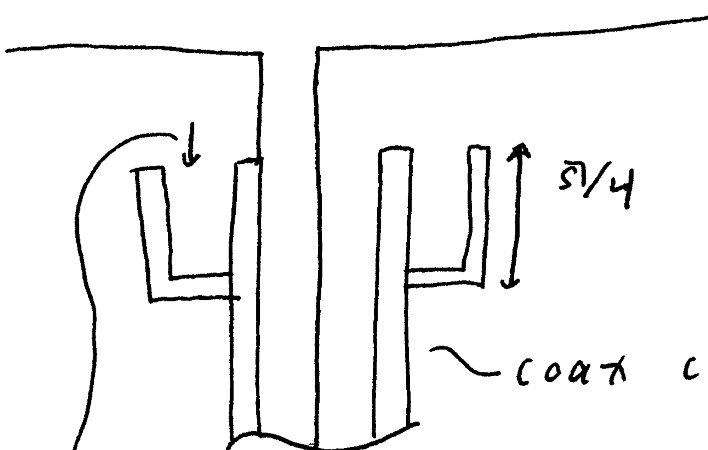
matching Balun.

Problem: coax feed to a Balanced ant:



induced currents on shield of coax results in the currents being <u>unbalanced</u>.

this is corrected using a "Balun"
"Balanced to unbalanced"



effective impedance to incoming wave $= \infty$