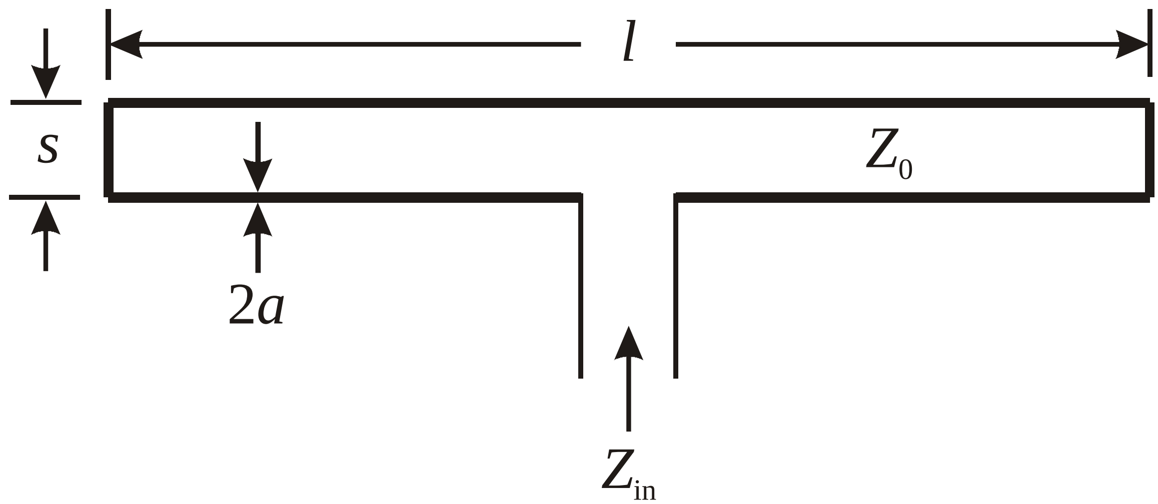
Driving/Matching Techniques For Yagi-Uda Antennas: Folded Dipole

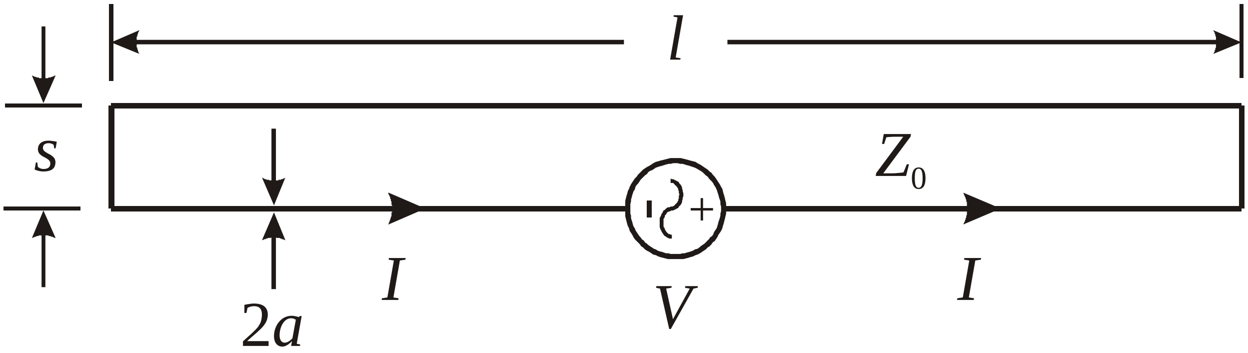
(Sections 9.5 & 9.7 of Balanis)

Folded Dipole:



- A good example of a folded dipole is an FM radio antenna.
- As shown, it is a thin ($s << \lambda$) rectangular loop.
- Typically used to provide a step-up in impedance (usually 4 to 1) when a regular dipole antenna has a lower impedance than the feeding transmission line. [e.g., 4 × 75 Ω = 300 Ω]
- Useful as driven element when a twin-lead transmission line is used to feed a Yagi-Uda antenna.
- Can be modeled as a combination of a short-circuited transmission lines and a dipole antenna
- The characteristic impedance for a uniform twin-lead transmission line is $Z_0 = \frac{\eta}{\pi}\cosh^{-1}\left(\frac{s}{2a}\right)$, where $\eta = \sqrt{\mu / \varepsilon_{\text{eff}}}$ is the characteristic impedance of the material.

Model:



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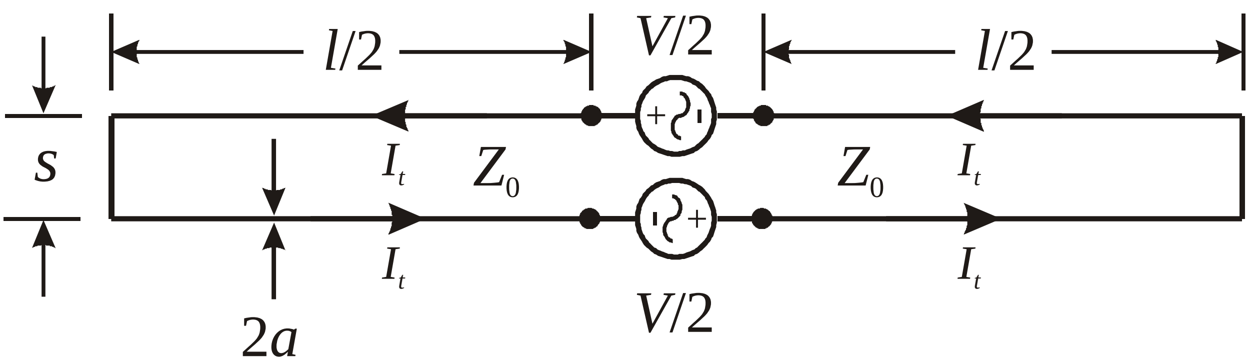
Transmission Line Mode:



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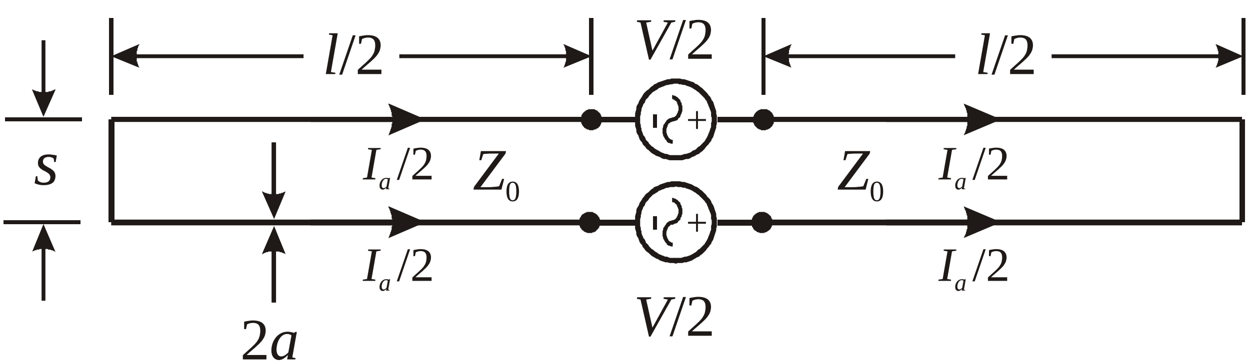
Antenna Mode:



This model can be further refined as:

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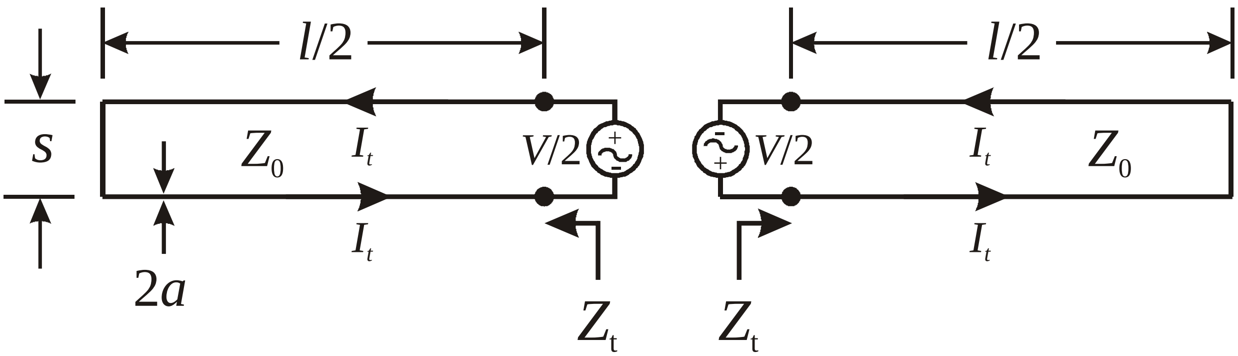
Transmission Line Mode:



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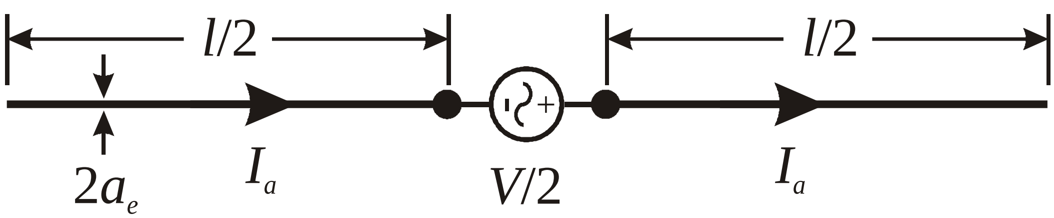
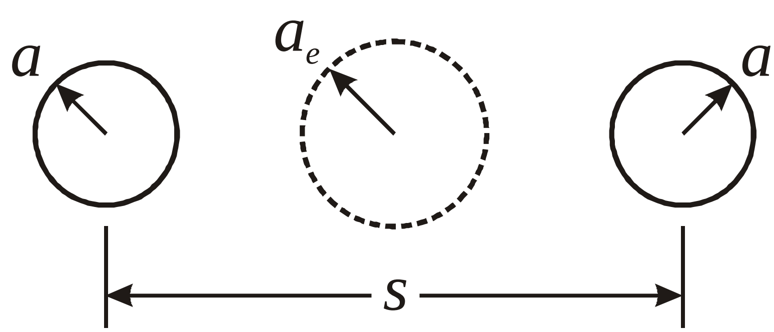
Antenna Mode:



where a_e is the effective radius of the two wires considered together. The text discusses equivalent radii for several geometries in section 9.4.5.

The twin wires of radii a separated by a distance s (where $s \ll \lambda$) that compose the folded dipole can be modeled as a single wire with an equivalent radius a_e as shown



where $a_e = \sqrt{as}$ (9-22a).

<u>Transmission line mode impedance and current</u>:

Transmission line(s) input impedance

$$Z_t = \frac{V/2}{I_t}$$

The input impedance and admittance, respectively, for a transmission line with a short-circuit load are

$$Z_t = jZ_0 \tan(kl/2) \text{ and } Y_t = \frac{-j}{Z_0 \tan(kl/2)},$$

where $k = \beta = 2\pi/\lambda$.

Note: $Z_0 \tan(kl/2) > 0$ for $0 < l < 0.5\lambda$ (typically the case encountered when using a folded dipole by itself or in a Yagi-Uda antenna), and $Z_0 \tan(kl/2) < 0$ for $0.5\lambda < l < \lambda$.

Solving for the current yields

$$I_t = \frac{V/2}{Z_t} = \frac{V}{j2Z_0 \tan(kl/2)}$$

Antenna mode impedance and current:

- The antenna mode input impedance for a dipole of radius a_e and length l is usually found numerically (e.g., Method of Moments program like NEC) or from figures.

- If a folded dipole is used as the driven element in a Yagi-Uda antenna, insert this equivalent dipole into the antenna when finding Z_a to (partially) account for interaction with other elements.

Definition of antenna-mode input impedance

$$Z_a = \frac{V/2}{I_a}$$

Solving for the current

$$I_a = \frac{V/2}{Z_a}$$

By symmetry, each wire carries half of the current (i.e., $I_a/2$) in the antenna mode.

Total impedance and current for folded dipole:

The current at the terminals of the folded dipole is

$$\begin{aligned} I = I_t + \frac{I_a}{2} &= \frac{V/2}{Z_t} + \frac{V/2}{2Z_a} \\ &= V\left(\frac{1}{2Z_t} + \frac{1}{4Z_a}\right) \\ &= V\left(\frac{2Z_a + Z_t}{4Z_a Z_t}\right) \end{aligned}$$

Solving for the input admittance and impedance

$$Y_{\text{in}} = \frac{I}{V} = \frac{1}{2Z_t} + \frac{1}{4Z_a} = \frac{Y_t}{2} + \frac{Y_a}{4}$$

$$Z_{\text{in}} = \frac{V}{I} = \frac{4Z_a Z_t}{2Z_a + Z_t}$$

Note: In order for $Y_t/2$ to cancel the susceptance of $Y_a/4$, when $0 < l < 0.5\lambda$ (susceptance of $Y_t/2$ is negative), the susceptance of Y_a must be positive (i.e., the reactance of Z_a is negative or capacitive).

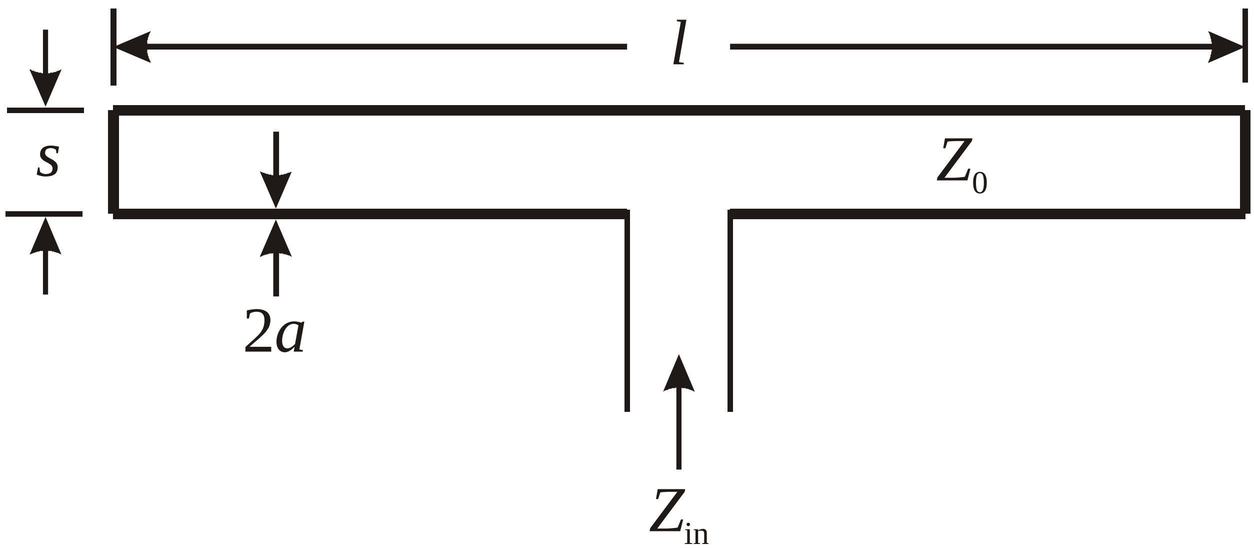
For the case that $l = \lambda/2$ (i.e., a half-wave dipole), the transmission line impedance and admittance become

$$Z_t = jZ_0 \tan(kl/2) = jZ_0 \tan(\pi/2) \to \infty \text{ and } Y_t = 0.$$

Then, the input impedance and admittance become

$$Z_{\text{in}} = \lim_{Z_t \to \infty} \frac{4Z_a Z_t}{2Z_a + Z_t} = 4Z_a \quad \text{and } Y_{\text{in}} = \frac{Y_a}{4}.$$

Example: Find the input impedance of a folded dipole described by the dimensions: $l = \lambda/2.2 = 0.4545\lambda$, $s = 0.00613\lambda$, and $2a = 0.001\lambda$.



Transmission line characteristic impedance

$$Z_0 = \frac{\eta}{\pi}\cosh^{-1}\left(\frac{s}{2a}\right)$$
$$= \frac{377}{\pi}\cosh^{-1}\left(\frac{0.00613\lambda}{0.001\lambda}\right)$$
$$= 300\ \Omega$$

Input impedance of transmission line mode

$$\frac{kl}{2} = \frac{1}{2}\left(\frac{2\pi}{\lambda}\right)\frac{\lambda}{2.2} = 1.428$$

$$Z_t = jZ_0 \tan(kl/2)$$
$$= j300 \tan(1.428)$$
$$= j2086.5458\,\Omega$$

Input impedance of antenna mode

The equivalent radius of the twin wires forming the folded dipole is

$$a_e = \sqrt{a\,s} = \sqrt{(0.001\lambda/2)(0.00613\lambda)} = 0.0018\lambda\,.$$

Using a Method of Moments program (e.g., NEC-2) to find the input impedance of a dipole of length $l = \lambda/2.2$ and radius $a_e = 0.0018\lambda$, yields

$$Z_a = 63 - j\,33\ \Omega.$$

The input impedance of the folded dipole is then calculated

$$\begin{aligned} Z_{\text{in}} &= \frac{4Z_a Z_t}{2Z_a + Z_t} \\ &= \frac{4(63 - j33)(j2086.5458)}{2(63 - j33) + j2086.5458} \\ &= 267.7 - j119.6\,\Omega \end{aligned}$$

Since $|Z_t| >> |Z_a|$, we could also use the approximation that

$$Z_{\text{in}} \approx 4Z_a = 4(63 - j\,33) = 252 - j132\ \Omega,$$

which is fairly close to our previous result.

When connected to a 300 Ω twin-lead transmission line, this folded dipole would have a reflection coefficient and VSWR of

$$\begin{aligned} \Gamma_{\text{in}} &= \frac{Z_{\text{in}} - Z_0}{Z_{\text{in}} + Z_0} = \frac{(267.7 - j119.6) - 300}{(267.7 - j119.6) + 300} \\ &= 0.21357\angle -93.216^\circ \end{aligned}$$

and

$$\text{VSWR} = \frac{1 + |\Gamma_{\text{in}}|}{1 - |\Gamma_{\text{in}}|} = \frac{1 + 0.21357}{1 - 0.21357} = 1.543.$$