The Yagi-Uda Antenna

Fig. 1. Shintaro Uda. (Courtesy of Library of Tohoku University, Sendai, Japan.)

Part 2

Presenter-Tom Kihm, KJ6PST

Part 2 Agenda

- Empirical design NBS TN
- Computer-aided design examples
- Mutual coupling effects on input impedance
- Matching approaches
- Conclusions

Yagi Antenna Design

- Historically Empirical Design
  - Uda’s Original Research
  - National Bureau of Standards (NBS) Technical Note
- Recently, Computer-aided designs
  - Method of Moments
  - Induced EMF method
  - Plus others

Several on-line calculators use NBS rules of thumb for reflector, DE and director lengths and spacings

NBS Design Curves

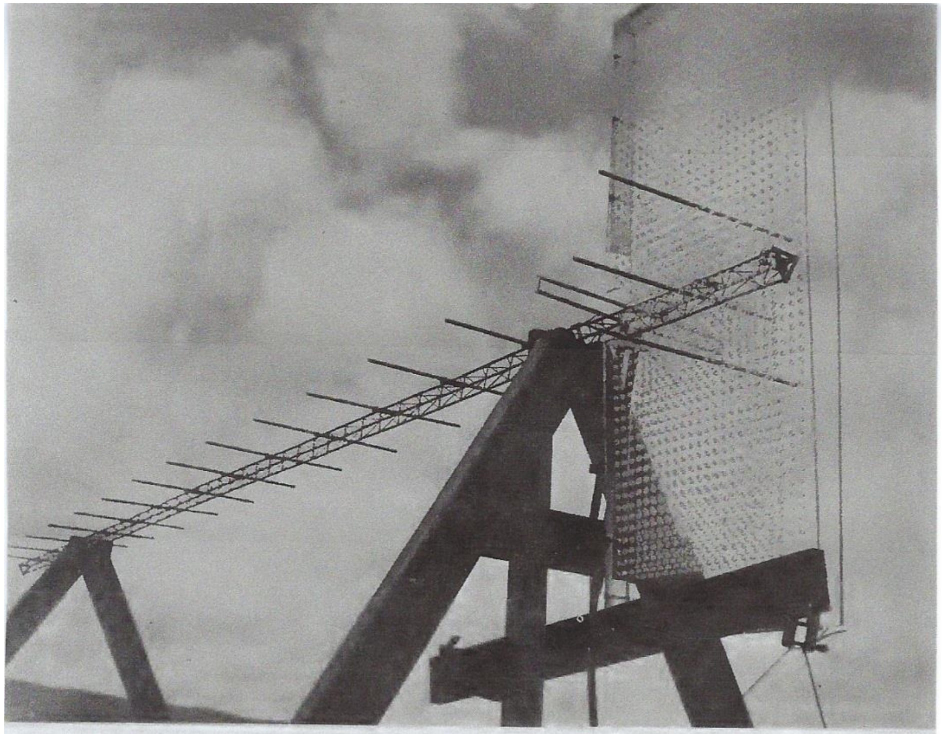


FIG. 3 PHOTOGRAPH OF THE TRIGONAL REFLECTOR EXPERIMENTAL SET-UP USED WITH THE 4.2λ YAGI

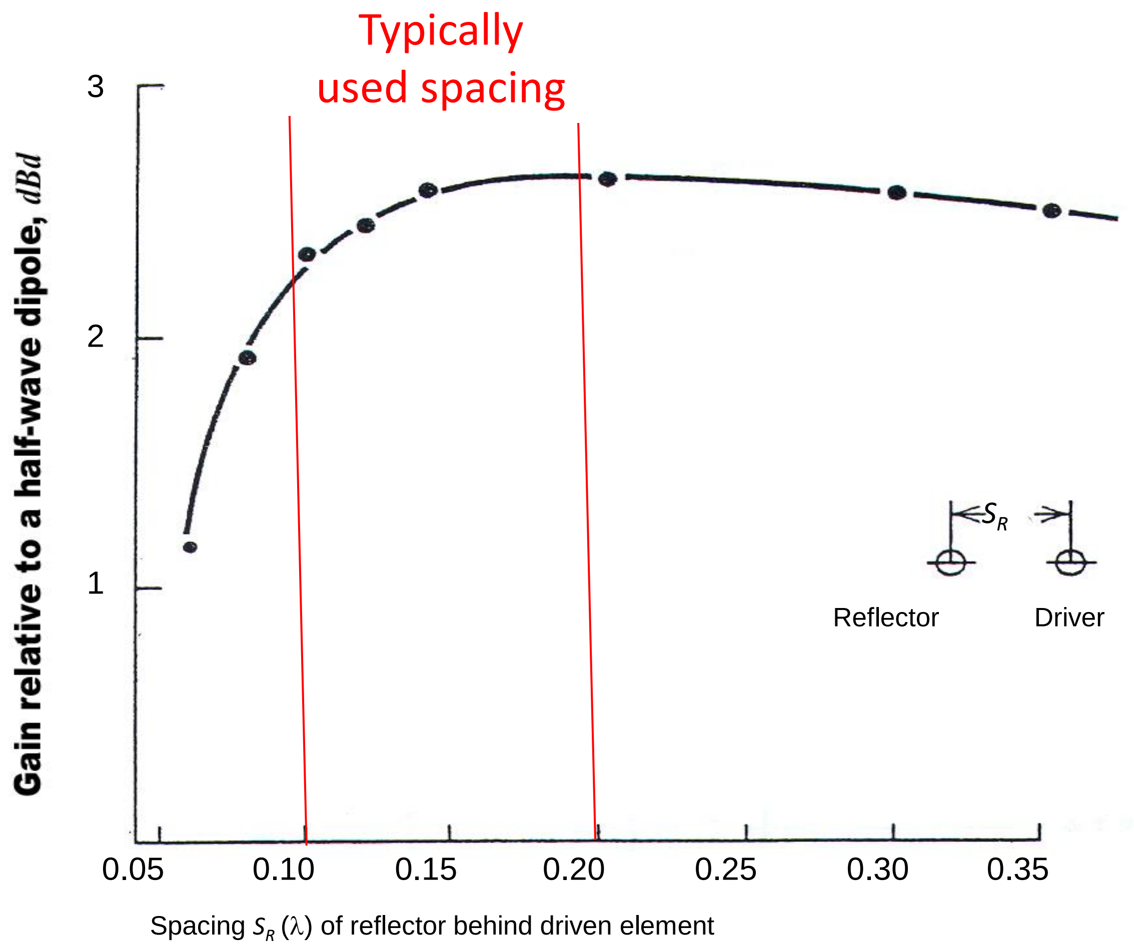
This photo shows a NBS 4λ test array

The following design curves were derived from experimental data taken at 400 MHz that explains data plotted over 10λ array lengths: focus is on gain , not F/B ratio

Gain Effect of the Reflector Element-NBS TN

Measured gain in dBd of a dipole and reflector element for different spacings S_R.

Dipole gain dBd= 2.15dBi



Optimum reflector spacing S_R (for maximum directivity) is between 0.10 and 0.20 wavelengths

Yagi Gain vs Number of Directors- NBS TN

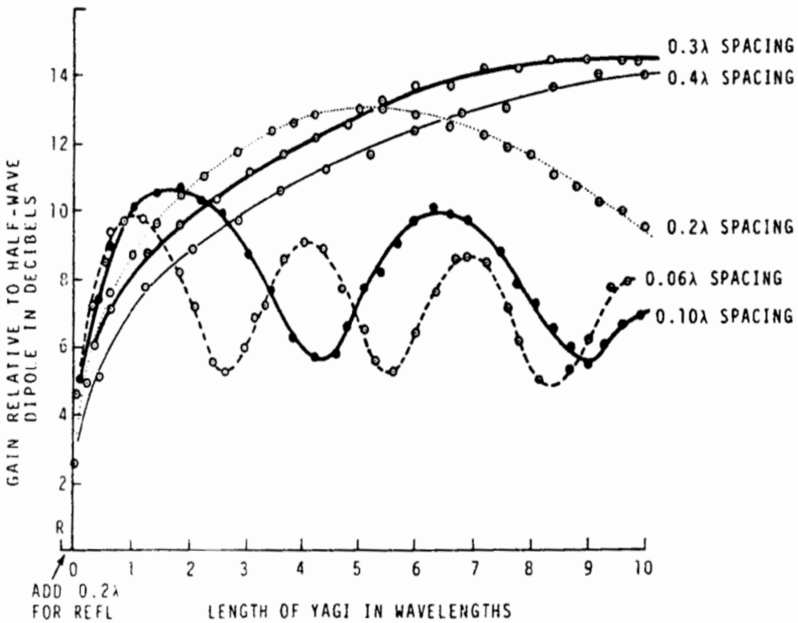


FIG. 4 GAIN OF A YAGI AS A FUNCTION OF LENGTH (NUMBER OF DIRECTORS) FOR DIFFERENT CONSTANT SPACINGS BETWEEN DIRECTORS OF LENGTH EQUAL TO 0.382λ

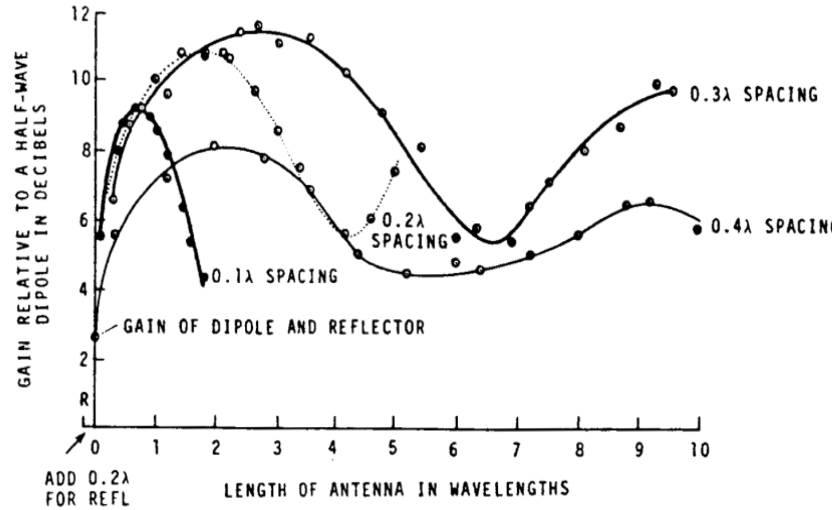


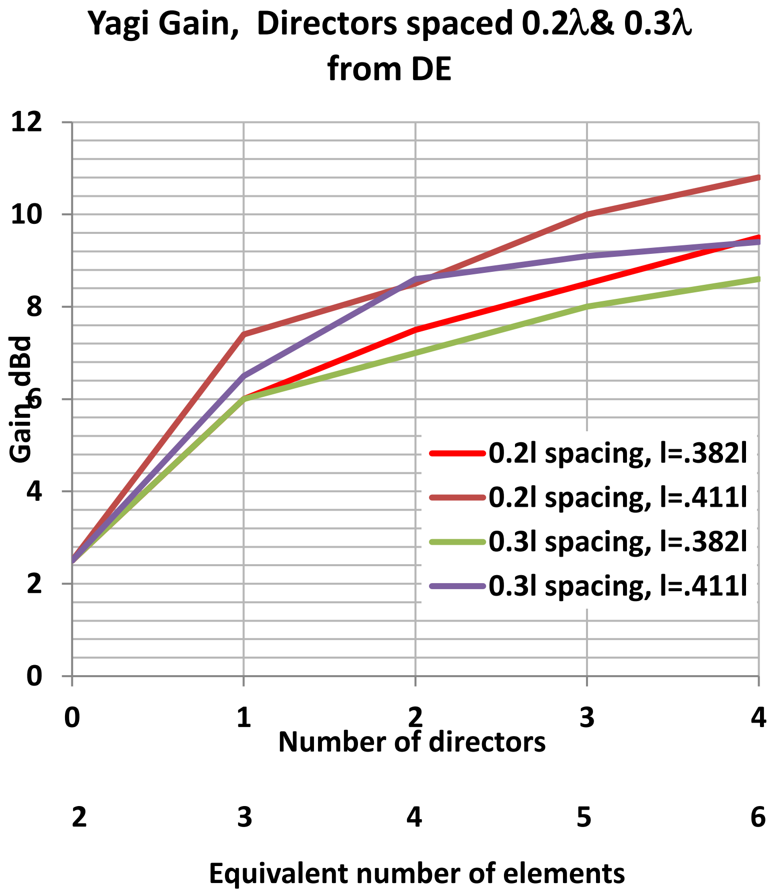
FIG. 5 GAIN OF A YAGI AS A FUNCTION OF LENGTH (NUMBER OF DIRECTORS) FOR DIFFERENT CONSTANT SPACINGS BETWEEN DIRECTORS OF LENGTH EQUAL TO 0.411λ

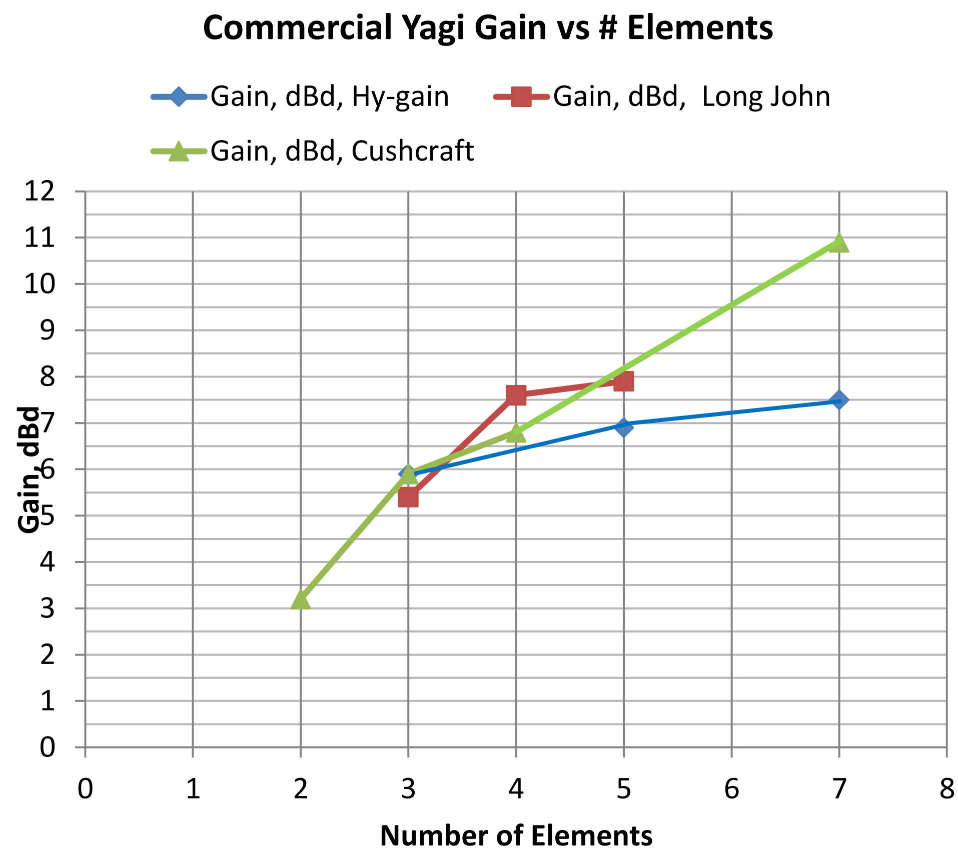
Note: the reflector is included

These curves cover long arrays. For HF, focus on data for ≤ 1λ array length. 0.2λ element spacing provides slightly more directive gain than 0.3λ spacing

An Interesting Comparison

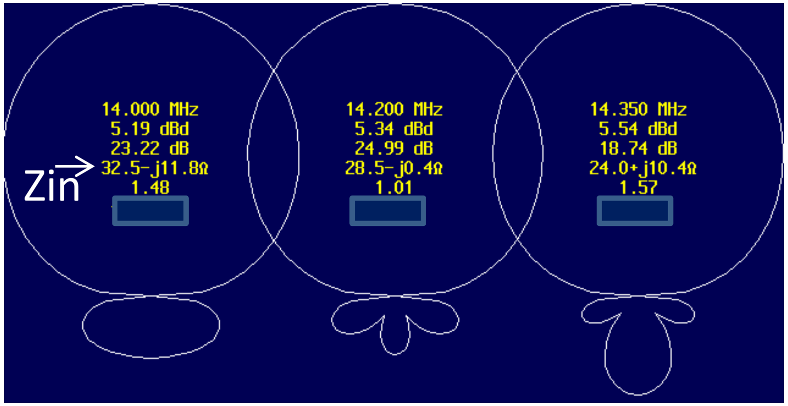
From NBS Tech Note



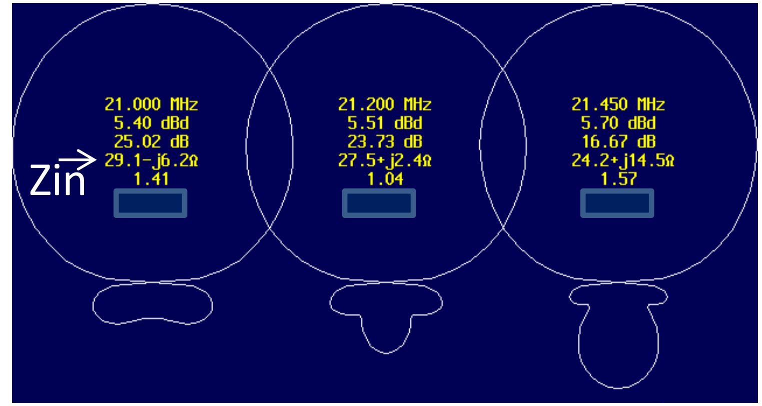


Note the approximate gain agreement for 3-5 elements

3 Element 20,15 &10 meter Design Examples

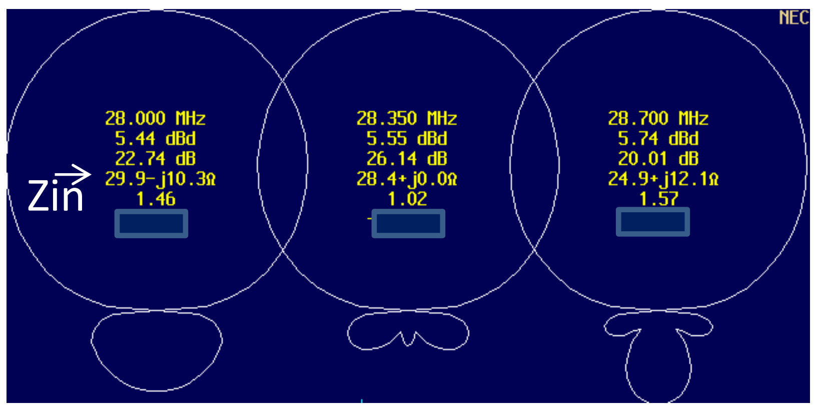


Freq.
Dir. Gain
F/B
Zin
SWR



Freq.
Dir. Gain
F/B
Zin
SWR

These results are from computer-aided design software



Freq.
Dir. Gain
F/B
Zin
SWR

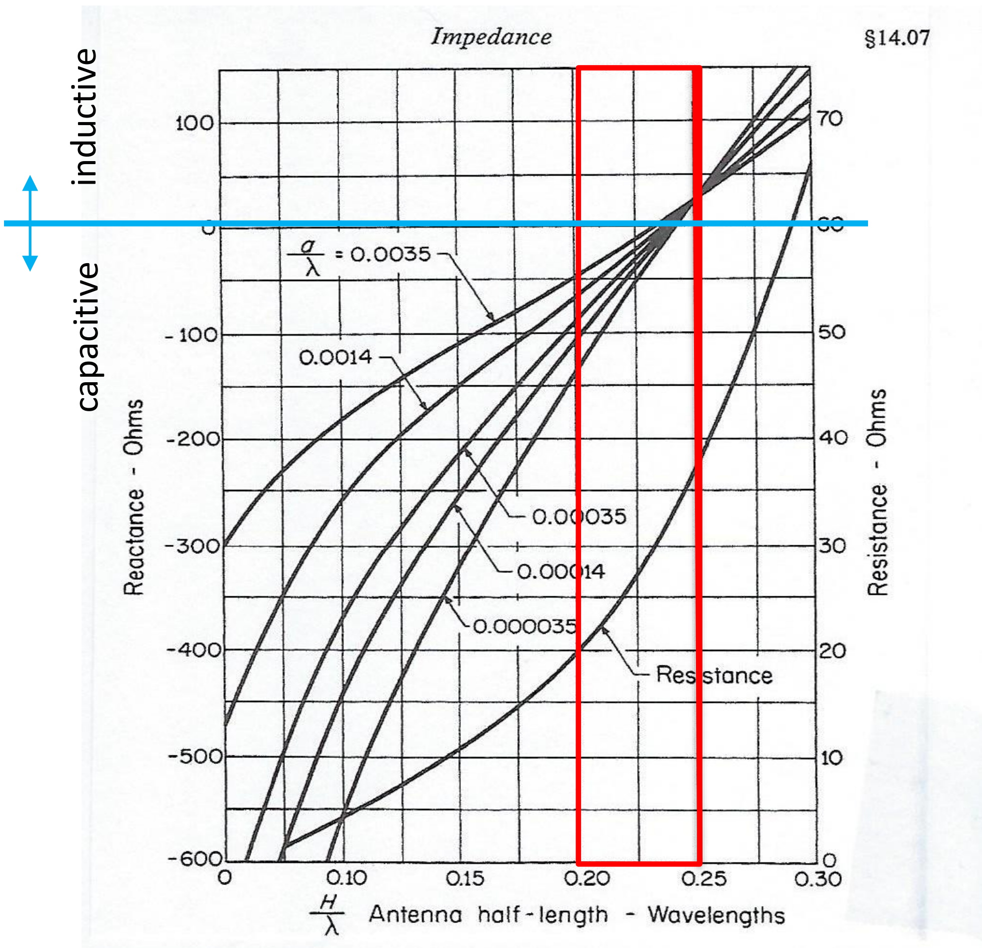
Note: Pattern gain, F/B, Zin, change with frequency and <u>Rin < 50 Ohms</u>

Yagi Input Impedance

- The driven element is often a dipole; some designs use a folded dipole to raise the impedance
- Expect ~ 73 Ohms resistive for free-space, half-wave dipole driving impedance
- However, the reflector and director(s) generally reduce that impedance due to mutual impedance

The Yagi input impedance commonly requires matching to a 50 Ohm transmission line by various techniques.

Driven Element Free-space Feed Impedance



These theoretical values are half those of the driven dipole element.

Note:

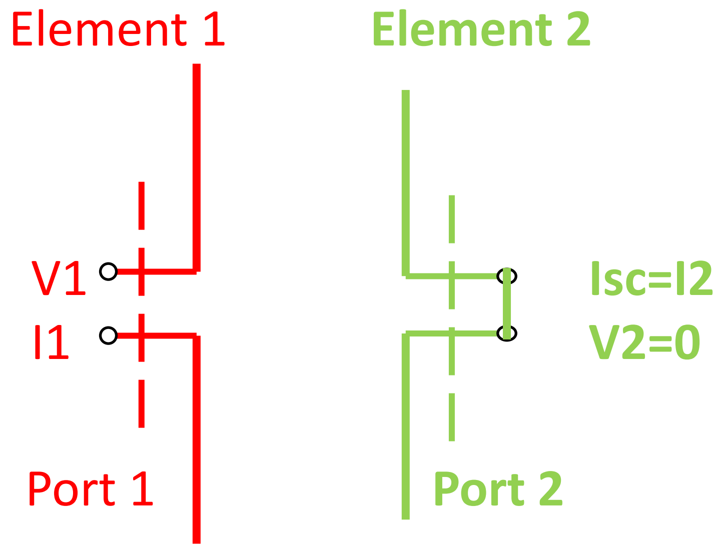
At resonant length, the reactance is not =0.

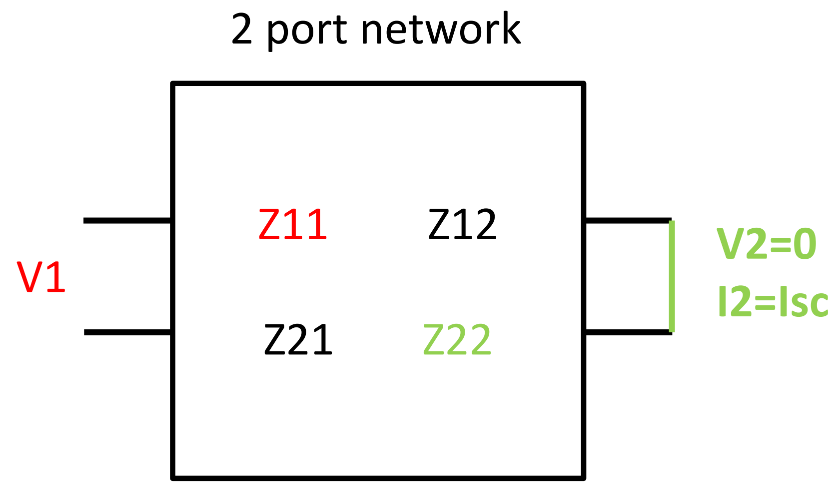
<u>Below resonance, the reactance is capacitive</u>

Above resonance, <u>the reactance is inductive</u>

Note: the DE self impedance is often tuned for slightly capacitive reactance when a Beta match is used.

Mutual Impedance Alters Input Impedance





Mutual impedance = Z12=Z21
Z12=Z21 reciprocity

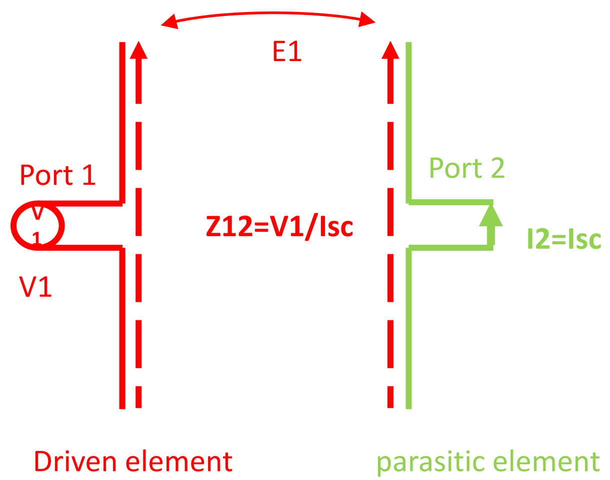
V1=Z11*I1+Z12*I2
V2=Z21*I1+Z22*I2

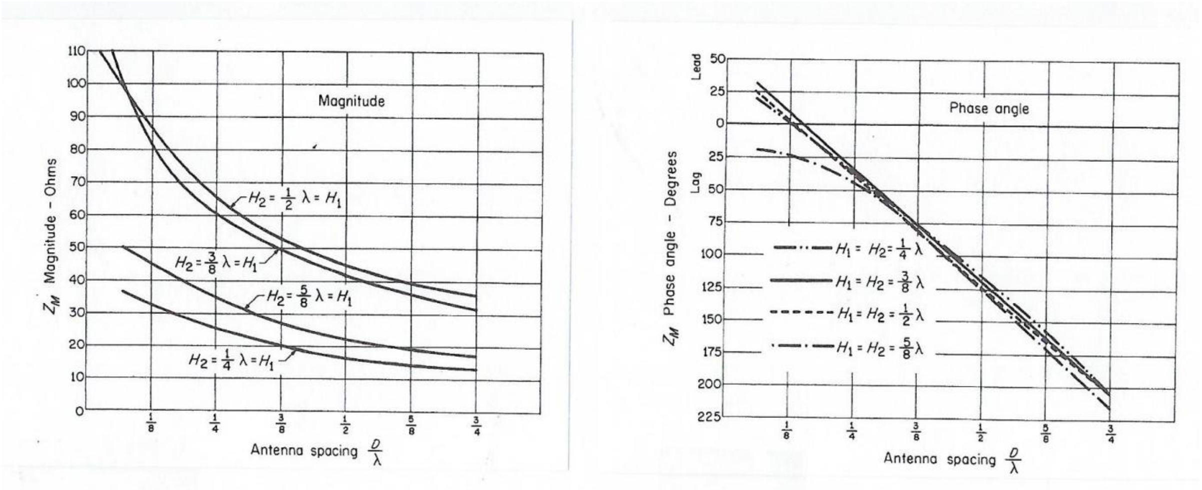
V2=0, I2=-(Z21*I1)/Z22

So V1/I1=Zin= Z11-$(Z12)^2$/Z22

The element 1 E field induces a current I2 in element 2. That element current radiates an E field inducing a port voltage in element 1, altering port 1 input impedance. Examples shown later.

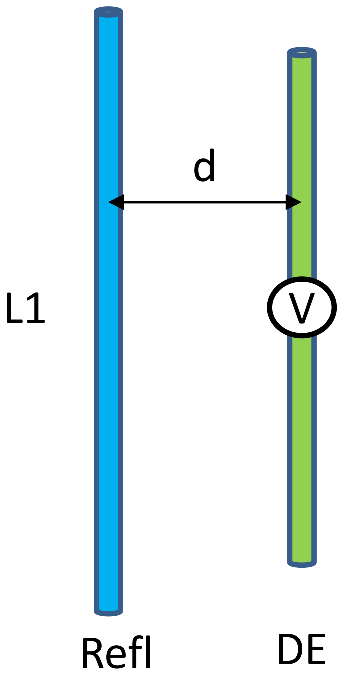
Mutual Impedance vs Element Spacing





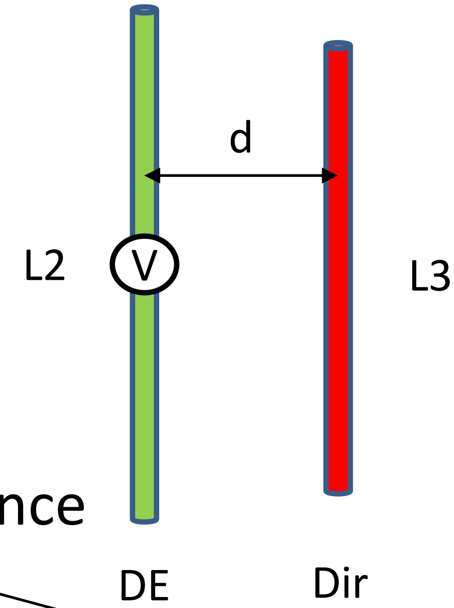
As element spacing increases mutual impedance decreases. Generally 0.2-0.3 λ spacing is used.

Simplest Yagi-Uda Array Impedance Examples



d=0.1 λ

L1=0.54 λ
L2=λ/2
L3=0.46 λ



Mutual impedance

Za = **92.47 + 104.19j** , 75.68 + 11.63j
75.68 + 11.63j , **73.07 + 41.37j**

Zb= **73.07 + 41.37j** , 59.77 + 4.35j
59.77 + 4.35j , **57.65 – 17.01j**

Note: the **reflector self impedance** is inductive while the **director self impedance** is capacitive. The mutual impedance values are needed to calculate the DE driving point impedance.

Matching The Yagi

- From the 20, 15 & 10 meter design examples, Re(Zin) generally is less than 50 Ohms
- Matching Choices
  - Impedance transformer; N:1 balun
  - Gamma match
  - T match and
  - Beta match

The choice is generally between the Gamma and Beta match

2019 Nov. QST Dipole Matching Methods

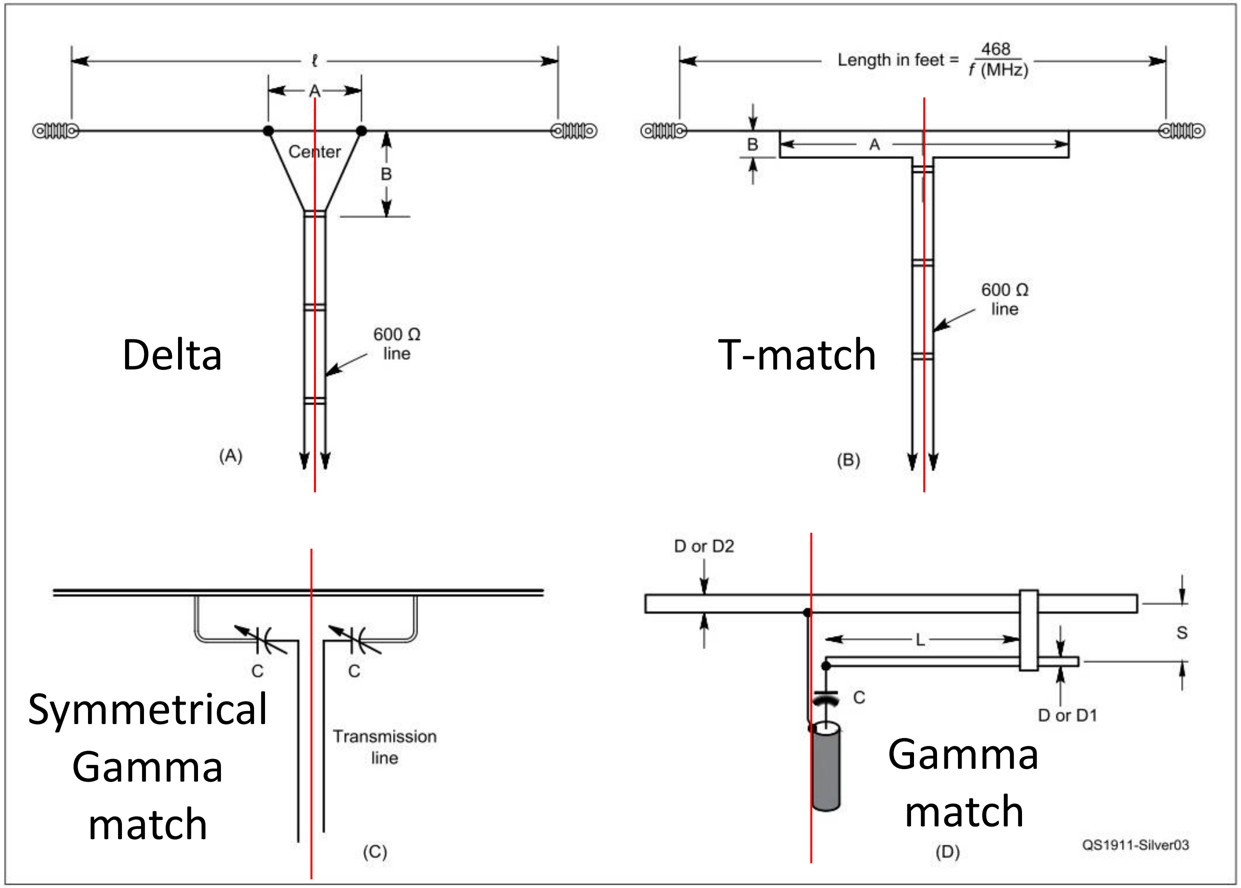


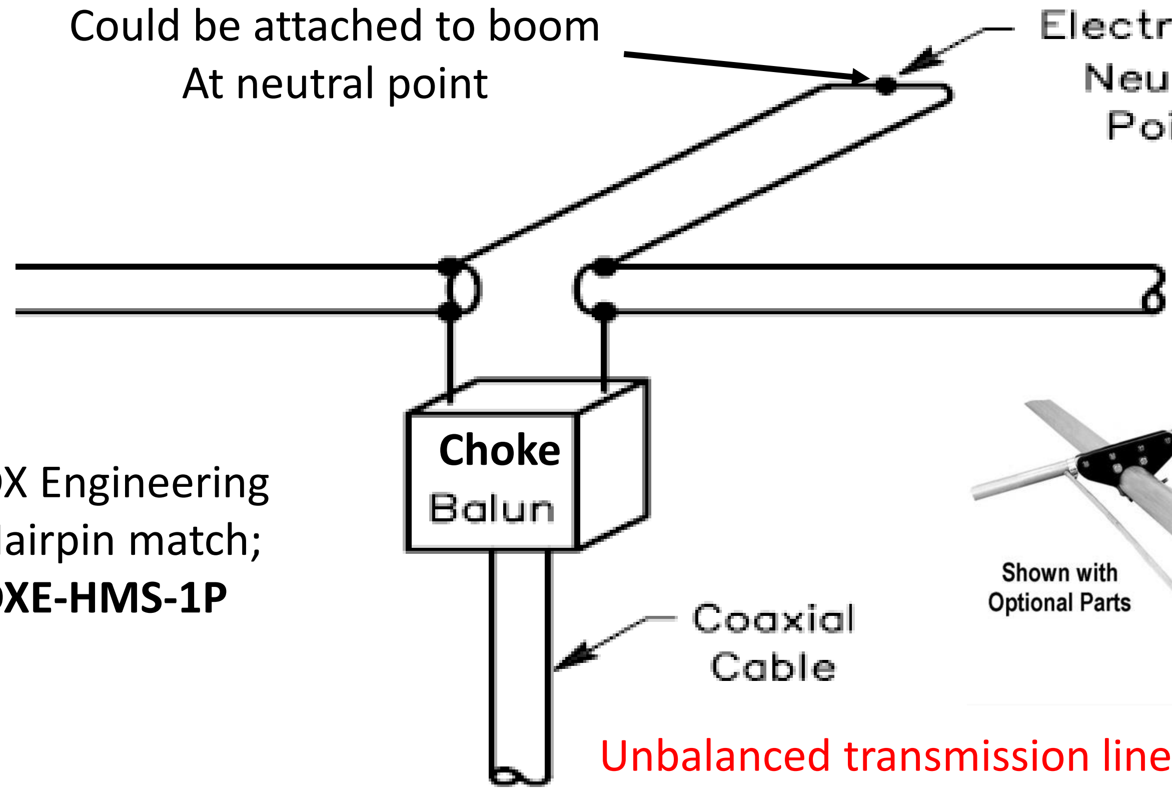
Figure 3 — The delta match (A) and **T** match (B) evolved (C) into the gamma match (D), which is popular for Yagis with a driven element attached directly to the boom. Dimensions A, B, D1, and D2 are adjustable for an approximate match, with C and L adjusted for the final match.

Notice balanced vs unbalanced techniques, preference is gamma match for a coax feed line

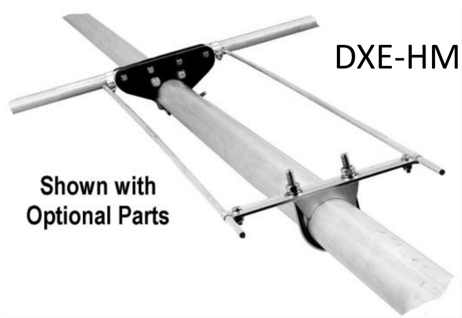
DX Engineering Quote

- “There are various ways to match the driven element to the feed-line successfully; Gamma Match, T-Match, and the Hairpin (aka Beta Match) are favorites. The Gamma match is an outdated, unbalanced system that typically distorts the antenna radiation pattern. The T-match is basically two Gamma Match systems on either side of the boom, which may correct the imbalance, but is a mechanical nightmare and is difficult to tune correctly.”

The Beta or Hairpin Match



DX Engineering
Hairpin match;
DXE-HMS-1P

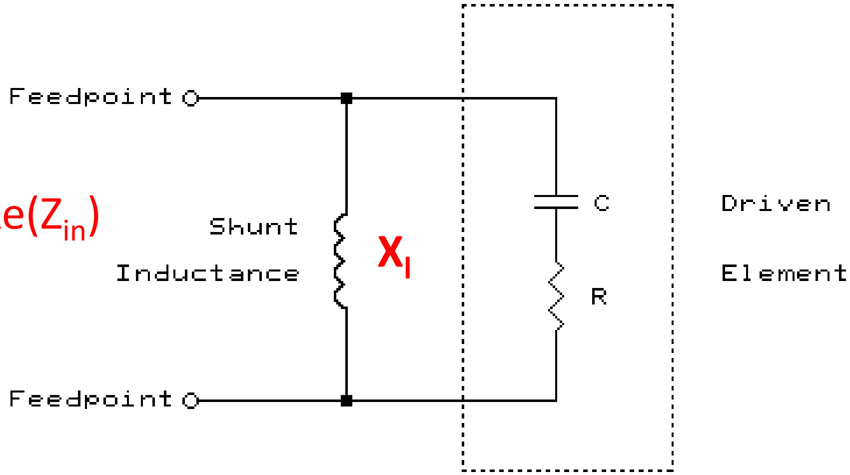


DXE-HMS-1P

Unbalanced transmission line

Used in MARC Yagis suitable for “balanced” driven element, it raises the Zin to minimize SWR to a 50 Ohm transmission line, <u>the driven element is isolated from the boom</u>

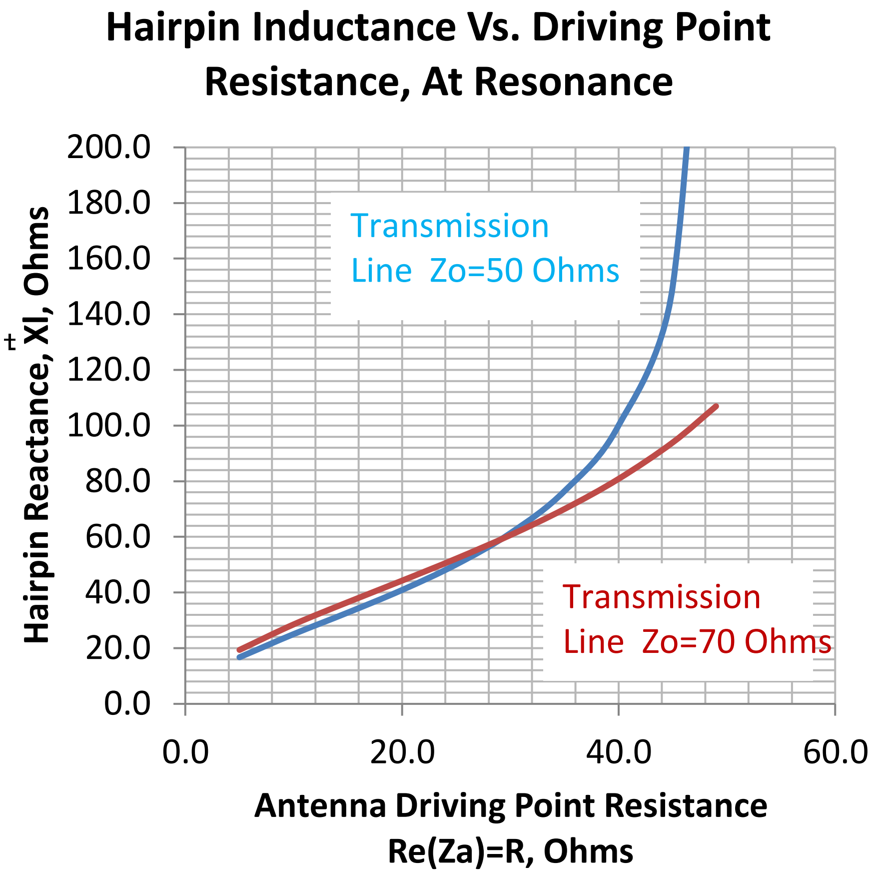
The Hairpin Effect



$R_{in}=Re(Z_{in})$

$$X_l= (R_{in} \times R^{1/2})/(R_{in}-R)^{1/2}$$

Set Rin=Zo



Shunt inductance, X_l, increases

the resistive part of Za=R, to match R_{in}.

Conclusions- Part 2

- The Yagi Array:
  - Can be designed using empirical data; “rules of thumb” or computer-aided design SW
  - Exhibits less than 50 Ohms driving point impedance due to mutual impedance
  - Is compatible with several matching techniques
- The Yagi performance:
  - Increases directive gain with more directors (longer array)
  - Varies with frequency; especially directive gain and F/B ratio
  - Uses hairpin match; a simple and effective technique

Bottom line : It is a winner

References

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