The Yagi-Uda Antenna

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

Part 2

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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
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 dBi 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
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

Yagi Gain, Directors spaced 0.2λ & 0.3λ from DE

Commercial Yagi Gain vs # Elements

- Gain, dBi, Hy-gain
- Gain, dBi, Long John
- Gain, dBi, Cushcraft

Note the approximate gain agreement for 3-5 elements
3 Element 20, 15 & 10 meter Design Examples

These results are from computer-aided design software

Note: Pattern gain, F/B, Zin, change with frequency and Rin < 50 Ohms
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.
Below resonance, the reactance is capacitive
Above resonance, the reactance is inductive

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

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 \( \lambda \) spacing is used.
Simplest Yagi-Uda Array Impedance Examples

\[ \text{Za} = 92.47 + 104.19j, \ 75.68 + 11.63j, \ 75.68 + 11.63j, \ 73.07 + 41.37j \]

\[ \text{Zb} = 73.07 + 41.37j, \ 59.77 + 4.35j, \ 59.77 + 4.35j, \ 57.65 - 17.01j \]

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

Could be attached to boom
At neutral point

DX Engineering
Hairpin match;
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, the driven element is isolated from the boom
Shunt inductance, $X_l$, increases the resistive part of $Z_a=R$, to match $R_{in}$.

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

Set $R_{in}=Zo$
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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