STUDENT PROJECT

PRINTED YAGI-UDA ANTENNAS

Antennas

1. INTRODUCTION

This popular linearly-polarised, medium-gain end-fire array consists of a number of linear dipole elements, one of which is driven directly, while the rest have currents induced by mutual coupling. The wire version is a practical radiator in the HF, VHF and UHF ranges, although printed varieties may be used well into the mm-wave band. The Yagi-Uda array was invented by Uda in Japan in the 1920's and popularised in the English-speaking world by his colleague Yagi.

In free space the driven element is resonant at slightly less than λ/2, typically 0.45 – 0.49λ. The parasitic elements in the direction of the radiation (directors) are slightly shorter than the feed element at around 0.4 – 0.45λ. In the case of the microstrip-fed version of the antenna, the reflector element also acts as the ground plane for the feedline. The element spacing is usually not much more than approximately 0.3λ. For non-printed Yagi arrays the element lengths must be increased to compensate for a supporting boom and decreased to compensate for an increase in element diameter. Printed Yagi-Uda arrays do not have supporting booms and are particularly useful in low power applications as manufacturing on copper clad substrate is quite easy.

This type of antenna can be optimised for a variety of requirements, e.g. gain, impedance or bandwidth. However, there is a trade-off between the performance characteristics, e.g. optimisation for increased bandwidth reduces the obtainable gain. For optimum designs, the director spacing and lengths are not uniform. Such designs were initially accomplished experimentally [Viezbicke] but are now optimised using numerical techniques. The dielectric substrate's effect on all the array elements' length and spacing should be taken into account.

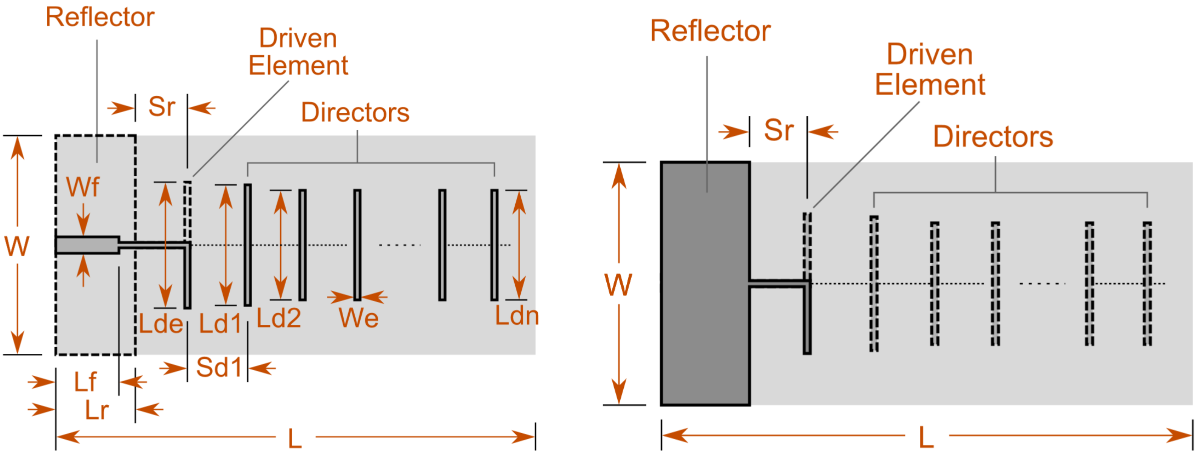

Figure 1. A Yagi-Uda antenna, (left) top view, and (right) bottom view.

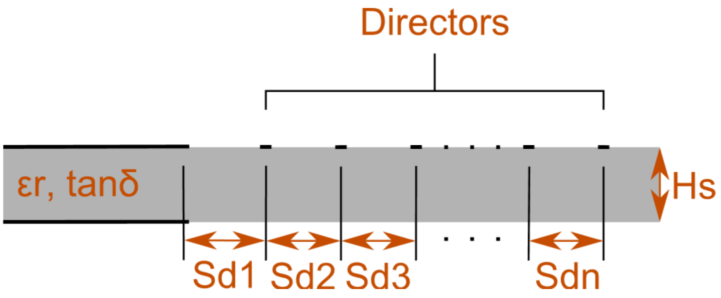

Figure 2. A Vivaldi antenna, side view.

2. DESIGN GUIDELINES

- To increase the gain, increase the number of director elements.
- To increase the operating frequency, reduce the lengths of all the elements by scaling all their dimensions
- To increase the input impedance, tweak the microstrip feed line width.
- To increase the input impedance, increase the reflector spacing.
- Changing the reflector spacing will also affect the back lobe and thus the front-to-back ratio.
- If increased bandwidth or specified input impedance is required, it is necessary to simulate this antenna repeatedly with variations in the element spacing and length, and to optimise for the specific requirement.

3. PROJECT PREPARATION

Given: Target frequency f_0 (e.g. 900 MHz or 2400 MHz).

Fixed parameters: Substrate parameters ε_r, $tan\delta$, H. The substrate should be FR4. Thickness ≈ 0.8 mm.

Output: $|S_{11}|$, input impedance Z_{in}, radiation efficiency/gain, resonance frequency f_r, radiation pattern.

STEP 1 — BASIC UNDERSTANDING AND SPECIFICATIONS

Task:

- Select center frequency f_0 (e.g., 2.4 GHz).

Questions:

- Why does a Yagi antenna exhibit high gain and directivity?
- What roles do the reflector, driven, and director elements play?

STEP 2 — DRIVEN ELEMENT DESIGN

Task:

- Estimate driven element length:
- $L_{de} \approx \lambda g / 2$, $\lambda g = \lambda_0 / \sqrt{\varepsilon_{eff}}$.
- Set width W_e for ~50–70 Ω impedance.

- Adjust feed offset S_r for proper coupling.

Questions:

- If L_{de} is shortened, how will the resonant frequency and $|S_{11}|$ change?
- Why might a folded driven element be used instead of a simple strip?

STEP 3 — REFLECTOR DESIGN

Task:

- Choose $L_r \approx 1.05 \times L_{de}$ (slightly longer).
- Set spacing $S_r \approx 0.1–0.2$ λg.
- Simulate to confirm improved front-to-back ratio.

Questions:

- What happens if S_r is too large?
- How does the reflected wave phase affect gain?

STEP 4 — DIRECTORS DESIGN

Task:

- Each director is slightly shorter than the driven element:
- $L_{d1} \approx 0.95 L_{de}$, $L_{d2} \approx 0.9 L_{de}$, etc.
- Typical spacing: $S_{d1}–S_{dn} \approx 0.15–0.3$ λg.
- Use 3–7 directors depending on desired gain.

Questions:

- How does increasing the number of directors affect beamwidth?
- What happens if director spacing is too small?

STEP 5 — FEED LINE AND COUPLING

Task:

- Design 50 Ω microstrip feed (L_f, W_f).
- Ensure a continuous ground plane below the feed.

Questions:

- Why must the feed region be isolated from the reflector?
- How can coupling be optimized without overexcitation?

STEP 6 — DIRECTIVITY AND GAIN ANALYSIS

Task:

- Simulate $|S_{11}|$ over the frequency band.
- Plot radiation patterns at three different samples.
- Extract gain and front-to-back ratio.

Questions:

- How does director length affect beam direction?
- Why does gain saturate beyond a certain number of directors?

STEP 7 — OPTIMIZATION

Task:

- Sweep L_{d1}, S_{d1}, and S_r to improve gain and matching.
- Use optimization tools for best $|S_{11}| < -10$ dB.
- Verify symmetrical radiation pattern and minimal side lobes.

Questions:

- Which parameters have the most effect on matching?
- How does a printed Yagi differ from a 3D wire Yagi?

4. FINAL EVALUATION

Acceptance criteria:

$|S_{11}| < -10$ dB across the band, efficiency > 60 %, gain ≥ 8 dBi, dimensions within design limits.

Final geometry table: (L_f, W_f, L_r, S_r, L_{de}, L_{d1}, L_{d2}, ..., S_{d1}, S_{d2}, ..., W, H_s). Plots: $|S_{11}|$, gain, and radiation patterns at multiple frequencies. Written answers to all step questions.

5. REFERENCES

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