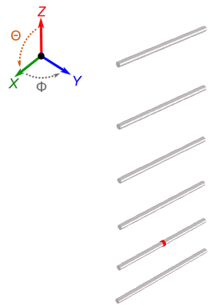
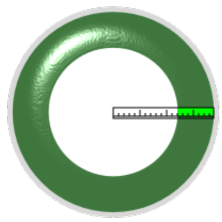
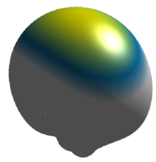
Yagi-Uda dipole array





Large (> λ/2)



Unidirectional

Quick Summary

Quantity	Typical	Minimum	Maximum
Polarisation	Linear	-	-
Radiation pattern	Broad uniaxial lobe	-	-
Gain	15 dBi	8 dBi	21 dBi
Performance bandwidth	10 %	5 %	67% (2:1)
Complexity	Medium	-	-
Impedance	25 Ω	5 Ω	50 Ω
Balun	Half or Quarter-wave balun	-	-
Beamwidth	30 °	17 °	60 °

Background

This popular linearly-polarised, medium-gain end-fire array consists of a number of linear dipole elements, one of which is driven directly, with the rest having currents induced by mutual coupling. It is a practical radiator in the HF, VHF and UHF ranges. The antenna was invented by Uda in Japan in the 1920’s and popularised in the English-speaking world by his colleague Yagi.

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. The reflector element is slightly longer than the feed element. The element spacing is not usually much more than around 0.3λ. Element lengths must be increased to compensate for a supporting boom and decreased to compensate for an increase in element diameter.

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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. Yagi-Uda arrays usually have low input impedance and narrow bandwidth but these characteristics can be improved at the expense of others such as gain and sidelobe levels. A folded dipole feed element is often used to step-up the input impedance. For optimum designs, the director spacing and lengths are not uniform. Such designs were initially accomplished experimentally [Viezbicke, P. P.] but are now optimised using numerical techniques. The antenna designed here by Magus is optimised for high gain rather than input impedance.

Physical Description

The antenna is usually constructed out of cylindrical aluminium tubes and is supported by a central boom, with which the reflector and directors may make electrical contact.

Feed Method

The dipole feed element is fed at the centre point between the two arms. Since the antenna is a balanced structure, a balun must be used if it is fed using a coaxial or other unbalanced transmission line. In some cases the dipole is replaced with a folded dipole, and the balun used to transform the impedance down to a value close to 50 Ω.

Operation Mechanism

The non-driven elements have currents induced on them by mutual coupling. Correctly spaced elements have similar currents with a progressive phase shift, making the array essentially a structure supporting a travelling wave. The first element acts as a reflector and the elements beyond the driven element as directors. Radiation is in the end-fire direction.

Performance

Because this antenna is typically optimised for different certain performance characteristics, it is difficult to describe typical performance. Reasonably high gain can be obtained but the impedance and bandwidth is relatively poor. Fairly wide performance bandwidth of up to 2:1 can be obtained, but this is at the expense of gain [Collins, B. S.].

Impedance Characteristics

The input impedance characteristic is extremely variable and a function of the element lengths and spacings.

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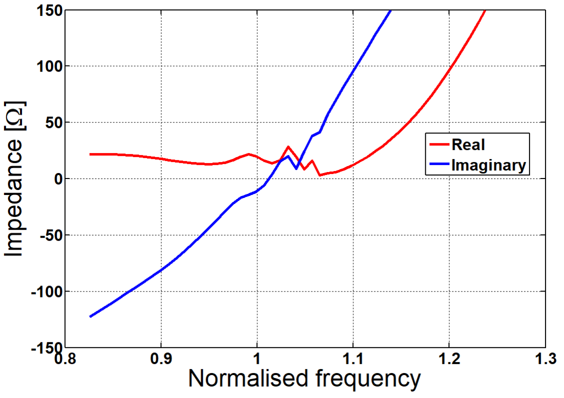
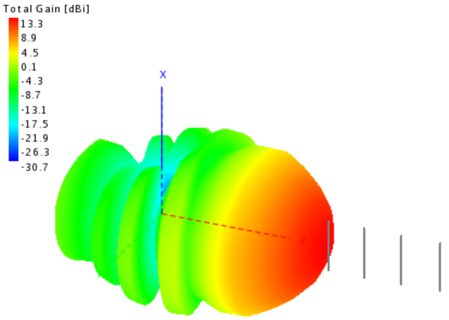


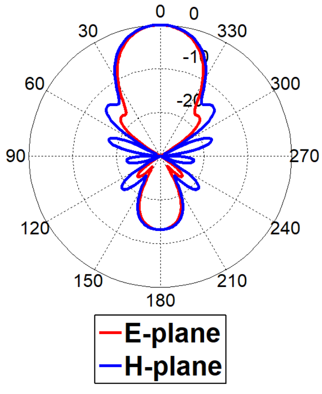
Typical input impedance

Radiation Characteristics

The radiation pattern shown below is for an 11-element array. At higher frequencies the main beam radiation direction rapidly changes from endfire to backfire due to phasing effects.



Typical total gain pattern at the centre frequency, f_0



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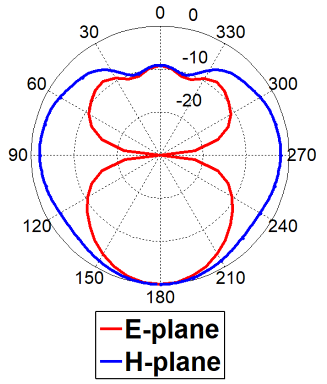
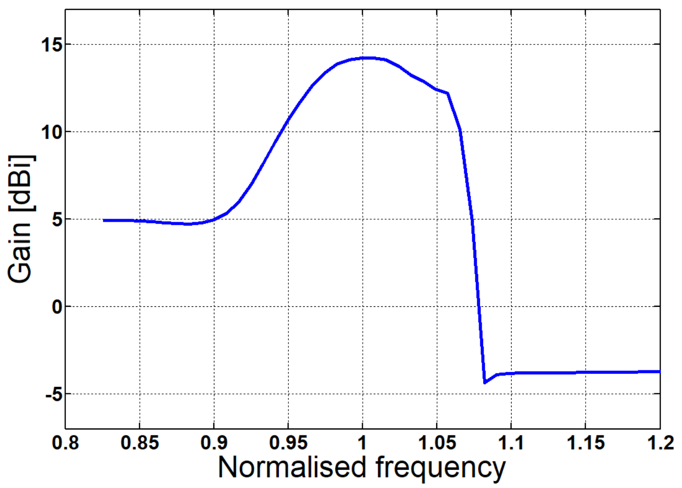
Typical co-polarised radiation pattern at the centre frequency



Co-polarised radiation pattern (normalised) at $1.1f_0$



Typical end-fire gain versus frequency

References

The ARRL Handbook, 1995 Edition, R. Schetgen (Ed.), The American Radio League, Newington, CT, USA, 1994, pp. 20.63-20.74.

H. E. Green, “Uniform Yagi-Uda arrays,” in H. Schrank, “Antenna designer’s notebook”, IEEE Antennas and Propagation Society Newsletter, June 1985, pp. 11-13.

P. P. Viezbicke, “Yagi antenna design,” NBS Technical Note 688, National Bureau of Standards, Boulder, Colorado, 1976.

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C. A. Balanis, Antenna Theory: Analysis and Design, 2_{nd} ed., Wiley, 1997, pp.513 -532

B. S. Collins, Ch. 29 in Antenna Engineering Handbook 4_{th} Ed., J. L. Volakis (Ed.), McGraw-Hill, 2007, pp. 29.17-29.19.

Model Information (FEKO)

Model 1

A thin-wire model of the antenna fed using a wire port.

This PEC model uses a thin-wire approximation. It is useful for antenna optimisation because of its speed, and for modelling where the wire diameter is electrically small, typically less than around 0.01λ.

Model 2

A cylinder model of the antenna fed using an edge port.

This PEC model models the wires as cylinder and is useful when the wire diameter is electrically large or when improved accuracy is required. However, it will have a longer runtime than a model using a thin-wire representation. This model is typically used for wire diameters greater than around 0.01λ.

Model Information (CST Studio Suite)

Model 1

Thin wire model of the antenna fed using a discrete port and solved with the I-solver.

This model uses a thin wire approximation to represent the antenna. The driven element is fed using a discrete and the model is run using the integral equation solver.

Model Validation

The models have been validated against measurements in the literature.

Each export model has been validated to give the expected results for several parameter variations in the design space.

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Magus Analysis

The internal performance estimation is expected to be similar to a full 3D-EM analysis. A thin-wire approximation is used. Expect:

- Small frequency offsets (-3% to +3%)
- Possibly inaccurate reflection coefficients below -15 dB

Design Guidelines

To increase the gain, increase the number of director elements.

To increase the operating frequency, reduce the lengths of all the elements.

If increased bandwidth or a 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.

To increase the input impedance, consider replacing the driven element with folded dipole.

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