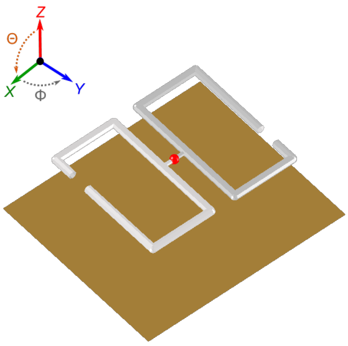
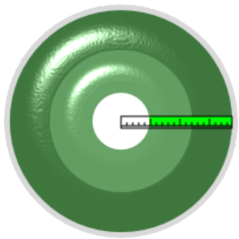
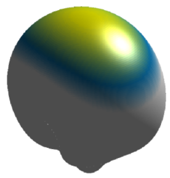
Rectangular Bi-loop





Medium - Large (> λ/6)



Unidirectional

Quick Summary

Quantity	Typical	Minimum	Maximum
Polarisation	Circular	-	-
Radiation pattern	Single broadside lobe	-	-
Gain	9 dBi	8 dBi	10 dBi
Performance bandwidth	18%	15%	20%
Complexity	Medium	-	-
Impedance	50Ω	20Ω	150Ω
Balun	Optional Quarter-wave balun	-	-

Background

Basic loop antennas consist of a metallic conductor bent into the shape of a closed curve. Loop antennas take many forms, including rectangular, circular, triangular and quadrilateral [Balanis, Tsukiji]. By introducing a gap in the loop, circular polarisation may be obtained [Morishita]. The circularly polarised rectangular Bi-Quad [Sumi] consists of a short dipole segment that is end-loaded by gapped rectangular loops above a ground-plane reflector. This relatively simple geometry provides good design flexibility and good circularly polarised performance over a moderate bandwidth. In practical terms it may be seen as the circularly polarised equivalent of the standard Bi-Quad, offering similar physical size, gain and performance bandwidth characteristics. An important difference is in the detail of the feed; while the standard Bi-Quad consists of two essentially independent loops fed in parallel, this antenna is fed like a dipole.

Physical Description

The circularly polarised rectangular bi-loop consists of a short dipole-like feed segment with both ends loaded by mirrored rectangular wire loops above a ground plane. The loops have gaps in the arms furthest from the feed, offset from the centre-line defined by the dipole segment. The loops are similar in that the one loop is the mirror image of the other loop (in the plane normal to the dipole segment), rotated by 180 degrees around the axis of the dipole segment.

The antenna element is constructed using rigid wires or metal tubes. The antenna element may be directly supported by a section of semi-rigid coaxial cable. Extra support may be provided by non-conductive spacers (e.g. Nylon screws) at the outer vertices of the loops.

Feed Method

Since the bi-loop is a balanced antenna, a balun should be used if it is fed using a coaxial or other unbalanced transmission line type. However, this antenna only suffers a moderate pattern squint when fed using coaxial feed, and may be used without a balun. From a feed perspective this antenna is like a standard dipole backed by a ground-plane reflector, hence similar feeding techniques may be used. A suitable printed balun is described in [Li].

Operation Mechanism

A standard loop antenna with a total circumference of about 1 wavelength produces linearly polarised radiation in both directions normal to the plane of the loop. Introducing a gap into the loop at the right location results in a travelling-wave current distribution that produces circularly-polarised radiation [Morishita]. The ground plane acts as a reflector, resulting in a unidirectional pattern and about 3 dB more gain. Ideally the ground plane should be a quarter of a wavelength away from the element to ensure that the axial ratio remains good, but mutual interaction with the ground-plane image antenna may require slight adjustment.

While the original circularly polarised loops proposed in [Morishita] had good circular polarisation bandwidths, their input impedances tended to have a large capacitive component resulting in poor S11 performance. The small dipole feeding-segment presented in [Sumi] allows the capacitive component to be tuned out.

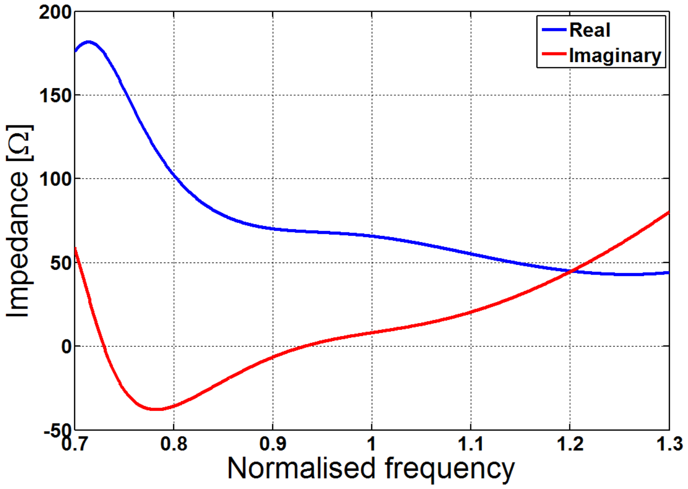
Performance

Circularly polarised bi-loop antennas have a circularly polarised gain of around 10 dBi and a moderate operating bandwidth. The radiation performance bandwidth is primarily limited by axial ratio. When properly designed the impedance and radiation performance bandwidths are similar.

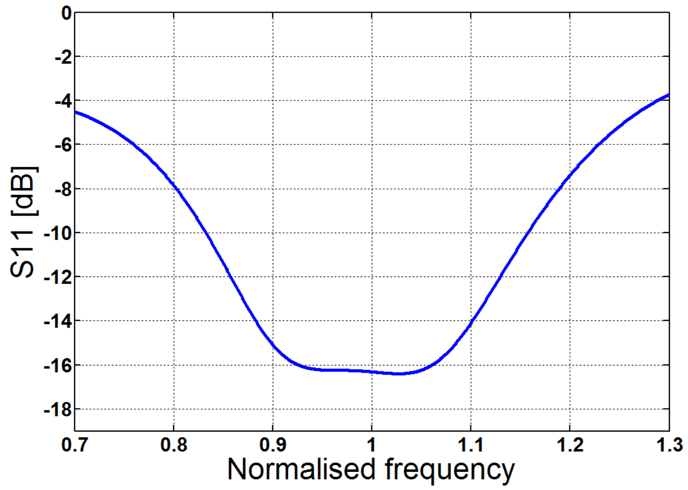
The plots below show the performance of a Magus 50 Ω design with a wire diameter of 2.5% of the centre frequency wavelength. Frequency is normalised by frequency_centre, the design centre frequency. The finite ground-plane results use a ground-plane size of 1.5 times the antenna size.

Impedance Characteristics

The impedance performance bandwidth is generally in the region of 15-30%, with thicker wires generally resulting in higher bandwidths. Impedance behaviour is sensitive to variations in feed spacing, feed wire diameter, element wire diameter and gap size. The gap position and the ratio of loop width to length also have secondary effects on input impedance. While it is quite simple to design for a given impedance level by varying the feed spacing and gap size, there is no straight forward method of ensuring that the impedance matching and circular polarisation occur at the same frequency.



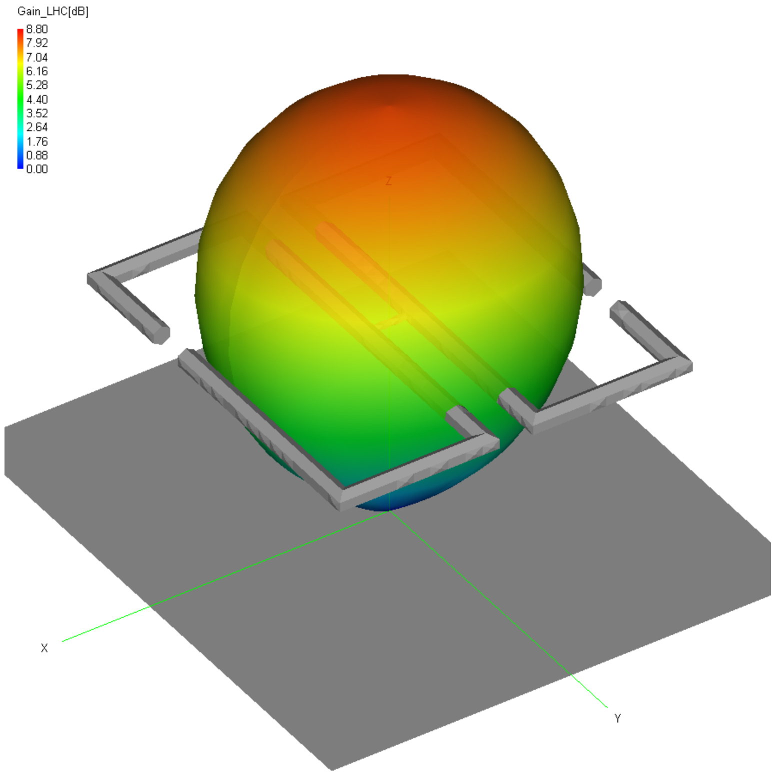
Typical input impedance versus frequency (normalised)



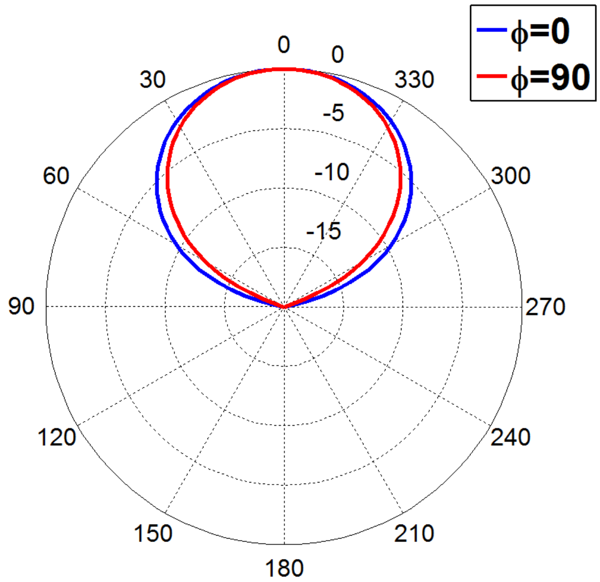
Typical reflection coefficient versus frequency (mormalised)

Radiation Characteristics

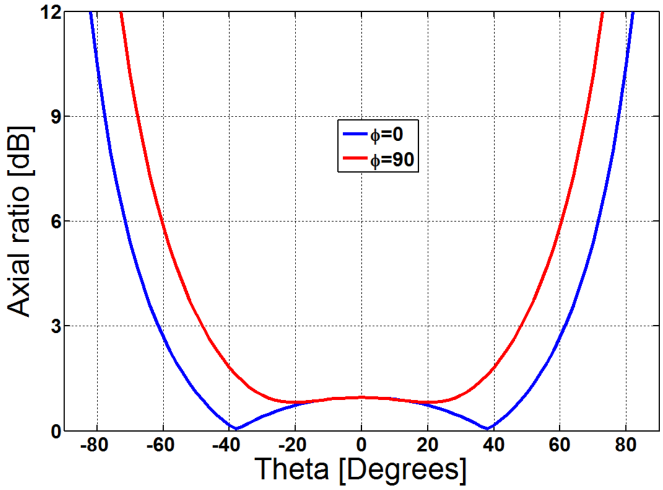
The circularly polarised bi-loop radiates a single, broadside, circularly-polarized lobe with a gain of around 10 dB. With an infinite reflector there are no side- or back-lobes. A finite reflector of practical size introduces moderate back-lobes, while the use of an unbalanced feed results in some pattern squint. An axial ratio of better than 3 dB is typically maintained over a 15-20% frequency bandwidth. When the ratio of loop width to loop length is close to 2 (usually thinner wire designs), the beam-width in both planes are quite close; in the case shown here the ratio is about 2.5, hence the Y-Z plane beam width is narrower than the X-Z plane beam width. The 3D gain is shown using a finite ground plane, which results in a slightly lower peak gain; enlarging the ground plane would cause the gain to approach the gain of an infinite ground-plane.



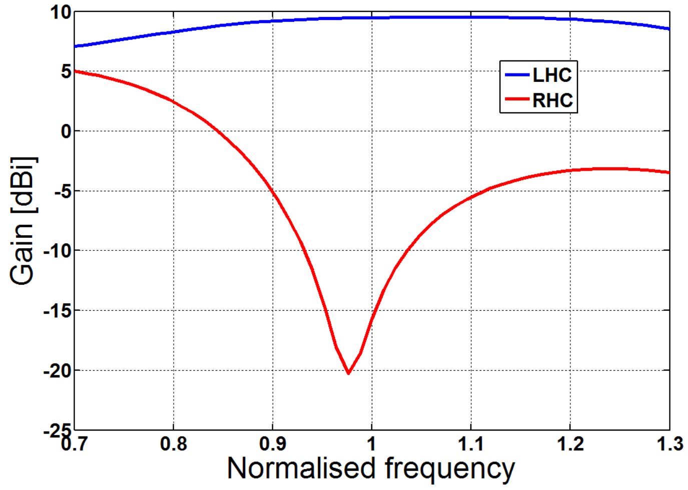
Left-hand circularly polarised 3D gain at the centre frequency.



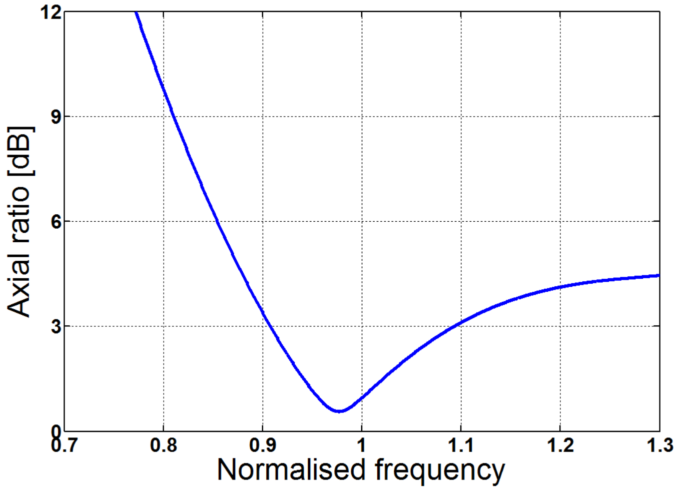
Typical normalised circularly polarised gain pattern in dB with an infinite ground-plane at centre frequency



Typical axial ratio pattern in dB with an infinite ground-plane at centre frequency



Typical left-handed (LHC) right-handed (RHC) circularly polarised gain at θ=0, φ=0 versus frequency (normalised)



Typical axial ratio (Major/Minor) at θ=0, φ=0 versus frequency (normalised)

References

C.A. Balanis, "Antenna Theory Analysis and Design", Second Edition, John Wiley and Sons, Inc. 1997, Sections 5.2 to 5.5.

T. Tsukiji and S. Tou, "On polygonal loop antennas", IEEE Transactions on Antennas and Propagation 28, no. 4 (1980): 571-575.

H. Morishita and K. Hirasawa, "Wideband circularly-polarized loop antenna", Proceedings of the IEEE AP-S International Symposium, 1994, pp. 1286–1289.

H. Morishita, K. Hirasawa, and T. Nagao, "Circularly polarised wire antenna with a dual rhombic loop", Microwaves, Antennas and Propagation, IEE Proceedings- , vol.145, no.3, pp.219-224, Jun 1998

M. Sumi, K. Hirasawa, S. Shi, "Two rectangular loops fed in series for broadband circular polarization and impedance matching", IEEE Transactions on Antennas and Propagation, vol. 52, issue 2, pp. 551-554

R. Li, G. DeJean, J. Laskar, and M.M. Tentzeris, "Investigation of circularly polarized loop antennas with a parasitic element for bandwidth enhancement," IEEE Transactions on Antennas and Propagation, vol. 53, 2005, pp. 3930-3939.

Model Information (FEKO)

Model 1

PEC cylinder model of the antenna with an ideal feed, using an infinite-plane reflector approximation

This model is optimised for speed by using an infinite PEC plane to model the reflector and an ideal feed. The wires are modelled as cylinders, hence finite thickness effects are taken into account, but analysis can take long when thin wires are used. The effect of the reflector's finite size is not taken into account.

Model 2

PEC cylinder model of the antenna with an ideal feed and a finite-sized reflector

This model uses an ideal feed and a finite-sized reflector. The wires are modelled as cylinders, hence finite thickness effects are taken into account, but analysis can take long when thin wires are used. The reflector size can be adjusted parametrically in the model.

Model 3

PEC cylinder model of the antenna with physical coaxial feed and line using an infinite-plane reflector approximation

This model has a realistic coaxial feed and is optimised for speed by using an infinite PEC plane to model the reflector. The wires are modelled as cylinders, hence finite thickness effects are taken into account, but analysis can take long when thin wires are used. Finite size effects of the reflector is not taken into account. The coaxial feed is constructed as a length of 50 Ω coaxial cable, and is excited where the coaxial structure contacts the reflector. For designs that are not 50 Ω, the parameters of the coaxial cable should be changed to match the design impedance.

Model 4

PEC cylinder model of the antenna with physical coaxial feed and line and a finite-sized reflector

This model has a realistic coaxial feed and a finite-sized reflector. The wires are modelled as cylinders, hence finite thickness effects are taken into account, but analysis can take long when thin wires are used. The reflector size can be adjusted parametrically in the model. The coaxial feed is constructed as a length of 50 Ω coaxial cable, and is excited where the coaxial structure contacts the reflector. For designs that are not 50 Ω, the parameters of the coaxial cable should be changed to match the design impedance.

Model 5

Thin-wire model of the antenna with an ideal feed, using an infinite-plane reflector approximation.

This model is optimised for speed by using a thin-wire approximation for the antenna element, an infinite PEC plane to model the reflector and an ideal feed. This model is accurate for wire diameters of up to about 1% of a wavelength . For larger wire thicknesses it should still predict general trends correctly. The effect of the reflector's finite size is not taken into account.

Model Information (CST MICROWAVE STUDIO)

Model 1

PEC cylinder model of the antenna with physical coaxial feed and line and a finite-sized reflector

This model has a realistic coaxial feed and a finite-sized reflector. The wires are modelled as cylinders, hence finite thickness effects are taken into account, but analysis can take long when thin wires are used. The reflector size can be adjusted parametrically in the model. The coaxial feed is constructed as a length of 50Ω coaxial cable, and is excited where the coaxial structure contacts the reflector. For designs that are not 50Ω, the parameters of the coaxial cable should be changed to match the design impedance. By default the excitation is de-embedded up to the antenna element; if impedances at the physical connector is required the de-embedding should be disabled.

Model 2

PEC cylinder model of the antenna with an ideal feed and a finite-sized reflector

This model has an ideal feed and a finite-sized reflector. The wires are modelled as cylinders, hence finite thickness effects are taken into account, but analysis can take long when thin wires are used. The reflector size can be adjusted parametrically in the model.

Model Validation

Export model impedance and pattern calculations were validated against calculations and measurements in [Sumi].

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

Magus Analysis

The internal performance estimation is expected to be similar to a full 3D-EM analysis. Expect:

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

- When estimating the performance of a design or tweak where the wire diameter is around 1% of the wavelength at the design frequency, small unexpected discontinuities may occur in parametric trends.
- The effect of a finite ground plane is not taken into account.

Design Guidelines

The Magus designs aim to provide good performance bandwidth rather than the best possible axial ratio and impedance match at the centre frequency. They were optimised to ensure than both impedance and radiation performance is good over the same frequency range.

- To increase (decrease) operational frequency, decrease (increase) the loop circumference. Other parameters will have to be adjusted to ensure circular polarisation purity and impedance match.
- To increase input impedance, increase the feed spacing, feed gap or absolute value of the gap inset.
- Increasing (decreasing) the wire diameter or the feed wire wire diameter decreases (increases) input impedance.
- To change polarisation handedness, mirror the positions of the loop gaps (Note that the "gap offset factor" parameter can be multiplied by -1 to achieve this in export models or in the Export mode before exporting antenna models).
- Increasing the absolute value of the gap offset tends to improve impedance bandwidth.
- increasing the ratio of loop width to loop length tends to improve axial ratio bandwidth at the expense of impedance bandwidth
- Slight adjustments of element height can be used to restore circular polarisation if other parameter changes are made. Adjustments of the element height can also be used to obtain a wider axial ratio bandwidth at the expense of a slightly worse best-case axial ratio.

When thicker element wire diameters are used, the diameter of the feed wire segment has a strong effect on the input impedance level.

While the guidelines above are useful, designs are typically obtained by numerically optimising for both S11 and axial ratio.

For suggestions on how to handle non-standard coaxial cables in the designs, please see the Frequently asked questions article in the Antenna Magus Info Browser.