Are genetically designed Yagis worthwhile? Richard Formato investigates.

Genes and Yagis

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The genetic algorithm is a powerful new antenna design and optimisation tool that is receiving progressively more attention. A natural question is "How good are genetic-algorithm-designed antennas?"

This note looks at that question by comparing four 12-element Yagis designed using genetic-algorithms. It does not examine how genetic algorithms work because there are many good references. Several are listed later.[1-6]

Here I emphasise Yagi performance, and how it changes in response to changing the parameters.

Genetic algorithm in action

The genetic algorithm searches a 'decision space' which is defined by specifying minimum and maximum values for each antenna parameter. Only antennas falling within these limits are allowable solutions to the optimisation problem. This is a characteristic of genetic algorithms that gives the antenna designer exceptional flexibility.

Each element in a Yagi-Uda array has three design parameters: length, spacing, and radius. The minimum/maximum range of each parameter can be set on an element-by-element basis, but the usual approach is to restrict all elements in the same way – with occasional exceptions as discussed below.

For the arrays described here, the element lengths were restricted as follows. All dimensions are in wavelengths, or 'waves'.

reflector	0.35-0.65 wave
driven element	0.35-0.60 wave
directors	0.3-0.6 wave

Element spacing was 0.05-0.5 wave, thus limiting the longest boom to 5.5 wavelengths. For designs 1-3, the element radius was constant at 0.003369 wave, while design design 4 allowed driven-element radii from 0.001 to 0.0075 wave.

The standard Yagi configuration is used. Here, element 1 is the reflector, and element number 2 is the driven element.

Figure of merit

The 'goodness' a particular Yagi design is determined by a figure-of-merit which is specified by the designer. For the arrays in this note, the figure-of-merit was:

$$FoM = \frac{aG - b|Z_o - R_{in}| - c|X_{in}|}{a + b + c}$$

Variable G is the forward gain – zero

Table 1. Performance analysis of the four Yagi designs.

Ant #	L	G	HPBW	Z_{in}	SWR	F-to-B	F-to-R	MaxSLL
1	2.53	13.56	35.5	47.9+j0.9	1.05	10.5	10.5	–17.4
2	3.44	15.28	31.0	19.8+j0.4	2.53	20.5	20.5	–16.2
3	3.45	15.86	27.6	5.3+j179	131	13.6	13.6	–16.3
4	3.29	14.53	32.0	48.8-j0.1	1.02	17.7	17.7	–16.4

degrees azimuth – in dBi, while Z_0 is the feed system characteristic impedance, in this case 50Ω resistive. Variable R_{in} and X_{in} are the Yagi's input resistance and reactance, respectively.

This figure-of-merit is used in reference 1, which is why it is used here. A genetic algorithm allows the antenna designer to choose any figure-of-merit that reflects the desired balance between various antenna performance parameters. For example, front-to-back or front-to-rear ratio, or maximum sidelobe level could also be included if the designer wished to optimise against these parameters.

Weighting coefficients a, b and c determine the relative importance of each antenna performance parameter. For all designs below, the coefficient a is 40. For designs 1 and 2, b=c=1, which are the values suggested in reference 1.

In design 3, the Yagi input impedance was removed from the figure-of-merit by setting b and c equal to zero. In design number 4, the input impedance was weighted somewhat more heavily by increasing the coefficients to b=2 and c=3.

Optimised Yagis

Optimisation was done by a piece of software called *Yagi Genetic Optimiser*[7] which computes antenna performance using the *Numerical Electromagnetics Code*, Version 2, double-precision, or NEC-2D.[8]

Seven segments were used for each array element in the NEC-2D model. Performance of the genetically designed arrays shown in **Table 1**. Important parameters include the boom length (wavelengths), forward gain (dBi), half-power (–3dB) beam width (degrees), input impedance (ohms), standing-wave ratio relative to 50Ω, front-to-back and front-to-rear ratios (dB//*G*), and maximum sidelobe level (dB//*G*).

Designs 2, 3 and 4 are the optimised Yagis, corresponding to the three sets of coefficients b and c, (1,1), (0,0) and (2,3), respectively. Design number 1 is a suboptimal design that appeared in the optimisation run for design number 2. It is included to illustrate another important genetic algorithm characteristic: a genetic algorithm does not produce a single 'best' design, but instead produces a *group* of designs, with each design in the group ranked from best to worst.

This feature can be very useful, because even suboptimal designs may be attractive. Design number 1, for example, may fill a real need because of its short boom length and excellent

Performance plots of the four genetically designed Yagi antennas.

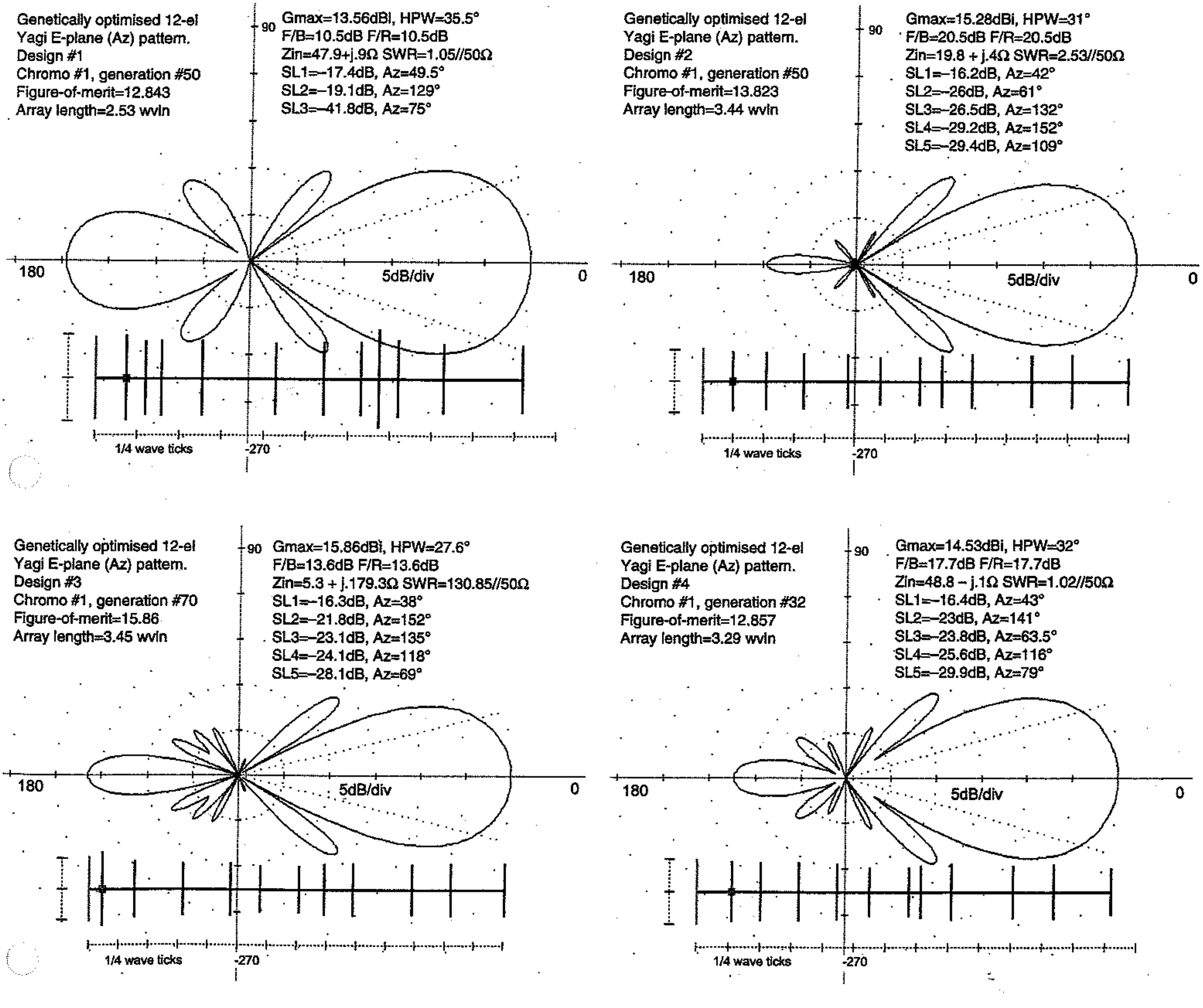

Table 2. Dimensions and spacings for the four Yagi designs.

	Design #1		Design #2		Design #3		Design #4	
Element	**L**	**S**	**L**	**S**	**L**	**S**	**L**	**S**
1(REF)	0.4794	0.0000	0.5006	0.0000	0.5006	0.0000	0.5006	0.0000
2(DE)	0.4853	0.1824	0.4549	0.2388	0.5784	0.1082	0.4588	0.2741
3	0.4165	0.1135	0.4388	0.2671	0.4400	0.2671	0.4365	0.2247
4	0.4329	0.0924	0.4318	0.3006	0.4188	0.4047	0.4341	0.3006
5	0.4341	0.2388	0.4141	0.3641	0.4188	0.3871	0.4259	0.3076
6	0.4047	0.4329	0.3624	0.2582	0.3624	0.2476	0.3647	0.2582
7	0.4224	0.2847	0.3718	0.3218	0.3718	0.3218	0.3718	0.3218
8	0.4176	0.2194	0.4012	0.1806	0.4012	0.2088	0.4012	0.0959
9	0.5671	0.1065	0.4200	0.2424	0.4200	0.2424	0.4212	0.2424
10	0.4388	0.1171	0.4035	0.4876	0.4035	0.4876	0.4035	0.4876
11	0.3906	0.2706	0.4176	0.3218	0.4176	0.3218	0.4176	0.3218
12	0.3847	0.4735	0.3471	0.4559	0.4224	0.4559	0.3482	0.4559

input impedance, even though its gain and FB/FR are worse than that of longer Yagis.

Antennas optimised using the genetic algorithm do indeed reflect different weighting in the figure-of-merit. In design number 2, for example, b and c were chosen to emphasise gain while still controlling the input impedance. The resulting antenna has a gain of 15.28dBi – a very respectable number – and it is nearly resonant with an input resistance of 19.8Ω. This moderate resistance level is easily matched, so that this antenna provides very good gain and impedance performance.

Gain above the theoretical maximum?

By contrast, design number 3 was optimised purely for gain, and nothing else. Its G of 15.86dBi is exceptionally good. In fact, this Yagi's gain appears to be slightly above the maximum theoretical gain for a 3.45-wavelength long boom as shown in the ARRL's Antenna Book.[9]

But, because the gain was maximised without any consideration of the input impedance, the Z_{in} figure for this design is a very poor match to 50Ω. Of course, it is possible to match this antenna, but it is almost certainly not worth the effort in view of designs 2 and 4.

Finally, the figure of merit coefficients for Yagi number 4 – chosen after the results of the two previous optimisation runs were analysed – were selected to improve further the balance between G and Z_{in}. In addition, the driven-element radius in design number 4 was allowed to vary, instead of being fixed at 0.003369 wave.

The reason for this change is that the self-impedance of a centre-fed dipole passes through a maximum as its diameter increases. This effect can be used to advantage to provide a better match to 50Ω because Yagis tend to be low-impedance antennas. The genetic algorithm confirmed this by increasing the driven-element radius to 0.005767 wave.

Best performer

Yagi number 4 exhibits very good performance. Its gain of 14.53dBi is only about 1.2dB less than the maximum theoretical gain for the boom length.[9] And, quite significantly, this array provides a near perfect 50Ω match.

Feeding this antenna with 50Ω coaxial cable requires only a balun. Completely eliminating any kind of matching network probably makes up for a good part of the 1.2dB gain reduction. The result is a Yagi that is simpler, less expensive, easier to adjust, probably has greater bandwidth, is less likely to fail than designs with matching networks, and requires little if any maintenance.

W1JR[10] makes a compelling case that Yagis should be designed to match 50Ω directly, and there are many amateur and professional antenna designers who share that view. Designs like Yagi number 4 show that achieving this objective with good overall performance is certainly possible. It is arguably the preferred approach.

The NEC-2D computed E-plane (azimuth) radiation patterns and a scale representation of the array geometry appear in the plots. It is interesting that element lengths and spacings in the genetically optimised antennas are neither uniform nor tapered as they are in deterministically optimised arrays.

Counter intuitive

Genetic-algorithm-optimised Yagis look 'different', which is another very interesting aspect of genetic algorithm antenna design. Genetically-designed antennas are often counter-intuitive and do not resemble what you would expect. This characteristic makes them intriguing, because the designer cannot predict what the next 'best' antenna might look like.

Dimensions – element length, L, and spacing, S, both in wavelengths – are shown in **Table 2**. All elements are 0.003369 wave radius, except element 2, the driven element, in design number 4, which has a radius of 0.005767 wave.

In summary

This note describes four genetically designed Yagis that illustrate how effective a genetic algorithm can be in designing complex antennas. Amateurs interested in antennas are likely to hear more about genetic algorithms, and may wish to learn more about them.

The genetic algorithm is a state-of-the-art design tool that is truly revolutionary in nature. Its potential in antenna design is just beginning to be explored, and may lead to some very interesting and unusual antennas. ■

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7. YGO™ (Yagi Genetic Optimiser™) freeware is available from Phadean Engineering Co., Inc., PO Box 611, Shrewsbury, MA 01545-8611 USA, tel. (508) 869-6077, fax (508) 869-2890, email: phadean@ma.ultranet.com.
8. NEC-2D is available from the Applied Computational Electromagnetics Society (ACES), Attn: Dr Richard Adler, ACES Executive Officer, ECE Department, Code ECAB, Naval Postgraduate School, 833 Dyer Road, Room 437, Monterey, CA 93943-5121 USA. NEC-2 download files are also available on the web at: http://www.qsl.net/wb6tpu/swindex.html.
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