In Practice

Care and feeding of VHF/UHF long Yagis

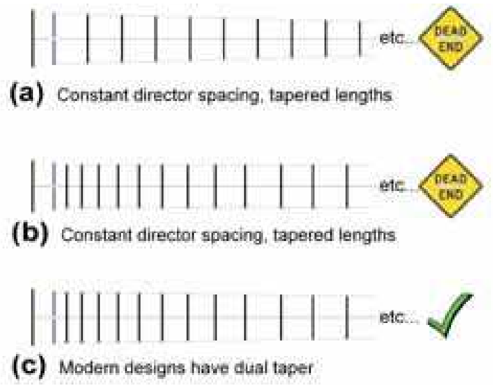

FIGURE 1: Director tapering schemes (exaggerated in drawings).

Q: What is the optimum feedpoint impedance for a VHF/UHF long Yagi?

A: As usual, it depends what you really mean by 'optimum'! If you can think clearly about that part of the puzzle, the factual part will fall into place.

I have covered the various aspects of VHF/UHF long Yagi performance in September 2004 and November 2009 **[1]**. There have been huge developments in the 40+ years that I have been involved with the subject, but much of the amateur folklore about Yagi design is still stuck in the past. From a more modern perspective, and very briefly, the aspects we need to consider are:

- Forward gain – the most wanted, but not absolutely the most important. Many Yagi designs have gone astray because the designer single-mindedly tried to maximise the forward gain, particularly in the early days when the only 'optimisation tools' were the hacksaw and drill. Today's designers forgo the last few tenths of a decibel of forward gain, to let other desirable performance parameters come through.
- Gain bandwidth – typically specified as the frequency range across which the forward gain remains within 1dB of its maximum value.
- Radiation pattern – considered in detail in the two columns referenced above.
- Pattern bandwidth – how consistent the radiation pattern remains as the frequency is varied.
- Ease of computer modelling and whether a design can be converted into real-life hardware with a minimum of uncertainty.
- Ease of feeding from 50Ω coax, although that doesn't always mean a direct 50Ω connection.
- VSWR bandwidth – typically the frequency range within which the VSWR remains below 1.5. This article is about the last two points: feed methods and VSWR bandwidth.

BANDWIDTHS. Most VHF/UHF long Yagis are much more broadband than you might imagine, at least in terms of gain bandwidth. Unfortunately this is very difficult to measure because the VSWR changes at the same time. Accurate gain measurements are already difficult enough; re-matching at every frequency in a swept gain measurement would be a nightmare. Therefore gain bandwidth is usually determined by computer modelling which completely removes the impedance matching issue.

We then discover that the gain bandwidth of well-optimised long Yagis can be much greater than people used to believe… because many of our long-established beliefs turn out to be based on very old Yagi designs that were actually rather poor. Some of the earliest long Yagis had either a fixed spacing between directors with gradually reducing director lengths (**Figure 1a**) or fixed director lengths and progressively increasing spacing (**Figure 1b**). Both of these 'tapering' **[2]** schemes are now seen as evolutionary dead-ends because they fail to produce the expected increase in gain with boom length. They also tend to have a highly asymmetric gain bandwidth curve like **Figure 2**, which increases gradually from the low frequency side but 'falls off a cliff' on the high side. Tuning the antenna for maximum gain at your favourite frequency (blue line) has a very undesirable side-effect because raindrops, frost and ice will lower the resonant frequencies of all the elements and thus shift the whole gain curve to the left (red line). That in turn causes a marked reduction in gain along with drastic changes in the radiation pattern. In other words, Yagis tuned for maximum gain have a high risk of being unusable in bad weather. It is far better to sacrifice a small amount of forward gain by positioning the entire gain curve further to the right, on the 'safer' side of the curve (Figure 2, green line).

The breakthrough in gain bandwidth came from Günter Hoch, DL6WU, who first proposed the idea of simultaneously tapering the director lengths and spacings (**Figure 1c**). This produced an immediate increase in gain bandwidth. The DL6WU designs were also dimensioned to be well on the 'safer' side of their gain curve, making them very tolerant of rain, ice and other disturbances. All modern designs taper both director lengths and spacings; there are countless different approaches to this, but all the good ones give quite similar results. With the help of computer optimisation, gain bandwidths of several percent are now regarded as normal and readily achievable without undue sacrifice of forward gain. The asymmetric gain curve of Figure 2 is still slightly apparent, but it tends to affect the details of the radiation pattern more than the forward gain itself.

That brings us finally to VSWR bandwidth. This is often the bottleneck in practical wideband Yagi design because there are several different ways of feeding and matching a Yagi, and some have notably better bandwidth than others.

If a Yagi is designed without any thought about its feedpoint impedance, it will almost certainly come out lower than 50Ω, often in the region of 20 – 30Ω. Direct 50Ω feed is achievable – lots of Yagis do it – but this higher feedpoint impedance requires some deliberate action on the part of the designer; it isn't likely to happen on its own.

When we adjust the Yagi for minimum VSWR at some chosen frequency (either on the computer or in real life) we normally adjust the length of the driven element. If the feedpoint impedance is (R ±jX), the reactance X is the part that varies most rapidly with frequency or element length, and when we minimise the VSWR we are mostly adjusting X to zero. This leaves us with a value of R that varies much more slowly with frequency or element length, and must now be matched to 50Ω. We then have two ways forward. Do we let the feedpoint impedance go where it will, adding a separate matching device to transform the R value to 50Ω; or do we redesign the whole Yagi structure to create a 50Ω impedance at the feedpoint? Either way can be made to work very well indeed.

MATCH A LOW IMPEDANCE. Exploring the matching route first, if the R part of the feedpoint impedance is in the region of 20 – 30Ω, we can home in on some specific values that offer easy methods of matching to 50Ω. One of these is 28Ω, which can be matched using a quarter-wave section of 37.5Ω line, easily made by paralleling two pieces of good quality 75Ω coax (**Figure 3a**). Martin Schreyer, DK7ZB, was one of the first to exploit this '28Ω feed' in a systematic way, and his website contains some excellent designs with plenty of practical information [1]. I have also found feedpoint impedances conveniently close to 28Ω when designing shorter Yagis for 50MHz. Another nearby target is 25Ω which can be matched using alternating short sections of 50Ω and 25Ω coax, the latter being made by paralleling two lengths of 50Ω cable (**Figure 3b**). At HF, the continuously adjustable SteppIR Yagis aim for 22Ω because that can be conveniently matched to 50Ω by a 3:2 broadband transformer (**Figure 3c**). Each designer follows his own path, but he has done much the same things for the same reasons: after optimising for a particular blend of gain and radiation pattern, the 20–30Ω region of

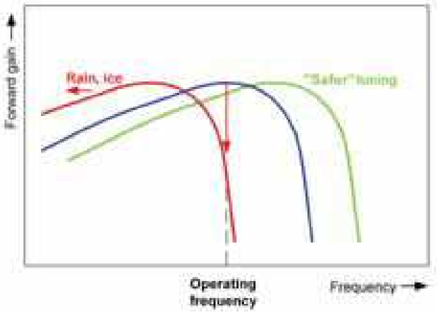

FIGURE 2: Maximising forward gain (blue line) makes the Yagi vulnerable to detuning by rain, snow and ice (red line).

feedpoint impedance is where the Yagi happened to have arrived. It then needed only a minor readjustment to reach exactly 28Ω, 25Ω or 22Ω without upsetting the optimised design.

Justin Johnson, G0KSC, has recently investigated the long Yagi designs that led to a much lower feedpoint impedance [1]. An obvious design target is 12.5Ω because this can be matched to 50Ω using two paralleled quarter-wavelengths of 50Ω coax (**Figure 3d**) or with a folded dipole. These very low feedpoint impedances used to be associated with high element currents, high I^2R losses and narrow bandwidths but G0KSC's computer analysis shows that these fears were much exaggerated. With modern optimisation techniques, Yagis with very low feedpoint impedances can be designed with very similar gain, radiation patterns and gain bandwidths to those of Yagis with higher feedpoint impedances.

But whenever a very low feedpoint impedance needs to be matched to 50Ω, that still leaves the problem of VSWR bandwidth. Some matching systems are inherently more narrow-band than others so we need to choose very carefully. Broadband matching transformers based on magnetic cores are used at lower frequencies, but are not really suitable for VHF or above. Probably the best choice for VHF and UHF is the coaxial line transformer of Figure 3d, which has a reasonably broad bandwidth and is very easy to build. I don't like T and gamma matches because the amateur cut-and-try approach can easily lead to an unnecessarily high operating Q and a reduction in the VSWR bandwidth.

DESIGN FOR DIRECT 50Ω FEED. We now turn to methods of achieving a direct 50Ω feedpoint impedance within the structure of the Yagi itself. Many features of Yagi design have been discovered and rediscovered several times over and in my view the credit shouldn't always go to the people who discovered these things first – the true credit belongs to the people who were first to understand what they had found, then made some systematic use of it.

The most common method of raising the feedpoint impedance to 50Ω is to add a closely spaced first director (**Figure 4a**). I believe that DL6WU was the first to have understood exactly

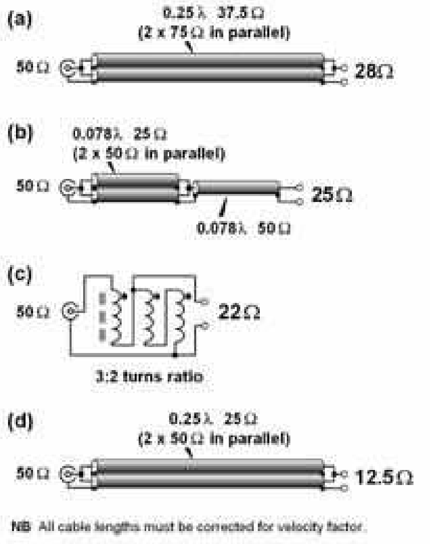

FIGURE 3: Four values of low impedance that can easily be matched to 50Ω.

what this would do: he used a first director spacing of 0.05λ, which makes the director and driven element carry almost equal and opposite currents. This increases the feedpoint impedance in a very similar fashion to a folded dipole (we will return to that comparison shortly). The resistance and the reactance at the feedpoint will then be affected by the length and spacing of that closely coupled director, as well as by the dimensions of the driven element.

The same idea was then discovered independently by Jim Breakall, WA3FET, in a design concept that he called the 'Optimized Wideband Array' or OWA [1]. Although the DL6WU Yagis had been developed by practical experiments, while the OWA family were developed a generation later with the help of computer analysis and optimisation, it isn't at all surprising that both techniques led to similar features such as the closely spaced first director (**Figure 4b**). The OWA concept has given rise to several excellent designs for the HF and lower VHF bands, including some multiband designs that combine two or more monoband Yagis on the same boom, sharing a common 50Ω feedpoint (for example, G0KSC has published 2- and 3-band designs covering 28, 50 and 70MHz). Follow this month's web links for more details. However, the OWA concept can also be used for much longer monoband Yagis; both G0KSC and the late L B Cebik, W4RNL, have developed a series of monoband OWA long Yagis aiming to achieve even greater gain bandwidths and pattern bandwidths that the DL6WU concept.

Another method of achieving a direct 50Ω feedpoint is G0KSC's 'Loop Fed Array' or LFA (**Figure 4c**) [1]. The width between the two legs of the driven loop is similar to the spacing of the first parasitic director in OWA and DL6WU Yagis, and has a similar effect of raising the impedance at the feedpoint. This method of feeding should not be confused with a folded

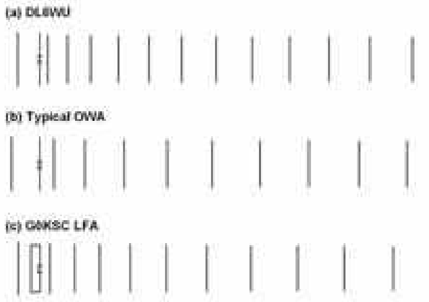

FIGURE 4: Three different ways to achieve a direct 50Ω feedpoint. As well as the obvious differences in element spacings, each design requires small but important differences in element lengths.

dipole; the width of the loop is significantly greater. Like the closely spaced parasitic director, the loop feed requires some space along the boom, and that in turn requires a significant reorganisation of all the other element lengths and spacings. However, the different method of excitation creates its own characteristic effects on the performance of the Yagi and by careful optimisation G0KSC has created a new range of direct feed Yagis that have excellent gain, pattern and bandwidths.

CONCLUSIONS. We have reached the stage where all competently designed and computer-optimised long Yagis for VHF/UHF are pretty darn good. Raw forward gain isn't really a deciding factor any more, because all good designs deliver the amount of gain that we should expect from their overall boom length, within a few tenths of a dB. The differences are now in more subtle areas such as minor lobe suppression and the ways that the forward gain, pattern and VSWR vary with frequency. These are all tradeoffs, depending on the combination of properties desired.

Turning to the specific point about feedpoint impedance, if you follow up the references [1] you will see that it isn't a major factor in the overall performance of these Yagis. Although many designs come out in the 20–30Ω region, Yagis with equally good overall performance can be designed for direct 50Ω feed and also for feedpoint impedances as low as 12.5Ω.

STAND BY FOR THE FINAL. When I stepped out onto the tightrope as a freelance technical writer, one of my business goals was to retire at age 60-65 like any normal person. Somewhat to my surprise, that time has now arrived, so the next In Practice will be my final one, with a look back at more than 200 monthly columns.

NOTES AND REFERENCES
[1] Please follow this month's links from the 'In Practice' website: http://tinyurl.com/inpractice
[2] In VHF/UHF Yagis, progressive changes in director lengths and/or spacing are often called 'tapering'. Not to be confused with a tapered or stepped reduction in the element diameter, which is often necessary at HF for mechanical reasons.