Microstrip made easy

Nick Wheeler explains that although there are complex procedures for designing high performance microstripline circuits, a few shortcuts result in a technique that is quick and easy to implement yet more than adequate for most applications.

Micro stripline consists of conductive traces of defined width on low-loss dielectric superimposed on a conducting ground plane. It can be created by etching one side of ordinary double-sided printed circuit board material.

Stripline on the other hand consists of flat, thin conductors sandwiched between two ground planes and usually embedded in dielectric. It has many useful properties such as inherently good screening, but it is difficult to use and is not further discussed here.

For micro-stripline, glass-reinforced epoxy is the preferred dielectric. The cheaper phenolic type is too lossy, and PTFE or ceramic substrates are both much more costly – PTFE boards cost in the region of £100 a square foot – and are difficult to work with. On the other hand, PTFE boards are usable far into the microwave region. In this article I refer only to G-10 and FR-4 substrates. Apart from being fire-resistant, FR-4 is very similar to G-10.

This article is directed towards those of you wanting to make high-performance equipment with relatively limited resources. I have interpreted this as meaning that trace widths are defined to an accuracy of no better than 0.01in. This means, roughly, that characteristic impedance Z_0 of a typical trace will be accurate to one or at worst a few percent.

A down-to-earth attitude is adopted in the ARRL Handbook.[1] What I have done below is to explain how their results can be replicated, while referring to more rigorous treatments of the subject to reassure readers that readily available techniques are virtually indistinguishable from the very best that can be done.

Microstripline principles

Most microstripline calculations refer to traces of width W on an infinite layer of dielectric whose dielectric constant is ε_r and of thickness h backed by an infinite ground plane, **Fig. 1**.

In practice – and more so with increasing frequency – the electric field is concentrated in the volume of dielectric lying directly under the trace. However, some of the field is in air, leading to the concept of ε_{eff}, the effective dielectric constant, which is lower than that of the dielectric.

The greater the width of the trace the more ε_{eff} tends towards ε_r. If the ground plane and dielectric are truncated, as in **Fig. 2**, there is little effect upon Z_0 if $T>2W$. If only the dielectric is truncated[2], as in **Fig. 3**, Z_0 is raised by less than 0.5% when T/W is greater than 0.5.

Because W/h is dimensionless, if the dielectric thickness is halved, the same Z_0 is achieved with half the trace width. There are many published formulae for accurately calculating Z_0. These take into account the thickness t of the trace and even whether the etching process has resulted in a trace of

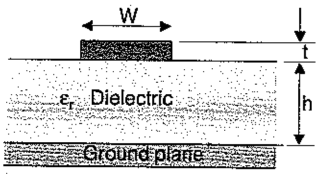

Fig. 1. Most microstrip calculations refer to traces of width W on an infinite layer of dielectric with constant ε_r, and of thickness h backed by an infinite backplane.

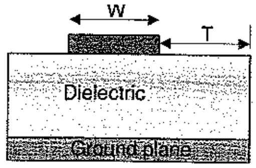

Fig. 2. In this microstripline example, both ground plane and dielectric are truncated.

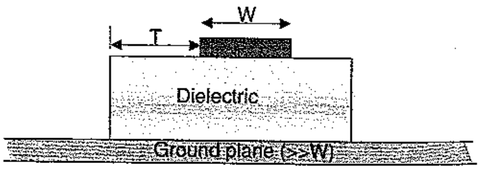

Fig. 3. If only the dielectric is truncated, Z_0 is raised by less than 0.5% for when T/W is more than 0.5.

trapezoidal rather than rectangular cross section.

For traces produced by etching ordinary 1oz circuit board material, with a thickness *t* of 0.0014in, and for typically useful values of Z_0, these considerations are very much second-order effects. The effect of varying *t* from 0.0014in to 0.0056in on ordinary G-10 board of 0.0625in thickness is to reduce the trace width for Z_0=50Ω from 0.11984in to 0.11691in. Incidentally, the trace width for 50Ω on this board is commonly specified as 0.1in but 0.12in is clearly a better approximation. This can be achieved by carrying out the following.

Evaluating complex formulae is tedious and there are many published tables relating *W*/*h*, ε_r and Z_0. The graph of **Fig. 4**, derived from several sources, gives trace widths for a useful range of Z_0 using commonly available double-sided glass-epoxy pcb material It should be accurate enough for most purposes. This is particularly so since G-10 and FR-4 are supplied by various manufacturers with ε_r varying over a range from 4.22 to 4.9. The most commonly quoted range though is 4.3-4.5.

Applying microstripline

There are in print several well-documented project descriptions.[1] These give a good overview of what can be done using this technique. Quarter wavelength, or $\lambda/4$, transformers for frequencies around 1GHz are particularly easily implemented, but bear in mind that the electrical length of microstripline is the reciprocal of $\sqrt{\varepsilon_{eff}}$ multiplied by the physical length. The term λ_g is commonly used to describe the on-board wavelength.

Perhaps one of the most useful applications is in conjunction with monolithic microwave ICs, or mmics, as these are 50Ω devices in most cases. On the other hand, many other devices can be matched.

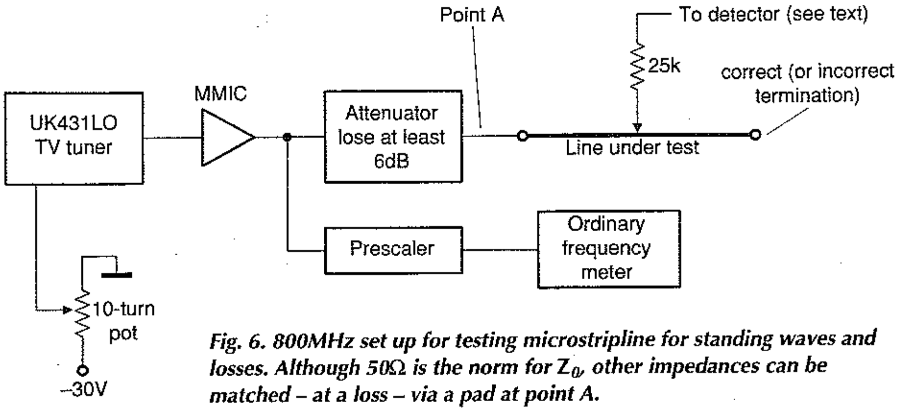

Fig. 6. 800MHz set up for testing microstripline for standing waves and losses. Although 50Ω is the norm for Z_0, other impedances can be matched – at a loss – via a pad at point A.

It is important to bear in mind that the cross-section of the trace of a typical microstripline is very small. If it is operated at significant power levels in a mismatched condition, destructive current antinodes may lead to failure.

Some general-purpose microstripline applications are dealt with below.

Applying microstrip

As reference 1 suggests, microstripline can be implemented by attaching, with superglue, 0.1in strips, or other widths, of thin copper foil to the plain side of single-sided pcb material. This works quite well, but I will now describe a reproducible photo-etch approach.

I use Windows 95 with one of the many available graphic design programs, in my case *Serif Draw Plus*, an *HP Deskjet 693C*, and the appropriate Premium Transparency Film. This combination I can vouch for, but there are doubtless other suitable films and many other software packages and printers that will work too. Do not attempt to use films designed to take spirit-based felt pens or films made for overhead projector transparency work.

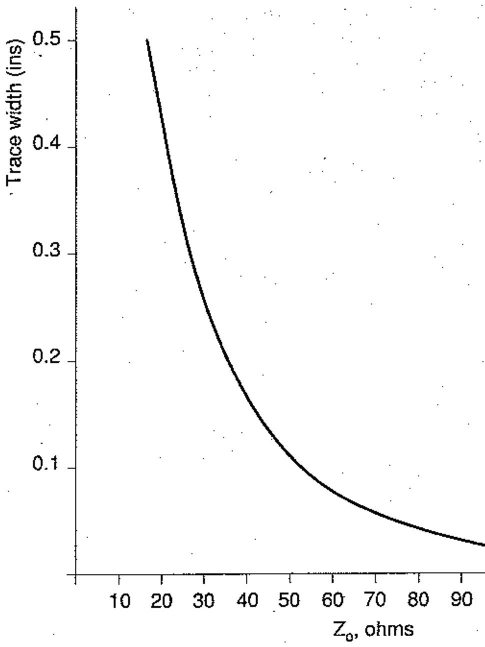

Fig. 4. Derived from several sources, this graph gives trace widths for a useful range of Z_0, assuming common glass-epoxy pcb.

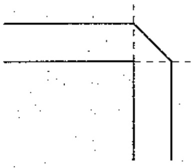

Fig. 5. Not an ideal microstripline bend shape, but it does the job for most applications.

The transparencies produced are fine as masters for conventional photo-etching. It is important to remember that printer ink takes a long time to dry on transparency film. I recommend leaving for at least half an hour. I will not describe this well-known technique, except to point out that the transparency should be flipped so that the pattern ends up in face down, in direct contact with the pcb material before exposure.

Serif Draw Plus V2.0 has the option of selecting a grid based on 0.1in, with a spatial increment of 0.01in. You will suffer serious problems if you try to create circuit boards on a metric grid of any coarser resolution than this. I've tried it.

Graphic programs define line widths in 'points.' As far as *Serif Draw* is concerned, 7 points closely approximate to 0.1in*. This makes 8 points a good line width for 50Ω on 0.0625 G-10 board.

Most transmission-line configurations can readily be implemented in microstripline. References 1-3 give many examples. The attraction here is that any Z_0, within a range generally quoted as being from 16Ω to 125Ω can be achieved without resorting to tedious methods such as replacing the inner conductor of co-axial cable with wire of a different diameter.

A few practical points. Parallel traces, separated by a distance of *W* or less couple and can be used to effect directional couplers. Undesired coupling can be virtually eliminated by making the spacing >2*W*. The design parameters for couplers are highly interactive, and the empirical approach – i.e. suck it and see – may be the least difficult.

Bends can be radiused or mitred. Bends through any angle with a radius, to the centre line of the trace, >4W do not have a significant effect on standing-wave ratio. Mitred bends, which occupy less board space, are theoretically complicated. However, using the approach of **Fig. 5** seems to yield generally satisfactory results.

The advantage of using the computer-graph-

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*A point is 1/72 of an inch – Ed.

approach is that your artwork is stored and can easily be altered before committing to transparency. Good results – within the limitations of the transfer sheets available – can be obtained much more directly by the use of etch-resistant pcb transfers. Note that not all transfers are etch-resistant, though they can save a lot of time in producing artwork for photo-etching.

Making measurements

In many cases, the success of a microstripline circuit design can be estimated by driving it from a source of the right impedance, terminating it correctly and looking for standing waves or excessive losses.

I made a line 210mm long on G-10 board. One source quotes ε_{eff} for a 50Ω line as about 3.4, when ε_r is 4.4. Using a test frequency of 800MHz, this accommodates just over a wavelength. An ε_r of 4.5 is favoured in reference 1.

Figure 6 shows a test setup. The signal source is a *UK431LO* television tuner, which has a local-oscillator output ranging from 431 to 900MHz. Many other tuners have local-oscillator outputs. This signal is buffered by a suitable mmic. Almost any of those currently available will suffice.

Frequency is measured using the gigahertz prescaler of reference 4. The detector probe is connected to the 75Ω input of the low-cost spectrum analyser described in reference 5.

A 25kΩ series resistor at the probe tip ensures negligible loading effects when applied to the line under test. Measurements are made by the null method of varying the attenuator to produce the same outputs at the points being tested.

As the spectrum analyser uses a television tuner there is obviously plenty of scope for the use of other tuners. Although I have not tried it, the raw intermediate frequency from any tuner could be amplified and inspected on a modest oscilloscope.

In the case of my test line, probing it when properly terminated with 50Ω disclosed no perceptible standing wave pattern. Operating with no termination produced deep voltage nodes separated by 100mm – almost exactly – on the board. These are, of course, $\lambda_g/2$ apart.

Working backwards through the relationships outlined above, you can deduce that in this case the apparent ε_{eff} is 3.5. This degree of agreement lies well within the limits which might be expected.

An error of 1% in the measurement of the distance between the nodes could account for more than half the difference. Because of the element of empiricism inherent in all microstripline calculations this seems to be a very good first attempt, and easily good enough for almost all applications.

In summary

I have shown that microstripline is a versatile technique, easily implemented to useful accuracy for many uhf applications. I recommend a computer-graphic approach for the generation of the artwork, since this gives quite precise control over trace widths.

The rigorous treatments of references 2 and 3 are available to those of you wanting to use more precise techniques. This will not normally be necessary unless high power levels are to be involved. ■

References

1. ARRL Handbook.
2. Waddell, BC, Transmission Line Design Handbook, Artech House 1991.
3. Edwards, TC, 'Foundations for Microstrip Circuit Design', Wiley 1981
4. Wheeler, NPE, Gigahertz prescaler. *Electronics World*, Sep. 1996
5. Wheeler, NPE, 'Spectrum Analyser on the Cheap,' *Electronics World*, Mar 1992.