Microstripline update

Using a UHF amplifier as a design example, Nick Wheeler explains how easy it is to apply microstripline.

My first article on this topic, 'Microstrip made easy,' described how most microstripline calculations refer to traces of width W on an infinite layer of dielectric whose dielectric constant is ε_r and whose thickness is h.[1] The dielectric is backed by an infinite ground plane.

In practice, the electric field tends to concentrate in the volume of dielectric lying just under the track. This tendency increases with increasing frequency.

Some of the field is in air though. This leads to the concept of the effective dielectric, ε_{eff}, which is which is lower than the that of the dielectric alone.

The greater the width of the track, the more ε_{eff} tends towards ε_r. While trace width is a strong determinant of impedance Z_0, it also has to be taken into consideration where the desired track length is frequency dependent, as in $^{\lambda}/_4$ transformers.

I sacrificed a sheet of double-sided photo-etch circuit board by laying down a set of traces ranging in width from 0.007in (0.5pt) to 0.5in (36pt). For such traces, Z_0 can be determined from **Fig. A**, duplicated from my earlier article.

Resistive pads were constructed to match each trace to a 50Ω source, the other ends being left open-circuited. λ_g was then determined for each line by probing for nodes, **Fig. B**.

Findings

The 'velocity ratio', V, is λg divided by the free-space wavelength, and for each trace ε_{eff} is determined by squaring $1/V$.

There are simple theoretical limits for ε_{eff}. When the line is infinitely narrow, ε_{eff} tends to $^1/_2(\varepsilon_r+1)$, where ε_r is the dielectric constant of the substrate. In this case 4.5 is assumed.

When the line is infinitely wide ε_{eff} tends asymptotically to ε_r, since the electric field is entirely within the substrate. The results obtained with the practical range of trace widths noted above are shown in **Fig. 1**.

Values taken from Fig. 1 are good enough for the production of artwork. In general, end effects tend to result in lines that are too long. They may need to be shortened by trial and error for best results. End effects include the parts attached to the lines at each end.

A UHF amplifier

Figure 2 is the circuit board artwork and circuit for the UHF amplifier. This is a broadband amplifier centred on 527MHz – roughly the centre frequency of my local television transmissions from Crystal Palace.

I have disregarded the Channel 5 transmission, since I can only receive it at a very low level. Other signals here are so strong that I do not need a preamplifier, but a television set is a good way of detecting impedance mismatch, which produces multiple reflections in the antenna lead. The circuit includes two microstriplines, the dimensioning of which I shall now describe.

The input circuit, L_1, is a conventional $^{\lambda}/_4$ strip earthed at one end and tapped to match the low impedance of the input from the antenna. With a dual-gate FET such as the *CF739*, which has a very high input impedance at G_1, it can be fed directly from the 'high' end of the line. Its input capacitance of just over 1pF will slightly reduce the optimum line length, as will other stray capacitances.

A wide, rather than a narrow, trace is chosen as a resonator. A wide trace has a lower Q than a narrow one, making the input circuit broadband.

The free-space wavelength of 527MHz is 56.7cm. From Fig. 1 you

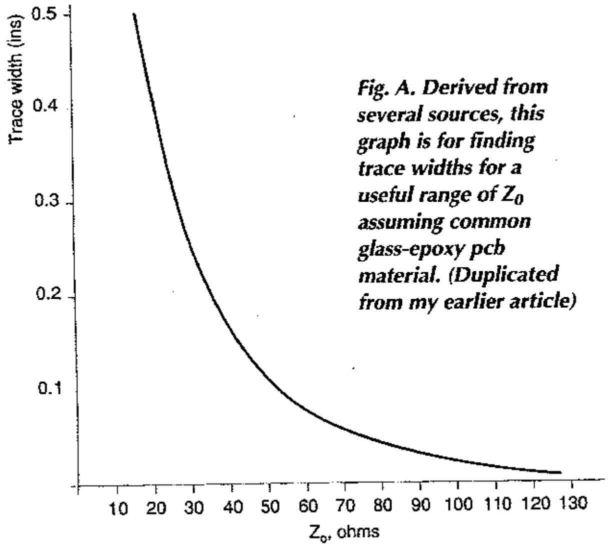

Fig. A. Derived from several sources, this graph is for finding trace widths for a useful range of Z_0 assuming common glass-epoxy pcb material. (Duplicated from my earlier article)

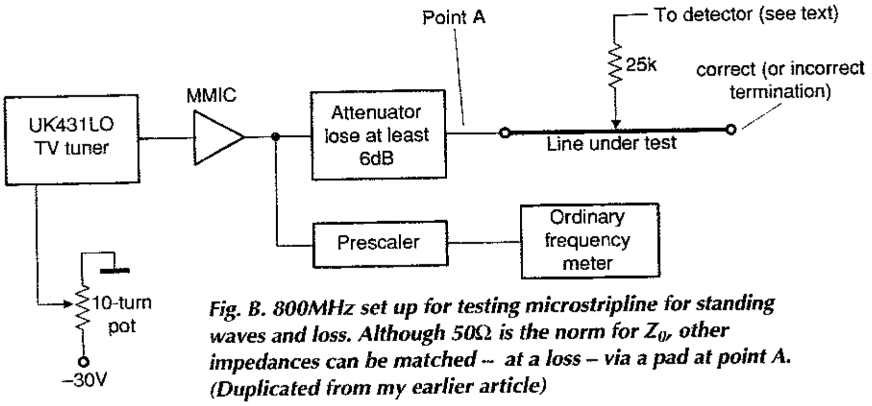

Fig. B. 800MHz set up for testing microstripline for standing waves and loss. Although 50Ω is the norm for Z_0, other impedances can be matched – at a loss – via a pad at point A. (Duplicated from my earlier article)

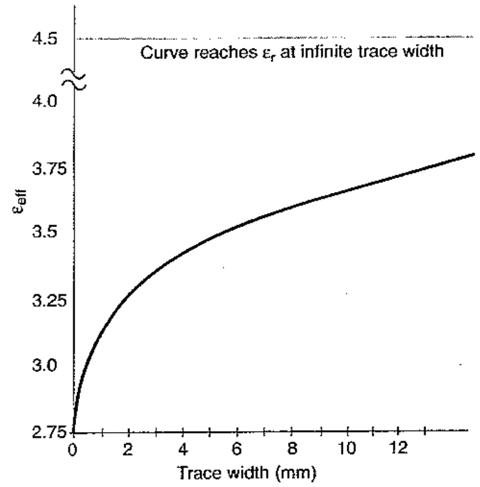

Fig. 1. A graph of effective dielectric value ε_{eff} versus trace width shows that the real dielectric value is different from that of the pcb substrate material ε_r. Here, ε_r is 4.5 and the substrate thickness is 1.6mm.

will see that for the chosen trace width of 2.8mm, ε_{eff} is 3.35. Hence λ_g is $56.7/(1/\sqrt{\varepsilon_{eff}})$, or 30.98cm, making $\lambda_g/4$=7.74cm.

As I pointed out earlier, the actual length required will be less than this. A relatively wide trace such as this can be terminated at the earthy end by drilling a 1mm hole through the centre line and earthing to the ground plane on the other side of the circuit board. Ordinary 'track pins' are suitable for this.

Start with the track too long and progressively shorten it, moving the input tap to be arbitrarily 1cm from the earth point.

Positioning is not too critical. I ended up with a track 70mm long. Resonance can be determined by the same means as was used for finding the nodes, though in this case we are looking for a voltage maximum, which cannot be done as accurately as finding a minimum.

Inductor L_2 is a $\lambda/4$ transformer, which matches the drain load of the the *CF739* to the 75Ω of the output to the TV set. Because the output impedance of a dual-gate FET is very high, the termination seen by signals reflected back from the TV set is equal to the drain load, as transformed, for all practical purposes.

In this case the dominant consideration is the Z_0 of L_2, since this equals $\sqrt{(R_{drain}\times 75)}$.

Using a graphic program such as *Serif Draw* it is convenient to choose trace widths offered in the program menus – particularly if there are to be bends. If a straight trace is acceptable, almost any trace width can be closely approached.

In this case, I chose a trace width of 2 points, which is around 0.7mm. Such a trace has Z_0 approximately equal to 92Ω, whence R_{drain} has to be 113Ω.

I used chip resistors of 150Ω and 470Ω in parallel.

With this trace width, ε_{eff} is close to the limiting minimum value of 2.75. From Fig. 1, I estimated it at 3.07, so $\lambda_g/4$=80.9mm. Note that this is appreciably more than the equivalent at a track width of 2.8mm.

I used 8cm, and this proved to be satisfactory. The performance at the edges of the band, BBC2 and ITV was good, but not quite as good as in the middle. The Channel 5 signal was not improved.

This amplifier has a gain of 7-10dB over the local TV band, but it is not intended as a serious contender in this field. It is described to illustrate the practical application of microstripline. The design also illustrates how microstripline complements SMD technology.

Experiments

I also tried to use a $\lambda/4$ transformer with a 0.35mm track. This worked well for one TV channel, but at the expense of the others.

The higher transformation ratio permits a larger drain load of 220Ω in parallel with 1.5kΩ, giving more gain. This is what you would expect. Broadbanding is always at the expense of gain.

The tracks were made straight for ease of experimentation, but provided they are curved on an adequate radius can be folded to give a more compact board layout

In summary

To get good results from a microstripline circuit board, practice and experimentation are necessary.

This brief article, read in conjunction my earlier one, sets out most of what you need to know. But because of the variables involved – not the least of which is the fact that circuit board obtained from ordinary sources is not tightly specified as regards ε_r – your first attempt may not work as well as you might expect.

I have rather taken to adding a few test tracks to each artwork print so that I can evaluate ε_{eff} for the material being used. ■

Reference

1. Wheeler, N., 'Microstrip made easy,' *Electronics World*, December 1997.

Drawing tracks to 0.001in accuracy with *Serif*

I use a general-purpose drawing package called *Serif Draw* for laying out circuit boards. Its menus allow a useful variety of line weights to be selected in point steps. A point is a typesetting measure equal to 1/72in by the way.

With patience though, it is possible to draw lines of any width to an accuracy of ±0.001in. At a magnification of 1000%, the smallest divisions on the vertical and horizontal ruler scales are a sixteenth of 0.1in, or 0.00625in.

You should find it possible to draw 13 'hairline' traces, separately identifiable, in the space of two of these small divisions. Abutting a hairline trace to another trace which is just too narrow allows the narrow to be widened in steps of 0.001in. This enables artwork to be created for microstripline to greater accuracy than is ever likely to be needed.

These lines can only be vertical or horizontal, since sloping or curved lines consist of a series of steps.

Fig. 2. UHF amplifier using a CF739 dual-gate mosfet and its circuit board artwork. Note that all component grounds shown on the circuit diagram go through to the ground plane on the reverse side of the pcb in practice.