Cross Polarization Tolerance Requirements of Square Microstrip Patches

We normally feed a rectangular patch along the centerline of the H-plane (non-resonant width), as shown in figure 1, to eliminate excitation of the patch in the other mode. The second mode radiates cross polarization. This column will provide the tolerance requirements given cross polarization. The rectangular microstrip patch radiates its peak cross polarization in the diagonal planes even when the antenna is fed perfectly. This cross polarization is low. When we locate the feed along the centerline of the H-plane of the patch, the impedance match to the mode TM_{01} is poor and the antenna does not radiate significant power at boresight to the patch. Often we design a square patch so that we can radiate orthogonal linear polarizations (or dual circular polarizations) by using two feeds. If we fail to place the feed probe, aperture, or microstrip line along the H-plane axis, the cross polarization level rises.

To review, in the design a patch we find the resonant length of the patch by using the effective dielectric constant of an equivalent transmission line after we consider the effective added length due to fringing capacitance. For a patch with a non-resonant width W on a substrate with dielectric constant ε_r and thickness H, the resonant length is found from

$$L_{10} = \frac{c}{2 f_{10} \sqrt{\varepsilon_{eff}}} - 2\Delta \qquad (1)$$

where the effective dielectric constant is

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + \frac{10H}{W}}}$$

The edge cut-back due to fringing fields is

$$\frac{\Delta}{H} = 0.412 \frac{(\varepsilon_{eff} + 0.300)}{(\varepsilon_{eff} - 0.258)} \frac{\frac{W}{H} + 0.262}{\frac{W}{H} + 0.813}$$

It easy to rearrange equation (1) to find the resonant frequency given dimensions. Small changes in the width of the patch changes the effective dielectric constant only slightly. Its easy to find the dimensions of a square patch through iteration [1].

Another method of considering a patch uses resonant cavity modes. The modes produce an infinite series of impedances, one term for each mode, electrically in series. These impedances are given by simple expressions that depend on the feed point [2]. Because the edges of the cavities are open circuits, the patch will support many higher order modes. Most modes have small amplitudes, but the TM_{10} and TM_{01} modes can be easily excited with large amplitudes for nearly square patches. Each mode radiates cross polarization of the other. To find the power delivered to each mode, we sum all terms of the series except the for the mode we are interested in. A simple microwave network analysis finds the power delivered to the load (the mode impedance). By repeating this for the TM_{10} and TM_{01} modes we can find the ratio of the power in each mode (cross polarization at boresight).

A large number of cases were calculated when the feeding probe was placed at the 50Ω point, but moved off the H-plane centerline. By using the scales given in figure 2 we can express results independent of bandwidth (substrate thickness), frequency, and substrate dielectric constant over the usual range of patch bandwidths. For example, to achieve 25 dB cross polarization we must place the feed probe along the centerline within 0.75% of the width. For a square patch operating at 3 GHz on 2.32 dielectric the width is about 3 cm and the 25 dB cross polarization tolerance is 0.22 mm.

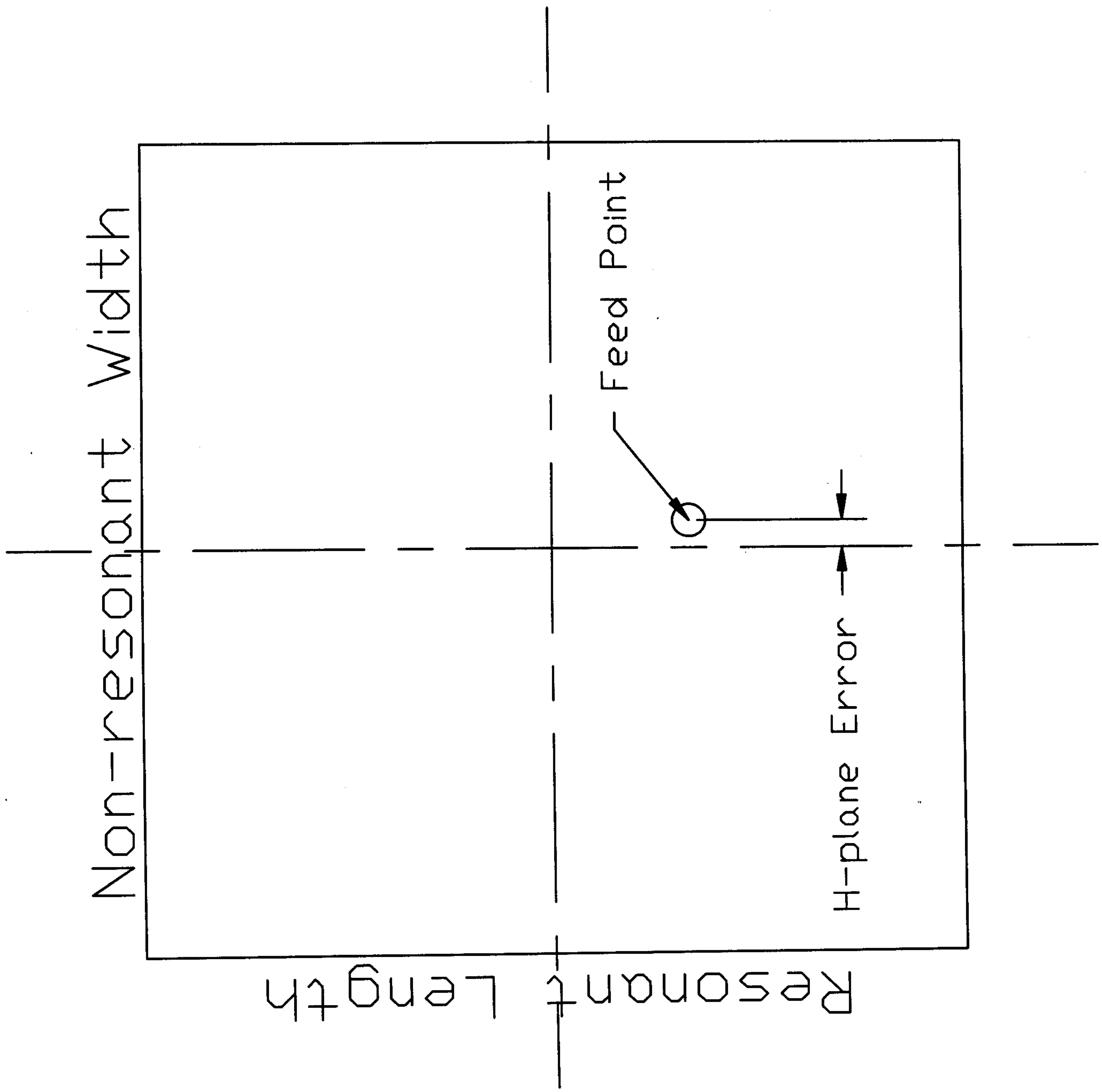
If we only need one sense of linear polarization, we can relax the tolerance by making the patch non-square. Figure 2 shows that shifting the resonant frequency along the width dimension by twice the 2:1 VSWR bandwidth of patch relaxes the tolerance from 0.75% to 2% of the width. For our example at 3 GHz the tolerance requirement becomes 0.6 mm. If we are designing at patch at 10 times this frequency (30 GHz), the acceptable tolerance is 1/10th. These tolerances will stress the manufacturing. We can use a iteration method to produce a patch with the two resonant frequencies that correspond to the length and width. The resonant length changes very little as we change the width. Just shifting the width by the ratio of the resonant frequencies gives an acceptable design and we can skip iteration steps.

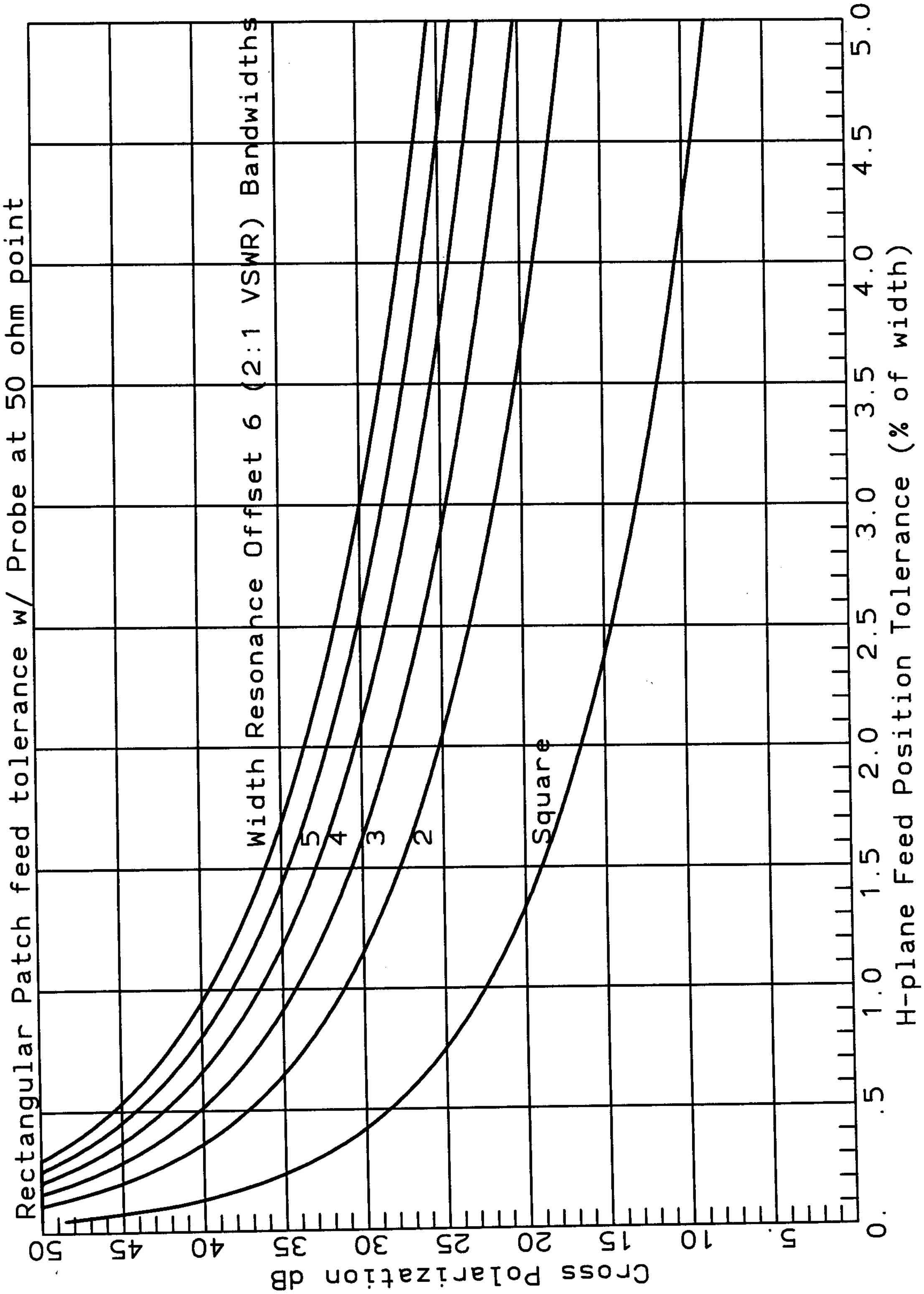
Figure 3 illustrates the result that moving the feed point to the edge reduces tolerance requirements because the feed distance from the centerline null plane (in E-plane) has increased. The tolerance is proportional to this distance as well. If operate the patch at a frequency approaching the resonance of the width, the cross polarization will increase for non-square patches. Figure 4 plots the tolerance at the 2:1 VSWR bandedge approaching the resonant frequency of the width. On figure 4 the line for a square patch does not change, but the other lines shift downward (tighter tolerances). The line for a shift of 3 times the 2:1 VSWR bandwidth on figure 4 is nearly the same as for 2 on figure 2.

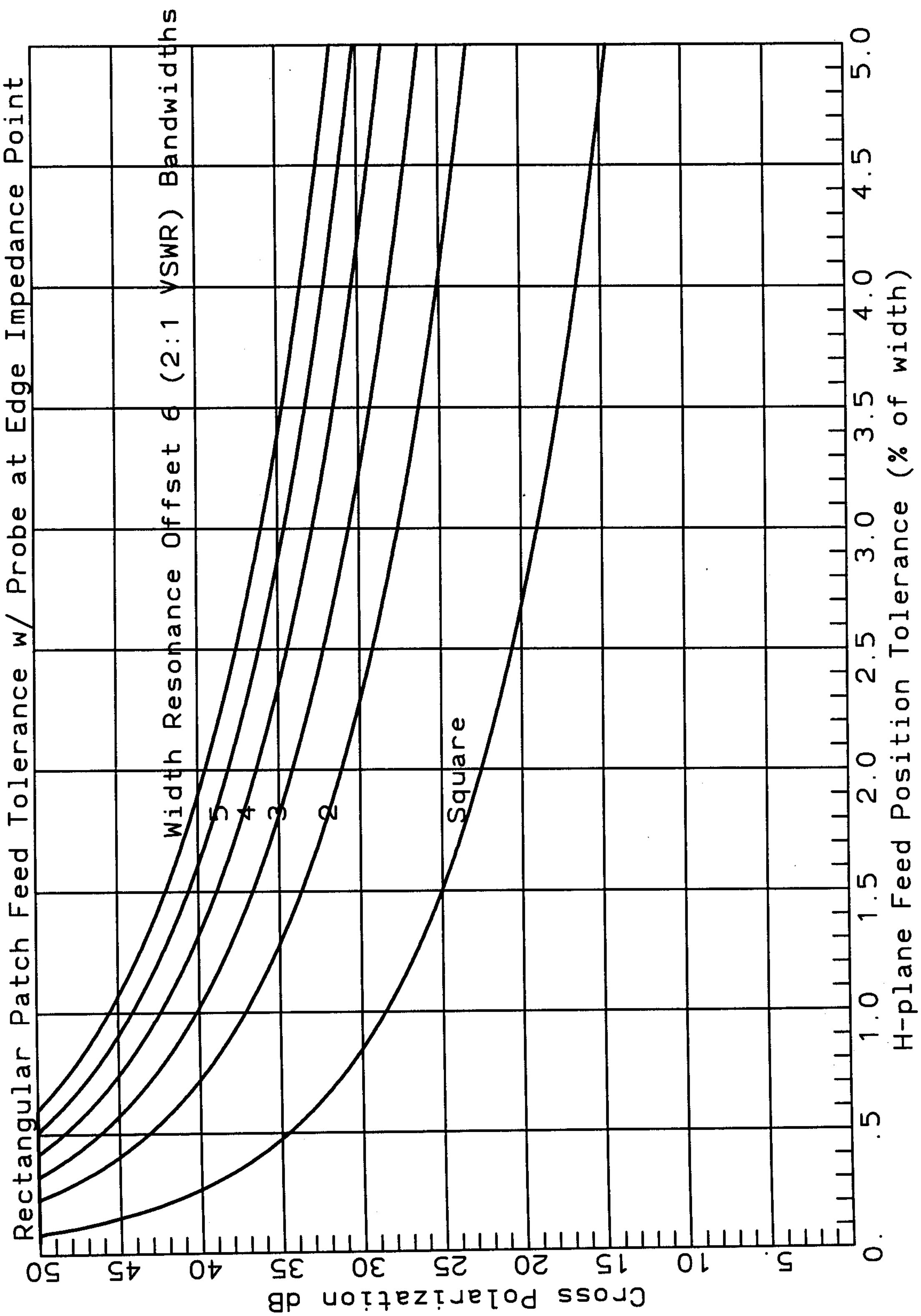
These charts show that the feed location tolerances on nearly square microstrip patches are tight when we need to achieve low cross polarization.

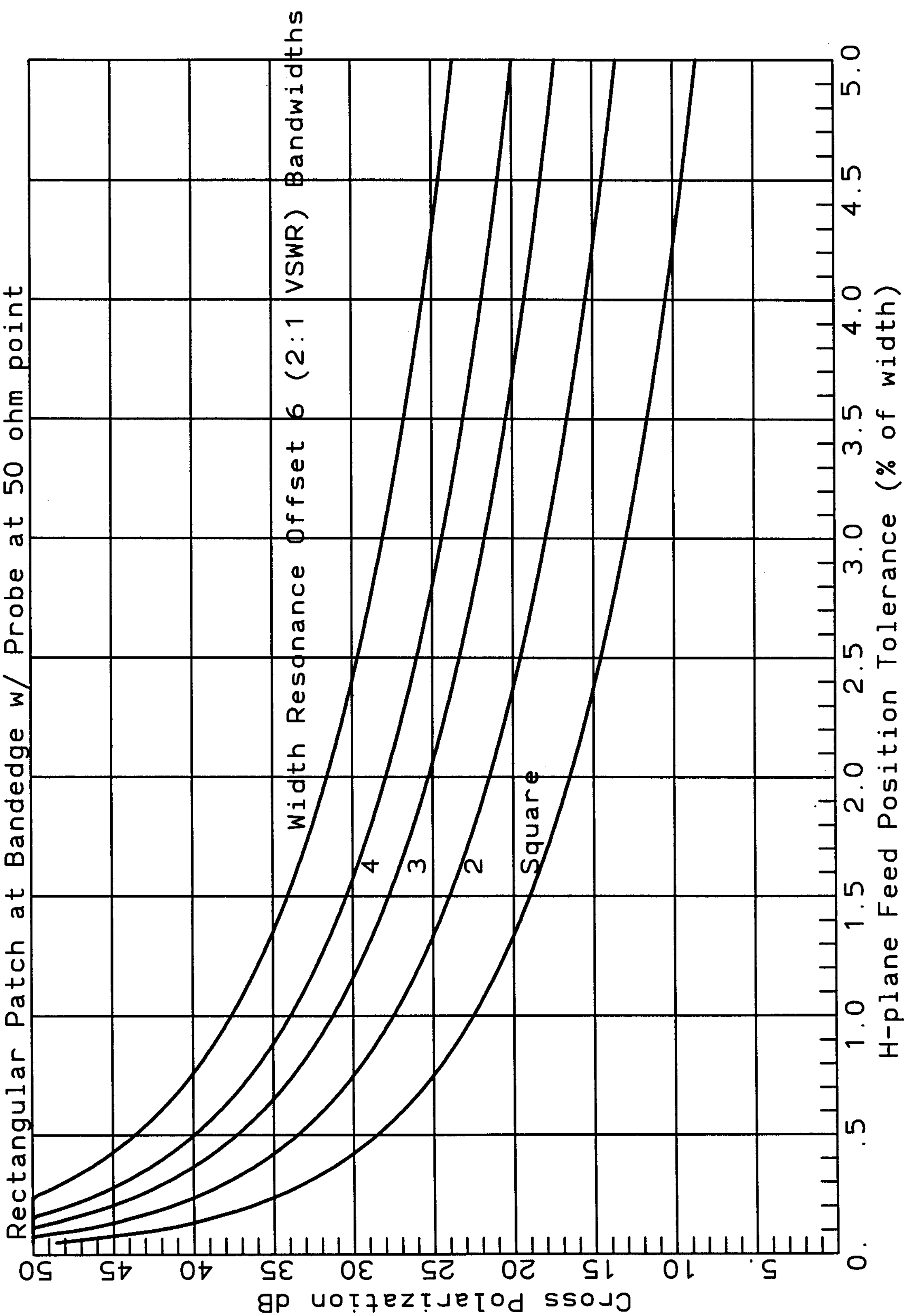
[1] Milligan, *Modern Antenna Design,* McGraw-Hill, New York, 1985, p. 100.

[2] A. Benalla and K. C. Gupta, 'Faster Computation of Z-matrices for Rectangular Segments in Planar Microstrip Circuits,' *IEEE Trans Microwave Theory Tech.*, vol MTT-34, pp. 733-736, 1986.


Non-resonant Width
Feed Point
H-plane Error
Resonant Length


Rectangular Patch feed tolerance w/ Probe at 50 ohm point
Width Resonance Offset 6 (2:1 VSWR) Bandwidths
5
4
3
2
Square
H-plane Feed Position Tolerance (% of width)
0.
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Cross Polarization dB
50
45
40
35
30
25
20
15
10
5.


Rectangular Patch Feed Tolerance w/ Probe at Edge Impedance Point
Width Resonance Offset 6 (2:1 VSWR) Bandwidths
5
4
3
2
Square
H-plane Feed Position Tolerance (% of width)
0.
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Cross Polarization dB
50
45
40
35
30
25
20
15
10
5.


Rectangular Patch at Bandedge w/ Probe at 50 ohm point
Width Resonance Offset 6 (2:1 VSWR) Bandwidths
4
3
2
Square
H-plane Feed Position Tolerance (% of width)
0.
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Cross Polarization dB
50
45
40
35
30
25
20
15
10
5.

