7.4 Slotted-cylinder antennas

As illustrated in Figure 7-3, a slot in an infinite plane is equivalent to a dipole of the same dimensions. In practice, a sheet much bigger than the slot is a nearly infinite plane. Kraus[25] bends the sheet into a U-shape, with the bend parallel to the long dimension of the slot, then joins the ends of the U to form a cylinder. The result is a slotted-cylinder antenna[26]. If the diameter of the cylinder is less than about 1/8 λ, the azimuth pattern for a vertical slot is nearly omnidirectional, with horizontal polarization. Larger diameters become more directional, with the maximum radiation from the side with the slot.
A half-wavelength slot is center-fed by a balanced transmission line (or balun) connected across the slot, with one side connecting to each edge of the slot, as illustrated in Figure 7-29. A transmission line inside the cylinder should have no effect on the radiation pattern.

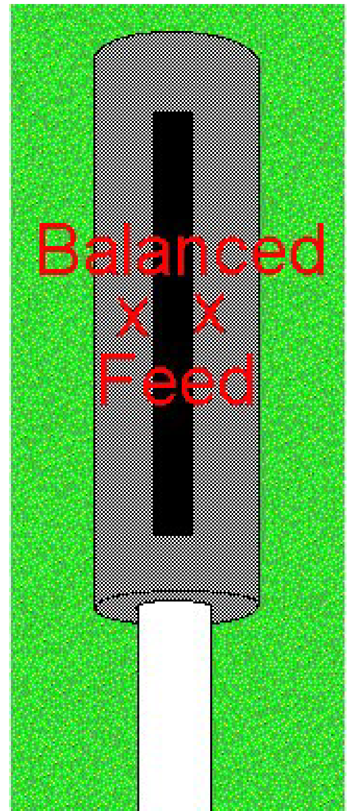


Figure 7-29

To find the resonant length of a slot, Kraus considers the slot as a balanced transmission line loaded by a series of shunt loops which together make up the cylinder. Thus, the antenna may be a solid cylinder like Figures 7-2 and 7-30 or a skeleton[27] or "rib-cage" with wire loops like Figure 7-31. The solid cylinder is just an infinite number of loops. The inductive loading of the loops increases the phase velocity, so that the resonant length is *longer* than a free-space dipole. The typical dimensions given by Kraus are:
diameter = 0.125λ, length = 0.75λ, and slot width about 0.02λ. The small diameter makes the slotted-cylinder antenna usable at frequencies too low for waveguide to be practical.

Figure 7-30

A quarter-wave version of the slotted-cylinder antenna is also possible, by leaving one end of the slot open. The feed is then at the open end.

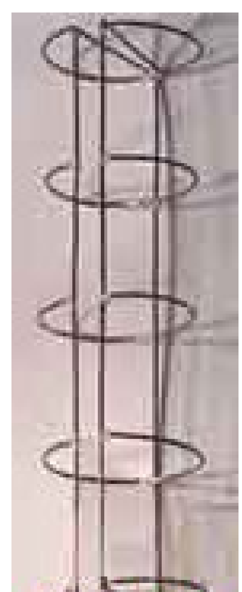


Figure 7-31

Why is the slot longer than a slot in a waveguide, which also behaves like a half-wave dipole? While the whole waveguide slot is excited by energy propagating inside the guide, the cylindrical slot is only fed at a single point. The small cylinder diameter is well below cutoff, so waveguide modes cannot propagate inside the cylinder. Therefore, the energy must propagate in the slot, which acts as a balanced transmission line.

A transmission line is modeled as a chain of incremental series inductors (nh/mm) and shunt capacitors (pf/mm). The cylinder adds shunt inductance in parallel with the shunt capacitors – the skeleton version in Figure 7-31 clearly has a series of loops. The solid cylinder just reduces the space between loops to zero; in either case, the loops add an incremental shunt inductance (nh/mm) in parallel with the incremental shunt capacitance. The net incremental admittance is the sum of the positive capacitive susceptance and the negative inductive susceptance (susceptance is the reactive part of admittance).

When the incremental susceptances are equal, the result is a parallel resonance. At frequencies well above this resonance, the net admittance is capacitive like a normal transmission line. Below resonance, the net admittance is inductive, tending to short out any propagation in the line – the cylinder is obviously a short circuit at low frequencies – so the slot has a cutoff frequency determined by the shunt inductance of the loops or cylinder and the shunt capacitance, between the two edges of the slot. The shunt capacitance is controlled by the slot width and wall thickness.

At frequencies just above this resonant or cutoff frequency, the net admittance is capacitive, but much smaller than the capacitance of the slot alone, since it is nearly canceled by the loop inductance. At the resonant frequency, the cancellation is complete; as the frequency approaches resonance from above, the net capacitance approaches zero. Since he velocity of propagation in a transmission line may be calculated from the incremental series inductance and shunt capacitance:

$$\text{Velocity of propagation} = \frac{1}{\sqrt{LC}} \ ,$$

we can see that increasing the shunt capacitance of a transmission line or antenna, by capacitive loading, reduces the velocity of propagation and thus the electrical wavelength. Conversely, the inductive loading of the slot reduces the net shunt capacitance, which increases the velocity of propagation and thus the electrical wavelength. Since the velocity of propagation in a line with air dielectric is already at the speed of light, increasing the velocity makes the wavelength *longer* than the free-space wavelength. (In waveguide, this apparent velocity greater than the speed of light is referred to as phase velocity; we shall use the same terminology here.)

At frequencies just above resonance, the net capacitance is approaching zero and the electrical wavelength becomes much longer than the free-space wavelength. If we consider the resonant frequency as the cutoff frequency, we may use the same calculation used for wavelength in waveguide in section 7.2.3 above.

7.5 Alford slot antenna

As explained by G3JVL[28,29], the Alford slot antenna operates close to cutoff to increase the phase velocity even further than Kraus suggests. Thus, a half-wavelength slot is much larger than a half-wavelength dipole in free space and provides gain due to the larger aperture. A typical Alford slot has a length around 2λo, or four times as long as a half-wave dipole, for a gain of perhaps 6 dB.

All slotted-cylinder antennas seem to be called an "Alford slot" by hams, but the name is not used in any antenna book I've seen. Even the waveguide slot antenna is occasionally called an Alford slot. Albert Alford invented the Alford loop antenna and a number of FM and TV broadcast antennas, but the only slot reference is a 1946 paper[30] entitled "Long Slot Antennas."

One problem with operating close to the cutoff frequency is that dimensions become very critical – a small change in cutoff frequency can produce a large change in electrical wavelength. Since the dimensions are critical and no formula published for cutoff frequency, it is probably best to copy proven dimensions. G3JVL provides several combinations for 1296 MHz[31,32,33] and 2304 MHz[34], including good radiation patterns for one of the latter versions. A 13cm version made by OH2KTB[35] is shown in Figure 7-30.These dimensions have a feed impedance around 200 ohms, ideal for a coax balun. As an example, one set of dimensions for 1296 MHz call for a slot 8 mm (0.035 λo) wide and 510 mm (2.2 λo) long in a tube with an O.D. of 35.0 mm (0.15 λo) and a wall thickness of 1.1 mm. The 2.2 λo length should provide roughly 6 dB of gain. SM6PGP[36] has measured radiation patterns for several of the G3JVL dimensions; the azimuth patterns are shown in Figure 7-32 and the elevation patterns in Figure 7-33. Figure 7-2 is a photo of one these antennas. These are pretty good omnidirectional antennas, with the azimuth patterns showing only about 3 dB variation in amplitude.

For other bands, N4MW has used slotted-cylinder antennas for beacons on several of the lower microwave bands and has published dimensions[37] for bands from 144 MHz to 10.368 GHz, all scaled from the G3JVL version for 2304 MHz.

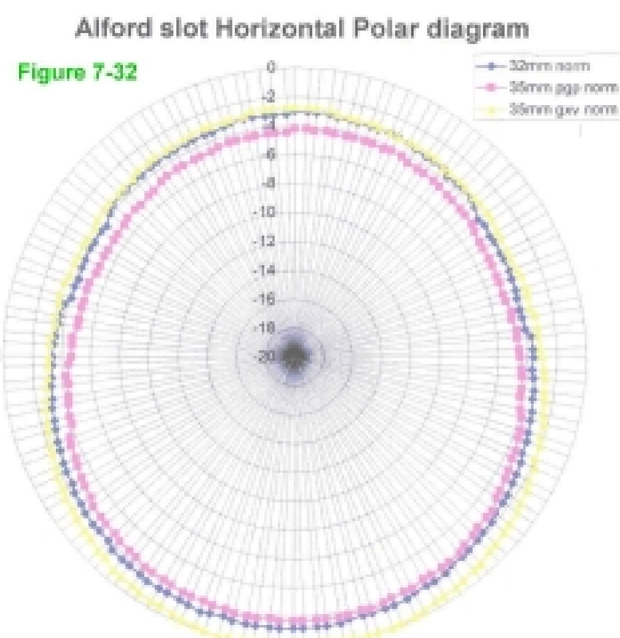


Figure 7-32

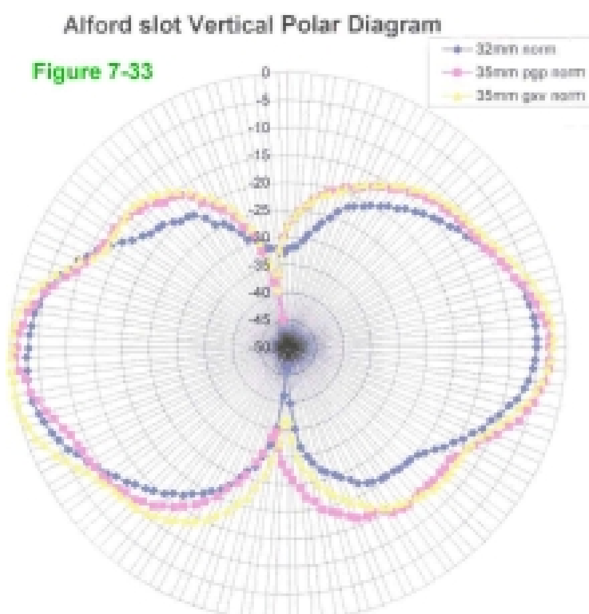


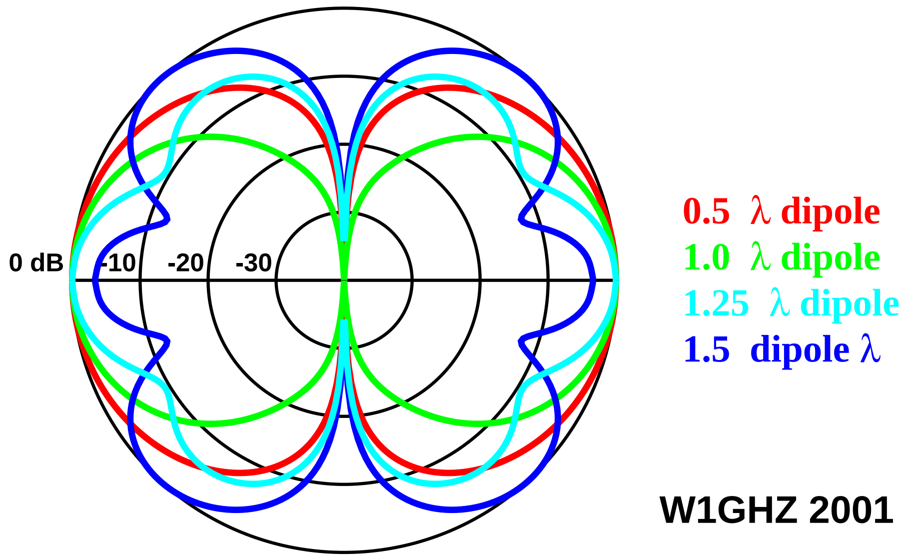
Figure 7-33

When exact dimensions are not available, some ham ingenuity is needed. W4WSR made the 2304 MHz Alford slot antenna shown in Figure 7-34 by rolling copper flashing into a cylinder, leaving a gap to form the slot. To compensate for the thin material, he adjusts the slot length by using sliding shorting rings over the cylinder as the ends of the slot.

If the phase velocity is wrong, the Alford slot antenna will no longer behave like a simple dipole. For instance, if the phase velocity were lower than desired, then the long slot would be equivalent to a much longer dipole. While it is difficult to model a slot antenna using a computer, it is easy to calculate radiation patterns for the equivalent dipoles. Figure 7-35 shows the elevation patterns calculated using **NEC2** for vertical dipoles of lengths from 0.5λ to 1.5λ. To understand these patterns, we can also look at the currents in the dipole with **NEC2**, shown in Figure 7-36. The half-wave dipole has a single current peak, so it appears as a single radiator, while the 1.5λ dipole has three current peaks, each acting as a source of radiation, so that we can expect interference like that shown in Figure 1-2e in Chapter 1 to produce sidelobes. The 1.0λ dipole appears to have two current peaks (center-feeding forces the additional central current shown as a dashed line), but they are of opposite phase so the antenna appears to radiate from a single point. We can see that dipoles longer than one wavelength will exhibit unwanted sidelobes, while shorter ones will not.

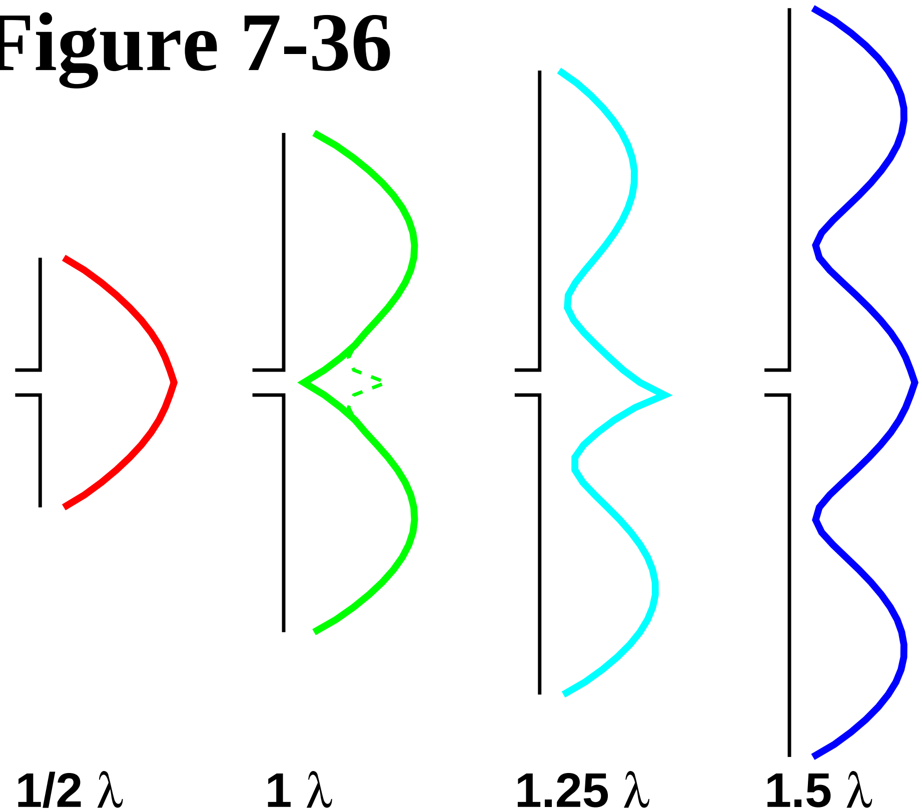
Dipoles 0.5 to 1.5 wavelengths long

Figure 7-35



We expect a dipole and a slot of the same electrical length to produce similar radiation patterns. Therefore, we can expect similar currents and voltages. The slot is the complement of the dipole: the slot must have minimum current at the open ends, while the slot must have minimum voltage (and maximum current) at the shorted ends. Thus, the voltage distribution in a slot antenna has the same shape as the current distribution in a dipole, shown in Figure 7-36, of the same electrical length

Current in dipoles vs length
Figure 7-36



Since we expect dipoles and slots to be equivalent, we would prefer to keep the electrical length of a slot to less than one wavelength, while making the physical length as large as possible. We can achieve this combination by operating close to cutoff; G3JVL[28,29] suggests that the optimum frequency range is 1.03 to 1.15 times the cutoff frequency.

If a slot is operated at a frequency farther from cutoff, then the electrical wavelength will be too short and it will operate as a longer dipole. One example is a 70 cm antenna made by WB0QCD; the measured elevation patterns[38] shown in Figure 7-37 at 426 MHz and Figure 7-38 at 439 MHz have large sidelobes nearly equal in amplitude to the main lobe. The patterns are very similar to those calculated for long vertical dipoles; at 426 MHz, the pattern is similar to a 1.2λ dipole, while the 439 MHz pattern is closer to a 1.5λ dipole. For this antenna to produce an elevation pattern with a single lobe, the operating frequency must be somewhat lower than 426 MHz. We may infer that the cutoff frequency is too low for the desired operating frequency so that the phase velocity is much lower than needed, and that the large sidelobes will reduce the maximum gain in the main lobe.

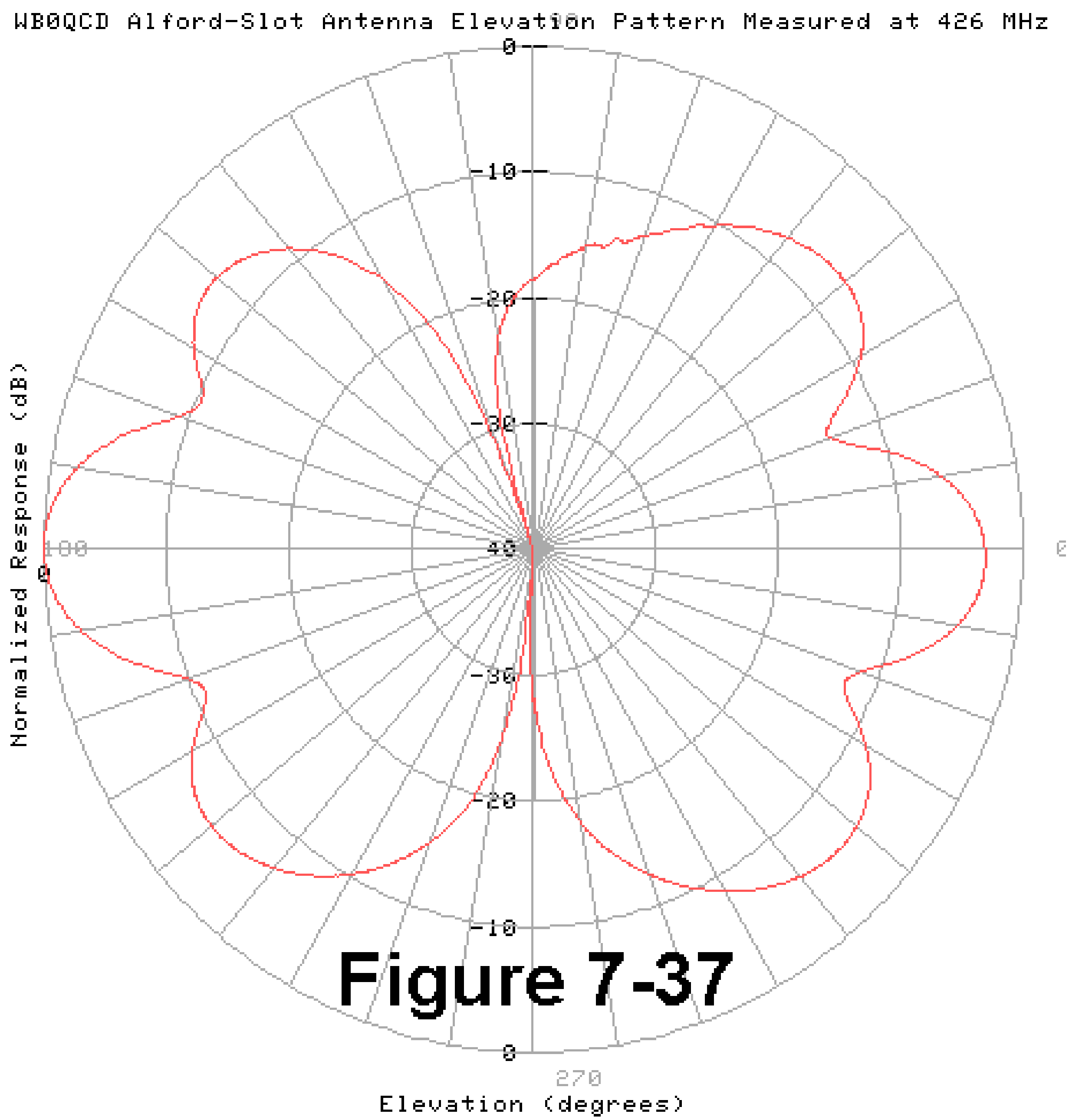


Figure 7-37

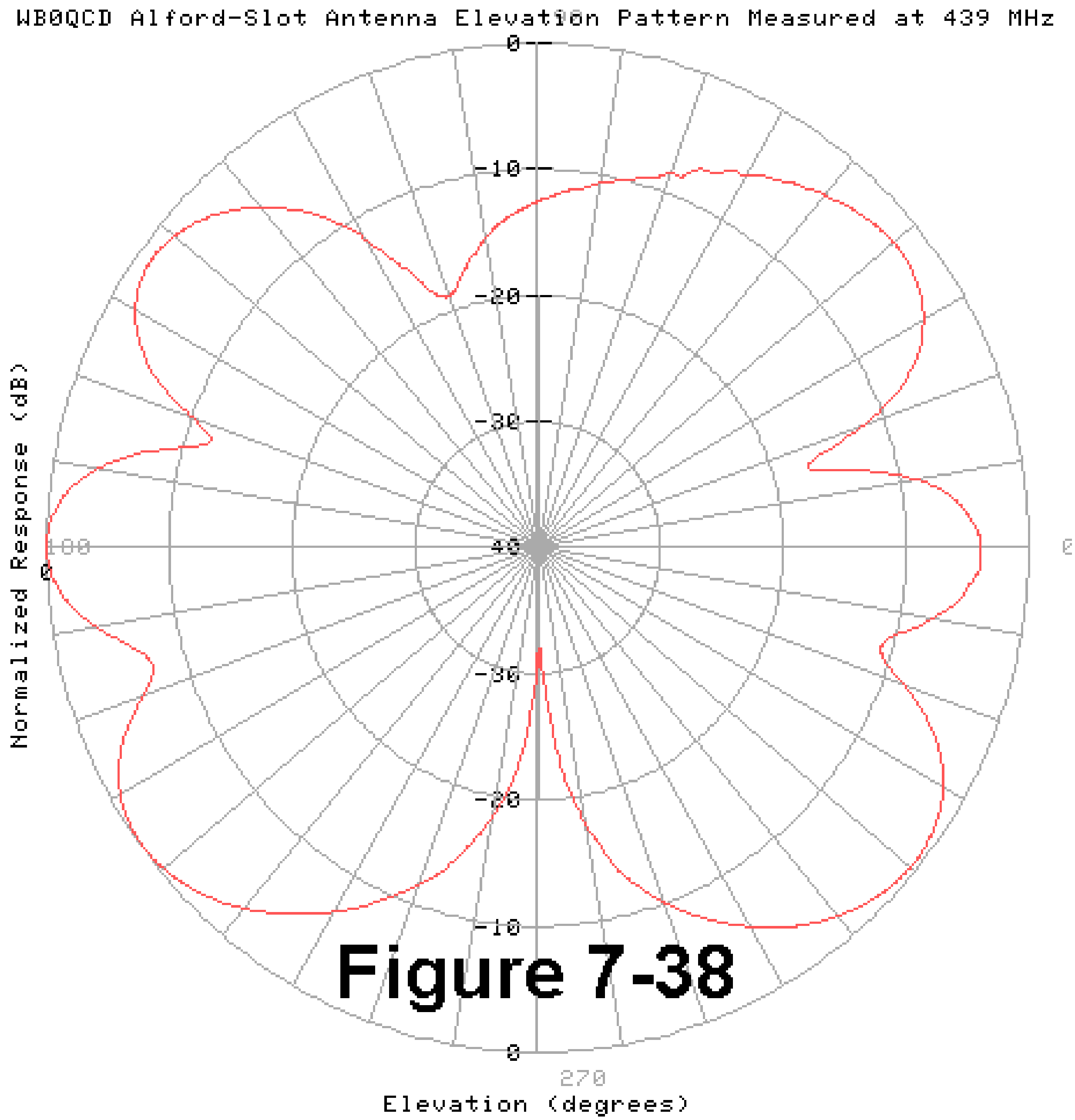


Figure 7-38

A properly dimensioned Alford slot antenna will produce a clean elevation pattern with a single lobe, like the one in Figure 7-39, measured by KB2BD[39] for a skeleton antenna like Figure 7-31. According to G3JVL[28,29], the cutoff frequency may be adjusted closer to the operating frequency to increase the electrical wavelength by decreasing the cylinder diameter, increasing the slot width, or using a thinner wall tubing. The alternative is to shorten the slot, decreasing the gain. Simple adjustments, like adding tabs at the feedpoint, may improve VSWR but will not change the resonant length since the incremental L and C distributed along the slot are not changed. Thus, tabs at the feedpoint will not improve the radiation patterns.

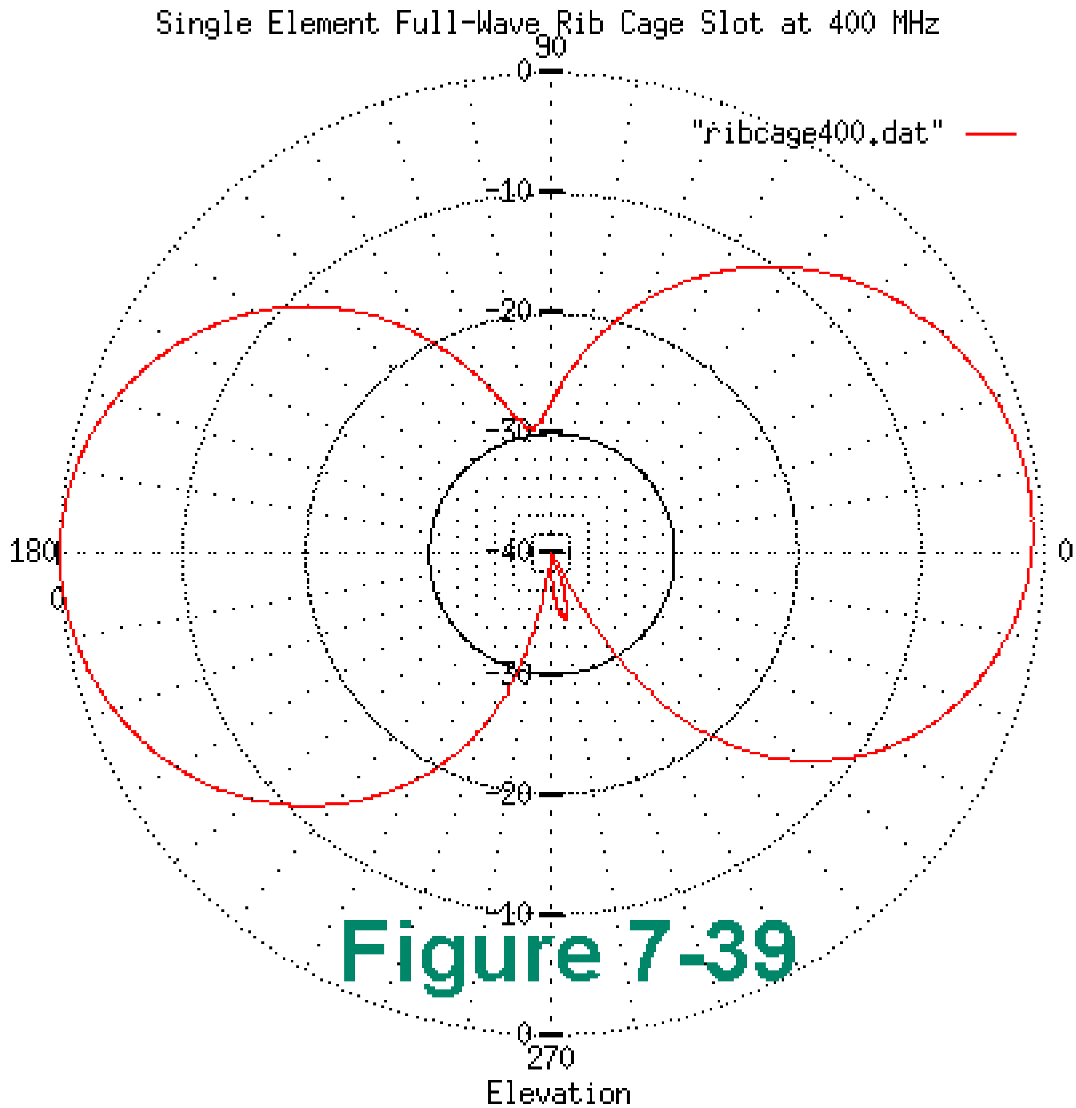


Figure 7-39

G3JVL also makes it clear that adjustment for a good VSWR is not enough, but that one must actually check the field distribution along the length of the slot at various frequencies using a probe. The field strength must taper uniformly from center to end, like a half-wave or full-wave dipole, without any additional peaks and dips that would be found in a longer dipole. Changing any of the dimensions without performing this test could easily result in undesirable patterns like Figure 7-38 or worse. For best results, the probe should not be held directly in front of the slot but offset 20 or 30 degrees. A photo I once saw on the Andrew Corporation web page[40] showed this procedure with the probe embedded in a foam block, which acts as both handle and spacer.

At lower frequencies, physical constraints usually limit the size to a single slot, but more gain is possible by stacking: adding additional collinear slots in a longer cylinder. Since the slots are fed by conventional transmission lines inside the cylinder, the usual power splitting and phasing methods apply. Slot spacing is not dictated by the transmission line, so it may be adjusted for best pattern or for convenience. In larger arrays, the tapered power distribution we saw previously might be applied to reduce sidelobes in the elevation pattern.