

Helical Antennas [Section 10.3.1 of Balanis, Fourth Edition]

- Developed by John D. Kraus at the Ohio State University (OSU) in 1946.
- These notes are heavily influenced by Antennas (Second Edition) by Kraus.

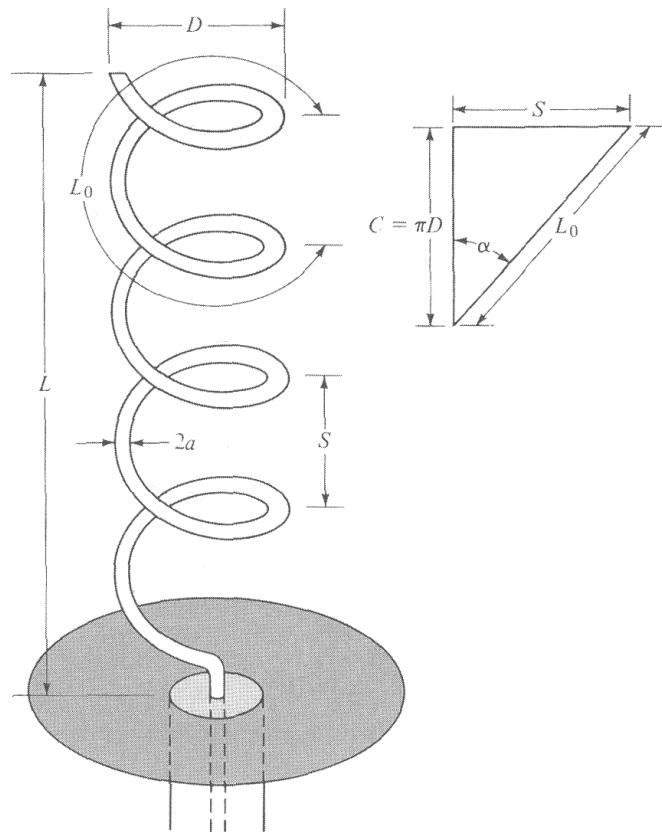


Figure 10.13 Helical antenna with ground plane. [Balanis, Fourth Edition]

As shown, the geometry of a helical antenna is complicated and requires many parameters to describe. They are:

$D \equiv$ helix diameter (from wire center to center)

$C = \pi D$ - helix circumference

$S \equiv$ turn spacing (from wire center to center) = $\frac{L}{N}$

$\alpha \equiv$ pitch angle = $\tan^{-1}(\frac{S}{\pi D})$ $0^\circ < \alpha < 90^\circ$

$N \equiv$ # of turns loop straight wire

$L \equiv$ axial length (helix height) = NS

Helix parameters cont.

$2a \equiv$ diameter of helix conductor/wire

$L_o \equiv$ length of one turn of wire $= \sqrt{(\pi D)^2 + S^2}$

$L_n = N L_o \equiv$ total wire length

Sense - helix can be right-handed (RH) or left-handed (LH) [Thumb of correct hand points down helix, away from feed, and fingers curl in direction of helix]

Radiation Modes:

- 1) Normal mode - radiates broadside to helix in a fashion similar to a short dipole or small loop (occasionally used to replace monopoles)
- 2) Axial mode - radiates in direction of helix axis (most common)
- 3) Conical mode - radiates in a cone around axis of helix (not useful)
- 4) others - hybrids of prior 3 modes, can be multi-lobed, not useful
 → won't discuss 3) + 4) further

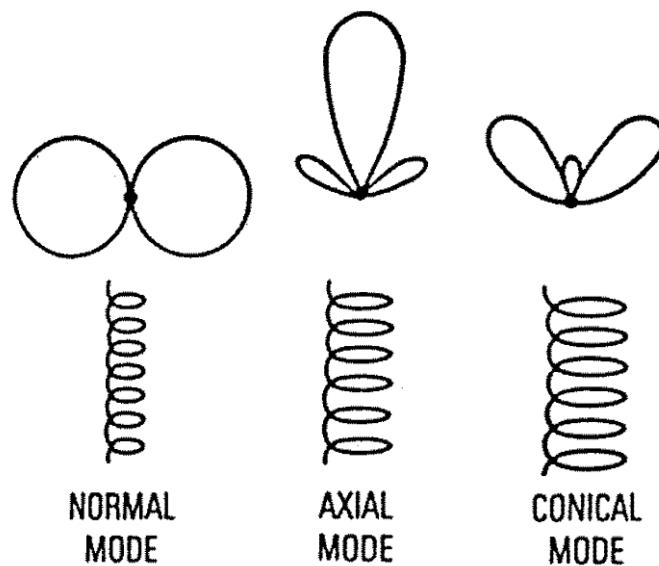


FIG. 13-1 Three radiation modes of a helical antenna. [Joy, notes]

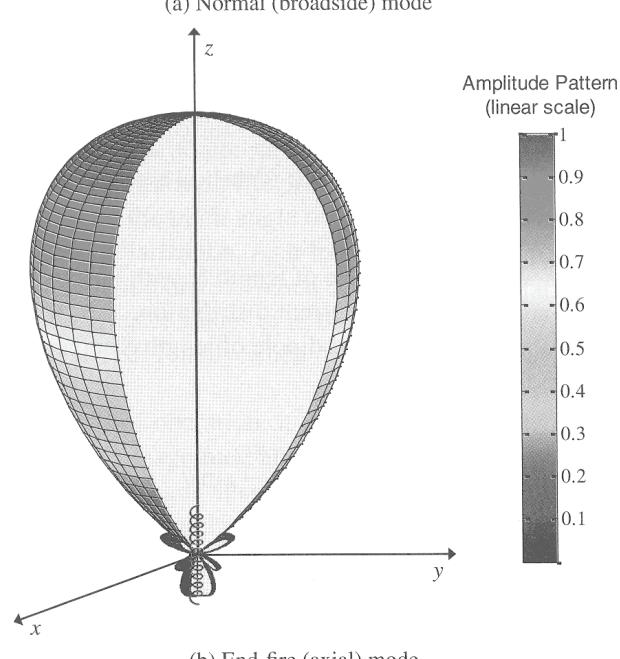
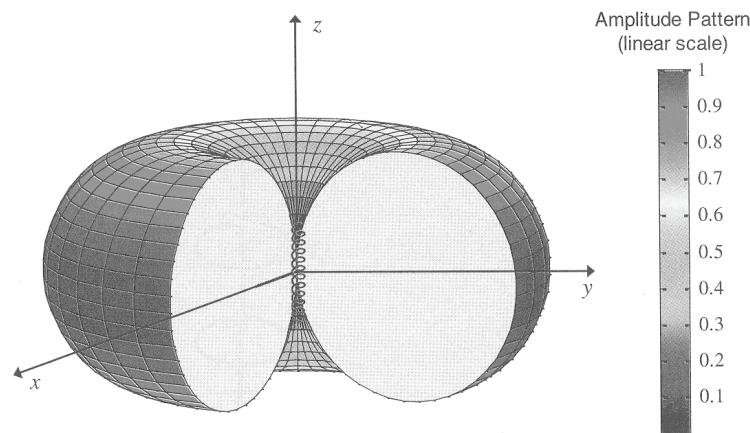


Figure 10.14 Three-dimensional normalized amplitude linear power patterns for *normal* and *end-fire* modes helical designs. [Balanis, Fourth Edition]

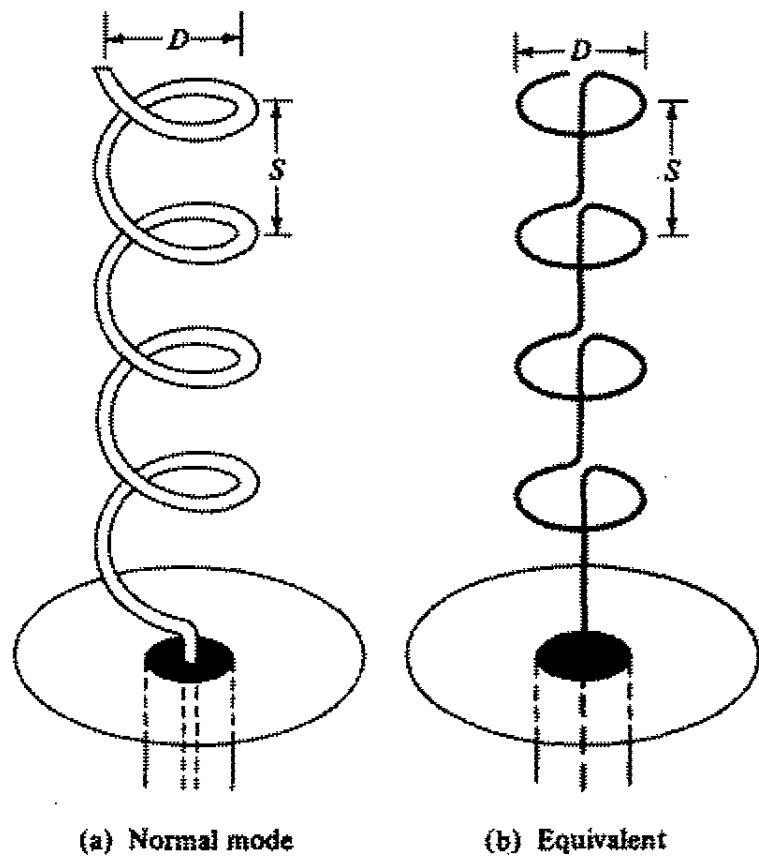


Figure 10.15 Normal (broadside) mode for helical antenna and its equivalent.
[Balanis, Fourth Edition]

- Model helix antenna as series of loop antennas of diameter D separated by short dipoles of length S .

Normal Mode cont.

- * As shown in Fig. 10.15, the helix is usually operated over a ground plane and can be modeled as a series of N small loops and short dipoles.
- * For normal mode operation, the helix dimensions must be small in terms of wavelengths i.e. $\theta \ll \lambda$ and $L_h = N L_0 \ll \lambda$
- * narrow BW + low radiation efficiency (little short dipoles/small loops)
- * Since the helix is small, we can assume the current is constant over the length of the helix and independent of # of turns (can encourage by proper termination of helix)

Dipole (short wl length $l = S =$ helix spacing)

$$E_\theta = j\gamma \frac{\kappa I_0 S e^{-jkS}}{4\pi r} \sin\theta \quad \leftarrow \text{far-field}$$

Loop (small wl radius $a = \theta/2$)

$$E_\phi = \gamma \frac{\kappa^2 (\theta/2)^2 I_0 e^{-jkS}}{4r} \sin\theta \quad \text{far-field}$$

Note: we have 2 orthogonal field components that are in time phase quadrature (90° out of phase) \Rightarrow elliptical or circular polarization!

Normal mode cont.

To characterize the relative strengths of the E_θ & E_ϕ , we use the axial ratio

$$AR = \frac{|E_\theta|}{|E_\phi|} = \frac{\left(\frac{\eta K |I_0| S \sin \theta}{4\pi r} \right)}{\left(\frac{\eta K^2 (\theta/2)^2 |I_0| \sin \theta}{4r} \right)}$$

$|j| = 1$
 $|e^{-jkr}| = 1$

$$AR = \frac{4S}{\pi K D^2} = \frac{2S\lambda}{(\pi D)^2} = \frac{2S\lambda}{C^2}$$

↳ we can manipulate/vary S & D to achieve essentially any AR (if the above eqn gives a # less than zero, it is $\frac{1}{AR}$ of a polarization ellipse, else it is the AR of a polarization ellipse)

Wheeler coil/helix (after H.A. Wheeler)

$AR=1$ Circular polarization, except at $\theta=0^\circ$ or 180° where there is no radiation

occurs when $C^2 = (\pi D)^2 = 2S\lambda \rightarrow S = \frac{(\pi D)^2}{2\lambda}$

$$\hookrightarrow C = \pi D = \sqrt{2S\lambda}$$

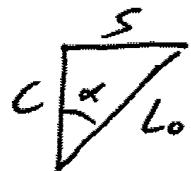
and so

$$\alpha_{cp} = \tan^{-1}\left(\frac{S}{\pi D}\right) = \tan^{-1}\left(\frac{\pi D}{2\lambda}\right)$$

↑
circular polarization

Normal Mode cont.

Alternatively, we can use Pythagorean's rule on the right triangle of Fig. 10-13



$$\begin{aligned} L_0^2 &= C^2 + S_{cp}^2 \quad \rightarrow \text{sub } C = \sqrt{2S\lambda} \\ &= 2S_{cp}\lambda + S_{cp}^2 \\ S_{cp}^2 + 2S_{cp}\lambda + L_0^2 &= 0 \quad \begin{matrix} \text{apply} \\ \downarrow \text{quadratic eqn} \end{matrix} \end{aligned}$$

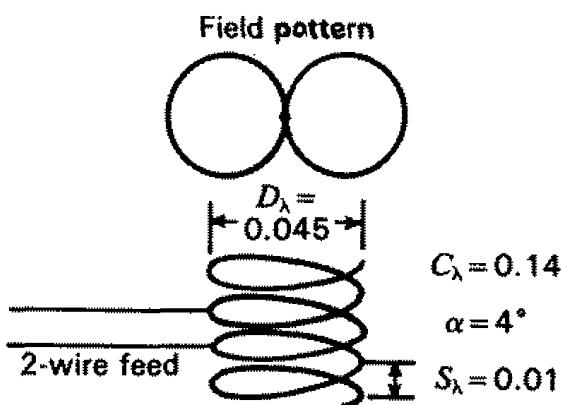
$$S_{cp} = \lambda \left[-1 \pm \sqrt{1 + (L_0/\lambda)^2} \right] \quad \text{choose}$$

$$\sin \alpha_{cp} = \frac{S_{cp}}{L_0}$$

and

$$\alpha_{cp} = \sin^{-1} \left[\frac{-1 + \sqrt{1 + (L_0/\lambda)^2}}{(L_0/\lambda)} \right]$$

$$\text{ex. } \sqrt{2S\lambda} = \sqrt{2(0.01)} = 0.141 = C_\lambda = \pi D_\lambda$$



$$\begin{aligned} \alpha_{cp} &= \tan^{-1} \left(\frac{S}{\pi D} \right) = \tan^{-1} \left(\frac{0.01}{0.141} \right) \\ &= 4.05^\circ \end{aligned}$$

Figure 7-65 Resonant narrowband circularly polarized monofilar normal-mode Wheeler coil. Pattern is that of a short dipole.

[Kraus]

Normal mode cont.

$\alpha \rightarrow 0^\circ$ \rightarrow essentially loop operation w/
horizontal linear polarization ($AR \ll 1$)

$\alpha \rightarrow 90^\circ$ \rightarrow essentially dipole operation w/
vertical linear polarization ($AR \gg 1$)

\Rightarrow The most common application of normal mode
helices is as a compact substitute for a
 $\lambda/4$ monopole over a ground plane or the
Normal Mode helix antenna (NMHA) AKA
Resonant (quarter-wave) stub helix antenna

Set $L_n = NL_0 = \lambda/4$ & $AR \gg 1$ (nearly vertical linear)

Why? * smaller / shorter than $\lambda/4$ monopole
* the inductive nature of a helix can offset
(resonate) the capacitive nature of short
dipoles.
* higher radiation resistance than a short dipole

$$R_g \approx 640 \left(\frac{L}{\lambda} \right)^2 \text{ where } L \text{ is helix height}$$

by comparison a short monopole has radiation
resistance $R_{g,\text{mono}} = \frac{1}{2} R_{g,\text{dipole}} \approx \underline{395 \left(\frac{L}{\lambda} \right)^2} \quad 0 < L < \frac{\lambda}{8}$ (4-108b)
(4-106) $= \underline{1222 \left(\frac{L}{\lambda} \right)^{2.5}} \quad \frac{1}{8} \leq L < \frac{\lambda}{4}$ (4-109b)

Normal mode cont.

ex. NMHA stub helix operating at $\lambda = 34\text{ cm}$ ($f \approx 883\text{ MHz}$) w/ a specified height of $2\text{ in} = 5.08\text{ cm}$ and using 5 turns

$$L_n = \frac{\lambda}{4} = N \sqrt{(\pi D)^2 + S^2} = N \sqrt{(\pi D)^2 + \left(\frac{L}{N}\right)^2}$$

$$\frac{34\text{ cm}}{4} = 5 \sqrt{(\pi D)^2 + \left(\frac{5.08\text{ cm}}{5}\right)^2}$$

$$\hookrightarrow D = 0.43385\text{ cm} = 0.01276\lambda$$

$$S = \frac{5.08\text{ cm}}{5} = 1.016\text{ cm} = 0.02988\lambda$$

$$\alpha = \tan^{-1}\left(\frac{S}{\pi D}\right) = \tan^{-1}\left(\frac{1.016}{\pi(0.43385)}\right)$$

$$\alpha = 36.702^\circ$$

$$AR = \frac{25\lambda}{(\pi D)^2} = \frac{2(1.016)(34)}{(\pi 0.43385)^2}$$

$$\underline{AR = 37.2} \leftarrow \text{nearly vertically linear}$$

$$R_r \approx 640 \left(\frac{L}{\lambda}\right)^2 = 640 \left(\frac{5.08}{34}\right)^2$$

$$\underline{R_r \approx 14.3\Omega} \leftarrow \text{not great but better than } \rightarrow$$

Per (4-109b),

$$R_{r,\text{monopole}} = 1222 \left(\frac{5.08}{34}\right)^{2.5} = 10.5\Omega + \frac{\lambda}{4} = 8.5\text{ cm}$$

(helix 60% of length of monopole)

Axial Mode

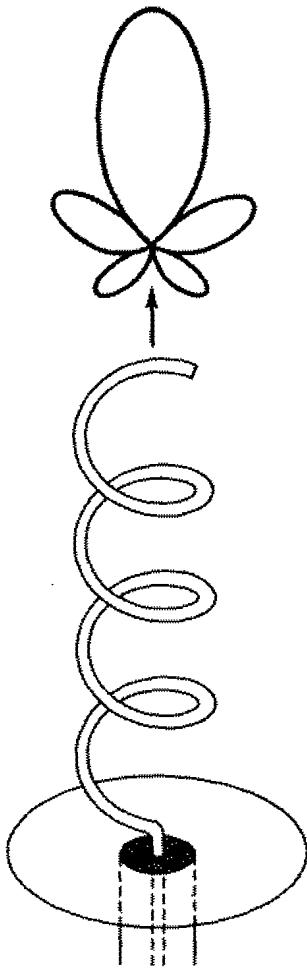


Figure 10.15 Axial (endfire) mode of helix. [Balanis, Second Edition]

- can be thought of as an endfire "supergain" array of loop antennas over a ground plane
- radiates a circularly polarized wave

For axial mode:

- * $\ell/\lambda \sim 1$ best $3/4 \leq \ell/\lambda \leq 4/3$ ✓ Stays in axial mode
↳ $D = \ell/\pi \sim 0.3\lambda$ (Diameter) ↳ $1.7 \text{ to } 1 \text{ BW!}$
- * Pitch angle α usually $12^\circ < \alpha < 14^\circ$ (near optimum)
- * Spacing $S \approx \lambda/4$ $\alpha = \tan^{-1}\left(\frac{S}{c}\right) = \tan^{-1}(0.25) = 14^\circ$
→ S & α inter-related

Axial mode notes cont.

- * Usually, use 4 or more turns, but axial mode operation possible w/ as few as 2 turns
- * Directivity & gain directly related to number of turns
- * Practically, gains up to ~18dBi can be achieved (before losses start to greatly diminish further increases in gain)
- * can be fed axially, peripherally, or via a tap connected along helix
- * helix conductor size/shape not critical. Usually, circular/round wire used where $0.005 \leq \frac{2a}{\lambda} \leq 0.05$
- * Current decays exponentially near feed, then forms traveling wave in middle section, small standing wave at end
- * helix can be self-supporting, wound around a dielectric form, supported by a center post w/ radial supports, ... using a dielectric form or pipe will shift the operating BW lower since $\epsilon_{eff} > \epsilon_0$
- * usually helix used over a ground plane, but reflector rings or wire mesh grid have been used. Some examples are shown in Fig. 7-13
- * Input impedance approximately/nearly resistive

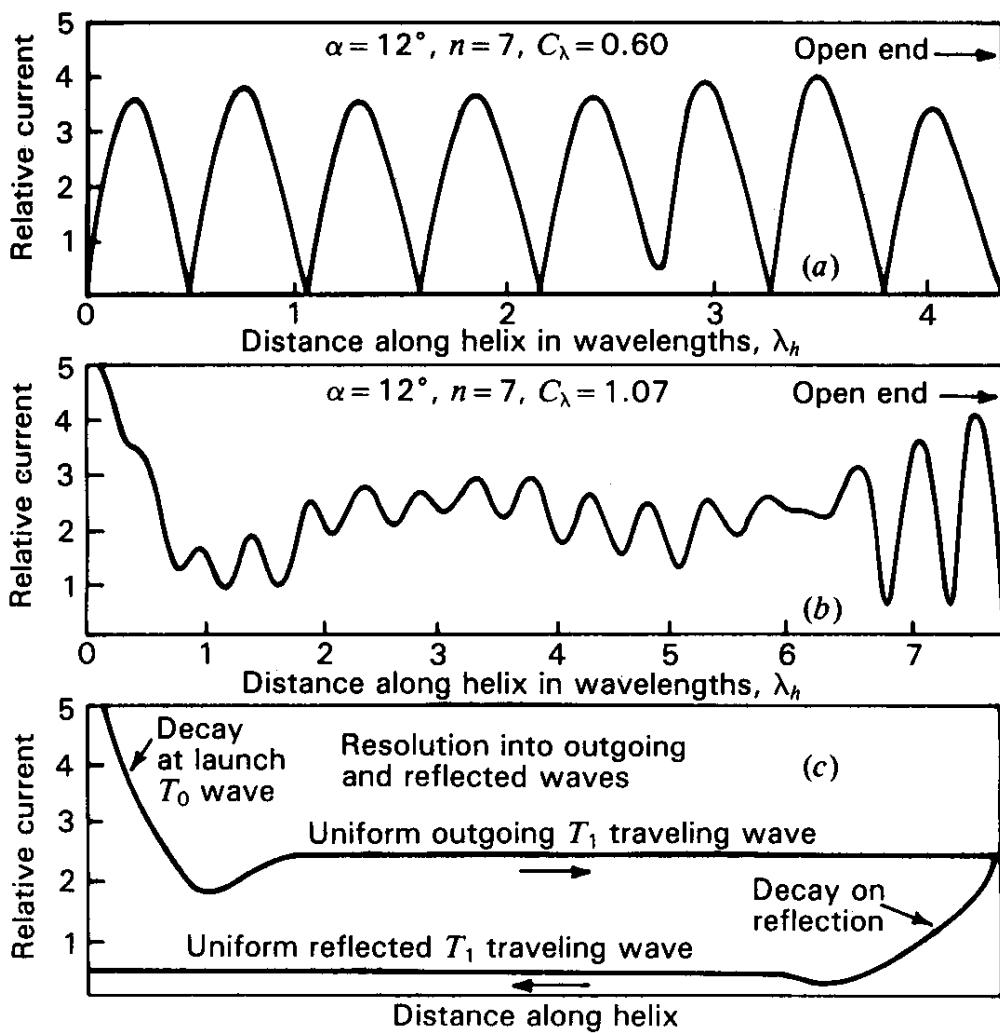


Figure 7-3 Typical measured current distribution (a) at a frequency below the axial mode of operation and (b) at a frequency near the center of the axial mode region. (c) Resolution of currents into outgoing and reflected waves. (From Kraus and Williamson, "Characteristics of Helical Antennas Radiating in the Axial Mode," J. Appl. Phys., 19, 87–96, January 1948.) Compare with distribution on the long, thick cylindrical conductor in Fig. 9-18. [From Antennas (2nd Edition) by Kraus]

- Note the standing wave current distribution for the helical antenna when operating at a frequency below the axial mode (top picture).
- When the helical antenna is operating in the axial mode (middle picture), note how the current magnitude initially falls exponentially near the feed (launching the axial mode radiation), stabilizes into a relatively constant traveling wave distribution in the middle of the helix, and has a standing wave current distribution near the open end of the helix.

Axial mode cont.

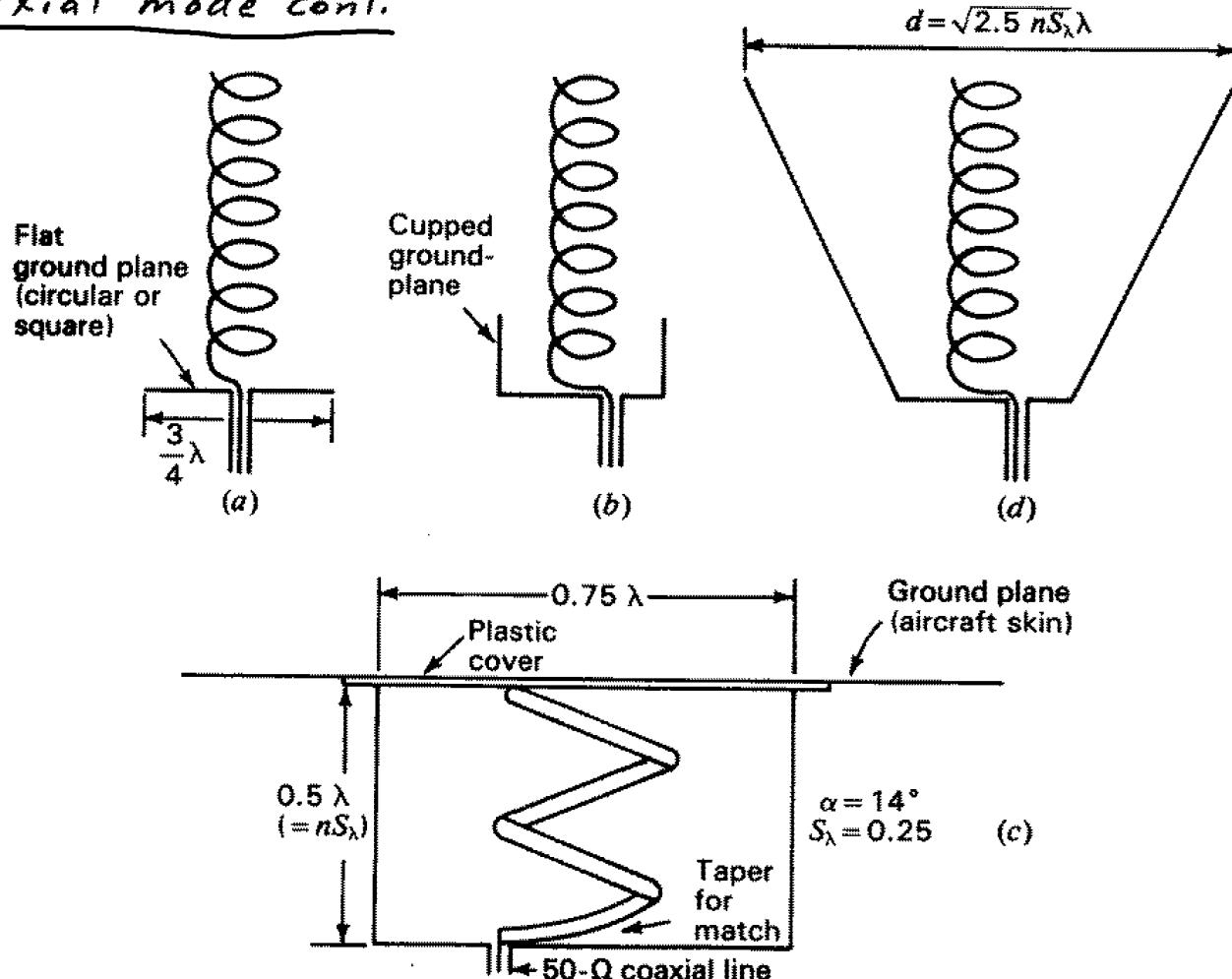


Figure 7-13 (a) Monofilar axial-mode helical antenna on flat ground plane and (b) in shallow cupped ground plane (see also Fig. 7-16c). (c) General-purpose flush-mounted 2-turn monofilar axial-mode helical antenna with taper feed for matching to a 50-Ω coaxial line (after Bystrom and Bernstein, ref. 1, p. 277) (see also Fig. 7-16a and b). (d) Deep conical ground-plane enclosure for reducing side and back lobes. (After K. R. Carver, ref. 2, p. 277). [Kraus, Antennas (Second Edition)]

Axial Feed input resistance (empirical)

$$R = 140 \frac{\epsilon_1}{\lambda} \pm 20\%$$

Peripheral Feed input resistance (empirical)

$$R \approx \frac{150}{\sqrt{\epsilon_1}} \pm 10\%$$

* Good for $N \geq 4$, $0.8 \leq \epsilon_1 \leq 1.2$, $+12^\circ \leq \alpha \leq 14^\circ$

Axial mode cont.

Over the usual $\frac{3}{4} < \frac{c}{\lambda} < \frac{4}{3}$ range, we can thus have

$$100 \leq R_{\text{axial}} \leq 190 \text{ mm}$$

$$130 \leq R_{\text{peripheral}} \leq 175 \text{ mm}$$

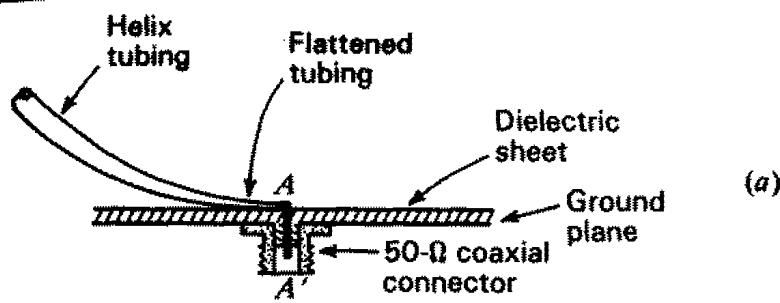
This presents a problem as we usually will drive a helix through a ground plane w/ a coaxial transmission line.

Options:

- A) Taper last $\frac{1}{4}$ turn of helix to gradually make it parallel to ground plane w/ a dielectric slab of height h and relative permittivity ϵ_r used as a spacer (see Figure 7-16) where the helix tubing is either flattened to a width w or the helix conductor is soldered to a flat plate/metal strip of width w .

$$h = \frac{w}{\left(\frac{2}{\sqrt{\epsilon_r} Z_0} \right) - 2}$$

Axial Mode cont.



Detailed cross-section through AA' as seen from right.

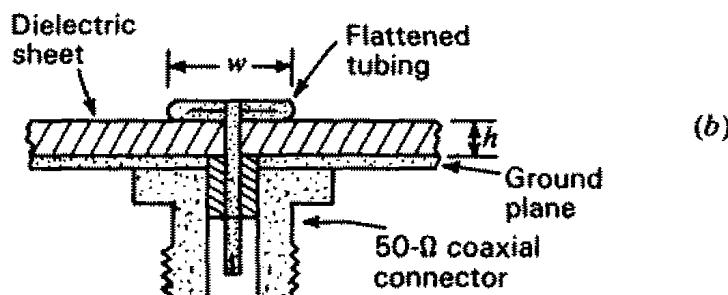
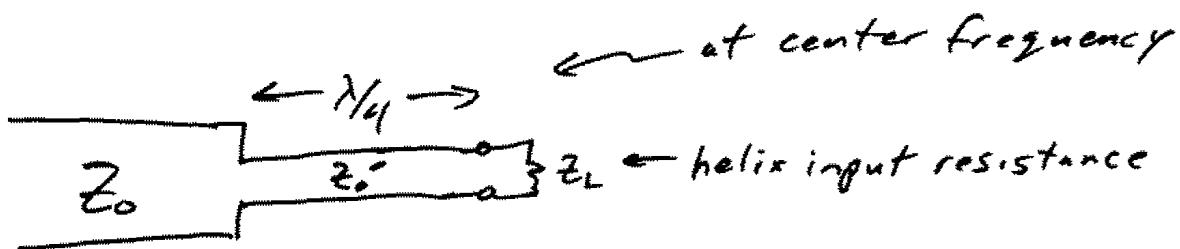


Figure 7-16 (a) Gradually tapered transition from helix to coaxial line with detailed cross section at (b).

[Kraus, Antennas (Second Edition)]

- B) Another possibility (w/ peripheral feed) is to use a $\lambda/4$ transformer or another type of microstrip impedance transformer



$$Z_0' = \sqrt{Z_0 Z_L}$$

Both options will decrease the BW of the helix (wrt VSWR or impedance being acceptable)

Axial Mode cont.Radiation Pattern & Beamwidth

→ Rather than input impedance/vswr, the factor that limits the useful frequency range of the axial-mode helical antenna is the radiation pattern. This is illustrated in Fig 7-19.

\leftarrow Normal mode

\rightarrow conical mode

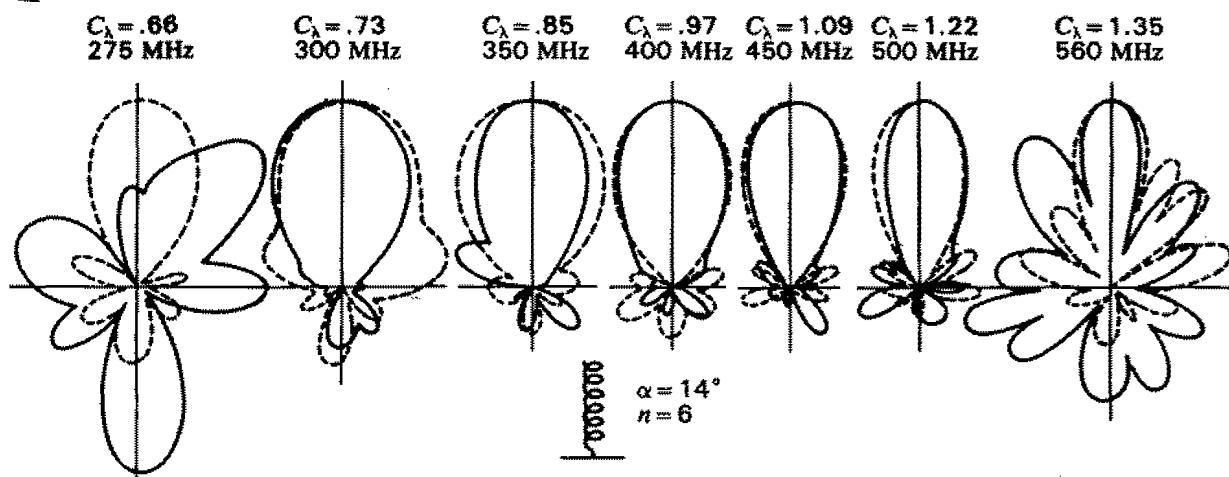


Figure 7-19 Measured field patterns of monofilar axial-mode helical antenna of 6 turns and 14° pitch angle. Patterns are characteristic of the axial mode of radiation over a range of circumferences from about 0.73 to 1.22λ . Both the circumference and the frequency (in megahertz) are indicated. The solid patterns are for the horizontally polarized field component (E_ϕ) and the dashed for the vertically polarized (E_z). Both are adjusted to the same maximum. (After Kraus.) [Kraus, Antennas (Second Edition)]

Note: The radiation pattern is characteristic of the axial mode for $0.73 \leq C_\lambda \leq 1.22$

From empirical measurements by Kraus et al in 1948-49 time frame

$$\text{HPBW (deg)} = \frac{52 \lambda^{3/2}}{C \sqrt{N} S}$$

Half-power
Beamwidth

$$\text{FNBW (deg)} = \frac{115 \lambda^{3/2}}{C \sqrt{N} S}$$

First-Null
Beamwidth

Axial mode cont.

Fig 7-21 illustrates what happens to the HPBW wrt C/λ as well as NS & N

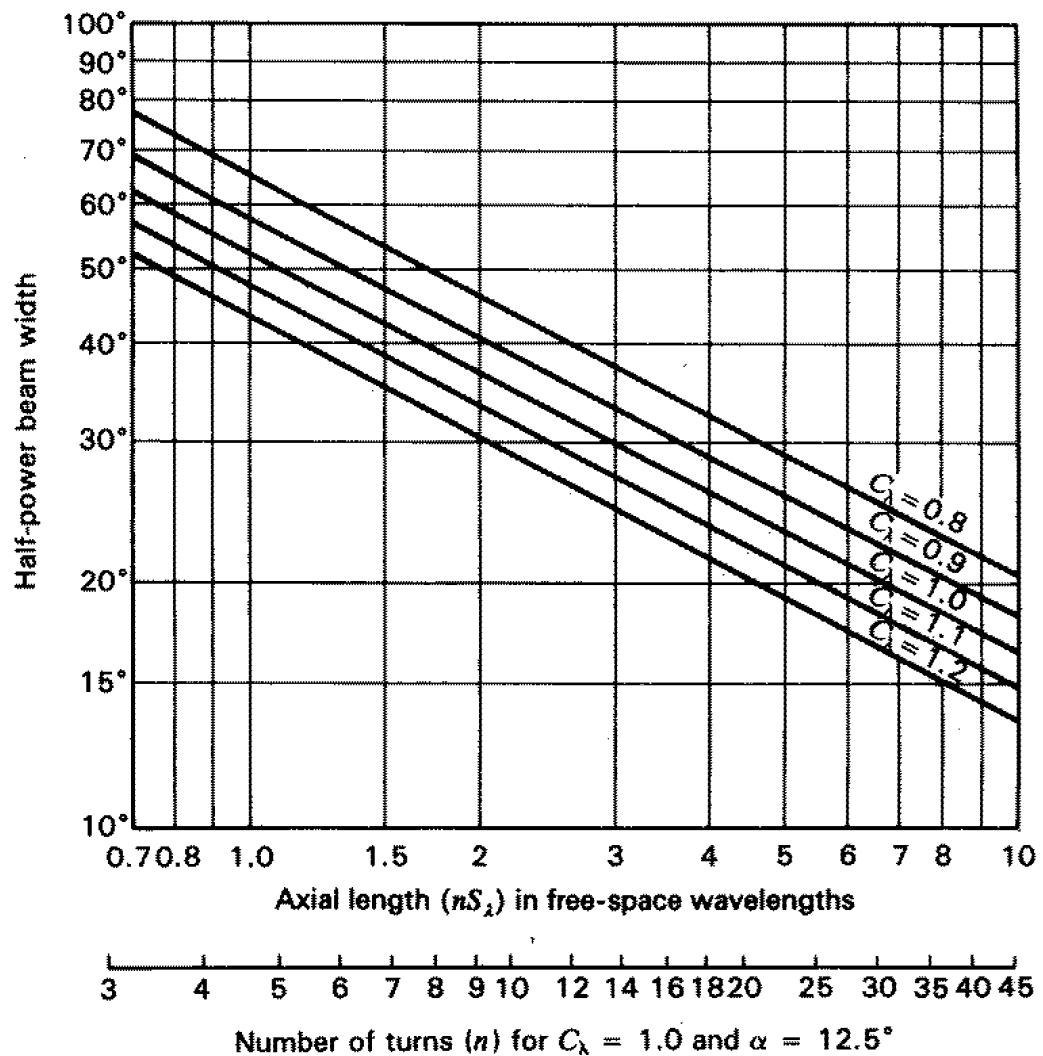


Figure 7-21 Half-power beam width of monofilar axial-mode helical antenna as a function of the axial length and circumference in free-space wavelengths and also as a function of the number of turns for $C_\lambda = 1.0$ and $\alpha = 12.5^\circ$ (lower scale). (After Kraus.) [Kraus, Antennas (Second Edition)]

Directivity

→ closely related to the HPBW is the directivity

In Chap 2, we had the approx. $D_0 \approx \frac{41,253}{\theta_{1d} \theta_{2d}}$

which, using the HPBW eqn, leads to

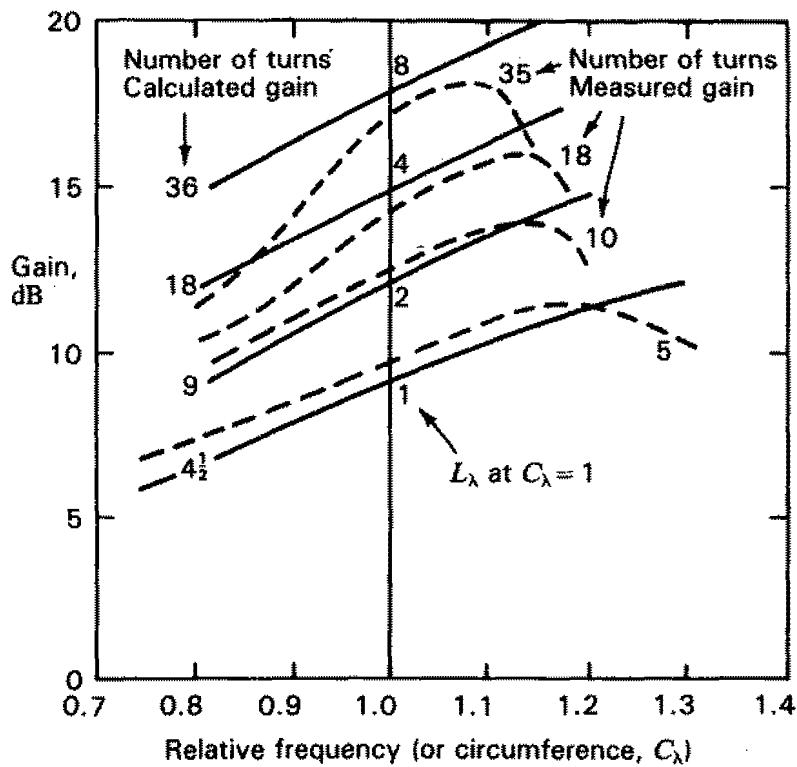
$$D_0 \approx 15 N \frac{C^2 S}{\lambda^3} \quad (\text{dimensionless})$$

Axial Mode cont.

However, according to Kraus, a better approx. is

$$\theta_0 \approx 12N \frac{C^2 S}{\lambda^3} \quad (\text{dimensionless})$$

to account for the effects of side lobes & other radiation pattern shape details. Fig 7-22 illustrates the above eqn as well as measured gains



Assume
 $G \approx D$
for axial mode
helices.

Figure 7-22 Measured (dashed) gain curves of monofilar axial-mode helical antennas as a function of relative frequency for different numbers of turns for a pitch angle of $\alpha = 12.8^\circ$. (After H. E. King and J. L. Wong, "Characteristics of 1 to 8 Wavelength Uniform Helical Antennas," IEEE Trans. Ants. Prop., AP-28, 291, March 1980.) Calculated (solid) gain curves are also shown for different numbers of turns. [Kraus, Antennas (Second Edition)]

- Notes : → get higher gains / directivities w/ bigger N
- trade-off narrower bandwidth
- peak measured gain at $C/\lambda = 1.1$ to 1.2
- measured results tended to be 1dB low due to how exp. helices were built

Axial mode cont.

Axial Ratio (AR)

→ measure of how good the circular polarization
is considered to be on axis

$$AR = \frac{2N+1}{2N}$$

as illustrated below
in Fig 7-38 for $N=7$

The equations for HPBW, FNBW, θ_0 , R , + AR are
good for $12^\circ < \alpha < 14^\circ$, $N > 3$, + $0.8 \leq \gamma_1 \leq 1.15$ (cmas)

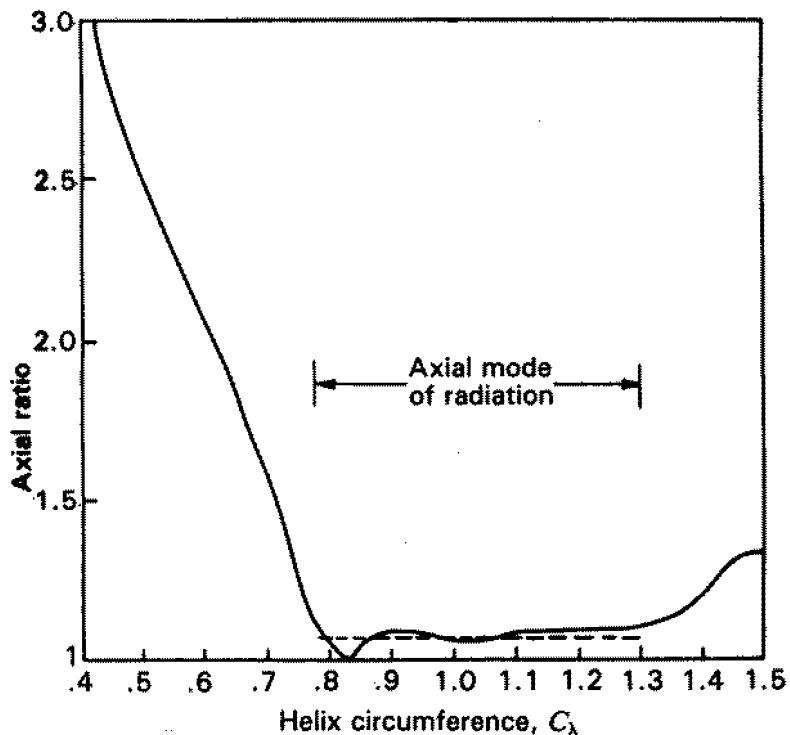


Figure 7-38 Axial ratio as a function of helix circumference C_λ for a 13° , 7-turn monofilar axial-mode helical antenna. The dashed curve is from (17). (After Kraus.)
[Kraus, Antennas (Second Edition)]

Fig 7-23 shows the HPBW, AR, vswr, R , + X for a $N=6$, $\alpha=14^\circ$ helical antenna

Axial Mode cont.

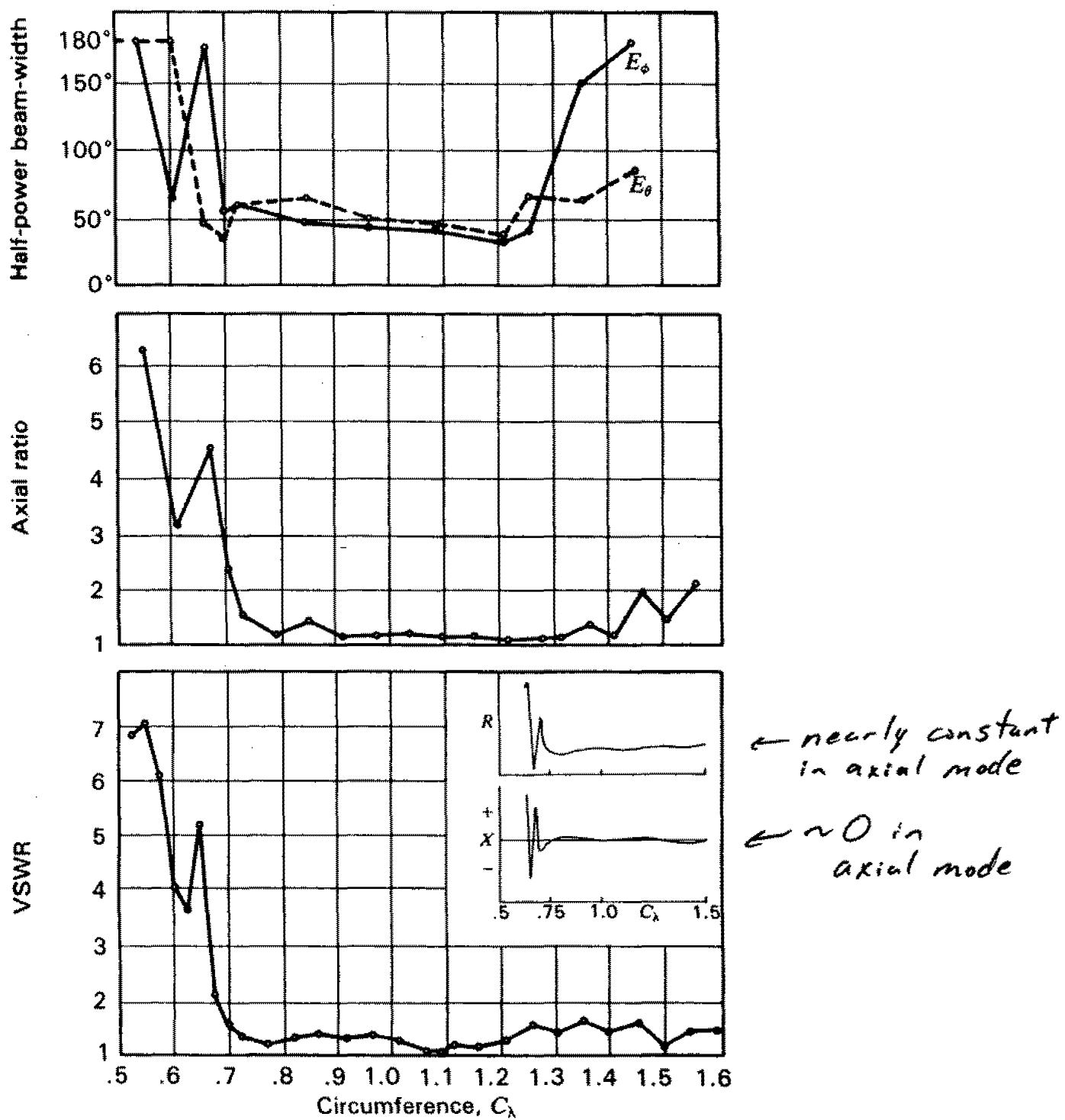


Figure 7-23 Summary of measured performance of 6-turn, 14° monofilar axial-mode helical antenna. The curves show the HPBW for both field components, the axial ratio and the VSWR on a 53- Ω line as a function of the relative frequency (or circumference C_λ). Trends of (relative) resistance R and reactance X are shown in the VSWR inset. Note the relatively constant R and small X for $C_\lambda > 0.7$. (After Kraus.) [Kraus, Antennas (Second Edition)]

Axial Mode cont.

- * Fig 7-39 shows how the helix dimensions relate to various performance attributes (Z , AR, Rad. Pattern)
- * To get good overall performance, do an "AND" operation
- * Good conditions: $AR < 1.25$, $R \approx \text{constant} + \text{real}$, Rad.Patt. \rightarrow Axial mode
- * Optimum α chosen for maximum bandwidth $12^\circ \leq \alpha \leq 14^\circ$

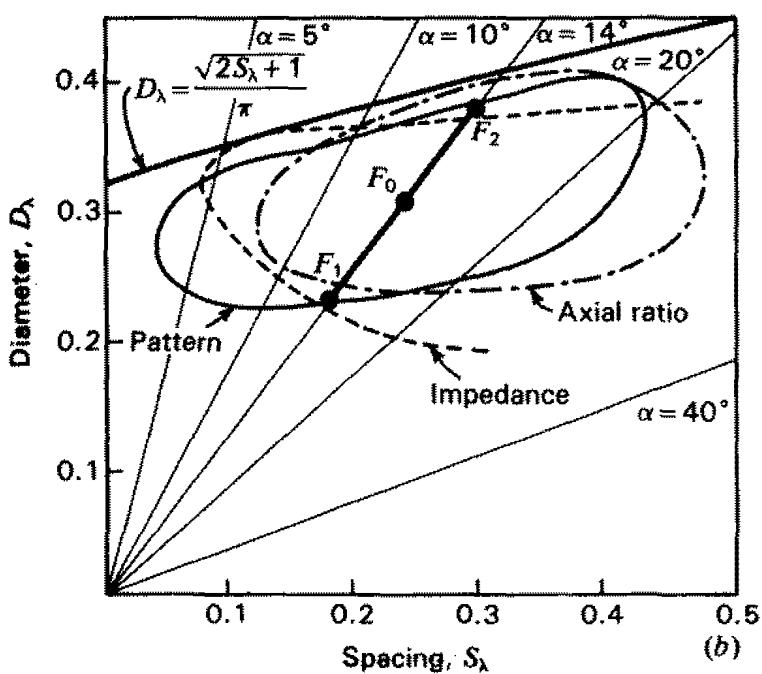
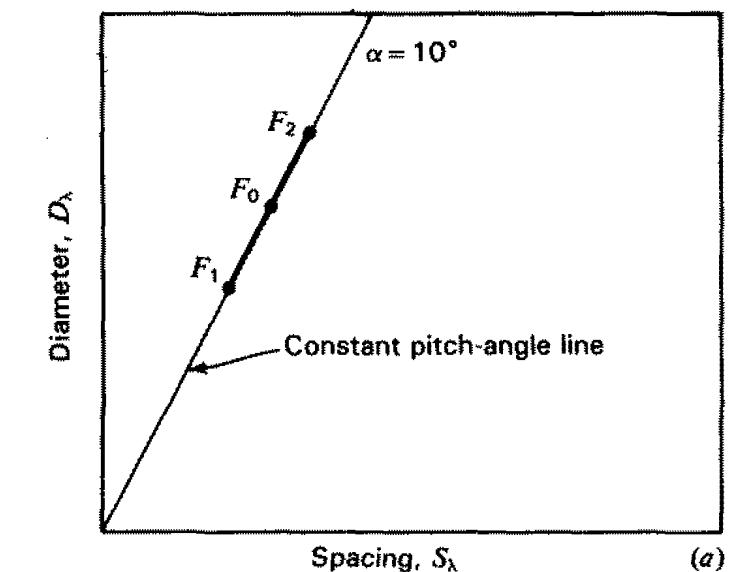


Figure 7-39 Diameter-spacing charts for monofilar helices with measured performance contours (b) for the axial mode of radiation.
[Kraus, Antennas (Second Edition)]

Axial Mode cont.

Ex. Say that a helix is constructed w/ the following dimensions: $L = 1\text{m}$, $D = 15\text{cm}$, and $N = 9$. Analyze some properties of this helix.

$$\alpha = \tan^{-1}\left(\frac{s}{\pi D}\right) \quad \text{where } s = \frac{L}{N} = \frac{1}{9} \text{ m}$$

$$= \tan^{-1}\left(\frac{\frac{1}{9}}{\pi(0.15)}\right) \quad \frac{s}{\lambda_c} = \frac{\frac{1}{9}}{0.47124} = 0.2358$$

$$\underline{\alpha = 13.2672^\circ}$$

Axial mode $C \approx \lambda_c = \pi D = \pi(0.15) = 0.47124\text{m}$
 (@ center freq)

$$f_{\text{center}} = \frac{C}{\lambda} = \frac{2.998 \times 10^8}{0.47124} = \underline{\underline{636.2 \text{ MHz}}}$$

$$\text{Est. low freq. } f_{\text{low}} \approx 0.75 f_c = 477 \text{ MHz}$$

$$\text{Est. high freq. } f_{\text{high}} \approx 1.3 f_c = 827 \text{ MHz}$$

\Rightarrow UHF TV Band:

@ f_c

$$HPBW = \frac{52 \lambda^{3/2}}{C \sqrt{NS}} = \frac{52 (0.47124)^{3/2}}{\pi 0.15 \sqrt{9(\frac{1}{9})}} = \underline{\underline{35.7^\circ}}$$

$$FNBW = \frac{115 \lambda^{3/2}}{C \sqrt{NS}} = \frac{115 (0.47124)^{3/2}}{\pi 0.15 \sqrt{9(\frac{1}{9})}} = \underline{\underline{78.9^\circ}}$$

$$\theta_0 = 12N \frac{C^2 S}{\lambda^3} = 12(9) \frac{(0.15\pi)^2 (\frac{1}{9})}{(0.47124)^3} = \underline{\underline{25.465 = 14.06 \text{ dB};}}$$

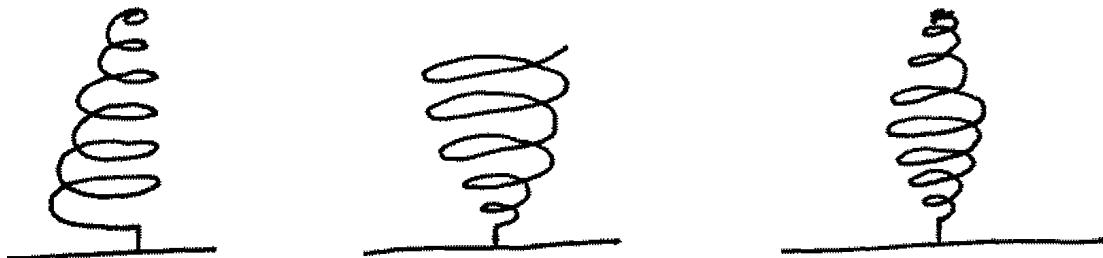
$$AR = \frac{2N+1}{2N} = \frac{2(9)+1}{2(9)} = \underline{\underline{1.05}}$$

Applications of Helical Antennas

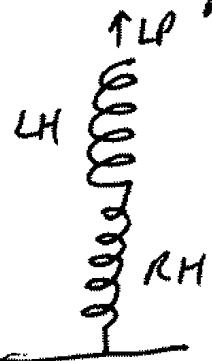
- space communications, often helix used to feed parabolic dish
- radio telescope
- arrays (low cross talk)
- can be used as a parasitic element or lens to change polarization from linear to circular etc.

Variations on Helical Antenna

- tapered helix for wider bandwidth



- directive linear polarized antenna



- No ground plane helix

