Broadband Quasi-Taper Helical Antennas

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A unique approach is described for widening the bandwidth of a helical antenna with improved gain, pattern, and axial ratio characteristics. The antenna may be described as a non-uniform or quasi-taper helix, which consists of a combination of uniform and tapered helix sections. Measured patterns, gain, axial ratio, and VSWR for various helical antenna configurations are presented and compared. It is shown that a non-uniform, quasi-taper helix can provide an operating bandwidth twice that of a conventional uniform-diameter helix.

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PREFACE

The authors wish to thank the FLTSATCOM Program Office, especially H. F. Meyer, Director, and P. J. Parszik for their interest and support of this antenna development. Thanks also go to G. G. Berry, L. U. Brown, H. B. Dyson, B. A. Jacobs, O. L. Reid, and J. T. Shaffer for constructing and testing of the various antennas.

CONTENTS

FIGURES

I. INTRODUCTION

Helical antennas are generally constructed with a uniform diameter [Ref. 1] or a tapered diameter [Refs. 2, 3]. The helical gain characteristics over a wide bandwidth are not readily available in the literature. The purpose of this report is to describe the characteristics of a non-uniform helix and to demonstrate how the bandwidth of a conventional uniform (constant diameter) helix can be extended by the use of non-uniform helical structures. The non-uniform helix consists of multiple uniform-diameter helical sections that are joined together by short, tapered transitions. With a non-uniform helix, it is possible to shape the gain vs frequency response to provide either enhanced gain at selected frequencies or a near-flat gain response over a broad bandwidth.

The non-uniform helix antenna was developed for operation in the 290 to 400 MHz band (~ 1.4:1 frequency ratio) with optimum gain characteristics at the low-frequency end. A conventional helix, which provides an effective operating bandwidth of approximately 25%, could not meet the desired gain performance characteristics. This report describes the results of 3/8-scale (773 to 1067 MHz) experiments made on a variety of helix antenna configurations including uniform, tapered, and non-uniform diameters.

II. GENERAL DESCRIPTION

Most of the experimental helices were wound with thin copper strips 0.468-in. wide. The plane of the strip (wide dimension of strip) was wound orthogonal to the helix axis, similar to a "slinky". Helices wound with round conductors or with metallic tapes (wound such that the plane of the tape is parallel to the helix axis) yielded similar results as experimentally verified by the authors. The "strip" approach was chosen because of mechanical convenience and ease of construction. It was found that an accurate helix could be made by properly joining a series of loops. The mean circumference of each loop was made equal to the length of one helical turn or, equivalently, the mean diameter of each loop was made equal to $\sqrt{D_M^2 + (S/\pi)^2}$, where D_M is the mean diameter of the helix and S is the spacing between turns (pitch). In the tapered portions of the helix the average taper diameter of each turn was selected for D_M. Styrofoam forms were cut to the desired mean helix diameter and slitted with a razor blade to the desired helical path. Each loop was joined end-to-end (butt joint) and soldered together with an overlapping strap. The loops are then inserted into the slitted foam.

A constant pitch spacing of 3.2 in. was selected, although a constant angular pitch provides similar electrical characteristics as verified by experiments (by the authors). The helix was backed by a cavity, 11.25-in. diameter × 3.75-in. high, which is a reasonable physical size, to reduce backlobe radiation and enhance the forward gain. A metallic center tube (1.125-in. diameter), which provided mechanical support, was used in all the helix models. The total length of the helix = NS + L_F, where N = number of helix turns at a spacing S, and L_F = feed strap length (the distance above the cavity plate where the first turn of the helix starts).

III. VSWR CHARACTERISTICS

The VSWR of all the antennas discussed herein is less than 1.5:1 over the test frequency range from 650 to 1100 MHz (except for the uniform helix) when a microstrip matching transformer is used. The transformer is placed on the cavity surface and it is tapered from 50 ohm at the coax input port to approximately 140 ohms at the helix feed point.

The solid-line curve of Fig. 1 is for a 18-turn uniform helix with a 4.59-in. diameter and a 12.5° pitch angle (3.2-in. spacing between turns). By tapering the last two turns to a 2.98-in. diameter and maintaining a 3.2-in. spacing between turns, the dashed-line curve shows a considerable improvement in VSWR. The resonant region ($C/\lambda > 1.1$) found in the uniform helix disappeared in the tapered-end helix. The VSWR characteristics for all the non-uniform helices in the subsequent discussions are similar to that of the tapered-end helix curve.

The characteristic change in VSWR by tapering the end also holds for a shorter helix as shown in Fig. 2. The solid-line curve is for a 7-turn uniform helix with a 5.28 in. diameter and a 10.92° pitch angle (3.2-in. spacing between turns). By adding two additional turns and tapering the helix diameter to 4.13-in. diameter (with the same 3.2-in. spacing between turns), a significant reduction in VSWR over a wide frequency band was observed as shown by the dashed curve. Also, it is noted that the low frequency characteristics are essentially unchanged with a cutoff at ~ 534 MHz, corresponding to $C/\lambda \sim 0.75$, where C is the circumference of the 5.28-in. diameter helix. The low frequency cutoff characteristics agree well with theoretical predictions [Refs. 1, 4 - 6].

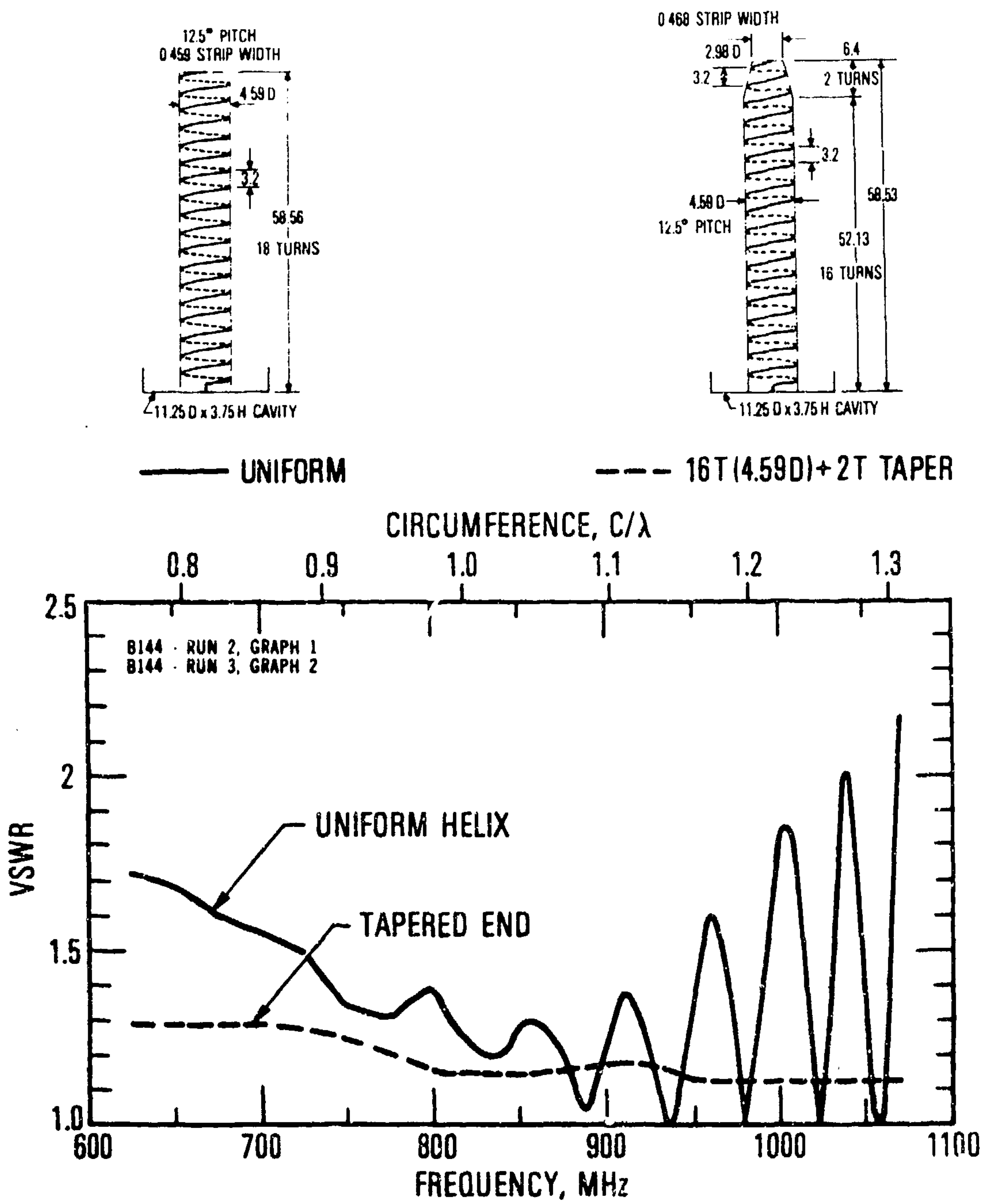

Fig. 1. VSWR of Two 18-Turn Helices: Uniformly Wound and Last Two Turns Wound on a Tapered Diameter

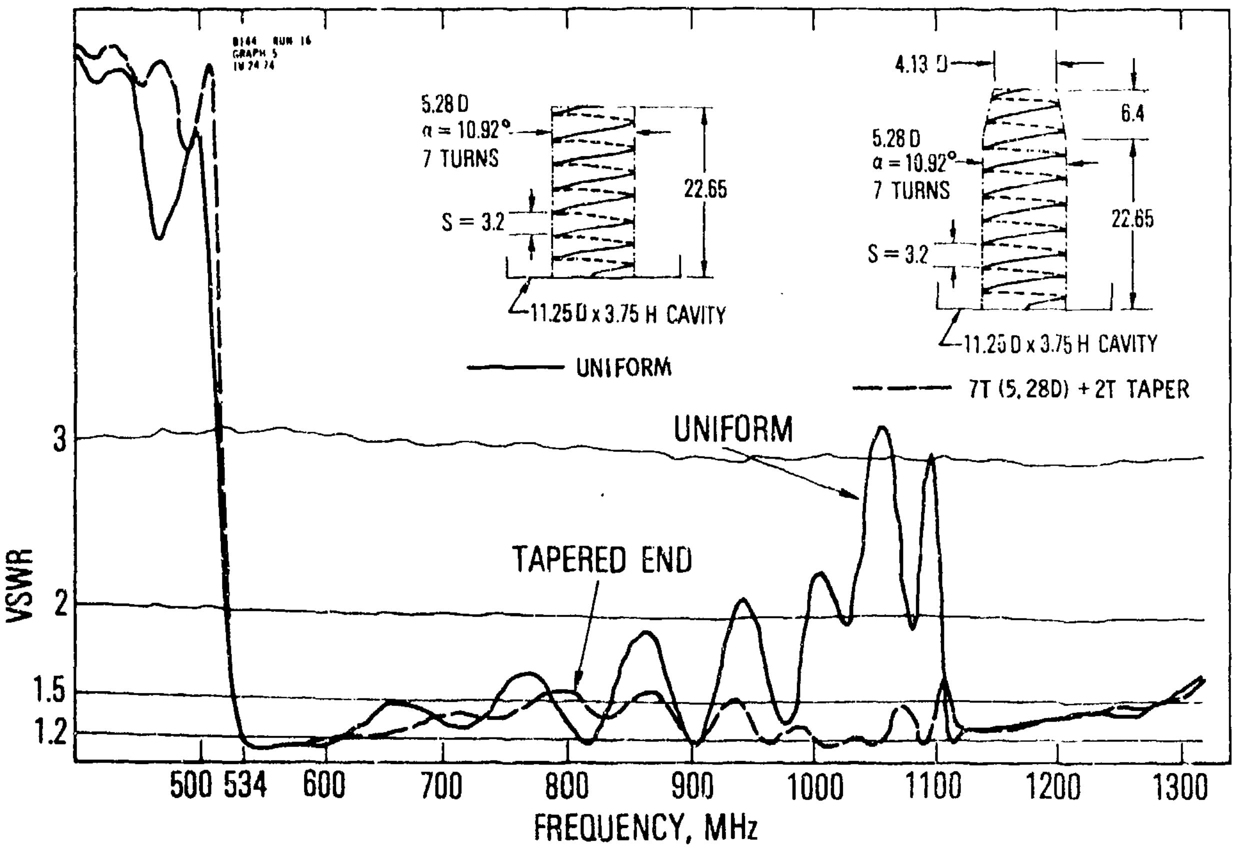

Fig. 2. VSWR of a Seven-Turn Uniform Helix and the Same Helix with Two Additional Turns on a Tapered Diameter

IV. PATTERNS AND GAIN

A. UNIFORM HELIX

Figure 3 shows the gain and axial ratio characteristics of a 18-turn uniformly wound helix, 4.59-in. diameter. By defining the bandwidth as the 2 dB points (from gain maximum) of the gain curve, the frequency ratio becomes 970/770 or 1.26:1. Also, note that for $C/\lambda < 1$ the gain slope varies approximately as f^4, where f = frequency. Representative patterns using a rotating linearly polarized source are shown in Fig. 4. The half-power beamwidths (HPBW) and the gain-beamwidth products ($G\theta^2$, where θ = HPBW) are shown in Fig. 5. Note that the HPBW is approximately inversely proportional to f^2 for $C/\lambda < 1.1$ while the gain is proportional to f^4 for $C/\lambda < 1.0$. (It should be pointed out that Kraus [Ref. 1] shows that the gain slope varies as f^3 and the HPBW varies as $f^{3/2}$.) Patterns are shown for only one principal plane as the measurements indicated that the patterns have good symmetry in azimuth. The HPBW in two orthogonal planes are generally within $\pm 0.25^\circ$.

B. TAPERED-END HELIX

By tapering the last two turns from 4.59-in. to 2.98-in. diameter, while maintaining the same overall length, an improvement in axial ratio [Ref. 7] was observed as compared to a completely uniform helix. Comparison between Fig. 3 and Fig. 6 reveals that the axial ratio characteristics of the tapered-end helix are improved and with some increase in gain at the high end of the frequency band but the peak gain is reduced slightly. Figure 7 shows the radiation patterns for the tapered-end helix. The same frequencies are chosen so that the patterns can be compared with those of the uniform helix of Fig. 4. Except for the axial ratio, the patterns are generally similar to those of the uniform helix. For interest, the HPBW and gain-beamwidth products of the 18-turn tapered-end helix are plotted in Fig. 8.

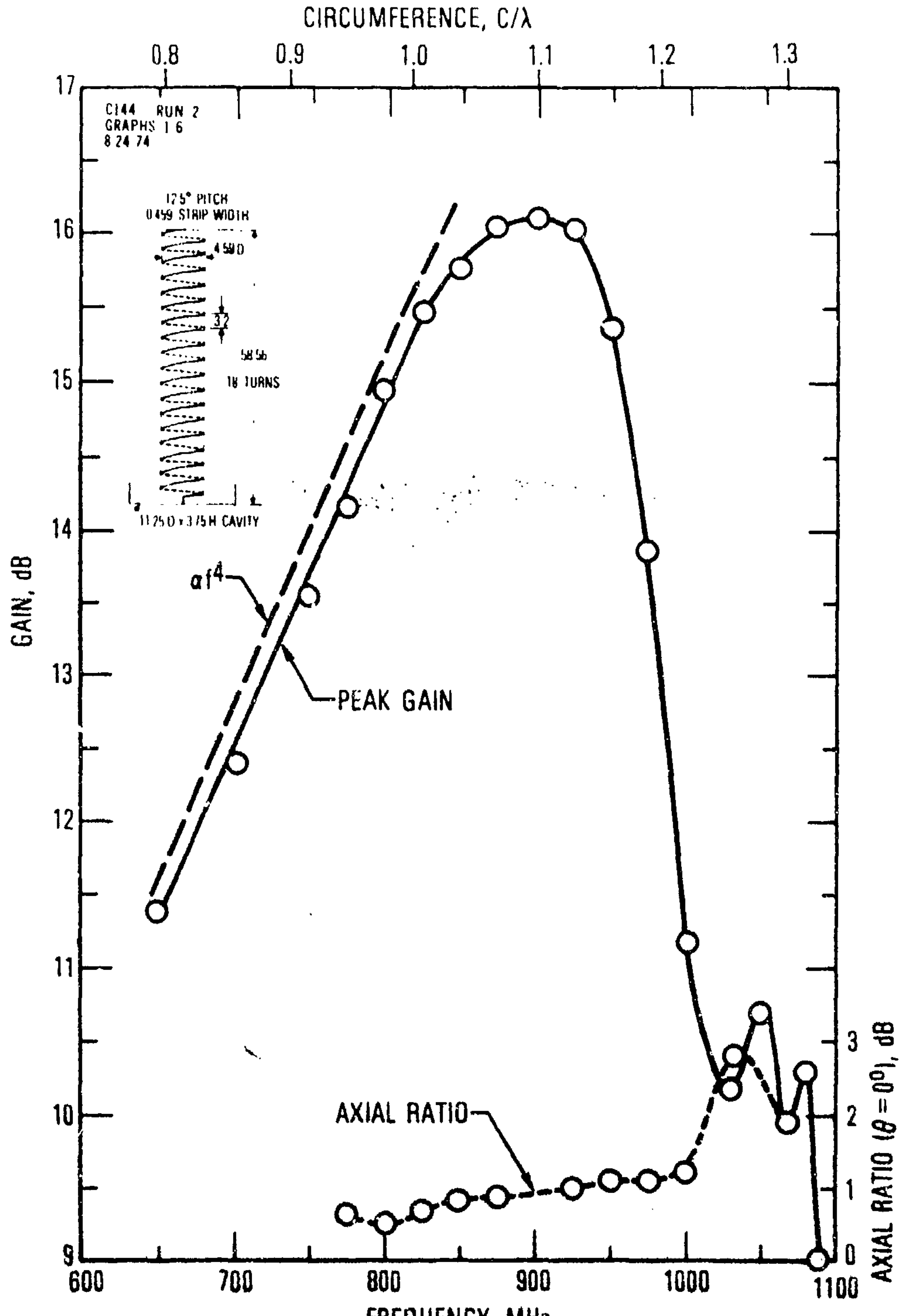

Fig. 3. Gain and Axial Ratio Characteristics of a Conventional Uniformly Wound 18-Turn Helix

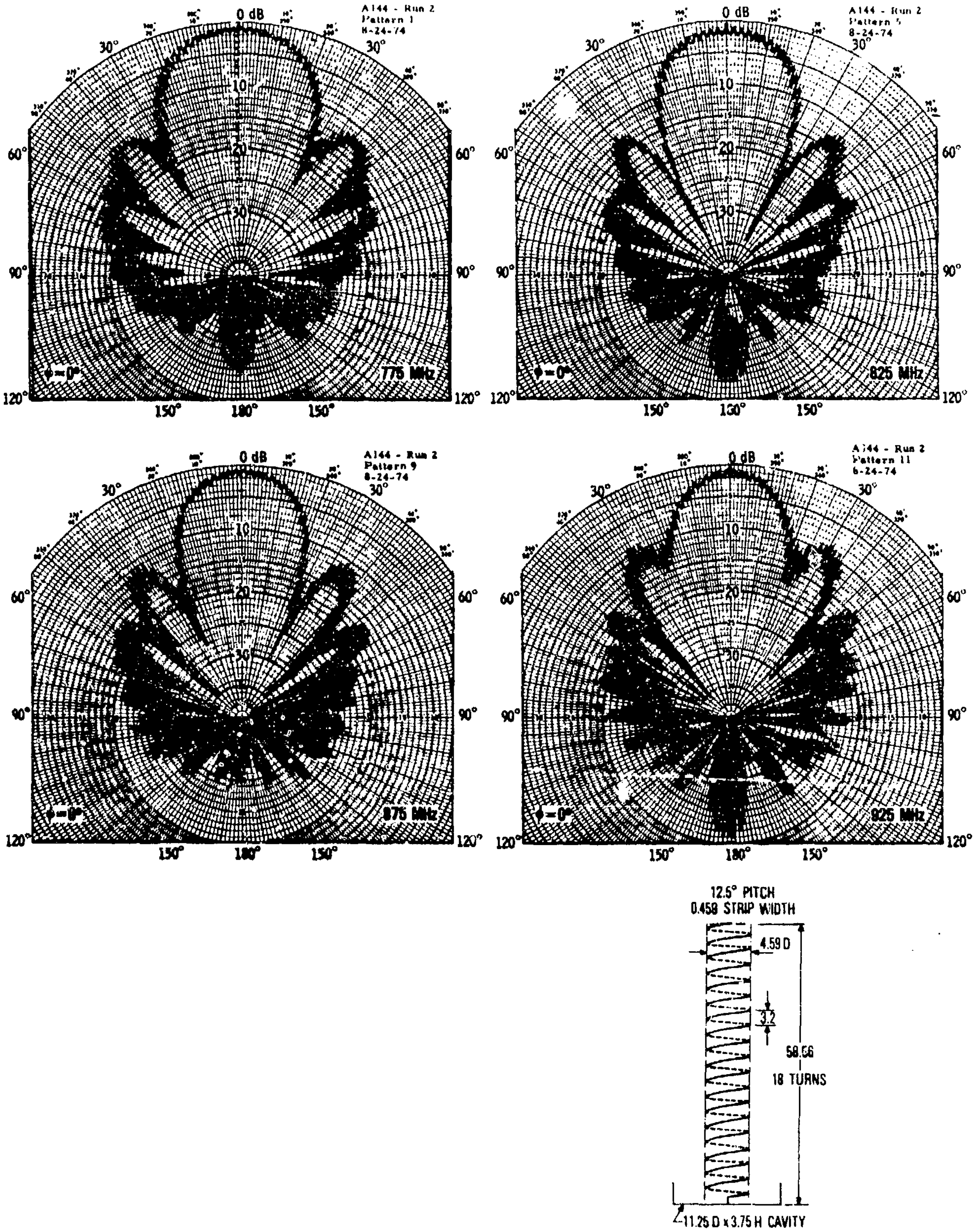

Fig. 4. Radiation Patterns of an 18-Turn Uniform Helix

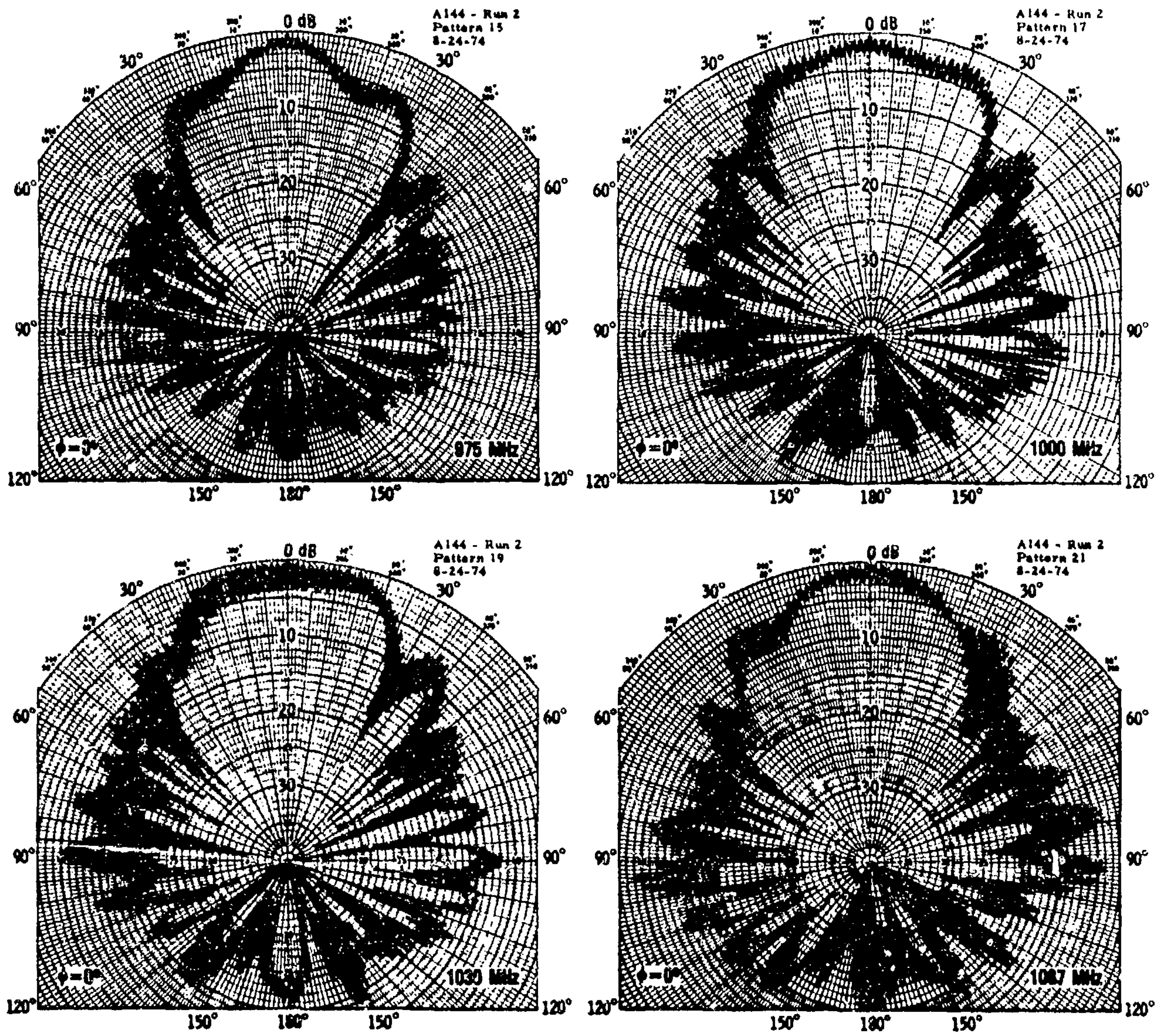

Fig. 4. Radiation Patterns of a 18-Turn Uniform Helix (Continued)

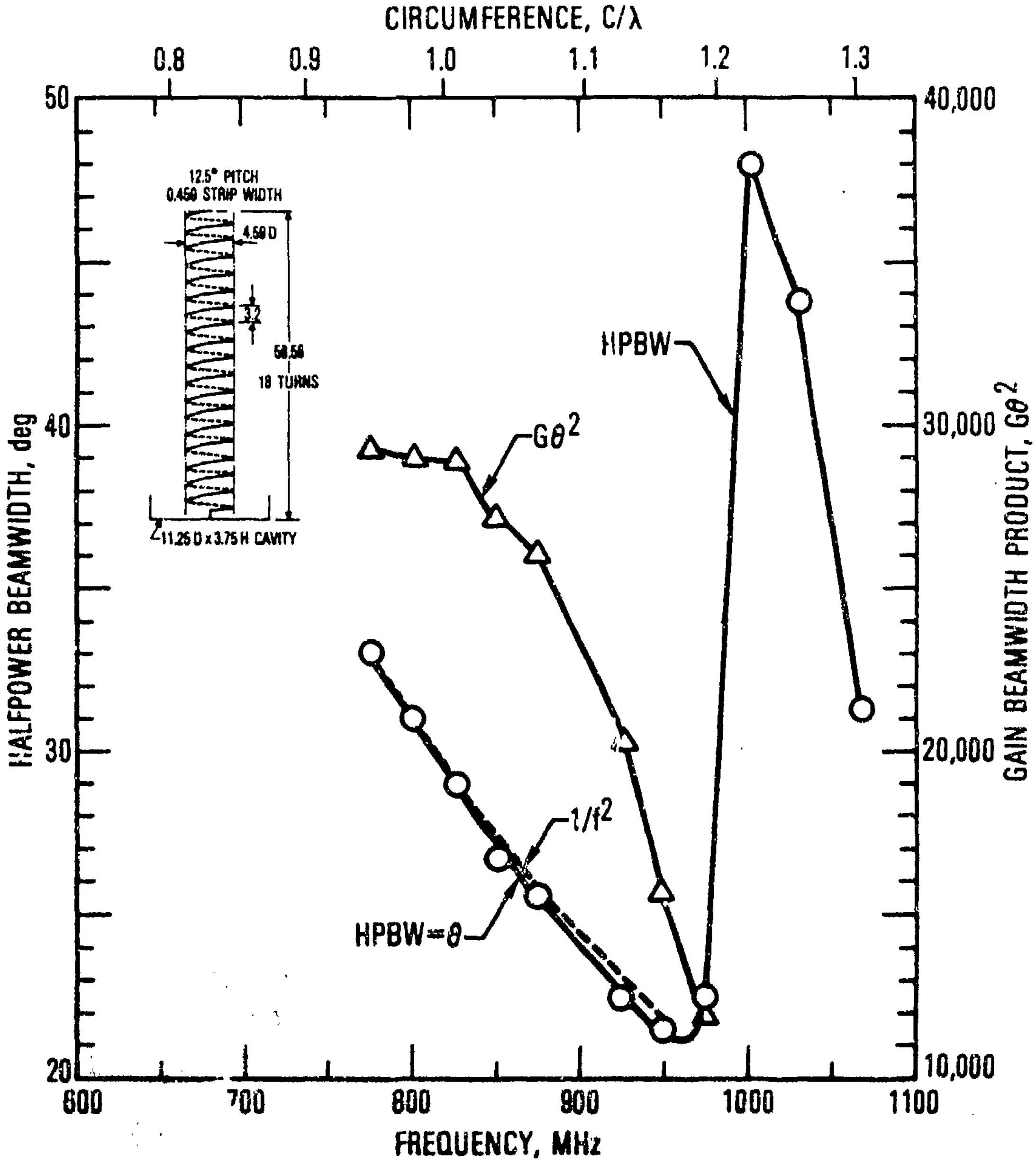

Fig. 5. Halfpower Beamwidth and Gain-Beamwidth Product of an 18-Turn Uniformly Wound Helix

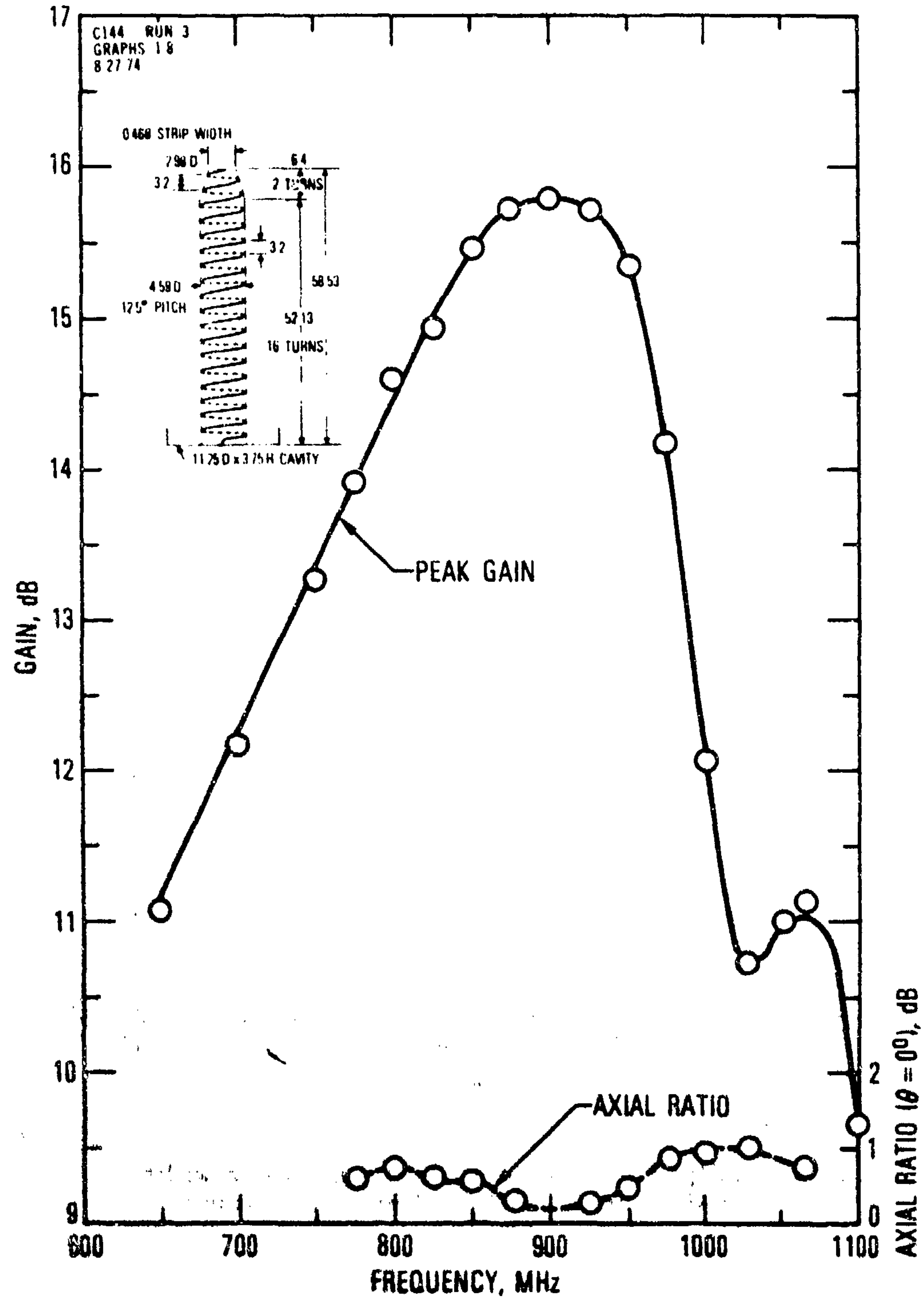

Fig. 6. Gain and Axial Ratio Characteristics of an 18-Turn Uniformly Wound Helix with a Two-Turn Tapered-End Section

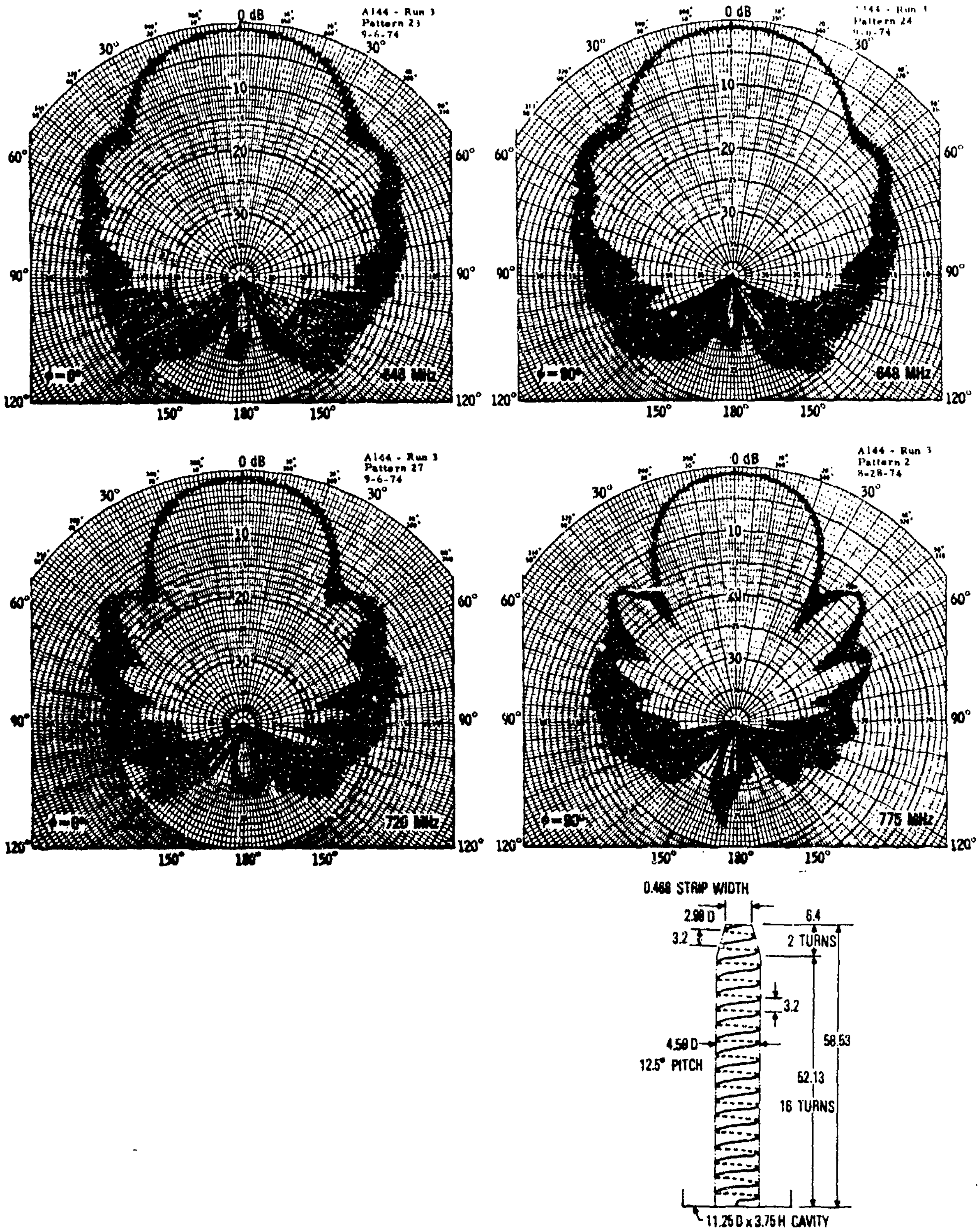

Fig. 7. Radiation Patterns of an 18-Turn Uniform Helix with a Two-Turn Tapered End Section

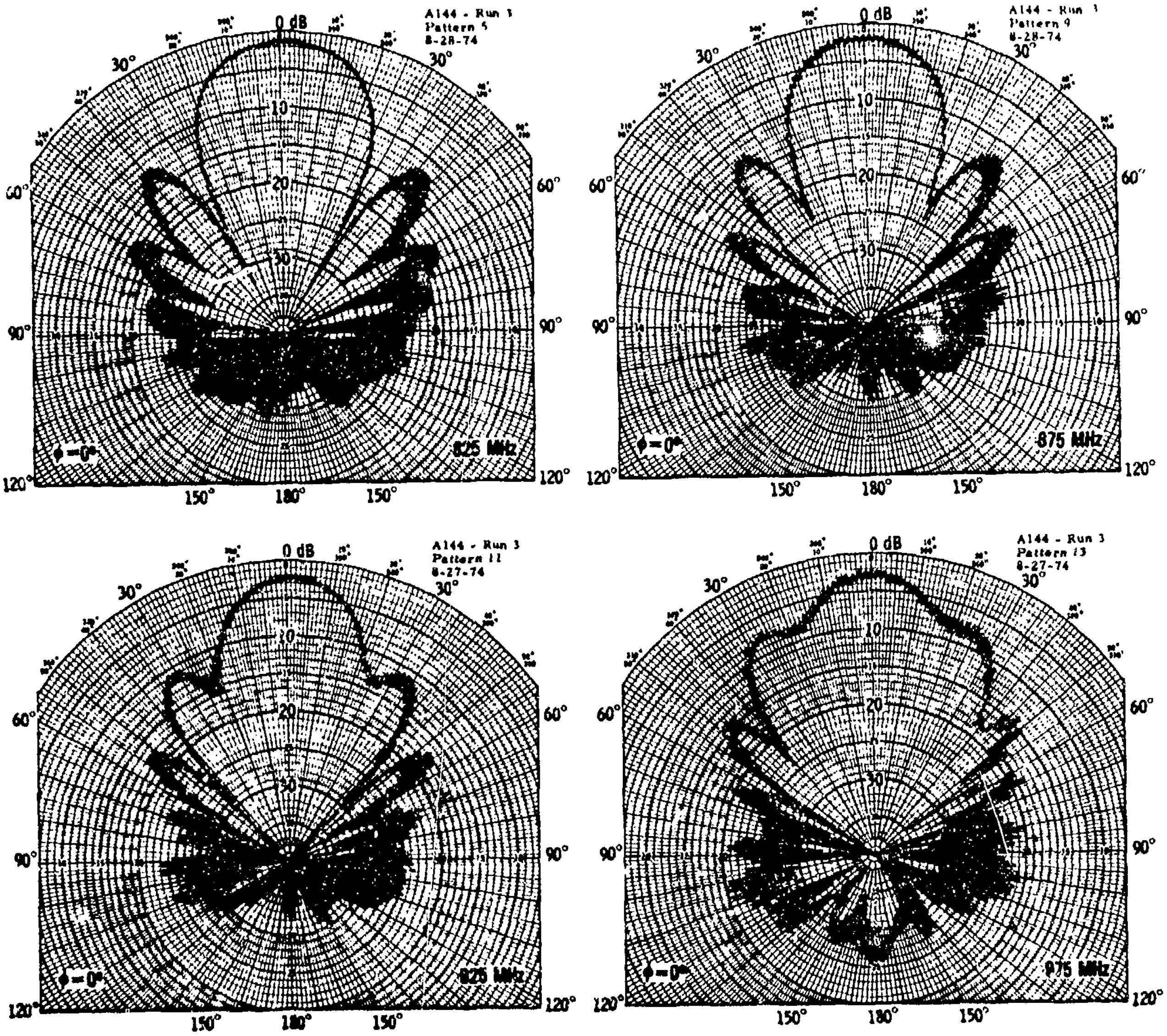

Fig. 7. Radiation Patterns of an 18-Turn Uniform Helix with a Two-Turn Tapered End Section (Continued)

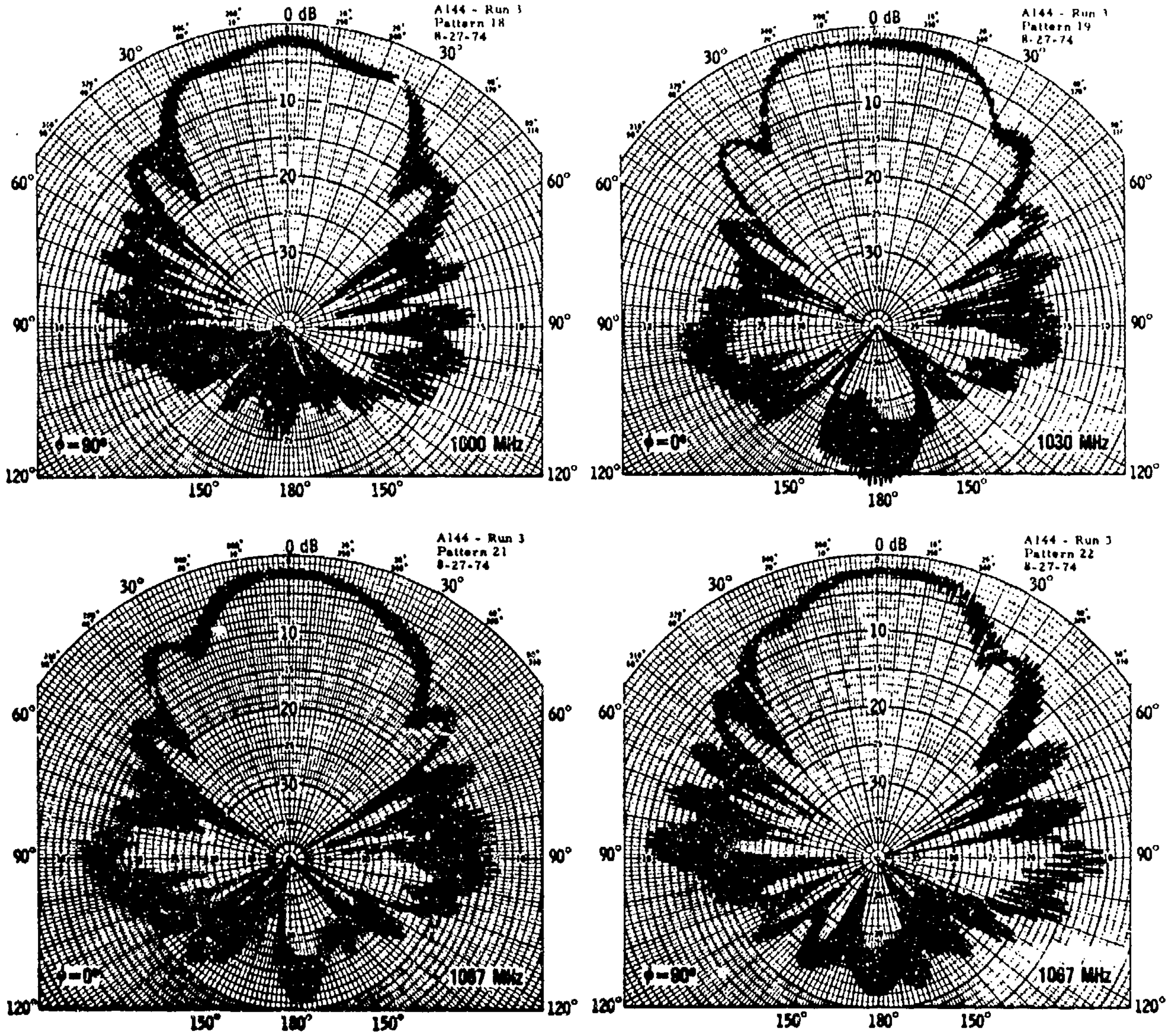

Fig. 7. Radiation Patterns of an 18-Turn Uniform Helix with a Two-Turn Tapered End Section (Continued)

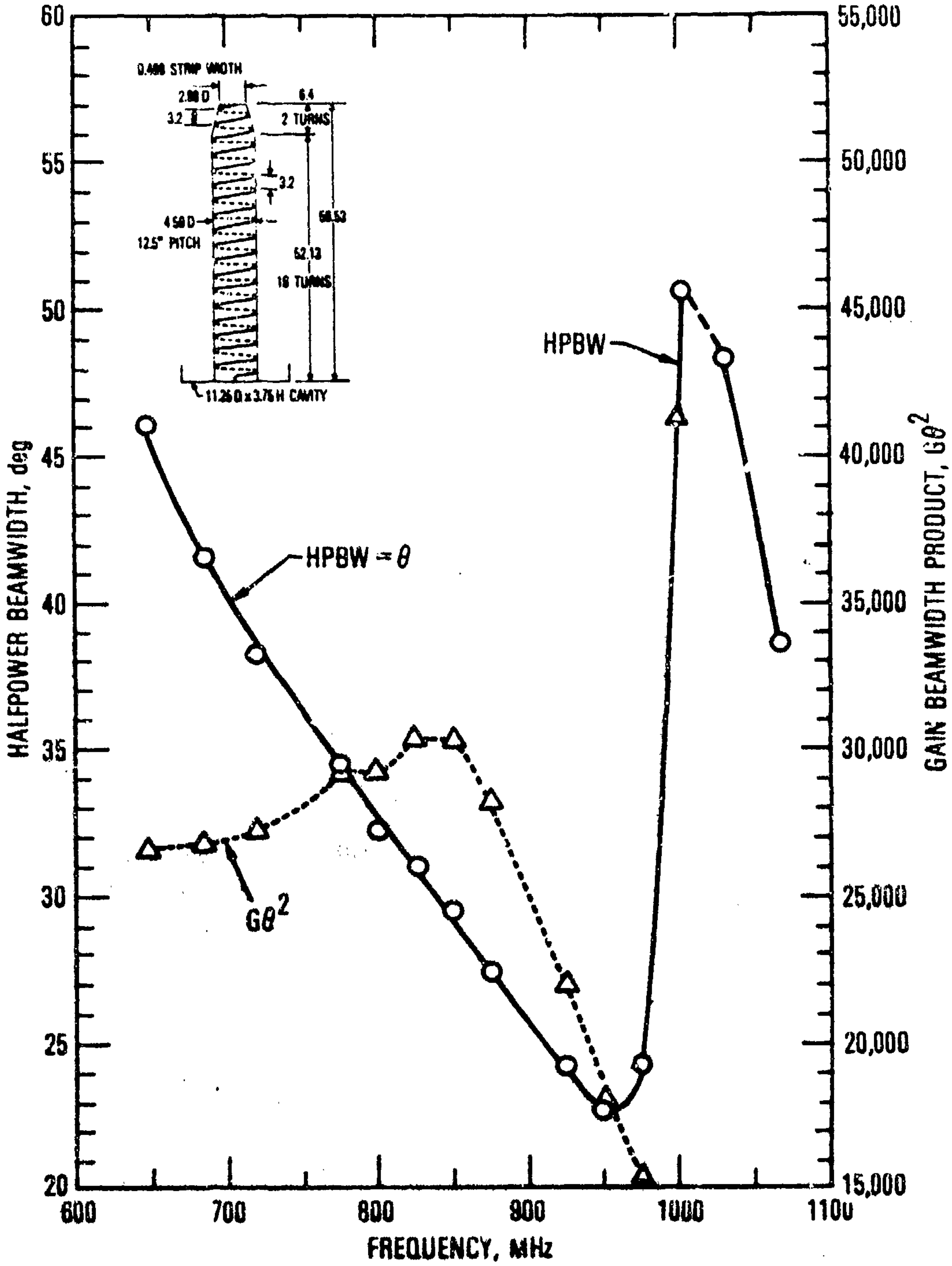

Fig. 8. Halfpower Beamwidths and Gain-Beamwidth Products of an 18-Turn Uniform Helix with a Two-Turn Tapered-End Section

It should be pointed out that the primary purpose of the present study was to optimize the gain of the helical antenna in the lower portion of the 773 to 1067 MHz band without substantial gain degradation in the upper portion of the band. Thus, the measurements performed for all the helices investigated in the present study cover this frequency range, which may exceed the theoretical limits for an axial mode uniform helix [Refs. 1, 4-6]. For a uniform helix with a 4.59-in. diameter and a 12.5° pitch angle, reasonable antenna performance can be expected from 650 to 1025 MHz, which correspond approximately to $0.8 < C/\lambda < 1.25$. Beyond this frequency range severe pattern distortion and gain degradation would result as can be evident from Figures 3, 4, 6 and 7.

C. CONTINUOUSLY TAPERED HELIX

A continuously tapered helix (literally known as conical helix) with a constant pitch spacing of 3.2 in. was tested. The helix consists of 17.64 turns with a 5.32-in. diameter at the base and 2.98-in. diameter at the top as shown in the sketch of Fig. 9. The peak gain is slightly lower than the uniform helix but the axial ratio and sidelobe characteristics are improved as can be seen from Figures 9 and 10. The HPBW and gain-beamwidth product are shown in Fig. 11. It is interesting to note that the high and low frequency limits are approximately determined by the mean circumference of the helix. The gain peaks at a frequency where the mean circumference is approximately 1.05λ. However, the gain-frequency response broadens considerably with substantial increase in gain at the high frequency end. For example, Fig. 9 shows the gain varies $\pm$ 1 dB from 820 to 1120 MHz, a 1.37:1 frequency ratio compared with 1.26:1 for a uniform helix.

D. QUASI-TAPER HELIX

As mentioned previously, the purpose of the present study was to develop a helical antenna capable of operation from 773 to 1067 MHz with optimum gain characteristics in the lower portion of the band. The uniform helix and the tapered-end helix were found to be incapable of meeting the gain-bandwidth re-

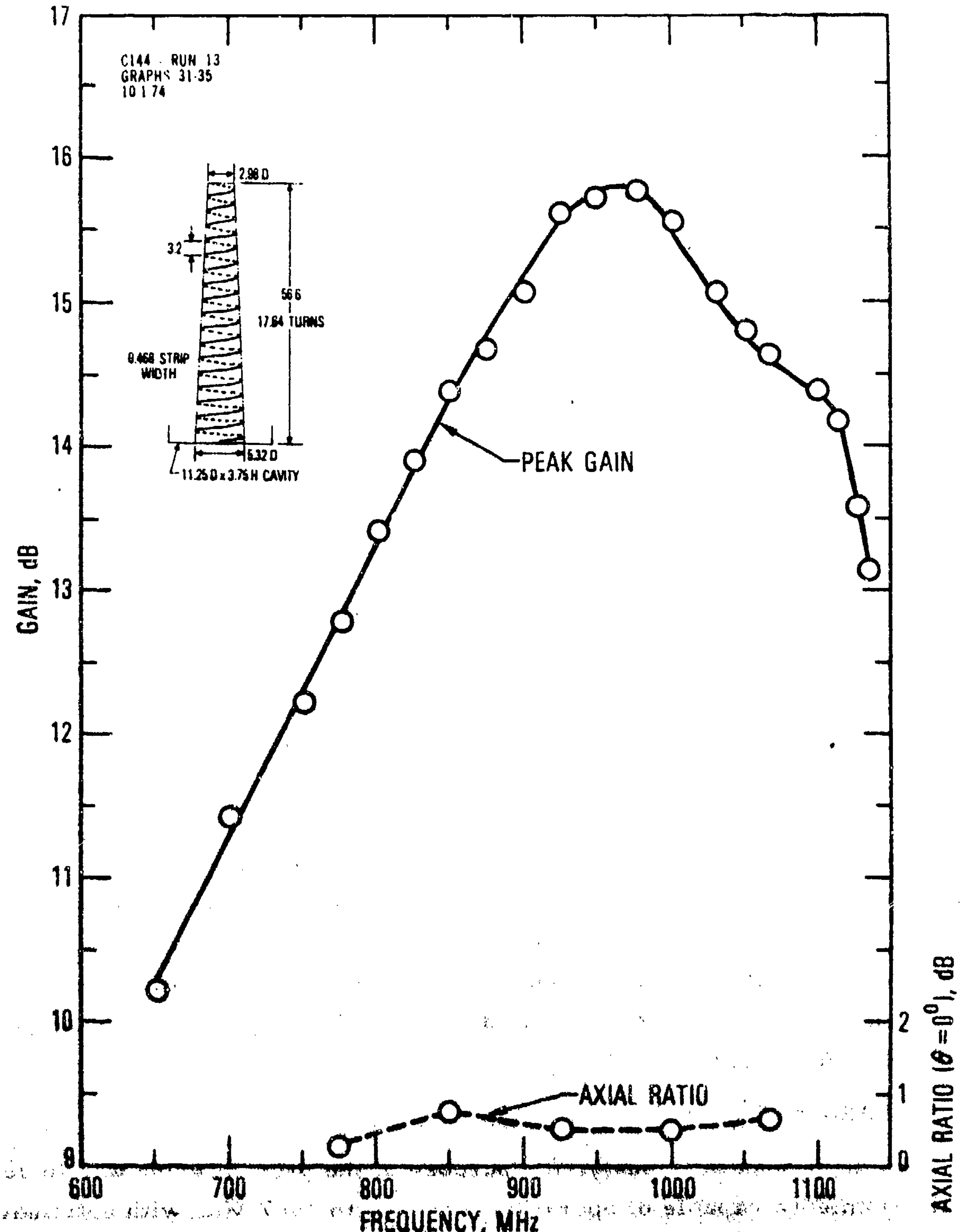

Fig. 9. Gain and Axial Ratio Characteristics of a 17.64-Turn Conical Helix

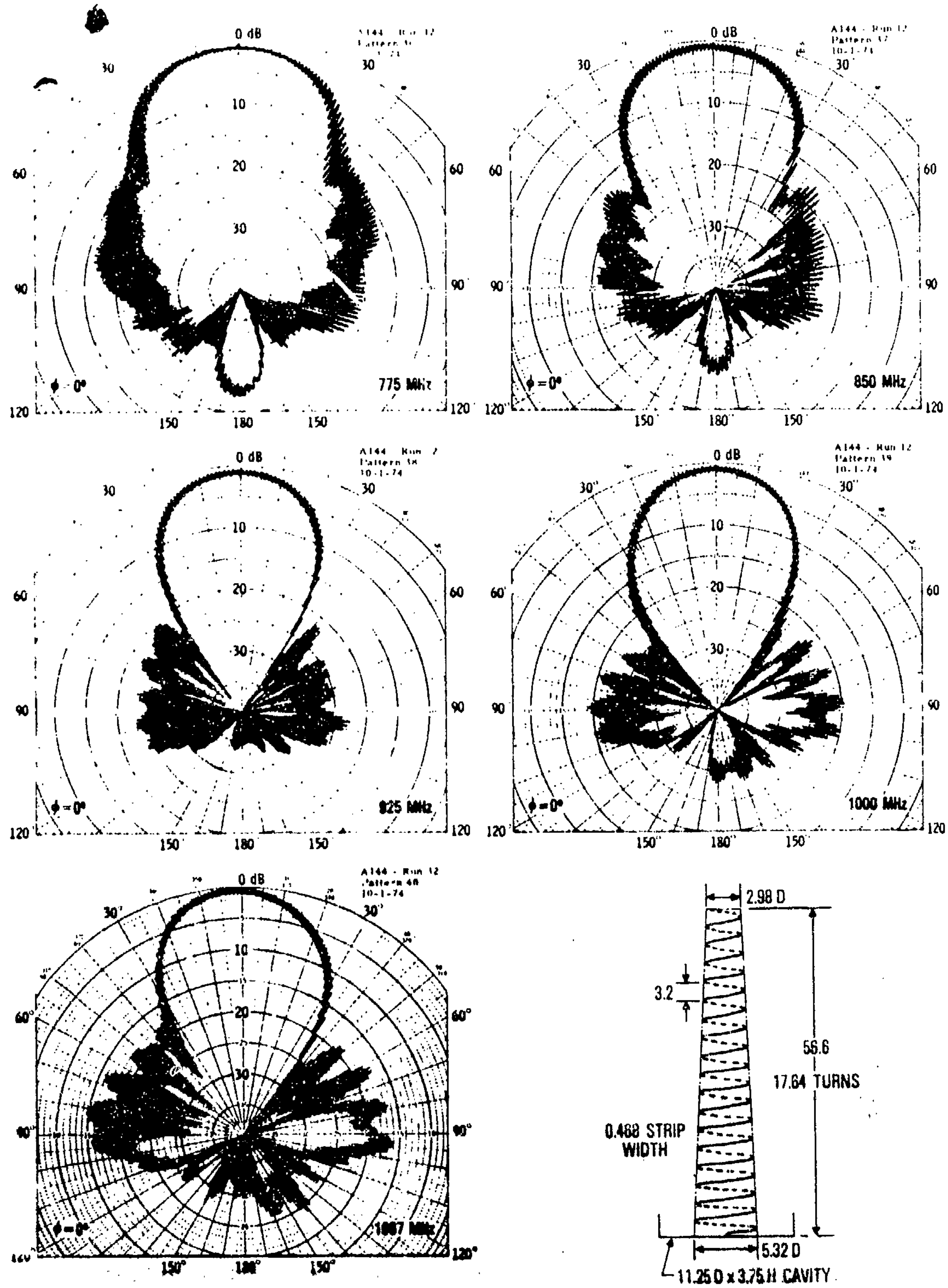

Fig. 10. Radiation Patterns of a 17.64-Turn Conical Helix

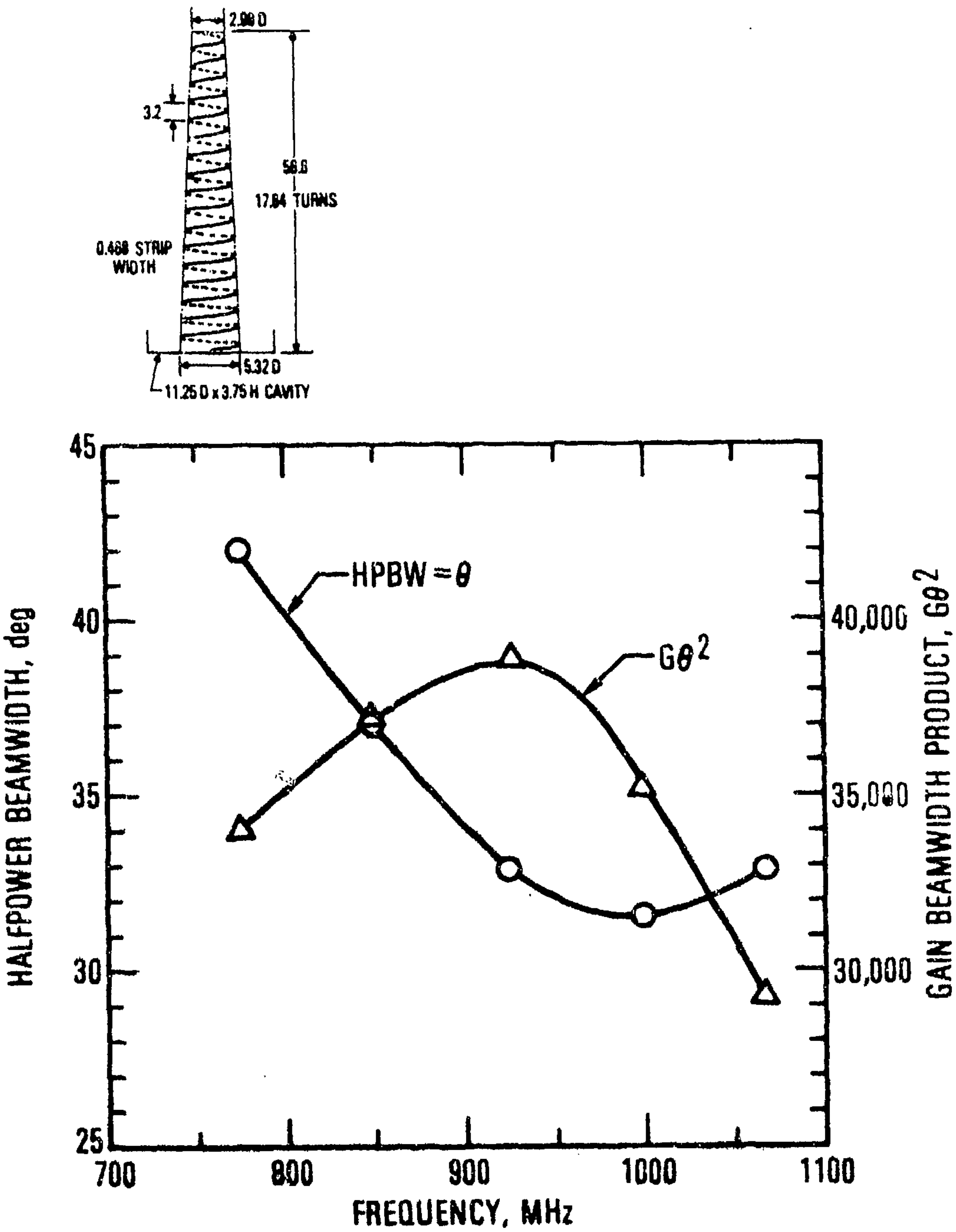

Fig. 11. Halfpower Beamwidth and Gain-Beamwidth Product of a 17.64-Turn Conical Helix

quirements. The continuously tapered helix provided broader frequency coverage with increased gain at the high frequency end, but the gain-bandwidth was still less than desired. In this section, the characteristics of a non-uniform or quasi-taper helix are discussed.

A non-uniform helix can be made in various forms. It may be constructed with two or more uniform helix sections of different diameters or a combination of uniform and tapered sections. Figure 12 shows a typical non-uniform helix consisting of principally two uniform-diameter sections — 5.28 and 4.13 inches. The helix is described as a 7-turn helix (5.28 D) + 2-turn taper (5.28 D to 4.13 D) + 6.64-turn (4.13 D) + 2-turn end taper (4.13 D to 2.98 D). A constant pitch spacing of 3.2-in. was maintained in all four helical sections. During the experimental phase a parametric study was made by varying the number of turns, the diameters of the helices, and the lengths of the tapered transition region. It was found that an antenna can be synthesized to yield a specified gain-frequency response.

Figure 13 illustrates the gain response for the non-uniform helix configuration of Fig. 12. This helix was optimized as desired over the low frequency region, with a gain of 14.7 $\pm$ 0.4 dB from 773 to 900 MHz and remained relatively flat (14.05 $\pm$ 0.25 dB) from 900 to 1067 MHz. The gain is constant within $\pm$ 1 dB over a frequency ratio $f_{max} / f_{min} = 1.55$ (710 to 1100 MHz) as compared to 1.26 for a uniform helix. The axial ratio is < 1 dB. The beam shape and sidelobe characteristics are considerably improved over those of a uniform helix as illustrated in Fig. 14. It is interesting to note that the high frequency cutoff is not limited by the larger, 5.28-in. diameter helical section ($C/\lambda \approx 1.55$ at 1100 MHz) but rather by the smaller, 4.13-in. diameter helical section ($C/\lambda \approx 1.21$ at 1100 MHz). The HPBW and $G\theta^2$ plots are depicted in Fig. 15. Note that the beamwidth remains relatively constant, $33^\circ \pm 3^\circ$ over the 773 to 1067 MHz test frequency range.

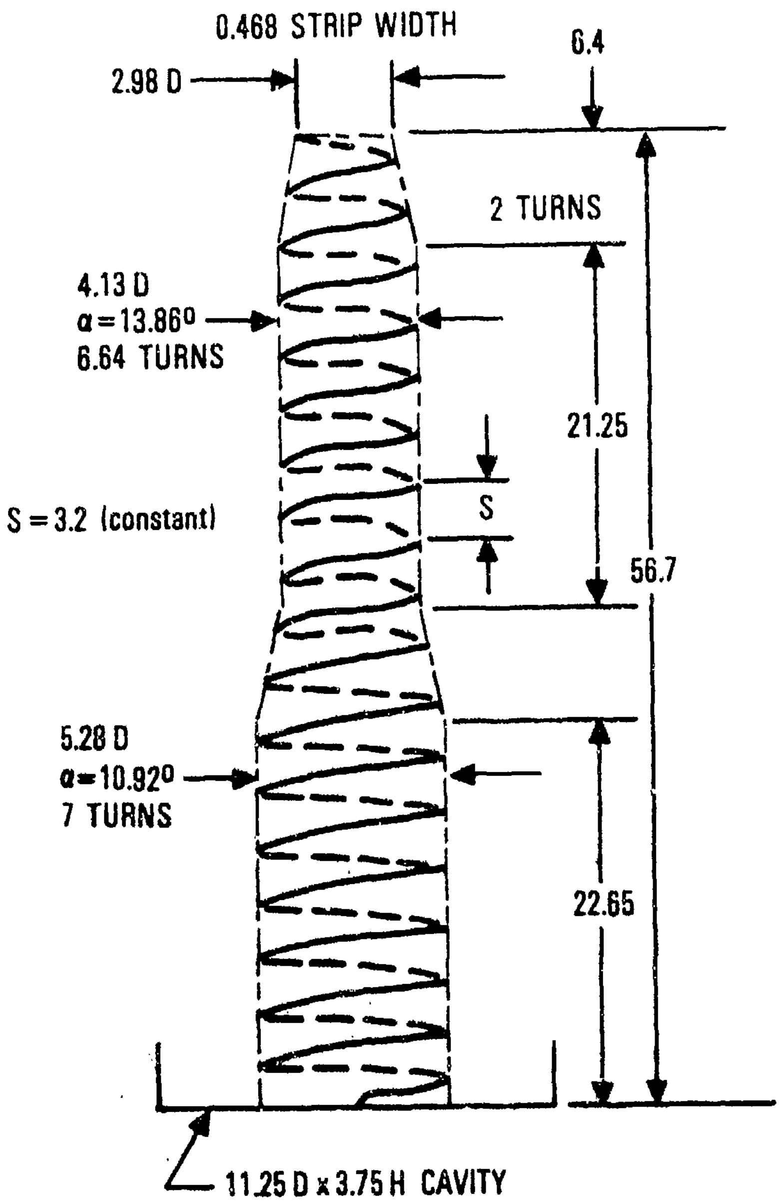

Fig. 12. Basic Dimensions of a Non-Uniform Diameter Helix

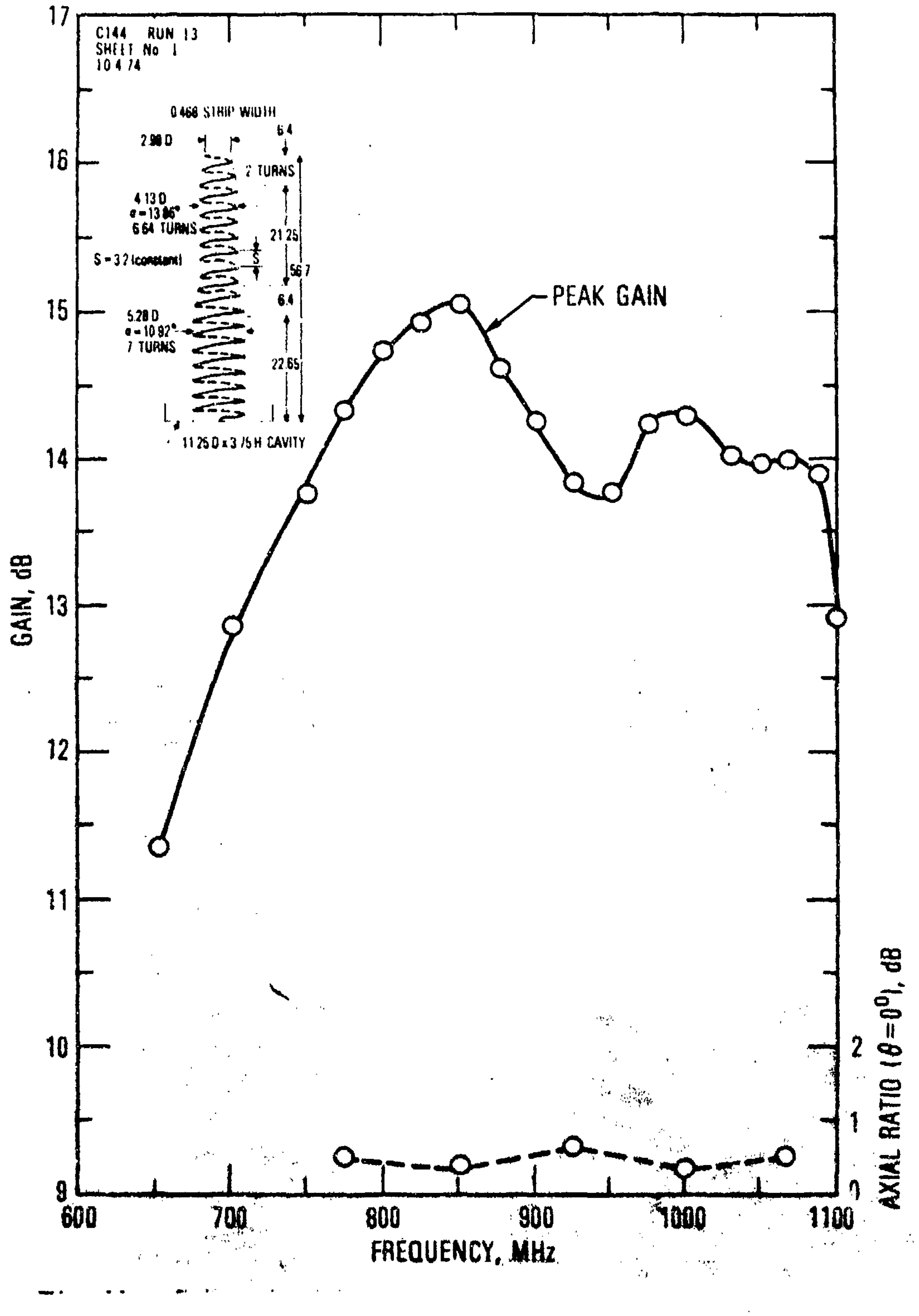

Fig. 13. Gain and Axial Ratio Characteristics of a Non-Uniform Diameter Helix

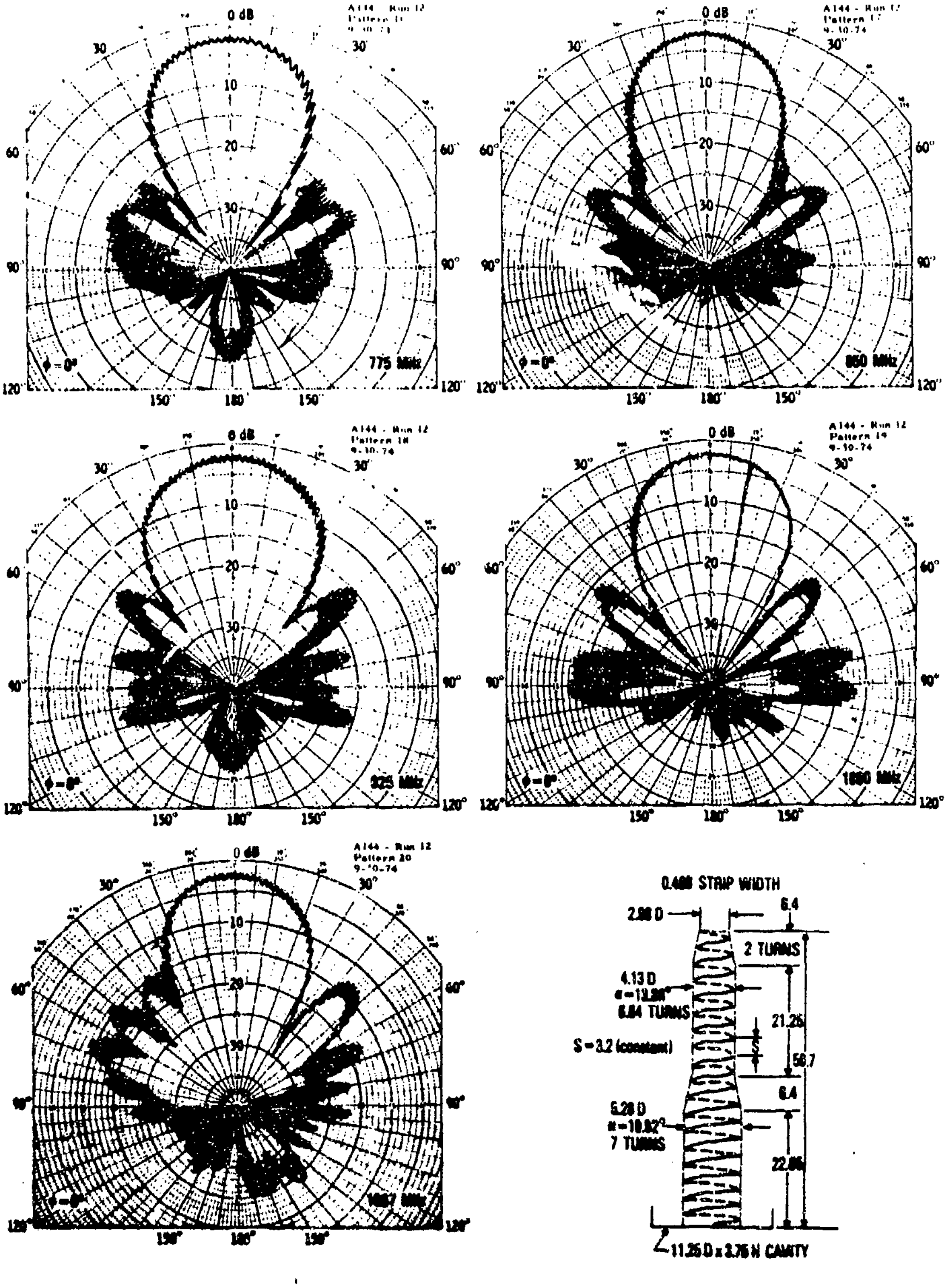

Fig. 14. Radiation Patterns of a 17.64-Turn Non-Uniform Diameter Helix

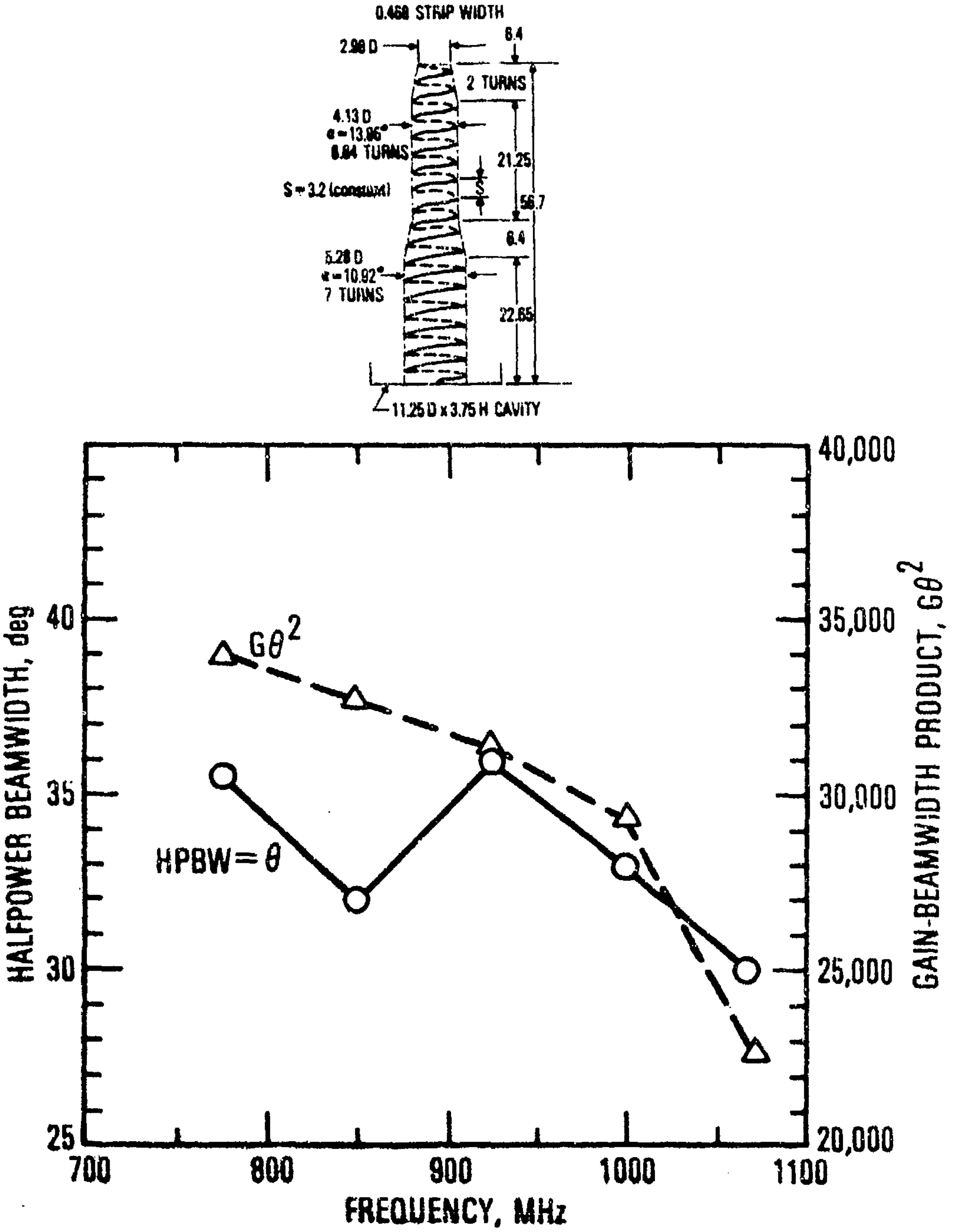

Fig. 15. Halfpower Beamwidth and Gain-Beamwidth Product of a 17.64-Turn Non-Uniform Diameter Helix

Another example of a non-uniform helix is shown in Fig. 16. This helix was constructed by tapering the top 10.64 turns of the helix of Fig. 12, which results in a helix consisting of a uniform section (5.28-in. diameter) plus a tapered section from 5.28 to 2.98-in. diameter. As shown in Fig. 16, the $\pm$ 1.1 dB gain bandwidth is wider than the non-uniform helix of Fig. 13, but the gain at the high frequency end is lower.

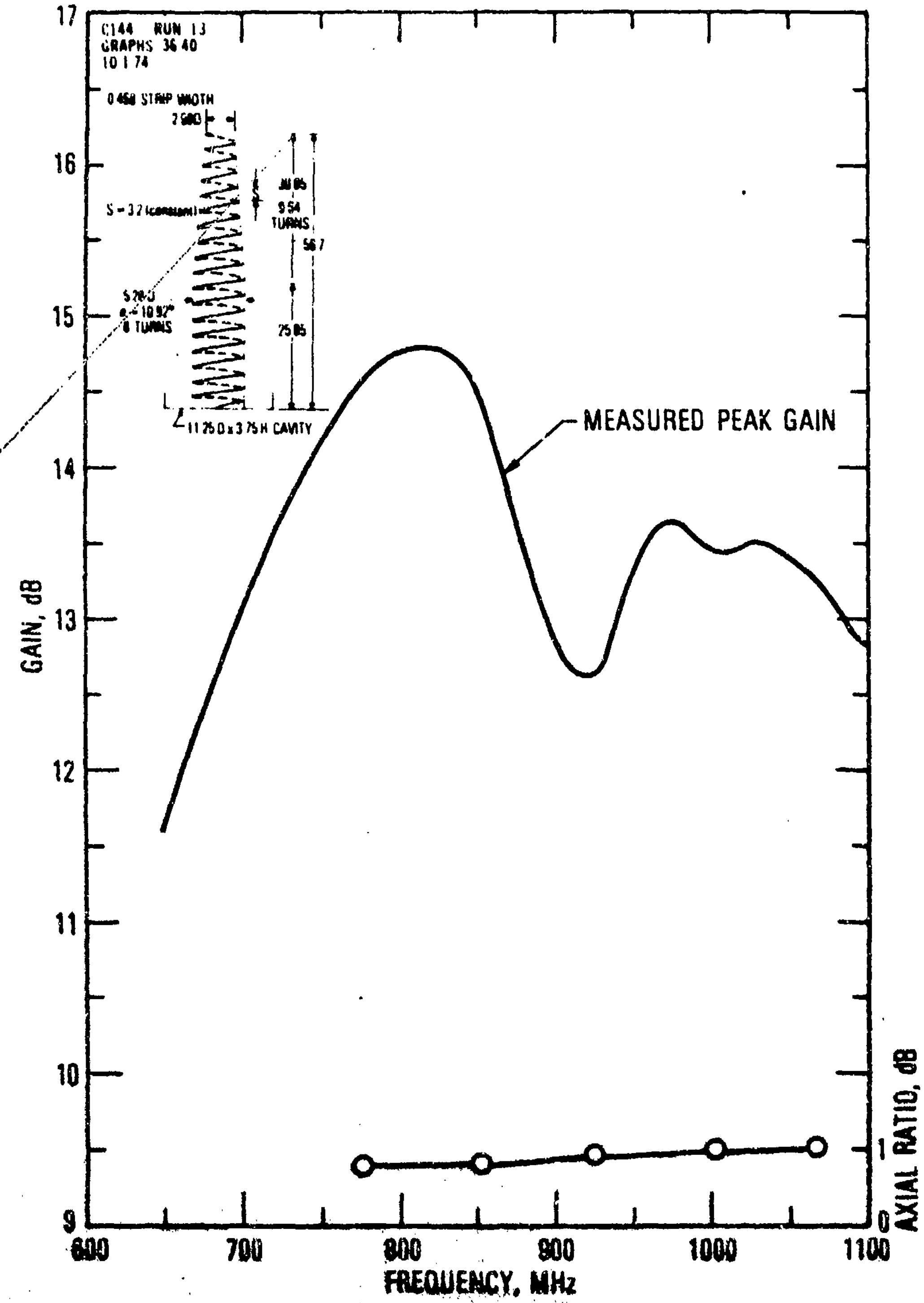

Fig. 16. Gain and Axial Ratio Characteristics of a Non-Uniform Helix Consisting of Eight-Turn Uniformly Wound + 9.64-Turn Continuous Taper

V. CONCLUSIONS

The uniqueness of a non-uniform helix antenna has been demonstrated. Such an approach yields wider bandwidths in gain, pattern, and axial ratio as compared to the conventional uniform-diameter helix. The non-uniform helix can also provide a means to synthesize an antenna to attain a specified gain-frequency response. A continuously tapered diameter helix does not have this flexibility nor the bandwidth of the non-uniform (quasi-taper) helix. The following table provides a comparison of the $\pm$ 1 dB gain bandwidth for the various helical antennas:

Type of Helix	Frequency Range with $\pm$ 1 dB Gain Variation	Frequency Ratio (f_{max} / f_{min})
Uniform	770 - 970 MHz	1.26:1
Tapered-End	770 - 980 MHz	1.27:1
Continuous Taper	820 - 1120 MHz	1.37:1
Quasi-Taper	710 - 1100 MHz	1.55:1

REFERENCES

1. J. D. Kraus, Antennas, McGraw-Hill Book Co., New York (1950), Ch. 7.

2. J. S. Chatterjee, "Radiation Field of a Conical Helix," J. Appl. Phys. 24, 550-559 (May 1953).

3. H. S. Barsky, "Broadband Conical Helix Antennas," 1959 IRE National Convention Record, Part 1, 138-146.

4. T. S. M. Maclean and R. G. Kouyoumjian, "The Bandwidth of Helical Antennas," IRE Transactions on Antennas and Propagation, AP-7, Special Supplement, S379-S386 (December 1959).

5. T. S. M. Maclean and W. E. J. Farvis, "The Sheath-Helix Approach to the Helical Aerial," Proc. IEE 109, Part C, 548-555 (1962).

6. T. S. M. Maclean, "An Engineering Study of the Helical Aerial," Proc. IEEE 110, 112-116 (January 1963).

7. D. J. Angelakos and D. Kajfez, "Modifications on the Axial-Mode Helical Antenna," Proc. IEEE 55, 558-559 (April 1967).