Measured performance of a broadband matching section for peripherally fed helical antennas+

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ABSTRACT

This paper describes the measured performance of an impedance matching section incorporated into the first turn of a peripherally fed helical antenna to transform its impedance to 50 Ω. The design of the matching section is briefly reviewed. The measured results show that very low VSWR (1,2:1) can be achieved over the usable frequency range of the antenna. In addition to showing the basic impedance matching performance, results are also presented to illustrate the effect of the number of helix turns and of the conductor diameter on the impedance match. Antenna pattern data show that improved performance can be achieved by a simple termination at the free end of the helix.

INTRODUCTION

Since its invention by Kraus [1] in 1947, the design of the helical antenna has remained virtually unaltered. The axially fed configuration introduced by Kraus has proved very popular and is still used widely today. The terminal resistance, R, of the axially fed helix is given by the empirical relation $R = 140\ C/\lambda\,\Omega$, where C/λ is the helix circumference in wavelengths. This impedance is usually transformed to 50 Ω by the use of 'add-on' matching sections such as: (a) coaxial quarter-wave transformers [2], [3], and (b) printed circuit microstrip transformers [4], [5]. The VSWR achieved by these methods is less than 2:1 over the entire frequency range of the helix and typically better than 1,5:1 over most of the usable range. A method for achieving directly a 50 Ω impedance for the helix has been described [6], but experimental adjustments are required to achieve the desired performance.

This paper briefly reviews the design of an impedance matching section incorporated directly into the first turn of a peripherally fed helical antenna. The matching section is simply a continuation of the helix conductor and the required impedance transformation is achieved by adjusting the spacing between the conductor and the ground plane over the first turn of the helix. Measured results show that by a suitable choice of the matching section profile VSWR's as low as 1,2:1 or even 1,1:1 can be achieved over the usable frequency range of the helix. Additional results examine the effects of the number of turns, conductor diameter and spiral truncation on the performance of the helical antenna.

MATCHING SECTION DESIGN

The design of the impedance matching section for peripherally fed helical antennas has been described earlier [7] and only the essence of that procedure is repeated to facilitate the discussion of the measured results. Fig 1 illustrates a peripherally fed helical antenna with an impedance matching section of length ℓ incorporated into the first turn. The impedance of the matching section gradually increases from 50 Ω at the input to the helix impedance, R. For this case $R = 150/\sqrt{C/\lambda}\ \Omega$ [7] which gives significantly less impedance variation with frequency than that of the more usual axially fed counterpart. The procedure described by Hecken [8] was used in reference [7] to determine the required values of the characteristic impedance, Z_c, at each point $s = 2x/\ell$ along the line to achieve the desired match (see Fig 1 for an expression for Z_c in terms of conductor spacing, h, and diameter, d).

The design procedure for the Hecken taper as applied to the peripherally fed helix has been used to develop a computer program where the antenna designer inputs the following data : helix diameter, conductor diameter, helix impedance (usually 150Ω) impedance of the feed line (usually 50Ω), relative dielectric constant of supporting medium ($\varepsilon_r = 1$ for air helix) and selects right or left circular polarisation. The program prints out the required Z_c and h values as functions of s and also plots h as a function of position around the circumference of the helix from the feed point to the helix proper. This plot is then used as a guide to lay out the matching taper when the antenna is assembled. Table 1 shows a sample printout for a Hecken taper with a maximum reflection coefficient of -21 dB and d = 1,8 mm. Since h is directly proportional to d, the required spacings for other diameters can be scaled directly from Table 1.

For a -21 dB reflection coefficient the design requires that the length of the impedance taper be 0,44 λ at the lowest operating frequency. The low-frequency characteristics of helical antennas have been studied [9] and a value of $C/\lambda = 0{,}7$ may be taken as setting the limit of acceptable performance. This means that the taper is 0,63 wavelengths long at the centre frequency i.e. where the circumference is a wavelength. For a -26 dB reflection coefficient the taper should be about 0,79 wavelengths at the centre frequency which means that the taper extends more than three quarters of the way around the helix circumference. This probably represents the practical limit for taper lengths since the taper starts to overlap itself when its length exceeds the helix circumference.

MEASURED PERFORMANCE

Influence of Conductor Diameter

Fig 2 shows enlarged Smith chart plots for the helix impedance (no matching at this stage) for a 12° pitch angle and conductor diameters of 5 mm (0,017 λ at centre frequency) and 1,8 mm (0,0064 λ). For the 5 mm conductor a carefully designed feed finger [3] is necessary to maintain a nearly constant impedance (about 150 Ω in this

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$\lvert s\rvert$	$G(B,s)$	$Z_c(+\lvert s\rvert)$ Ω	$h(+\lvert s\rvert)$ mm	$Z_c(-\lvert s\rvert)$ Ω	$h(-\lvert s\rvert)$ mm
0.00	0.00000	86.60	2.01	86.60	2.01
0.05	0.05473	89.25	2.09	84.04	1.94
0.10	0.10939	91.97	2.18	81.55	1.87
0.15	0.16390	94.76	2.28	79.15	1.80
0.20	0.21819	97.63	2.38	76.82	1.74
0.25	0.27218	100.57	2.49	74.58	1.69
0.30	0.32580	103.57	2.61	72.41	1.64
0.35	0.37899	106.65	2.74	70.33	1.59
0.40	0.43166	109.78	2.88	68.32	1.55
0.45	0.48375	112.96	3.03	66.39	1.51
0.50	0.53519	116.20	3.19	64.54	1.47
0.55	0.58591	119.48	3.36	62.77	1.44
0.60	0.63586	122.81	3.54	61.07	1.41
0.65	0.68495	126.16	3.74	59.45	1.38
0.70	0.73314	129.55	3.95	57.89	1.35
0.75	0.78036	132.95	4.18	56.41	1.33
0.80	0.82655	136.37	4.41	55.00	1.31
0.85	0.87166	139.79	4.67	53.65	1.29
0.90	0.91564	143.21	4.94	52.37	1.27
0.95	0.95844	146.61	5.22	51.15	1.25
1.00	1.00000	150.00	5.52	50.00	1.23

NOTES: 1. $s = 2x/\ell$, where ℓ is the length of the taper.

2. $G(B,-s) = -G(B,s)$ (see reference [8] for details)

3. $\varepsilon_r = 1,0$.

TABLE 1 - Characteristic impedance, $Z_c(s)$, and conductor spacing, $h(s)$, as a function of distance, s, along the impedance matching section (helix conductor diameter d = 1,8 mm)

case) from the input connector to where the feed finger joins the helix conductor. It is clear from Fig 2 that the larger conductor has a lower impedance than the smaller one and the former has a smaller impedance variation with frequency. Helical antennas with larger conductor diameters are generally easier to match, but above about 500 MHz conductors larger than about 5 mm in diameter become difficult to work with.

At the free end, the helix is terminated by the addition of two or more turns in the form of a planar Archimedes spiral (see Fig 1). This simple termination decreases the frequency variation of the helix impedance for $C/\lambda > 1,1$.

Matching Section Performance

The experimental helixes were all wound using copper conductors and a circular ground plane with a diameter equal to the helix circumference was used to back the helix in all cases.

A 70 mm diameter helix (centre frequency 1,364 GHz) with conductor diameter 1,8 mm and pitch angle 13,8° was matched using the design data of Table 1. The solid curve in Fig 3 shows the measured reflection coefficient without the Archimedes spiral end taper. The dashed curve shows the effect of adding a two turn spiral to the free end of the helix. Below about 1,4 GHz, the termination has very little effect, however, it extends the high-frequency limit to almost 2 GHz. The design of Table 1 is for a -21 dB reflection coefficient (VSWR = 1,2:1), it is clear that the terminated helix maintains this performance from about 0,98 to 1,97 GHz which covers the entire usable frequency range of the antenna. The low-frequency cut-off of the antenna is extremely well defined by the very rapid rise in reflection coefficient below about 1,0 GHz.

In an attempt to achieve still better performance a Hecken taper for a -26 dB reflection coefficient (VSWR = 1,1:1) was incorporated into the first turn of an 89 mm diameter helix (centre frequency = 1,073 GHz) with a 12° pitch angle. From Fig 4 it is clear that this performance is maintained to about 1,2 GHz which does not quite cover the usable range of the antenna which extends to 1,3 GHz. The reason for this is evident from Fig 2(b) which shows that the helix impedance varies fairly rapidly for frequencies above about 1,2 GHz. The performance in Fig 4 nonetheless represents exceptional wideband matching for a helical antenna.

Effect of Number of Turns

A 70 mm diameter helix similar to that of Fig 3 was wound with nine turns and matched for a -21 dB reflection coefficient (no spiral termination at free end). Without adjusting the matching section, helix turns were cut off from the free end two at a time and the measured reflection coefficient is shown in Fig 5. As the number of turns is reduced from 9 turns to 5 turns the match stays relatively stable although small changes in low-frequency cut-off behaviour are evident. When only 3 turns remain the match and cut-off behaviour degrade quite drastically.

Pattern Performance

Fig 6 shows antenna patterns for an 89 mm diameter helix (d = 1,8 mm) supported in a groove cut 1,8 mm deep into a PVC cylinder. For Fig 6(a) a two turn Archimedes spiral end taper is added to the free end of the helix. For this case the on-boresight axial ratio is about 0,5 dB and excellent circular polarisation is maintained over the main beam. When the end taper is removed (Fig 6(b)), the on-boresight axial ratio is about 1,3 dB and the circular polarisation performance is degraded over the main beam. The improved pattern performance with the end taper is also evident at other frequencies.

CONCLUSIONS

Measured data has been presented to show that excellent VSWR performance can be achieved with an impedance matching section designed according to the Hecken taper and incorporated into the first turn of a peripherally fed helical antenna. Larger diameter helix conductors have more stable impedance characteristics as a function of frequency than very thin conductors. Provided the number of turns is not too small (≥4, say) the antenna match is very stable. Termination of the free end of the helix improves the high-frequency VSWR performance as well as the axial ratio of the patterns.

ACKNOWLEDGEMENTS

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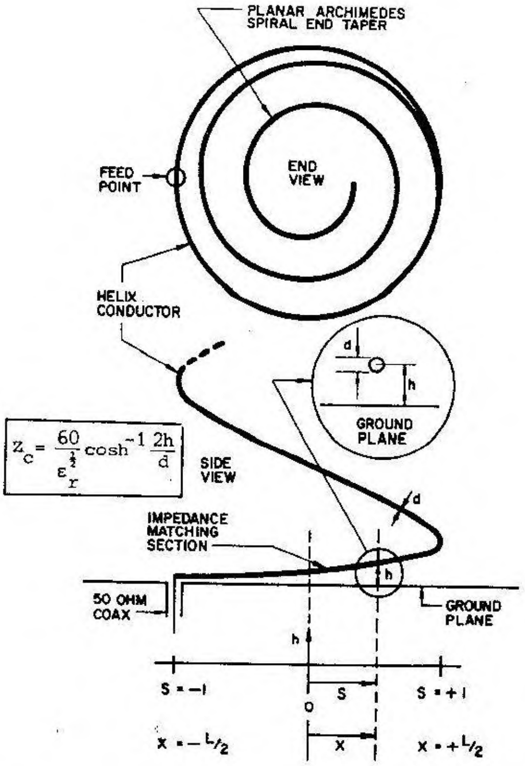


Fig 1 Schematic diagram of a peripherally fed helical antenna illustrating the matching section profile and the termination at the free end

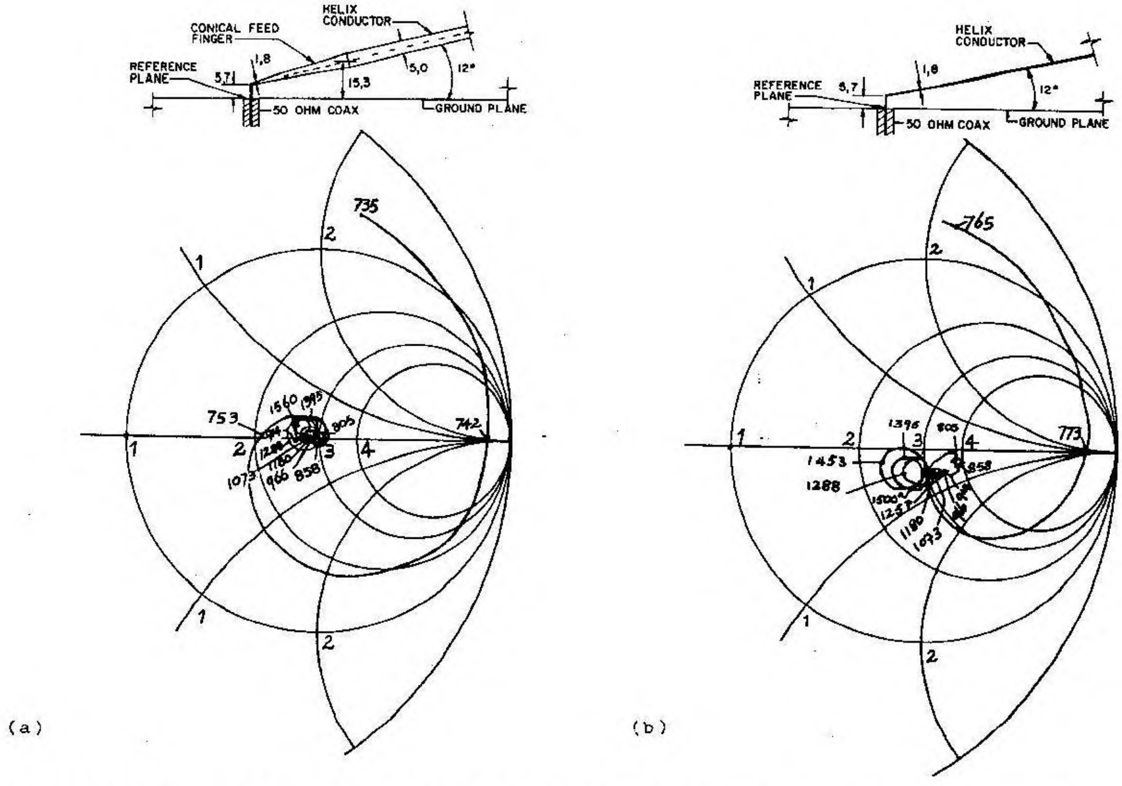


Fig 2 Impedance of 89 mm helix for d = 5 mm (a) and d = 1,8 mm (b)

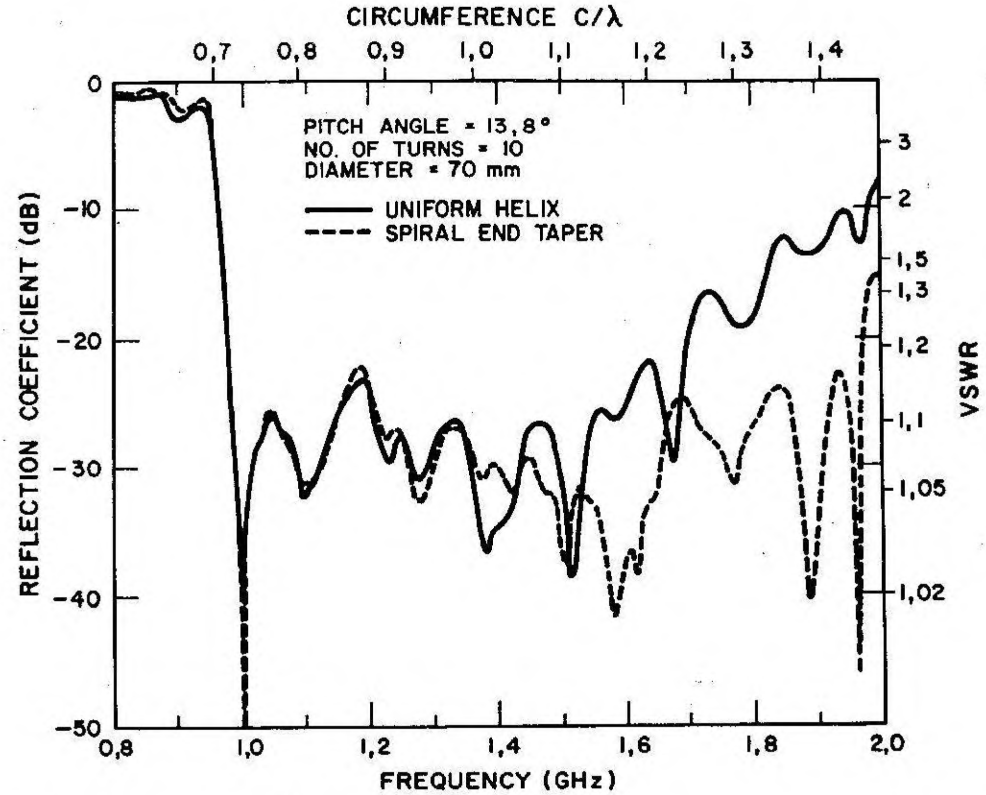


Fig 3 Reflection coefficient of a 70 mm diameter helical antenna with pitch angle of 13,8° and conductor diameter of 1,8 mm showing the effect of the Archimedes spiral end taper

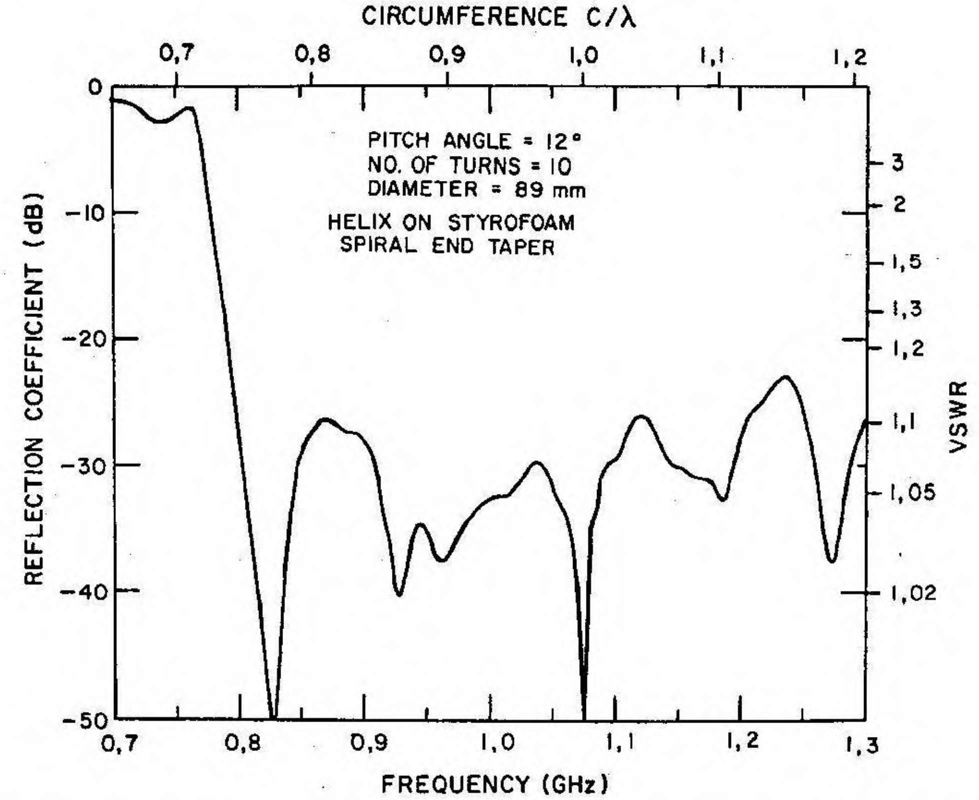


Fig 4 Reflection coefficient of a 89 mm diameter helical antenna with pitch angle of 12° and conductor diameter of 1,8 mm

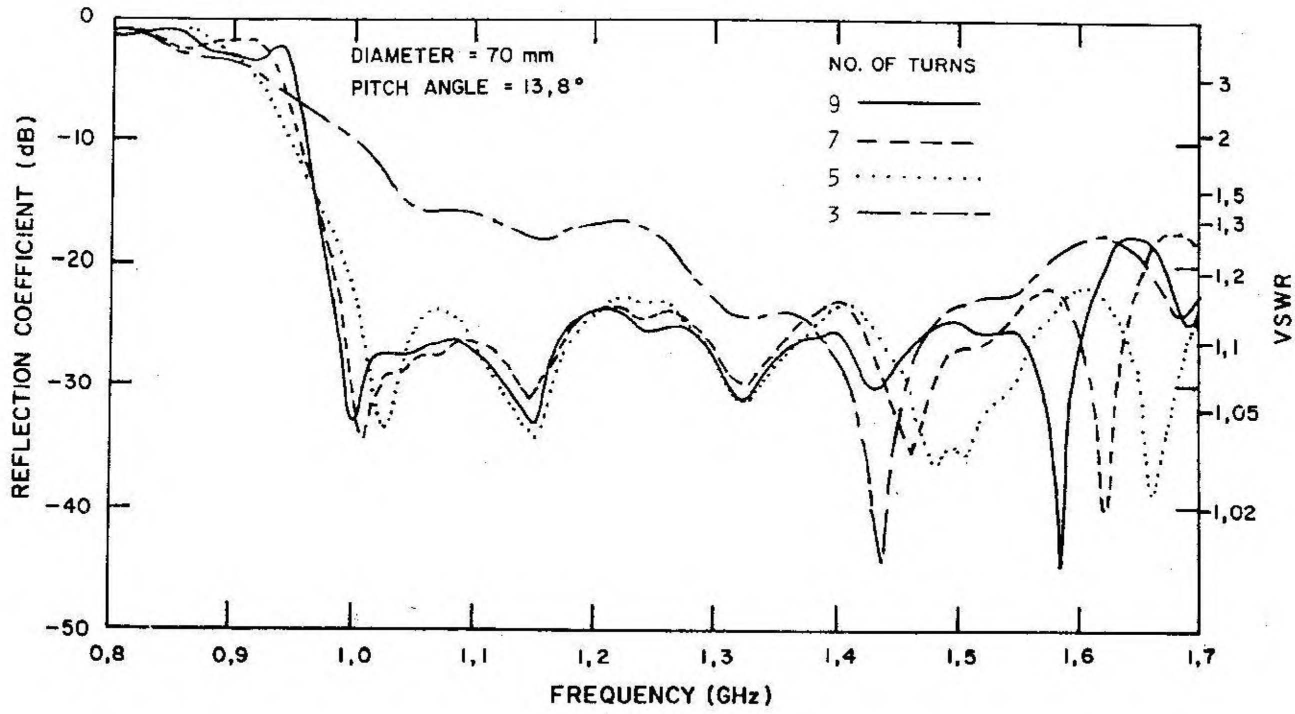
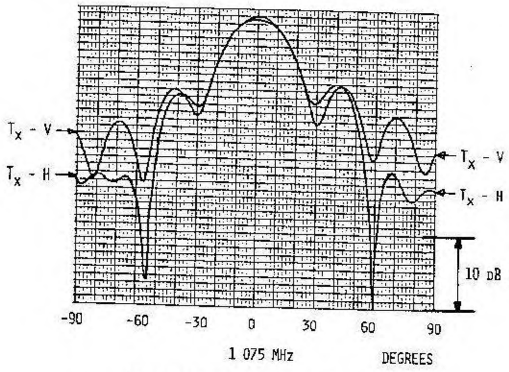


Fig 5 Effect of the number of turns on the impedance match

89 MM HELIX ON PVC + SPIRAL END TAPER



89 MM HELIX ON PVC, NO END TAPER

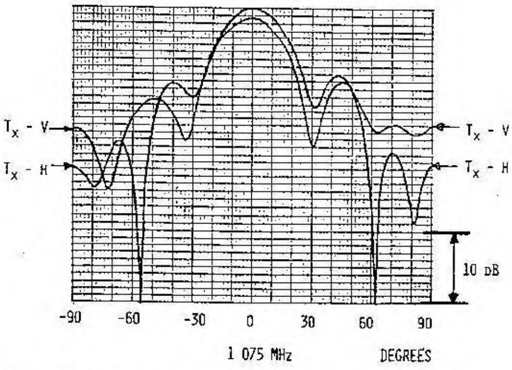


Fig 6 Effect of spiral end taper on circular polarisation response