THE INCLINED LOG-SPIRAL ANTENNA, A NEW TYPE OF UNIDIRECTIONAL, FREQUENCY-INDEPENDENT ANTENNA

by

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Memorandum No. ERL-M170
17 August 1966

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Manuscript received: 6 June 1966

Manuscript submitted to IEEE Correspondence Section, 10 August 1966.

The research reported herein was supported wholly by the National Science Foundation under Grant GP-2203.

SUMMARY

A new type of unidirectional, frequency-independent antenna, the inclined log-spiral antenna,was developed and tested. The basic idea, formulated by Rumsey, is that frequency-independent antennas do not radiate into the space which would be occupied by the infinite structure. Experimental results show frequency-independent behavior with large front-to-back ratio and circular polarization in a broad frequency range.

Since the first introduction of the concept of frequency-independent antennas by Rumsey in 1957,[1] many equiangular spirals and log-periodic antennas have been developed.[2] Special emphasis has been laid on the achievement of unidirectional, frequency-independent radiation. Dyson's investigation of the conical log-spiral antenna provided empirical information for the design of practical antennas[3] with these properties. In his case, high front-to-back ratios could only be obtained by using small included cone angles $2\theta_o$ and large spiral angles α.[3] In comparison to the flat spiral, these structures require larger linear dimensions for a given frequency range, which might be a disadvantage for specific applications.

A new type of unidirectional, frequency-independent antenna, the inclined log-spiral antenna, has been developed. It reduces the back-radiation effectively, without impairing other characteristics. In constructing this antenna, successful use has been made of the fact that frequency-independent antennas do not radiate into that region of the space, which would be occupied by the infinite structure. Figure 1 illustrates this behavior.

The inclined spiral antenna was obtained after the experimental investigation of the radiation characteristics of various types of "three dimensional spiral structures":[4] the "rectangular spiral", the "straight continuous spiral", the "outwardly inclined continuous spiral" and the

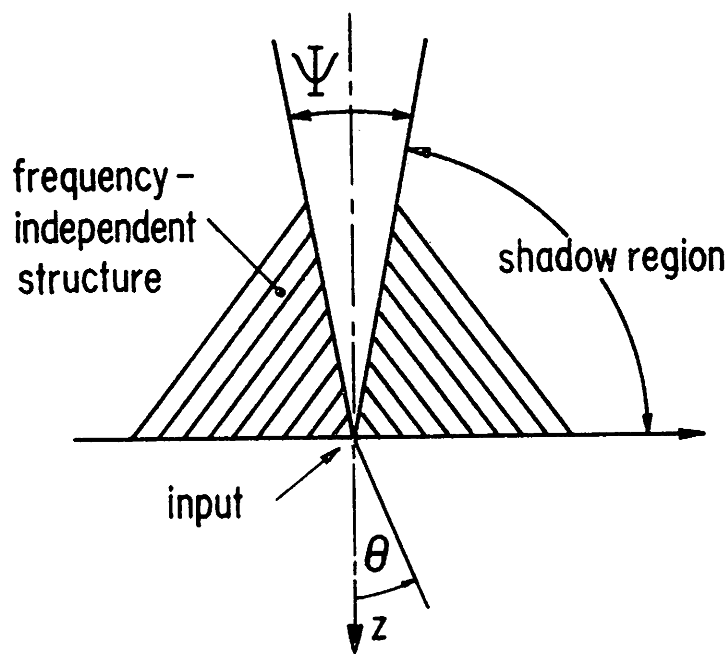

Fig. 1. Radiation region and shadow region of a three-dimensional frequency-independent antenna. The radiation is confined into the directions $\theta \leq \pi/2$ and $\theta \geq \pi-\psi/2$.

"inwardly inclined continuous spiral". Because of its good pseudo-frequency-independency, the "rectangular spiral" should find special attention, even though the strong variation between the repeating frequencies of this log-periodic structure limit its practical applicability.

Figure 2 shows one arm of the inwardly-inclined log-spiral antenna with expansion factor τ, inclination angle α, and apex angle ψ. The maximum and minimum diameters are D_{max} and D_{min}, respectively. Let the radius vector of the base-curve be given by

$$r_1 = C_1 \exp(-a_1 \phi_1)$$

where C_1 = constant, depending on D_{min}, a_1 = expansion coefficient, r_1, ϕ_1, θ_1 = spherical coordinates. The two copper sheets which made up the antenna, had the form of spirals when laid out flat with r_2 and r_3 as the inner and outer radius vectors, respectively:

$$r_2 = C_1 \exp(-a_2 \phi_2)$$

$$r_3 = C_3 \exp(-a_2 \phi_3)$$

with

$$a_2 = a_1 / \sin \alpha$$

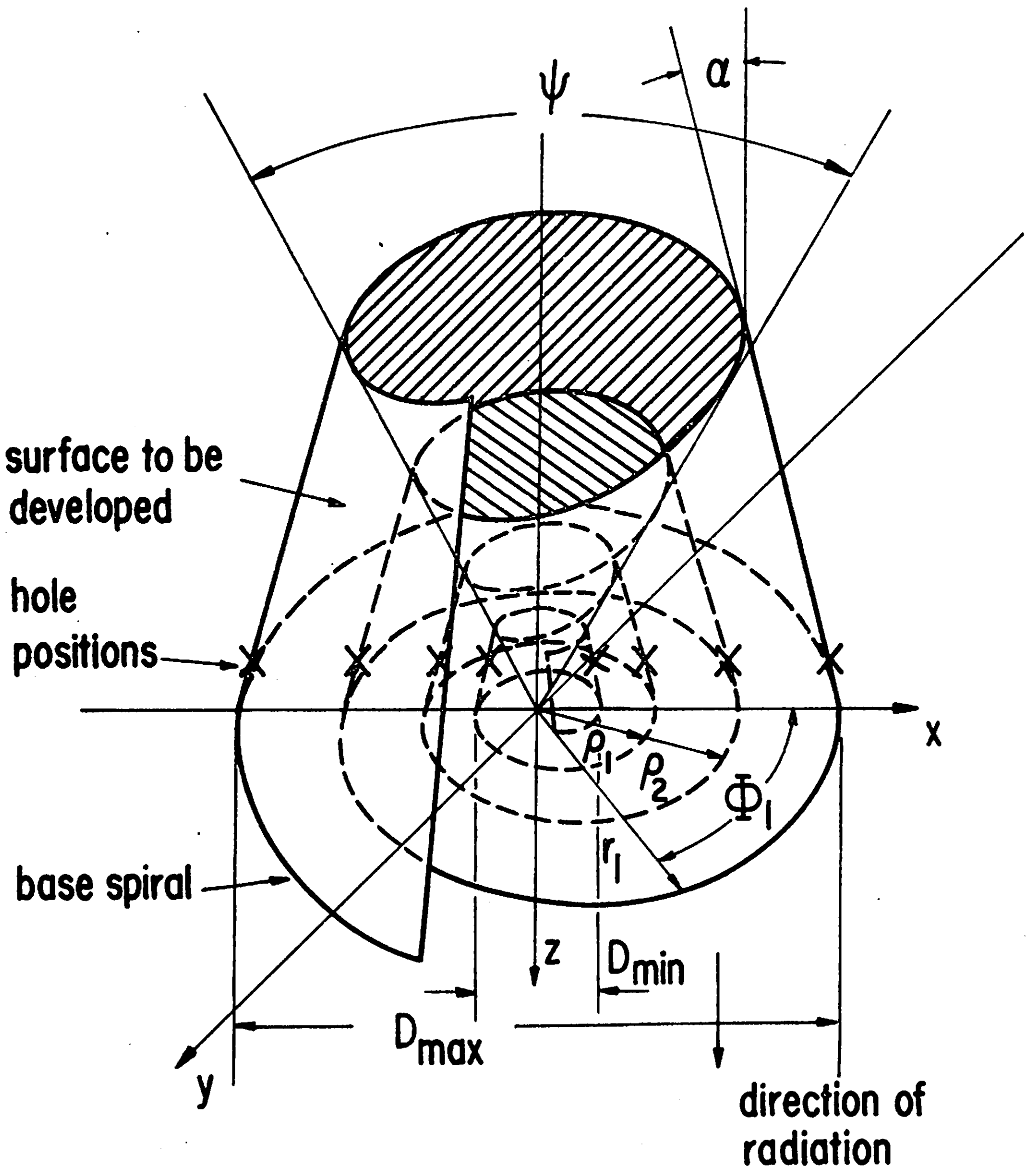

Fig. 2. Geometry of one arm of the inclined log-spiral antenna.

ϕ_2, ϕ_3 and C_3 are constants, which depend on the spiral geometry.[4] The spiral was kept in place by nylon strings, which were led through small holes near the copper base and at different heights. The curves of the developed spirals as well as the positions of the holes were calculated by a 7094 Digital Computer. The holes were made before assembly. After the nylon strings were pulled through the appropriate holes, the spirals automatically arranged themselves in the determined form. The strings were fastened to a wooden frame, which did not influence the radiation pattern because it was in that space, which would be occupied by the infinite structure. A miniature diode was placed across the terminals at the center of the spiral. The audio lines from the diode were soldered to the outside sheets of the spiral.

The experimental results show essentially frequency-independent radiation patterns between 3.0 and 12.4 GHz (Fig. 3). E- and H-plane patterns at $\phi = 0^\circ$ and 90° (corresponding to changes in frequency from f_0 to $\sqrt{\tau}\, f_0$) indicate good circular polarization in all directions (axial ratio better than 1.1 in the center frequency range). The front to back ratio was better than approximately 20 dB throughout the total investigated range. Considering the -10 dB beamwidth, a value of approximately 155° was obtained for both polarizations at the repeating frequencies.

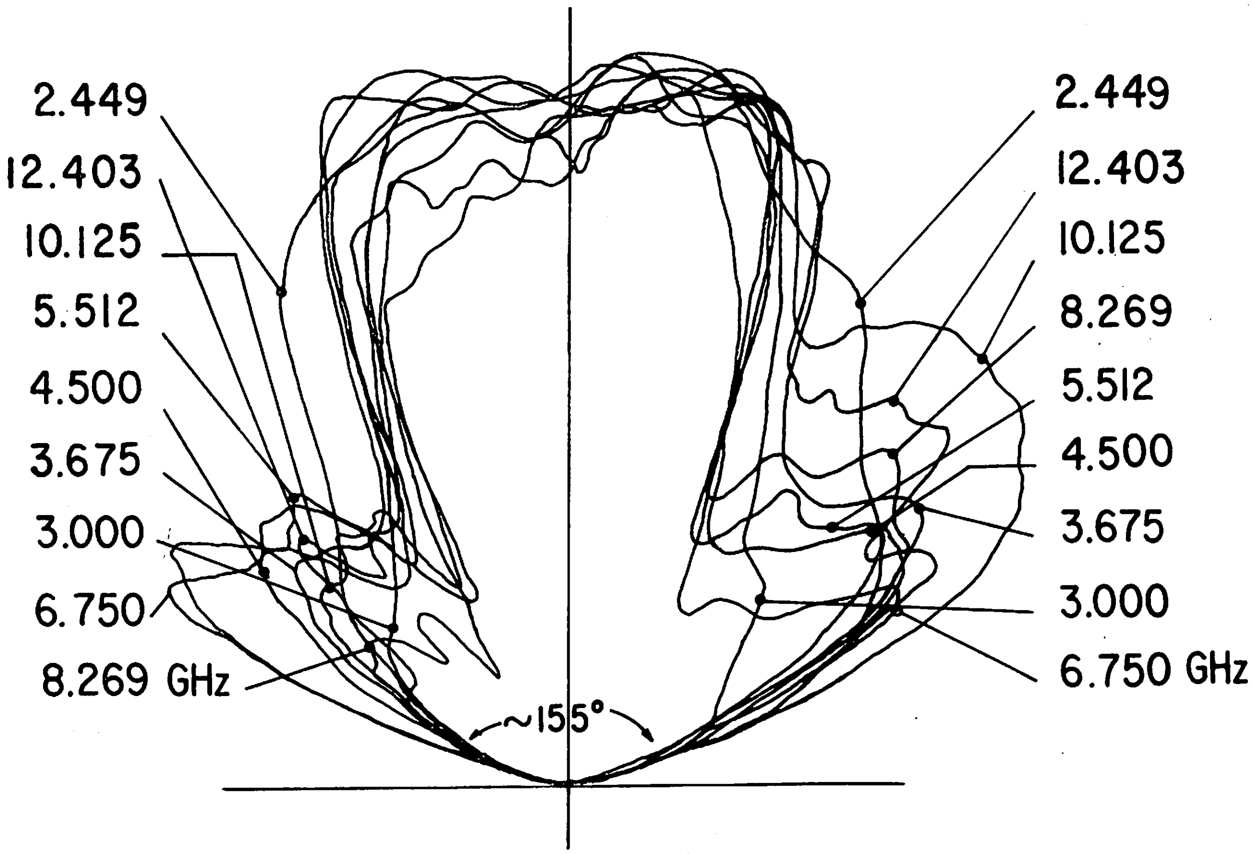

Fig. 3a. Frequency independent radiation pattern of the inclined log-spiral antenna at repeating frequencies ($\phi_0 = 0^o$ and 90^o) between 2.449 and 12.403 GHa, $E_\phi = f(\theta)$.

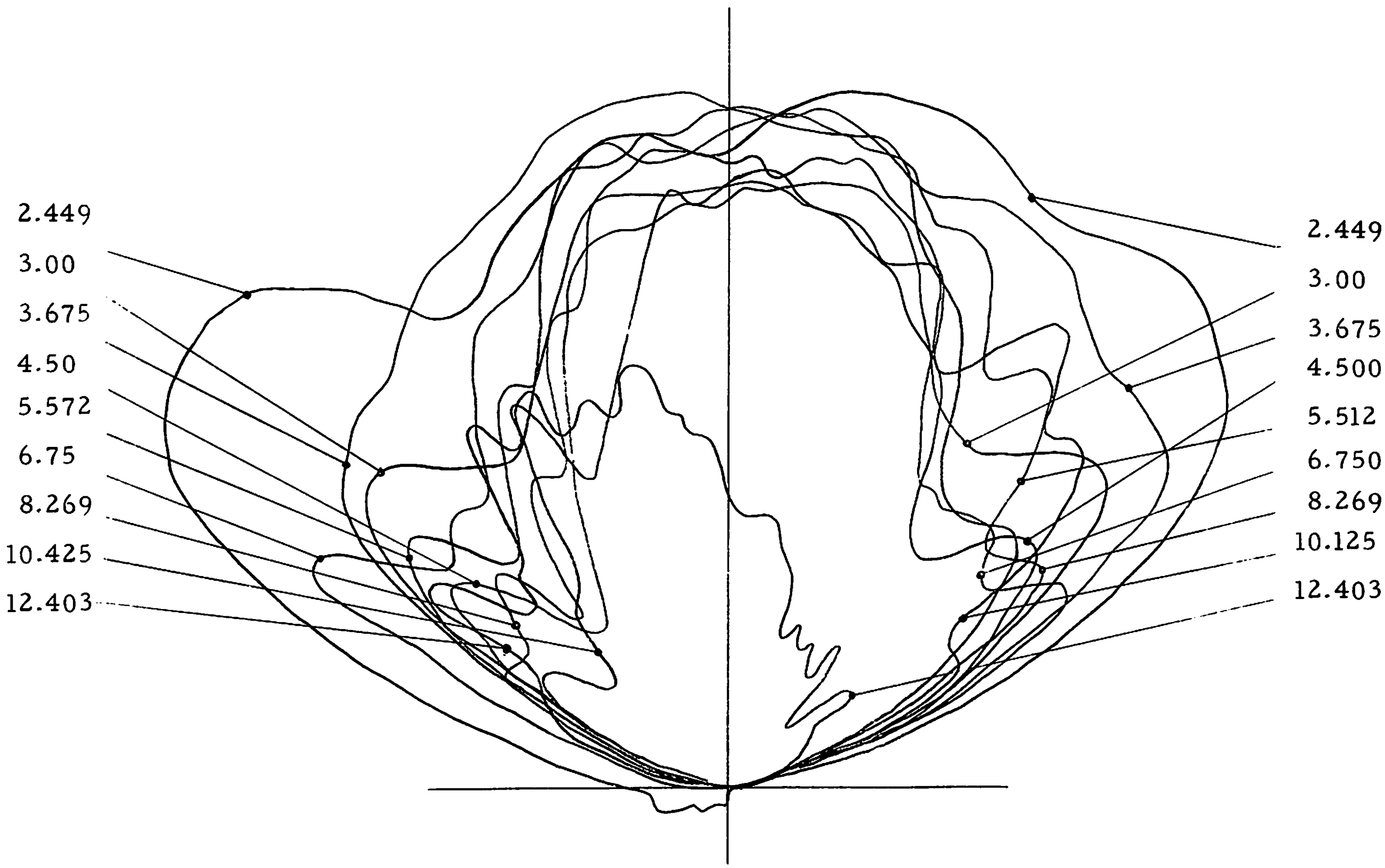

Fig. 3b. Frequency independent radiation pattern of the inclined log-spiral antenna at repeating frequencies (ϕ_0 = 0° and 90°) between 2.449 and 12.403 GHz. $E_\theta = f(\theta)$, power level of transmitting antenna identical for Fig. 3a and 3b (at resp. frequencies).

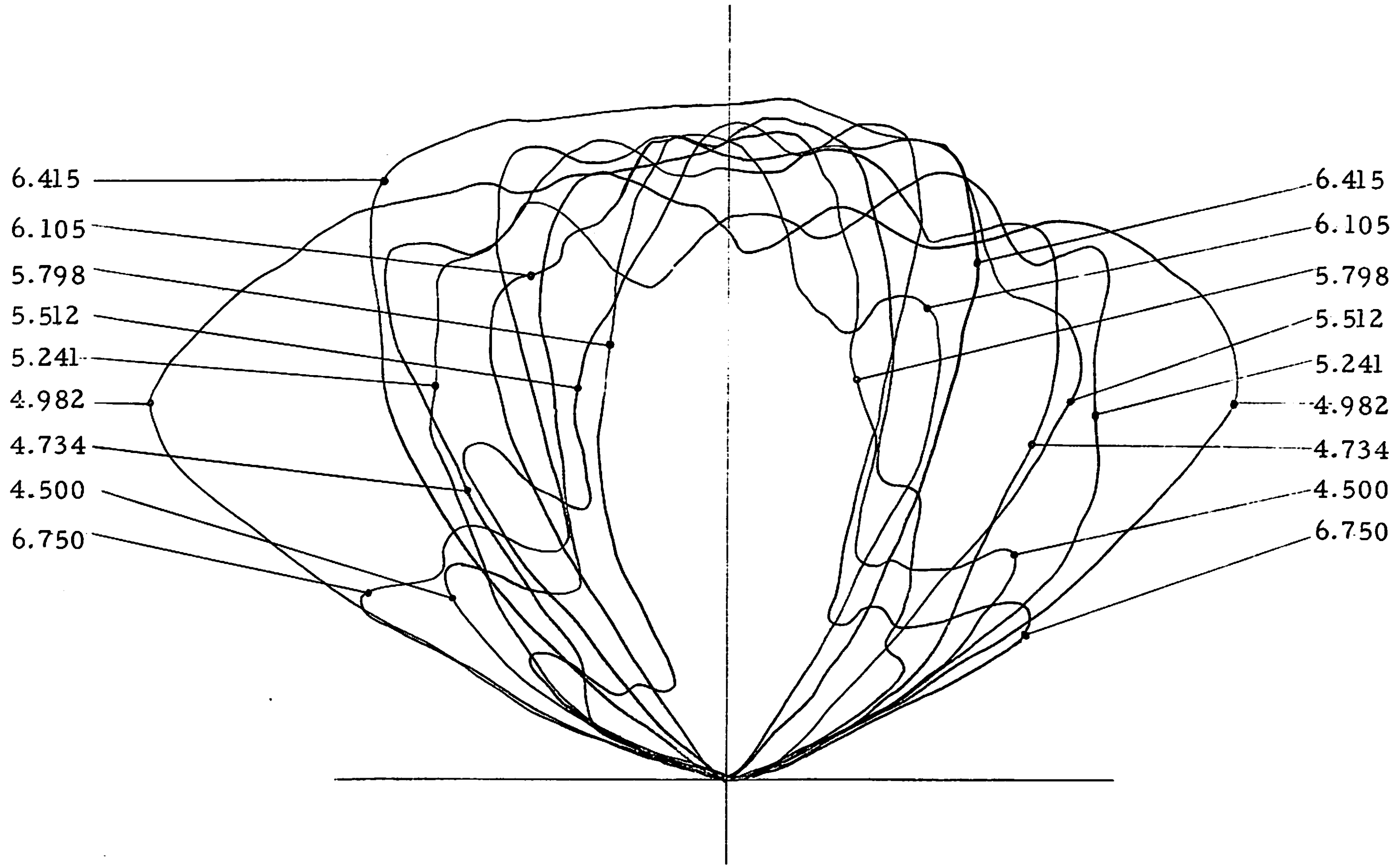

Fig. 3c. Pattern variation within one period of the inclined log-spiral antenna, $4.500 \le f \le 6.750$ GHz, $E_\phi = f(\theta)$.

Within one period, smaller values were recorded. In the higher frequency range (beyond 10 GHz) the influence of the feeding arrangement caused increasing nonsymmetry, even though the characteristic beamshape of the repeating pattern could be observed up to 12.4 GHz. Below 3.0 GHz a marked change of the pattern and end effects were present. The experimental results show that unidirectional, frequency-independent radiation can be obtained from the inclined log-spiral antenna in a theoretically unlimited frequency range. The back-radiation is reduced by reducing the apex angle ψ. The lower limit for this angle is given by the requirement for a balanced feed to the terminals through this conical aperture. Independent of the apex angle ψ, the inclination α will primarily determine the amount of attenuation and with this the size of the "active region," which is mainly responsible for the radiation. The smaller the angle α, the larger the active region and the more directive the antenna. For the chosen parameter ($\alpha = 30^{o}$), the lower frequency limit corresponded to a wavelength of 10 cm ($= \lambda_{min}$). The ratio D_{max}/λ_{min} was 5.0 in this case, as compared to the flat spiral ratio of approximately 1.0. For $\alpha = 0^{o}$ (straight continuous spiral) no truncation effect could be observed. This can be explained by the fact that the antenna was made up of two triangular (instead of spiral) sheets of copper, representing a slowly expanding parallel transmission-line with no truncation effect. $\alpha = 90^{\circ}$ represents the limit case of the plane equiangular spiral antenna.[5]

A further advantage of this particular type of construction is that unidirectional multimode propagation is easily obtained by using additional spiral arms: whereas the additional arms might intersect each other in the planar case, they do not in case of the three-dimensional structure.

ACKNOWLEDGMENT

The work reported was suggested by Professor V. H. Rumsey, University of California, Berkeley, to whom the author wants to express his sincere gratitude for his guidance during the study and for correcting the manuscript. The author wishes to thank Mr. Y. S. Yeh for his help in programming the geometrical spiral structure.

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