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Computational Studies on Tapered Polyetylene Rod Antennas

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Abstract

Several Investigations has been carried out to study the radiation patterns of Polystyrene, Perspex, Teflon and Nylon dielectric rod antennas are reported in the literature. In the present work computational studies on the radiation patterns of tapered Polyethylene rod antennas are carried out. The objective of the computational study is to find the best possible dimensions of the antenna. The length of the Polyethylene rod is varied from $2\lambda_0$ to $6\lambda_0$. For each one of these lengths, the radiation patterns of Polyethylene rod antennas with different taper angles are computed. The variation of HPBW (Half Power Beam Width) and SLL (Side Lobe Level) with length and taper angle has shown that a 4^0 taper over a length of $3\lambda_0$ to be the best possible choice. The principle plane patterns for 3λ0 length with different taper angles are presented.

Keywords: Dielectric rod antenna, Taper angle, Polyethylene, HPBW, SLL, Directivity.

1. Introduction

The dielectric rod antennas are used in applications requiring a non metallic antenna or a radiating element with its largest extent in longitudinal direction rather than a relatively large aperture in the plane transverse to the desired direction of maximum radiation. Since the rod seals the aperture of its excitation system, it can be used in applications where the excitation system has to be sealed. The dielectric rod antenna is mechanically strong, robust, but rain and moisture on the surface of the rod show an effect on the antenna gain. Many researchers have reported in the literature on Polystyrene, Perspex, Teflon and Nylon dielectric rod antennas [2] [3] [6]-[11].

In these computational studies, it is proposed to determine the length and taper angle of tapered Polyethylene rod antenna of circular cross section having dielectric constant ε_r=2.3 at 10GHz [5], for which the best possible radiation characteristics i.e. maximum directivity and minimum SLL may be obtained, by computing the radiation pattern using expressions for far-field quantities as given by Ananda Kumar and Rajeswari Chatterjee [1].

2. Field Equations for a tapered dielectric rod antenna

The radiation characteristics of a dielectric rod antenna mainly depend on the dielectric material used to fabricate the antenna, its physical structure, and the excitation method used to feed the antenna. Hence the design criteria of dielectric rod antennas include the selection of dielectric material with proper dielectric constant, provision for exciting the dielectric rod in HE_{11} mode, and the determination of diameter, length, and taper angle of the rod [6].

The dielectric rod antennas are tapered until the impedance of the antenna becomes equal to that of free space. Tapering the rod minimizes reflections at the free end of the rod. By this means the amplitude of side lobes and back lobe radiations may be reduced [1].

The fields radiated by a dielectric rod antenna are analyzed by Anand Kumar and Rajeswari Chatterjee [1] using the Schelkunoff's equivalence principle. The principle states that the "Electromagnetic field inside a source free region bounded by a closed surface S, the given source distribution outside S, can be replaced by a distribution of electric and magnetic currents $\mathbf{K_i^e}$ and $\mathbf{K_i^m}$ respectively over the surface S". The current densities of this equivalent source distribution are given by

$$\mathbf{K_i^e} = \hat{\mathbf{n}} \times \mathbf{H^i} \tag{1}$$

$$\mathbf{K_i^m} = -\hat{\mathbf{n}} \times \mathbf{E^i} \tag{2}$$

where $\mathbf{E^i}$ and $\mathbf{H^i}$ is the field distribution over the closed surface S and $\hat{\mathbf{n}}$ is a unit normal (inward) vector on S. The geometry of tapered dielectric rod is shown in Figure 1.

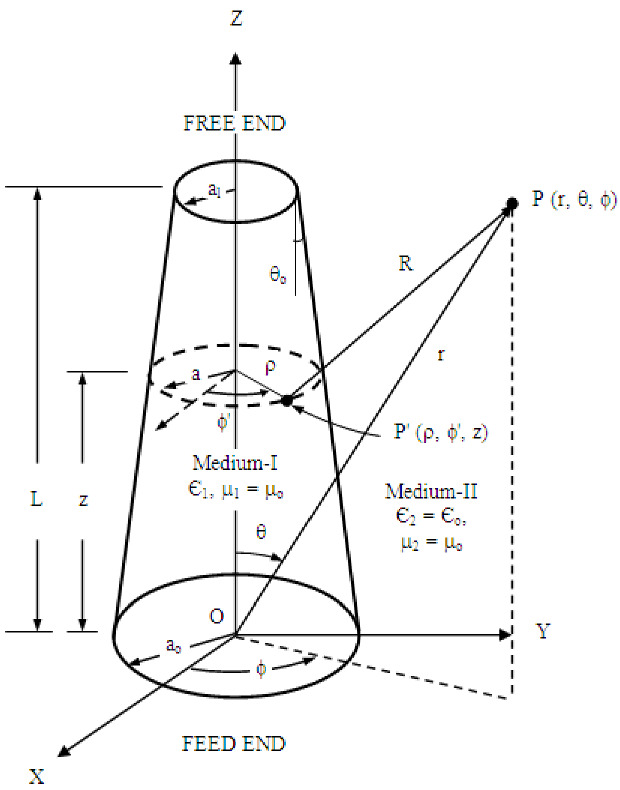


Figure 1: Geometry of tapered dielectric rod antenna.

The radiation field at a point $P(r,\theta,\phi)$ due to the current distribution (1) and (2) is given by

$$E_\theta = \eta_0 H_\phi = -(j/2\lambda_0)[\eta_0 L_\theta^m + L_\phi^e]\exp(-j\beta_0 r)/r \tag{3}$$

$$E_\phi = -\eta_0 H_\theta = -(j/2\lambda_0)[\eta_0 L_\phi^m - L_\theta^e]\exp(-j\beta_0 r)/r \tag{4}$$

where the electric radiation vector $\mathbf{L^e}$ and the magnetic radiation vector $\mathbf{L^m}$ of the current distribution are given by

$$\mathbf{L^e} = \int_S \exp(j\beta_0)(r - PP')\,\mathbf{dp^m} \tag{5}$$

$$\mathbf{L^m} = \int_S \exp(j\beta_0)(r - PP')\,\mathbf{dp^e} \tag{6}$$

where PP' is the distance of the point $P(r,\theta,\phi)$ from the source point $P'(\rho,\phi,z)$ and

$$(r - PP') = z\cos\theta + \rho\sin\theta\cos(\phi - \phi') \tag{7}$$

$\mathbf{dp^m}$ and $\mathbf{dp^e}$ are the moments of electric and magnetic current elements situated at the source point $P'(\rho, \phi, z)$ and are given by

$$\mathbf{dp^e} = \mathbf{K_i^e}\, ds = (\hat{n} \times \mathbf{H^i})\, ds \tag{8}$$

$$\mathbf{dp^m} = \mathbf{K_i^m}\, ds = -(\hat{\mathbf{n}} \times \mathbf{E}^i)\, ds \tag{9}$$

in which ds is an element area located at the source point P' in Figure 1, and $\mathbf{E^i}, \mathbf{H^i}$ are given by (1)-(3) of [1]

Following the above procedure the expressions for components of the electric field radiated by a tapered dielectric rod are obtained as:

$$\begin{aligned}\left(2\lambda_0\, {}^{r}\!/\!_{A}\right) j\exp(j\beta_0 r)\, E_\theta = & -j(1/f\varepsilon_1)\sin\phi\, I_1 + j(1/2f\varepsilon_1)\cos\phi\sin 2\phi\, I_2 \\ & - j(\lambda_0/2)\cos\theta\cos\phi\sin 2\phi\, I_3 \\ & - j\lambda_0\cos\theta\sin\phi\, I_4 + j\,2\pi\eta_0\sin\theta\sin\phi\, I_6 \\ & - \pi\left((1+\delta_1\eta_1^e) + [(\beta_1/\beta_0) + \eta_0\delta_1]\cos\theta\right)\exp(j\beta_1 l)\sin\phi\, I_7 \\ & - \pi\left((1-\delta_1\eta_1^e) + [(\beta_1/\beta_0) - \eta_0\delta_1]\cos\theta\right)\exp(j\beta_1 l)\sin\phi\, I_8\end{aligned} \tag{10}$$

and

$$\begin{aligned}\left(2\lambda_0\, {}^{r}\!/\!_{A}\right) j\exp(j\beta_0 r)\, E_\phi = & -j(1/f\varepsilon_1)\cos\theta\cos\phi\, I_1 - j(1/2f\varepsilon_1)\cos\theta\sin\phi\sin 2\phi\, I_2 \\ & + j(\lambda_0/2)\sin\phi\sin 2\phi\, I_3 - j\lambda_0\cos\phi\, I_4 + j\,2\pi\sin\theta\cos\phi\, I_5 \\ & + \pi\left((1+\delta_1\eta_1^e)\cos\theta + [(\beta_1/\beta_0) + \eta_0\delta_1]\right)\exp(j\beta_1 l)\cos\phi\, I_7 \\ & + \pi\left((1-\delta_1\eta_1^e)\cos\theta + [(\beta_1/\beta_0) - \eta_0\delta_1]\right)\exp(j\beta_1 l)\cos\phi\, I_8\end{aligned} \tag{11}$$

where

A is the excitation constant for H modes and

$$I_1 = \int_0^L \exp(j\beta z)\ \delta\, rJ_1(r)\left\{\sin^2\phi\, J_o(\xi) + \cos 2\phi\,[J_1(\xi)/\xi]\right\} dz \tag{12}$$

$$I_2 = \int_0^L \exp(j\beta z)\,\delta\, k_1 rJ_1(r)\left[2\frac{J_1(\xi)}{\xi} - J_0(\xi)\right] dz \tag{13}$$

$$I_3 = \int_0^L \exp(j\beta z)\, k_1 rJ_1(r)\left[2\frac{J_1(\xi)}{\xi} - J_0(\xi)\right] dz \tag{14}$$

$$I_4 = \int_0^L \exp(j\beta z)\, k_1 rJ_1(r)\left[\cos^2\phi\, J_0(\xi) - \cos 2\phi\ \frac{J_1(\xi)}{\xi})\right] dz \tag{15}$$

$$I_5 = \int_0^L \exp(j\beta z)\left[rJ_0(r) - (1-\delta\eta_1^e)J_1(r)\right] J_1(\xi)\,dz \tag{16}$$

$$I_6 = \int_0^L \exp(j\beta z)\left[\delta rJ_0(r) + \left(\frac{1}{\eta_1^m} - \delta\right)J_1(r)\right] J_1(\xi)\,dz \tag{17}$$

$$I_7 = \int_0^{a_1} R\, J_0(R)\, J_0(\xi_1)\, d\rho \tag{18}$$

$$I_8 = \int_0^{a_1} \left[2J_1(R) - RJ_0(R)\right]\left[2\frac{J_1(\xi_1)}{\xi_1} - J_0(\xi_1)\right] d\rho \tag{19}$$

with $\xi = \beta_o\, a \sin\theta$ and $\xi_1 = \beta_o\, \rho \sin\theta$

In equations (12)-(19), δ is the ratio of excitation constants for E and H modes. The values of δ and k_1 may be obtained, by representing their variation given in Figure 2 of [1], by piecewise linear models as:

$$\delta = 0.007 \text{ for } a/\lambda_0 \le 0.1 \tag{20}$$
$$\delta = (2.9 - a/\lambda_0) / 400 \text{ for } a/\lambda_0 \ge 0.1 \tag{21}$$

and

$$k_1 = 0.5\,(15 - a/\lambda_0) \text{ for } a/\lambda_0 \le 0.2 \tag{22}$$
$$k_1 = 0.2\,(15 - 17\, a/\lambda_0) \text{ for } a/\lambda_0 \ge 0.2 \tag{23}$$

δ_1 is the value of δ at z = L in Figure 1.

The H-plane pattern may be obtained by setting $\phi = 0^0$, and the E-plane pattern may be obtained by setting $\phi = 90^0$ in (10) and (11). The radiation patterns are plotted by programming the field equations using matlab software.

3. Results

The computational studies were performed on Polyethylene (ε_r=2.3) dielectric rod antennas. The length of Polyethylene rod is varied from $2\lambda_0$ to $6\lambda_0$ .The principle plane patterns are computed for each length (L) with different taper angles (θ_o). The HPBW, SLL and Directivity are determined from the principle plane patterns for each length. The Directivity may be computed using Kraus's formula [4]:

$$\text{Directivity}\,(D_0) = 41253/\,(\theta_E \times \theta_H) \tag{24}$$

Where θ_E = HPBW in E-Plane (degrees)

θ_H = HPBW in H-Plane (degrees)

The results are presented in Table-1 – Table-5 for each length.

Table 1: Tapered Dielectric Rod Aerial (Length=**2λ_0**).

SNO	θ_0 (Deg.)	HPBW (Deg.)		SLL (dB)		D0 (dB)
		ϕ =00	ϕ =900	ϕ =00	ϕ =900	
1	0	40	24	-15.92	-1.21	16.33
2	2	68	32	-16.48	-10.46	12.77
3	4	56	42	-15.39	-17.72	12.44
4	6	64	53	-13.97	-18.42	10.84
5	8	72	64	-14.42	-19.17	9.51
6	10	68	64	-16.47	-19.57	9.76
7	11.5	62	60	-17.72	-20	10.44

Table 2: Tapered Dielectric Rod Aerial (Length=**3λ_0**).

S.NO	θ_0 (Deg.)	HPBW (Deg.)		SLL (dB)		D0 (dB)
		ϕ =00	ϕ =900	ϕ =00	ϕ =900	
1	0	28	64	-6.57	-6.74	13.65
2	2	38	30	-10.46	-13.56	15.55
3	4	56	26	-11.7	-15.39	14.52
4	6	88	86	-11.21	-13.98	7.37
5	7.5	82	88	-14.42	-15.65	7.57

Table 3: Tapered Dielectric Rod Aerial (Length=**4λ_0**).

S.NO	θ_0 (Deg.)	HPBW (Deg.)		SLL (dB)		D0 (dB)
		ϕ =00	ϕ =900	ϕ =00	ϕ =900	
1	0	64	36	-8.75	-7.96	12.52
2	1.5	32	28	-5.04	-4.3	16.63
3	2.5	42	38	-7.96	-12.04	14.12
4	3.5	58	68	-9.12	-8.4	10.19
5	4.5	76	82	-8.64	-10.46	8.21
6	5.5	82	86	-11.54	-10.47	7.67

Table 4: Tapered Dielectric Rod Aerial (Length=**5λ_0**).

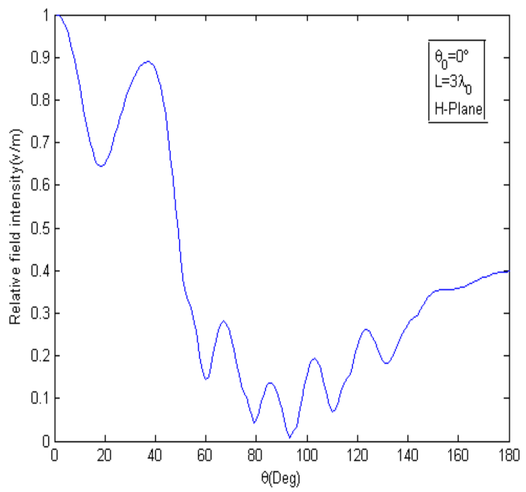
S.NO	θ_0 (Deg.)	HPBW (Deg.)		SLL (dB)		D0 (dB)
		ϕ =00	ϕ =900	ϕ =00	ϕ =900	
1	0	38	22	-7.54	-3.54	16.93
2	1.5	40	46	-8.88	-15.39	13.50
3	2	36	38	-6.94	-18.06	14.79
4	2.5	46	52	-7.96	-5.76	12.36

5	3	60	70	-5.85	-4.81	9.92
6	3.5	68	76	-6.29	-6.94	9.02
7	4	74	78	-8.87	-9.9	8.54
8	4.5	78	82	-10.03	-11.06	8.09

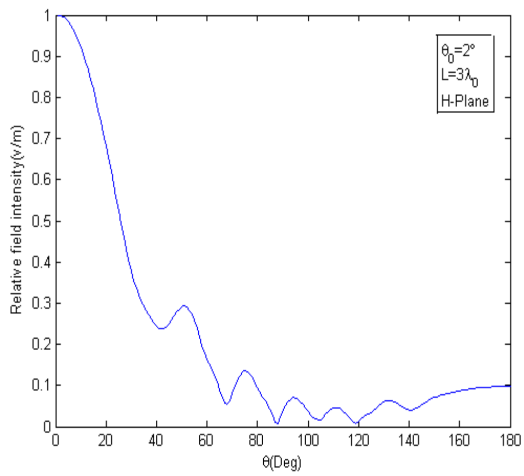
Table 5: Tapered Dielectric Rod Aerial (Length=**6λ_0**).

S.NO	θ_0 (Deg)	HPBW (Deg.)		SLL (dB)		D0 (dB)
		ϕ =00	ϕ =900	ϕ =00	ϕ =900	
1	0	50	56	-1.31	-6.02	11.68
2	1	55	44	-6.94	-12.04	17.04
3	1.5	52	48	-9.37	-13.98	12.18
4	2	40	48	-11.37	-12.39	13.32
5	2.5	58	68	-3.61	-1.52	10.19
6	3	66	72	-5.04	-5.34	9.39

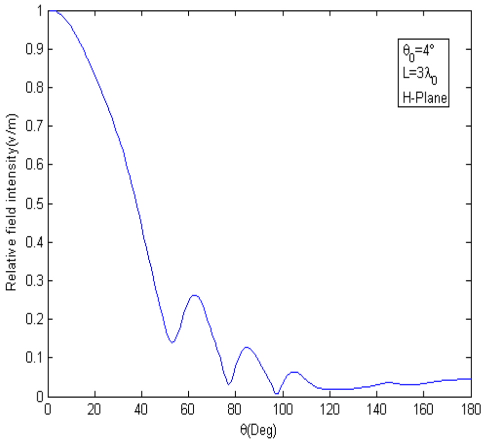
The best possible dimension of the dielectric rod antenna is the length for which the best possible radiation characteristics i.e. minimum SLL and maximum directivity can be obtained. From the tables it may be observed that a Polyethylene rod of length 3λ_0 with a taper angle of 4^0 seems to be the best possible choice. The principle plane patterns (E-Plane and H-Plane) are presented, for a Polyethylene rod of length 3λ_0 with different taper angles, in Figure 2 and Figure 3.

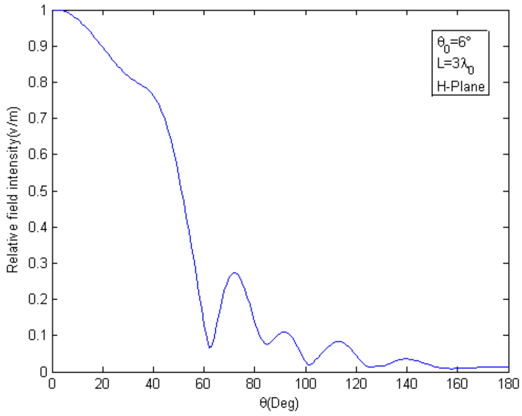


(a)



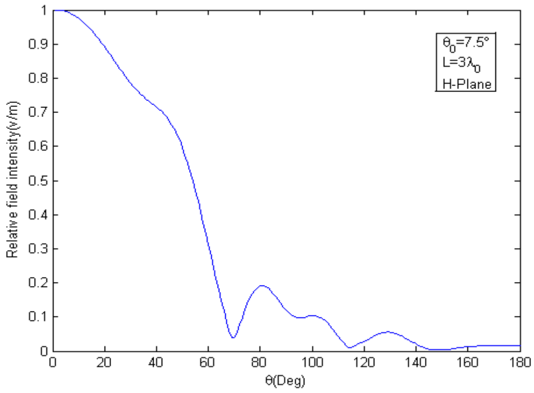
(b)





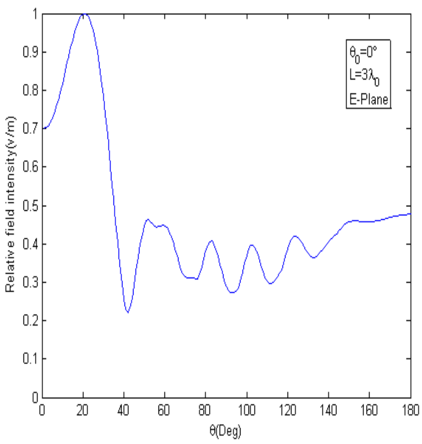
(d)

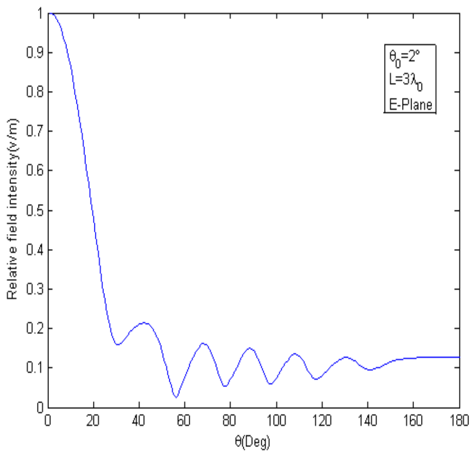
(c)



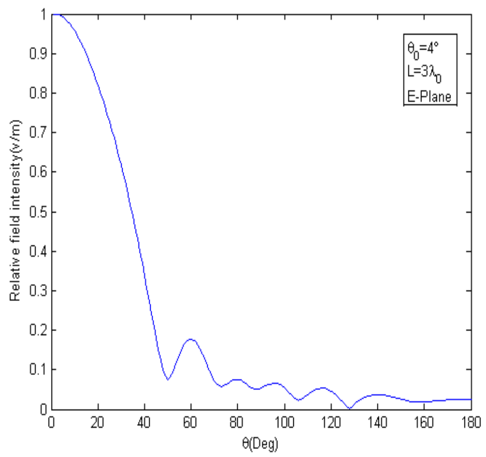
(e)

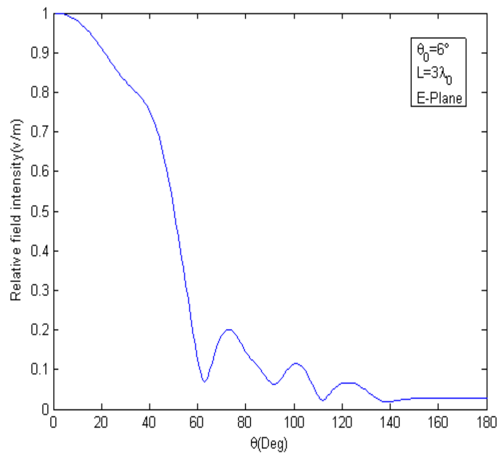
Figure 2: Radiation patterns of tapered Polyethylene rod antennas in H plane.





(a) **(b)**





(C) **(d)**

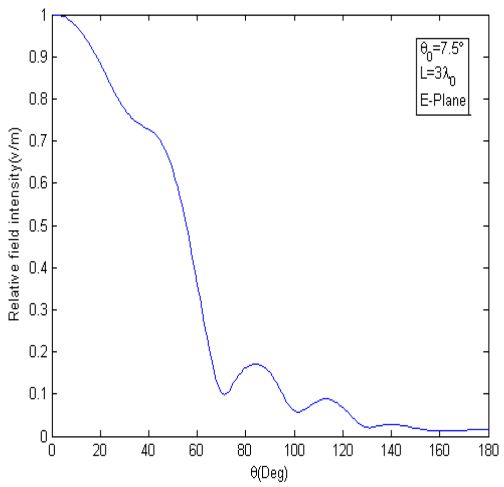


Figure 3: Radiation patterns of tapered Polyethylene rod antennas in E plane.

The Polyethylene tapered rod antenna of length $3\lambda_0$ with a taper angle of 4^0, having a directivity of 14.52 dB, may be used as radiating element in Planer and Circular arrays to produce a narrow beam radiation pattern. The directivity of $3\lambda_0$ length and 2^0 taper angle is 15.55 dB, but side Lobe Level (SLL) is slightly higher than the best possible dimension antenna. When more directivity is needed the antenna of length equal to $3\lambda_0$ and taper angle equal to 2^0 may be used as a radiator in array applications.

List Symbols

S No.	Symbol	Meaning
1	f	Frequency
2	λo	Free space wave length

3	ε	Permittivity of medium
4	μ	Permeability of medium
5	βo	Phase shift constant of free space
6	β	Phase constant of guided waves inside the dielectric rod antenna
7	$\beta 1$	Value of β at $z = L$ in Fig 1.
8	ηo	Free space wave impedance
9	$\eta 1e$	Wave impedance of electric field component
10	$\eta 1m$	Wave impedance of magnetic field component
11	x, y, z	Rectangular coordinates
12	ρ, ϕ, z	Cylindrical coordinates
13	r, θ, ϕ	Spherical coordinates

14 D_0 Directivity

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