Summary of a study on the TM01 radiation pattern of corrugated conical horn antennas with small flare angle

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Summary of a study on the $TM_{01}$ radiation pattern of corrugated conical horn antennas with small flare angle.

by

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Summary of a study on the $TM_{01}$ radiation pattern of corrugated conical horn antennas with small flare angle

Th. Scharten

This summary is based on the technical reports Nr ETA-3-1969 and Nr ETA-30-1969 (Eindhoven University of Technology)

1. The configuration and its electromagnetic description

1.1 Corrugated conical horn antenna

We assume a simple harmonic time dependence $e^{j\omega t}$.

We suppose $t_1 + t_2 \ll \lambda_{guide}$ and $R_0 \gg a \gg \lambda_{guide}$. Furthermore we suppose the flare angle to be so small that -if a $TM_{01}$ mode is excited in the horn- the aperture field can be approximated by the $TM_{01}$ mode field of a circular cylindrical, corrugated waveguide with inner radius $a$, but now with a quadratic phase distribution in the radial aperture direction. For in that case the longitudinal phase factor of the aperture field, $e^{ipn2}$, has to be replaced by the factor $e^{j\beta_n (R_f - R_o)}$, where $R_f = R_o \sqrt{1 + \frac{c^2}{R_o^2}} \approx R_o + \frac{c^2}{2R_o}$. So this factor reads $e^{j\beta_n \frac{c^2}{2R_o}}$. 

Figure 1

1.2 Electromagnetic model

Figure 2
2. Fields on the horn surfaces

2.1 Outer surface. On the outer surface we assume the wall currents to be zero; so we have

\[ \hat{n} \times \vec{E} = \vec{0} \]
\[ \hat{n} \times \vec{H} = \vec{0} \quad \text{on } S_c \]

2.2 Inner surface. The surface impedance on the inner horn surface is determined by the relation

\[ Z_r = jX_r = \frac{t_1 Z_{\text{groove}} + t_2 Z_{\text{dam}}}{\varepsilon_{1} + \varepsilon_{2}} \]

\[ = \frac{t_1}{\varepsilon_{1} + \varepsilon_{2}} Z_{\text{groove}}, \quad \text{on } S_r \]

where

\[ Z_{\text{groove}} = jX_{\text{groove}} = j\sqrt{\frac{\mu_0}{\varepsilon_0}} \frac{J_0(ka) \psi_0(ka + kd) - J_0(ka + kd) \psi_0(ka)}{J_1(ka) \psi_0(ka + kd) - J_0(ka + kd) \psi_1(ka)}, \]

being the input impedance of a shortened radial waveguide, \( a \leq \varphi \leq a + d \), propagating a TEM wave.

2.3 Aperture. The aperture fields are found by considering a circular cylindrical waveguide (radius \( a \)) having the reactance wall condition, given above, and propagating a TM_{0n} mode \( \exp[i\beta_z z] \). Taking into account the quadratic phase distribution we find

\[ E_{\phi n} = -i\beta_n \psi_0 \psi_1(ka) \exp(i\beta_n \rho^2/2\rho_0) \]
\[ H_{\phi n} = -i\omega \varepsilon_0 \lambda_n \psi_0 \phi_1(ka) \psi_0(ka + \varphi) \exp(i\beta_n \rho^2/2\rho_0), \quad \text{on } S_a \]

where \( \lambda_n \) is the \( n \)th root of the TM_{0n} characteristic equation

\[ \lambda J_0(\lambda a) - \omega \varepsilon_0 \psi_0 \lambda J_1(\lambda a) = 0. \]

In our case \( ka \gg 1 \); so the surface reactance can be approximated by

\[ X_r = \sqrt{\frac{\mu_0}{\varepsilon_0}} \frac{t_1}{\varepsilon_{1} + \varepsilon_{2}} \tan kd. \]

It is shown that the characteristic equation has two imaginary solutions (surface wave solutions) if

\[ k \tan kd > \frac{2(t_1 + t_2)}{t_1a}, \]

and real, single valued solutions if

\[ k \tan kd < \frac{2(t_1 + t_2)}{t_1a}. \]
3. The radiation pattern

The energy-flow density can now be evaluated in the usual way, giving

\[ S_n(R, \theta) = (k \cos \theta + \beta_n)^2 \left| \int_0^\infty J_1(\lambda_n \rho) J_1(\lambda \rho \sin \theta) e^{i \beta_n \rho^2} \rho d \rho \right|^2 \]

4. Results

Horn dimensions

- \( a = 0.132 \) (m)
- \( d = 0.009 \) (m)
- \( t_1 = 2.5 \) (mm)
- \( t_2 = 4.0 \) (mm)
- \( R = 0.493 \) (m)
- \( \phi_0 = 15^\circ \)

dimensions of the 'equivalent' waveguide

Figure 3 Dispersion curves for the circular cylindrical, corrugated waveguide

Figure 4-10 Theoretical and experimental \( \text{TM}_{01} \) radiation patterns in the frequency range \( 8.5 - 11.5 \) GHz

Figure 11 Half beamwidth characteristics
$a = 0.137 \text{ (m)}$

$d = 0.009 \text{ (m)}$

$t = 0.385$

Dispersion curves

Figure 3
$TM_{01}$ radiation patterns
theoretical —
experimental ----
frequency: 8.5 GHz

Figure 4
Figure 5

$\text{TM}_{01}$ radiation patterns
theoretical ——
experimental ----
frequency: 9 GHz
$TM_{01}$ radiation patterns
theoretical ———
experimental ----
frequency: 9.5 GHz

Figure 6
Figure 7

$TM_{01}$ radiation patterns

theoretical ———
experimental -----
frequency: 10 GHz
Figure 8

$TM_{01}$ radiation patterns
theoretical ------
experimental -----
frequency: 10.5 GHz
Figure 9

$TM_{01}$ radiation patterns

- Theoretical: solid line
- Experimental: dashed line

Frequency: 11 GHz

Relative power vs. degrees
TM\textsubscript{01} radiation patterns
theoretical \text---
experimental \text----
frequency: 11.5 GHz

Figure 10
Half beamwidth at 0, 10, 20, 30 dB level respectively, as a function of frequency.