Fig. 4. Comparison between computed and measured element patterns of a scale model of the EISCAT line feed for longitudinal polarization. (a) Transverse pattern. (b) Longitudinal pattern.

The calculation formula includes the polarization of the radiation field. We can easily see that a longitudinal dipole causes a purely longitudinal polarization and a transverse dipole causes a purely transverse polarization in a plane normal to the cylindrical scatterers. However, if we consider a cone about the longitudinal axis, the field of a transverse dipole is not purely transversely polarized.

A particular problem should be pointed out. If there are two or more cylindrical scatterers, one or more transverse electromagnetic (TEM) waves may propagate along the scatterers. Such field solutions have not been included in the element pattern formulation in (19). However, they may be important as they can cause large mutual coupling between the array elements. This is the fact in the EISCAT antenna where the two beam-forming rods act as a Lecher line.

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A Simple Expression for Estimating Attenuation by Fog at Millimeter Wavelengths

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Abstract—At millimeter wavelengths, fog attenuation is a function of the fog density, extent, index of refraction of the fog medium, and wavelength. The attenuation is usually determined by first estimating the index of refraction of water for the wavelength and temperature of interest and then calculating the attenuation using the Rayleigh approximation. In this communication fog attenuation is computed for a large set of wavelengths and indices of refraction. A regression analysis of the attenuation is then conducted as a function of wavelength and temperature. It is shown that an almost perfect fit can be obtained with a four-term regression on wavelength and temperature for the ranges of $3 \text{ mm} < \lambda < 3 \text{ cm}$ and $-8^\circ\text{C} < T < 25^\circ\text{C}$, respectively. This expression produces a normalized fog attenuation; the total attenuation is easily computed by multiplying the normalized attenuation by the fog density and extent. If fog density data are not available, a formula for estimating the density from fog visibility is given.

Attention due to fog is a complex function of the particle size distribution, density, extent, index of refraction, and wavelength. At microwaves, fog attenuation is relatively low; however, at millimeter wavelengths it becomes appreciable, continually increasing as the wavelength becomes shorter. Fog attenuation is usually determined by first estimating the index of refraction of water for the temperature and wavelength of interest and then calculating the attenuation using the Rayleigh approximation. Fog droplets rarely have diameters larger than 0.1 mm so the Rayleigh approximation is valid throughout essentially the whole millimeter wavelength region. For these wavelengths, scattering losses are negligible so the drop shape is not important, only the density.

The main objective of this communication is to obtain an expression for calculating the normalized fog attenuation directly, given only the wavelength and fog temperature. Fog attenuation was computed for a large set of wavelengths and temperatures

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using indices of refraction that have been tabulated by Rozenberg [1]. Attenuations normalized to fog density and extent are plotted in Fig. 1 as a function of wavelength for a wide range of temperatures. It is seen that the curves are well behaved for wavelengths greater than about 3 mm and temperatures slightly above -10°C . At shorter wavelengths and lower temperatures the curves begin to cross over. Thus the regression analysis was limited to wavelengths greater than 3 mm. From a practical standpoint this is a useful range for determining fog attenuation; at wavelengths greater than 3 cm the attenuation is relatively low and at wavelengths smaller than 3 mm the attenuation due to water vapor may exceed that due to fog so the total attenuation becomes prohibitive. As for temperature, the likelihood of fog occurring at temperatures below -8°C or above 25°C is small. Therefore, the regression analysis was conducted over wavelength and temperature ranges of $3\text{ mm} < \lambda < 3\text{ cm}$ and $-8^{\circ}\text{C} < T < 25^{\circ}\text{C}$, respectively. The resulting regression produced the following expression:

$$A = -1.347 + 0.0372 \lambda + \frac{18.0}{\lambda} - 0.022 T \quad (1)$$

where

A attenuation in dB/km/g/m³

λ wavelength in mm

T temperature in $^{\circ}\text{C}$.

The R^2 statistic (correlation coefficient squared) for this regression is 0.9883 which is very close to a perfect fit. The standard error of the estimate is only 0.146 dB. It is recommended that (1) not be used outside the wavelength and temperature ranges for which the regression was carried out since it has been optimized for these ranges and the accuracy deteriorates very sharply outside these ranges.

The total fog attenuation is obtained by multiplying the normalized attenuation by the fog density in g/m³ and the fog extent in km. Unfortunately, the fog density and extent are not easily obtainable so the uncertainty in these parameters often produces a larger error than that resulting from the approximation that was used to calculate the normalized attenuation.

Fog is often characterized by visibility, which is defined as the greatest distance at which it is just possible for an observer to see a prominent dark object against the sky at the horizon, since it is much easier to measure than density. However, it should be emphasized that visibility is an optical parameter, a function of the scattering characteristics of the droplets, whereas the attenuation at millimeter wavelengths, as mentioned previously, is strictly a function of the fog density. Although there is a correlation between fog visibility and total liquid water content, [2], [3] this relationship must be used with caution because the correlation coefficient is strongly dependent on the type of fog. Fog is often divided into two types; radiation fog which forms when the ground becomes cold at night and cools the adjacent air mass until it becomes supersaturated and advection fog which forms when warm, moist air moves across a cooler surface. The average drop size of an advection fog is usually larger than that of a radiation fog.

Eldridge [2] has derived the following empirical formula for

Fig. 1. Attenuation by fog at millimeter wavelengths.

fog visibility as a function of fog density;

$$V = 0.024 M^{-0.65} \quad (2)$$

where V is the visibility in km and M is the density in g/m³. He believes that this formula is valid for drop diameters between 0.3 microns (μ) and 10 μ . If there is an abundance of very small drop sizes as for the case of dense haze or other special type fogs, then he recommends the coefficient 0.024 be replaced by 0.017. It would seem that his formula should be satisfactory for a radiation fog since the drop diameters are typically less than 10 μ . However, for an advection fog, which may have drop diameters as large as 100 μ , the predicted visibility may be too low. This has been discussed in a paper by Platt [3]. Solving (2) for the fog density one obtains

$$M = \left(\frac{0.024}{V} \right)^{1.54} \quad (3)$$

Thus, if fog density data are not available but visibility data are, then (3) may be used. However, this equation probably underestimates the density of an advection fog, so it will in turn, most likely, lead to an underestimate in the corresponding attenuation.

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