ANALYSIS OF FIELD PATTERNS SCATTERED BY AN UNDERGROUND VOID OF CIRCULAR CYLINDER

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1. Introduction

The applicability of geotomography schemes [1] in locating high-contrast geological anomalies such as underground empty cavity is limited because the refraction and the diffraction by the cavity are far beyond the correction level [2]. In a real situation, the rock formation around the cavity is usually quite weathered, jointed, and heavily fractured and it is not easy to single out the contribution of the scattering by the empty cavity alone from the strong interferences of the fields interacted with the inhomogeneities of the surrounding rock.
A cross-borehole continuous wave electromagnetic probing [3] is advantageous to cope with this real situation since its single frequency scheme gives greater dynamic range and is not affected by the host medium dispersion. If the wavelength of the transmitted signal is about the radius of the empty cavity, double dips in the amplitude pattern of the received signal appear at two locations corresponding to the top and the bottom boundaries of the empty cavity. Three different views (one parallel and two different off-set) of these double dips provide the location of the cavity without any further data processing [3]. The double dips in the amplitude pattern of the received signal are confirmed by the measurement as well as by the numerical calculations [3] using the moment method [4] when the incident magnetic field is polarized in the direction of the cylinder axis. This simple numerical calculation, however, does not reveal the physical mechanism of these double dips. It is shown here that these double dips become double nulls in the near field region when the wavelength of the transmitting signal is properly chosen. A circular air cylinder embedded in a denser host medium is chosen for the analysis and the nulls are shown to be formed when the scattered field equals the incident field with its phase reversed.

2. Analysis of Double Nulls

When an E-polarized plane wave u_i is incident upon a circular air cylinder of the radius a embedded in a dielectric medium of its relative dielectric constant ϵ_r, as shown in Fig. 1, the total field u outside the cylinder may be obtained analytically by a sum of u_i and the scattered field u_s [5]. In order to see the double dip characters in detail, the scattered field is calculated in the plane $x = x_o$, where the radius of the air cylinder is chosen to be 1 meter, ϵ_r of the host medium to be 2, and the frequency of the transmitting signal to be from 90 MHz to 330 MHz.
A typical double dip pattern of the total field is shown in the top figure of Fig. 2. Amplitude and phase variation of the corresponding scattered field is shown in the bottom figure for 154 MHz and $x_o = 4$ meters. Two dips occur at $y = y_{p1}$ and y_{p2}, where the phase of the scattered field differs by 180° from that of the incident field. Amplitudes of the scattered field at these points, y_{p1} and y_{p2}, are slightly smaller than that of the incident field and the corresponding amplitude dips of the

total field become about 35 to 50 dB below that of the incident field.
Double nulls exist at the slightly lower frequency of 158.617 MHz (the corresponding wavelength in the host medium is 1.337 meters), as shown in Fig. 3, for which 180° phase points of y_{p1} and y_{p2} coincide with equal amplitude points, y_{a1} and y_{a2}, where the amplitude of the scattered field is equal to that of the incident field. As the signal frequency increases further to 164 MHz, the 180° phase point y_{p2} becomes smaller than the equal amplitude point y_{a2} as shown in Fig. 4 while y_p is larger than y_a for 154 MHz as in Fig. 2. This crossing over of two points, y_p and y_a, clearly shows the existence of the double nulls in the near field region at $x_o = 4$ m. In the far field region, however, the amplitudes of the scattered fields are smaller than that of the incident field and nulls in the amplitude pattern of the total field can not occur. For the air cylinder of 1 m radius and $\epsilon_r = 2$, this critical distance x_o is calculated to be 4.7215 meters. One may find out signal frequencies where the double nulls occur by plotting 180° phase points (y_p) and equal amplitude points (y_a) versus frequency, as shown in Fig. 5. For $x_o = 4$ m, two frequencies, 158.617 MHz and 218.336 MHz, provide $y_p = y_a$ and the double nulls occur at these frequencies. One may calculate other double nulls in the higher frequencies above 330 MHz by the same way, which is not shown in Fig. 5.

3. Conclusion

Selecting a proper frequency of cross-borehole continuous wave electromagnetic probing as outlined above, two nulls in the amplitude pattern of the total field scattered by a circular air cylinder embedded in a denser host medium occur at locations corresponding to the top and bottom boundaries of the air cylinder. This phenomenon provides an effective tool to detect and locate underground cavities without employing conventional reconstruction algorithms which need tremendous data processing.

References

[1] K. A. Dines and R. J. Lytle, "Computerized geophysical tomography," *Proc. IEEE*, vol. 67, pp. 471-480, 1979.

[2] M. Slaney, A. C. Kak, and L. E. Larsen, "Limitations of imaging with first-order diffraction tomography," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-32, pp. 860-874, 1984.

[3] R. J. Lytle, E. F. Laine, D. L. Lager, and D. T. Davis, "Cross-borehole electromagnetic probing to locate high-contrast anomalies," *Geophysics*, vol. 44, pp. 1667-1676, 1979.

[4] J. H. Richmond, "TE-wave scattering by a dielectric cylinder of arbitrary cross-section shape," *IEEE Trans. Antennas Propagat.*, vol. AP-14, pp. 460-464, 1966.

[5] D. S. Jones, *The Theory of Electromagnetism*. New York: Pergamon, 1964.

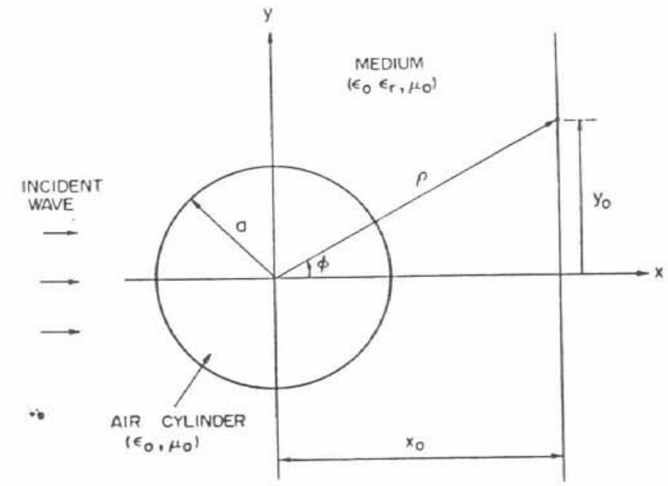

Fig. 1. Two dimensional scattering by a circular cross-sectional air cylinder embedded in a dielectric medium.

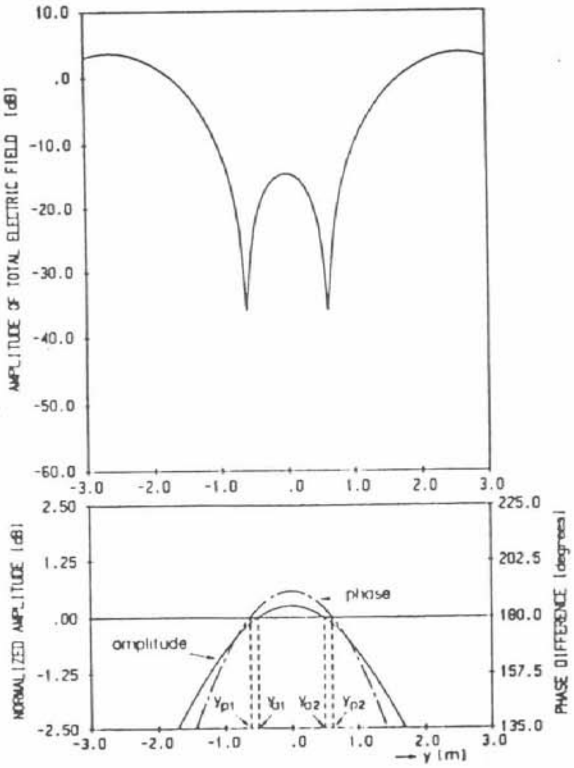

Fig. 2. Amplitude pattern of the total field (top) and the amplitude and phase patterns of the scattered field normalized by the incident field (bottom) for $x_o = 4$ m and $f = 154$ MHz.

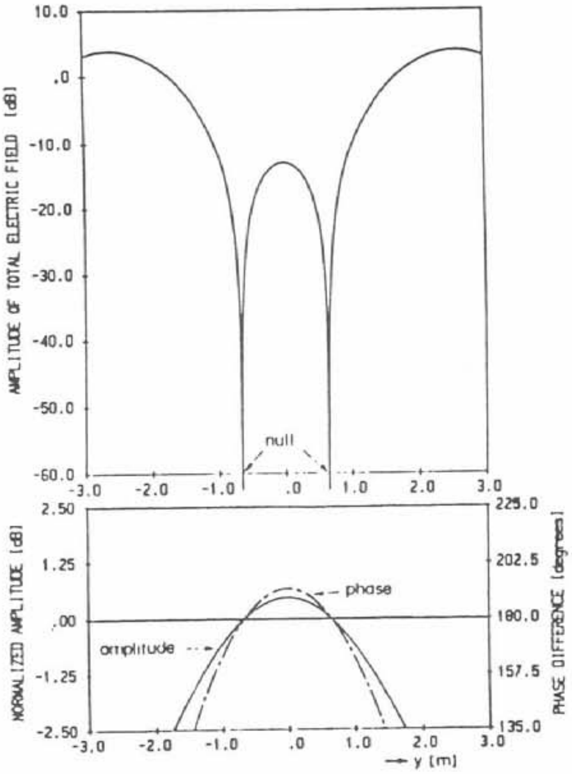

Fig. 3. Double nulls in the total amplitude pattern and the normalized amplitude and phase patterns of the scattered field for $x_o = 4$ m and $f = 158.617$ MHz.

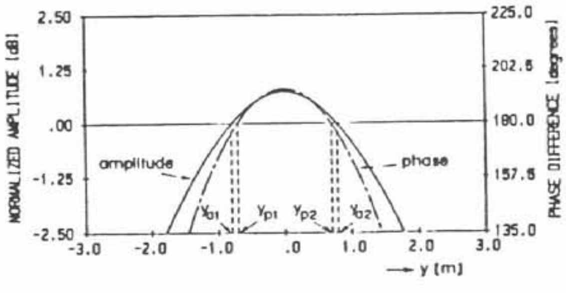

Fig. 4. Amplitude and phase patterns of the scattered field for $x_o = 4$ m and $f = 164$ MHz.

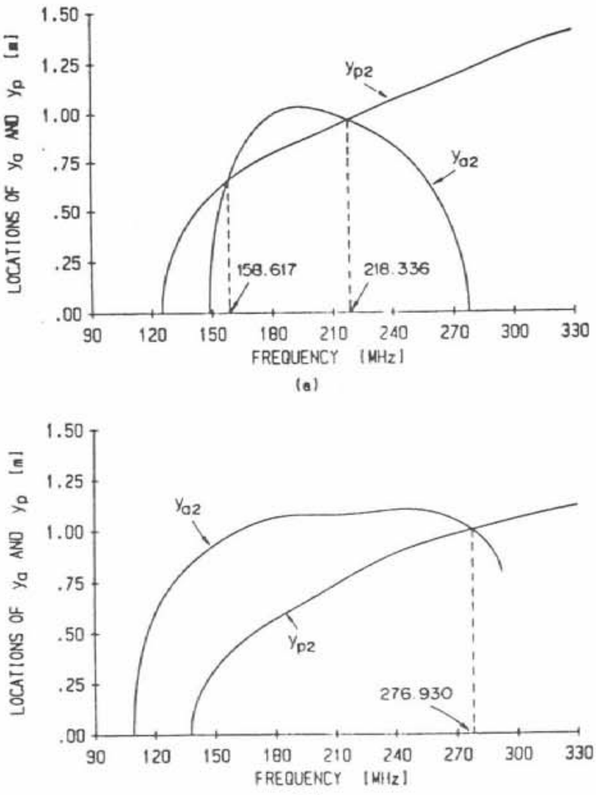

Fig. 5. Loci of equal amplitude point y_{a_2} and 180° phase point y_{p_2} as a function of the signal frequency from 90 MHz to 330 MHz for $x_o = 4$ m.