TRANSMISSION LINES FOR CONTINUOUS-ACCESS GUIDED COMMUNICATIONS IN MINES AND TUNNELS

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Abstract

A combined experimental and theoretical investigation of unorthodox transmission lines for continuous-access guided communications in mines and tunnels is described. A theoretical model for loose-braided coaxial cable with a contaminating layer of dirt is introduced and a novel experimental technique is discussed for measurements on such lines at VHF/UHF frequencies.

Introduction

Radio communication in mines and tunnels is still in an early stage of development. Simple radiation from individual antennas is of limited use due to the severe losses in tunnel walls. Some form of guided signal with continuous access is required that will give a radio system capable of following the path of a tunnel with minimum effect due to the tunnel walls. This basic concept is shown in fig. 1. Until recently, most work has been done on the use of a 2-wire ribbon feeder for this purpose. However, such a transmission line, while providing continuous access and low attenuation along its length when new, is subject to severe deterioration in typical working environments due to deposits of dirt, grease and water. The need for greater protection for the cable has led to the suggestion[2] of a specially made coaxial cable having a less than normal area coverage by the outer braiding and also to the investigation of a coaxial cable with periodic slot coupling to the surrounding region.[3]

The work described in this paper consists of a combined experimental and theoretical investigation of unorthodox coaxial cables and results will be reported for the particular case of loose-braided coaxial cable.

Theoretical Model

Fig. 2 shows the theoretical model for this loose-braided cable (dimensionally similar to RG-8), in which the contaminating dirt or water, etc., is represented by a homogeneous, circumferentially uniform layer in region v. The overall multi-layered cable is treated as a waveguide and solutions to the Helmholtz equation are sought for the frequency range from 27 MHz to 460 MHz, which includes the main frequency bands of use in mobile radio systems.

In each region, the source-free Helmholtz equation is given by

$$\nabla_t^2\phi_j + h_j^2\phi_j = 0 \qquad j = 1,2,3,4$$

for lowest order TM mode ϕ_j represents the longitudinal electric field E_z given by

$$E_{zj} = [A_jJ_o(h_jr) + B_jN_o(h_jr)]e^{-\gamma z} \qquad j = 2,3$$

where h_j = transverse parameter
where $\gamma = \alpha + j\beta$ = propagation coefficient along the structure with $h_j^2 = \gamma^2 + k_j^2$
where $k_j^2 = \omega^2\mu_0\varepsilon_j - j\omega\mu_o\sigma_j$
where ω = angular frequency
where ε_j = permittivity of j^{th} region
where μ_0 = permeability of free space
where σ_j = conductivity of j^{th} region.

E_{z4}, the electric field in air is given by

$$E_{z4} = A_4H_o^2(pr)$$

where $p^2 = h_4^2 = \gamma^2 + k_4^2$,
where $k_4^2 = \omega^2\mu_o\varepsilon_o$.

All the arguments of Bessel functions and Hankel functions are complex in the above equations.

The magnetic field $H\phi_j$ in j^{th} medium is given by

$$H\phi_j = -\frac{\sigma_j + j\omega\varepsilon_j}{h_j^2}\frac{\partial E_{zj}}{\partial r} \quad .$$

Proportions of power guided inside and outside the coaxial cable is given by

$$W = \int_s \underline{P} \cdot \underline{ds}$$

where P, the Poynting vector given by

$$\underline{P} = \frac{1}{2}\,\mathrm{Re}(\underline{E} \times \underline{H}^*)$$

and for TM modes

$$P_{zj} = \frac{1}{2}\,\mathrm{Re}(E_{rj}\ H\phi_j^*) \quad . \qquad j = 2,3,4$$

Now

$$E_{rj} = \frac{\gamma}{\sigma_j + j\omega\varepsilon_j} H\phi_j$$

$$P_{zj} = \frac{1}{2}\,\mathrm{Re}(\frac{\gamma}{\sigma_j + j\omega\varepsilon_j}|H\phi_j|^2) \text{ in } j^{th}$$

medium.

The transverse wave number p in air is given by

$$p = p' + jp''$$

where p' and p" are negative real constants The situation here is similar to the case of Sommerfeld-Goubau waves supported by a lossy cylindrical surface[4], where the fields in air involve Hankel functions of complex arguments and the corresponding equiphase surfaces are tilted forward towards the surface in the direction of propagation.

It should thus be possible theoretically to investigate a wide range of possible installations, including the effect of contamination by dirt, etc. and that of nearness to other objects such as tunnel walls, as well as the coupling loss to a mobile set in the vicinity of the line.

Experimental Technique

To give confidence in the theoretical predictions, an experimental test arrangement has been built, as shown in fig. 3. Approximately 10 feet of cable is suspended vertically and a circulating water system enables a continuous water film to be produced on the outer jacket of the cable at a controlled flow rate. In addition, the acidity of the water can be varied and typical dirt particles can be introduced in a controlled manner into the water stream. This simulates the very severe case of a guided communications cable installed in a vertical mine shaft that must be kept continuously wet for reasons of safety.

While the cable is being deliberately contaminated, insertion loss measurements can be made as shown at the frequency of interest. A field probe (not shown) is also present to measure the transverse field behaviour both radially and circumferentially.

Results and Conclusions

A theoretical model for braided coaxial cable for use in guided communication in mines and tunnels has been developed. The transcendental equation obtained by using the boundary conditions for E_z and $H\phi$ solved for σ_3 the conductivity of the outer conductor in the model. The solutions of the equation were sought for the frequency range between 27 MHz to 450 MHz, which includes the main frequency bands of use in mobile radio system. The calculated conductivity σ_3 of the outer conductor and other parameters v_p, α, β etc., obtained from the manufacturer's data sheet for the cable under consideration are shown in table 1 below. The attenuation due to the outer conductor is separated from the total attenuation by using relations given by Spicer[5].

The theoretical radial behaviour of the electric field is shown in fig. 4 for different frequencies. Percentage of guided powers inside and outside the cable is similarly shown in fig. 5. These graphs indicate the expected result that as the frequency is lowered, the fields extend further outside the guiding structure and the attenuation along the cable is reduced, as with all slow-wave open-guiding structures.

f MHz	v_p/c %	α dB/100 ft	σ_3 v/m	p_{-1} m
450	78	3.00	10^4	$-.007-j7.55$
150	78	1.73	10^4	$-.004-j2.52$
27	78	.74	10^5	$-.002-j0.45$

Experimental results will be presented and compared with these initial theoretical results.

These same techniques will be extended to measurements and analyses of other suggested cables, including those with a single longitudinal slot or a continuous array of small closely spaced slots. The overall aim is to develop a full understanding of the behaviour of unorthodox transmission lines, or open-waveguiding structures, in particular environmental circumstances, and hence to suggest new types of cable construction that would be both economical and relatively unchanged by environmental contamination.

References

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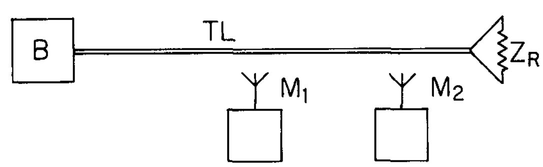


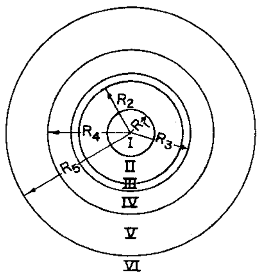
B —— BASE STATION

TL —— TRANSMISSION LINE

Z_R —— MATCHED LOAD

M_1M_2— MOBILE SETS WITH ANTENNAS

FIG 1 CONTINUOUS - ACCESS GUIDED COMMUNICATION



I — INNER CONDUCTOR

II — DIELECTRIC IN COAXIAL CABLE

III — OUTER CONDUCTOR (INCOMPLETE SCREEN)

IV — JACKET OF CABLE

V — WATER AND / OR DIRT

VI — AIR

FIG 2 THEORETICAL MODEL

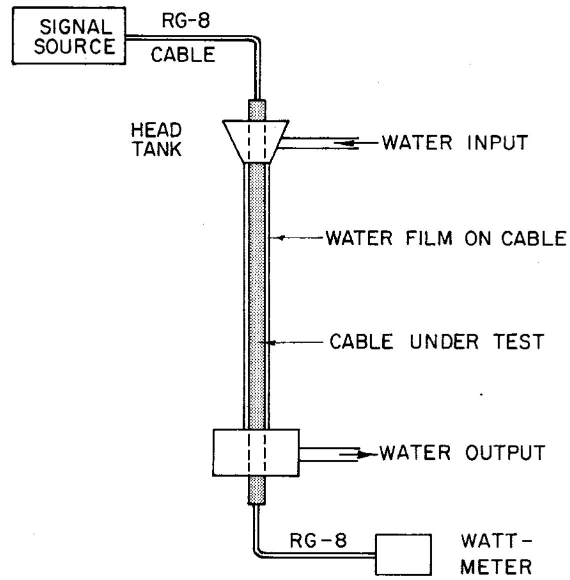


FIG 3 EXPERIMENTAL ARRANGMENT

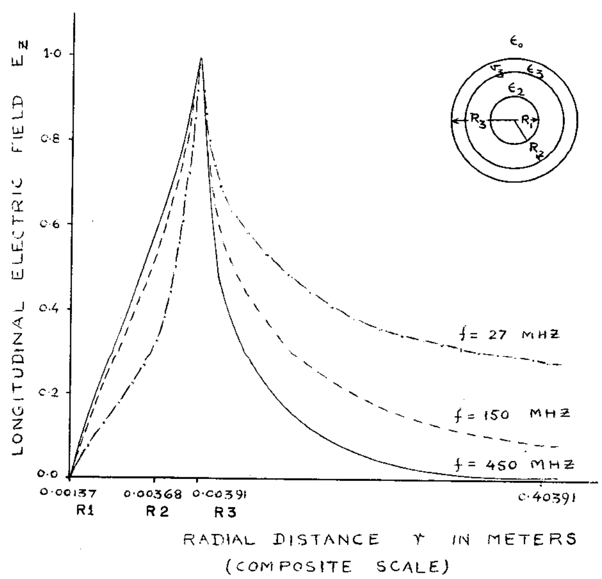


FIG 4 RADIAL BEHAVIOUR OF ELECTRIC FIELD

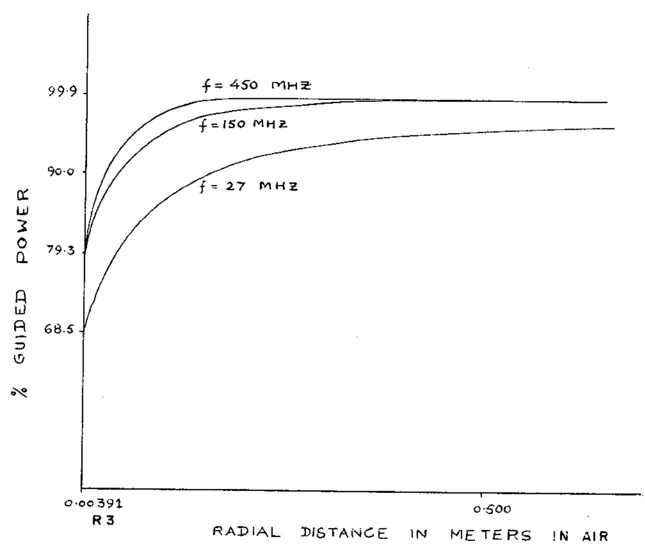


FIG 5 POWER GUIDED WITHIN A GIVEN RADIUS