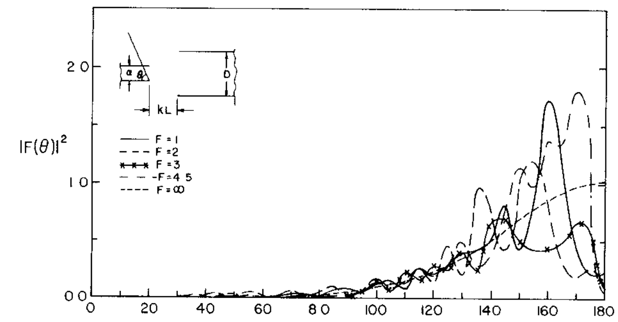

Fig. 3. Radiation patterns of two collinear semi-infinite waveguides of equal widths, $d=0.6\lambda$, $kL=50$, $F=D/d$.

TABLE I
REFLECTION AND TRANSMISSION COEFFICIENTS FOR $d=0.6\lambda$, $ks=10$

ϕ	Reflection Coefficient Mode 1		Transmission Coefficients					
			Mode 1		Mode 3		Mode 5	
	Amp.	Phase	Amp.	Phase	Amp.	Phase	Amp.	Phase
0°	0.285	-111°	0.5	-159°				
30°	0.142	-98°	0.28	-12°	0.17	-163°		
60°	0.163	-122°	0.18	10°	0.172	-179°	0.156	-8°
150°	0.193	-82°	0.188	34°	0.533	168°		
179.9°	0.108	-26°	1.05	36°				

TABLE II
REFLECTION AND TRANSMISSION COEFFICIENTS FOR $d=0.6\lambda$, $kL=50$

$F=\frac{D}{d}$	Reflection Coefficients Mode 1		Transmission Coefficients					
			Mode 2		Mode 3		Mode 5	
	Amp.	Phase	Amp.	Phase	Amp.	Phase	Amp.	Phase
1	0.199	-135°	0.261	141°				
2	0.182	-135°	0.146	-140°				
3	0.196	-134°	0.166	77°	0.082	164°		
4.5	0.213	-130°	0.161	29°	0.066	106°	0.066	-36°
∞	0.191	-134°						

To study the effect of coupled-waveguide width, the separation distance kL of two waveguides is retained constant, while kD the width of the coupled waveguide is modified. The computed radiation patterns are shown in Fig. 3. In this figure, $kL=50$, $d=0.6\lambda$, and the factor $F=D/d$ is changed from unity to infinity. The case of $F=1$ represents two coupled waveguides of equal widths, whereas $F=\infty$ represents an isolated open-ended waveguide. The results for different values of F oscillate with θ, the azimuthal angle, around the pattern of a single open-ended waveguide ($F=\infty$). The existance of the coupled waveguide produces multiple diffractions between the edges, which decreases in amplitude as the separation between the edges increases. Increasing F results in more propagating modes in the coupled waveguide and the number of simultaneous equations increases, which increases the computation time.

The reflection and transmission coefficients for the previous cases are shown in Tables I and II. The reflection coefficient fluctuates around that of a single waveguide and for $\phi=0°$ they are the same as those obtained in [2]. For $\phi=179.9°$, the transmission coefficient is almost unity, while the reflection coefficient is very small.

In conclusion, the moment method was used to study the coupling between two semi-infinite waveguides of unequal widths. An integral equation for the induced currents on the walls was obtained and was solved to give the reflection and the transmission coefficients and the evanescent currents. For certain selected data, radiation patterns were also computed.

ACKNOWLEDGMENT

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Slotted and Loose Braid Cables: Brief Conclusions of a Comparative Study

ANTÓNIO SIMÃO DE CARVALHO FERNANDES

***Abstract*—An analytical comparison is made of the electromagnetic characteristics of the coaxial mode of longitudinally slotted coaxial cables and loose braid coaxial cables in free space. Four aspects are considered: radial decay of the fields, percentage of power that travels outside the coaxial structure, characteristic impedance, and conductor loss.**

I. INTRODUCTION

Leaky cables are open structures that have been used to guide electromagnetic waves in continuous access communication systems [1], [2]. The loose braid outer conductor and the continuously longitudinally slotted outer conductor types are the two most used. These two types of leaky cables have been studied by several authors (e.g., Wait *et al.* [3]–[5], Fernandes [6]; Delogne *et al.* [7], Delogne [8], Hurd [9], Fernandes [10]). In a free-space situation the conclusions of these studies indicate that two fundamental, no cutoff frequency modes can propagate along these two structures: a coaxial mode (bifilar mode) whose energy is mainly (up to UHF) inside the coaxial structure with some leakage to the outside, and a monofilar mode whose energy is mainly outside, with some leakage to the inside of the coaxial structure.

For the loose braid cable, use was made of the surface transfer impedance concept (Z_{ST}) in order to characterize the braid [3]–[6], which was assumed thin with mesh dimensions small

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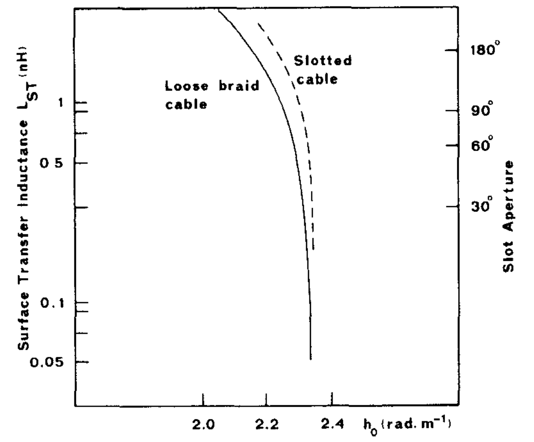

Fig. 1. Dependence of the outer transverse wavenumber on the surface transverse inductance (loose braid cable) and slot aperture (slotted cable); $r_2/r_1 = 8$; $\epsilon_r = 2.26$; $f = 100$ MHz.

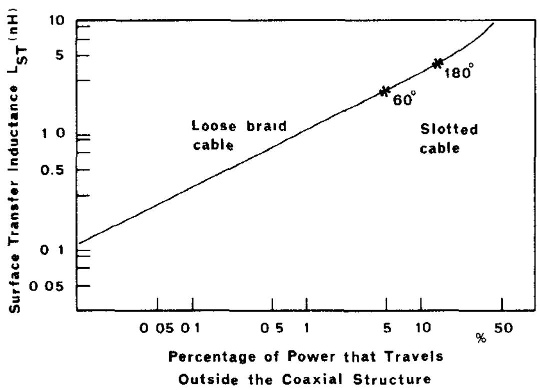

Fig. 2. Dependence of the percentage of power that travels outside the coaxial structure, on the surface transfer inductance (loose braid cable). The asterisks show the values for slotted cables with 60° and 180° slot apertures; $r_2/r_1 = 8$; $\epsilon_r = 2.26$; $f = 100$ MHz.

compared with the distance between the inner and the outer coaxial conductors. Wait and Hill [4], [5] also studied this cable as a dielectric coated conductor that is sheathed by a finite number of counterwound helices.

For the slotted cable, modal analyses were used [8]–[10] representing the fundamental mode as a sum of an infinite number of waves all propagating with the same phase velocity.

These two types of leaky cables are commercially available and, indeed, they have similar electromagnetic performances; however, there are differences that should be known by a continuous access communication system designer. This paper intends to point out briefly the differences on propagation characteristics of these two types of cables, when in free space and for the coaxial mode.

The four following aspects will be considered: 1) radial decay of the outside field, 2) percentage of the power that travels outside the coaxial structure, 3) characteristic impedance, and 4) conductor losses.

1) Radial Decay of the Outside Field

The radial decay of the outside field is a parameter that depends essentially on the frequency; for example, with 1 W of input power at low HF, signals above the thermal noise level can be received up to one or two hundred meters from the cable. We will compare the two types of cable at a frequency of 100 MHz by observing the dependence of the outer transverse wavenumber (h_0) with the slot aperture and the braid's surface transfer inductance, $L_{ST} = Z_{ST}/(j\omega)$. If β is the wave's propagation constant and $k_0 = 2\pi f\sqrt{\mu_0\epsilon_0}$ the free space outside wavenumber, the outer transverse wavenumber is $h_0 = \sqrt{\beta^2 - k_0^2}$, which is real and positive; the outside radial decay of the fields is approximately proportional to the exponential function $\exp[-h_0 r]$, such that from the relative values of h_0, one can appreciate the rate of radial attenuation of the fields. Fig. 1 shows the dependence of the outer transverse wavenumber on the slot aperture and the braid's surface transfer inductance (an increase of the braid's surface transfer inductance implies a decrease of the electromagnetic as well as the optical coverage). As the optical coverage decreases drastically, the radial decay is only slightly affected. As far as this parameter is concerned, a 90° slot cable is equivalent to a loose braid cable, of outer conductor radius $r_2 = 0.005$ m, with a surface transfer inductance $L_{ST} \approx 0.4$ nH.

In a continuous access communication system, in free space or above a ground plane, the radial decay of the fields is an essential parameter in order to determine the area within which communication facilities are to be provided. For both types of cable, it can be concluded that the electromagnetic coverage of the outer conductor has a very poor influence on this aspect.

2) Percentage of Power that Travels Outside the Coaxial Structure

Once again, this aspect depends very much on frequency. In general terms, one may say that for higher frequencies the field tends to be concentrated in the immediate vicinity of the cable; on the other hand, for lower frequencies the wave travels predominantly inside the coaxial structure with a small amount of outside energy decaying very slowly in the radial direction. The percentage of power that travels outside the coaxial structure depends also on the electromagnetic coverage of the outer conductor. From Slaughter [12] we know that loose braid cables (like the ones used for comparison in Fig. 2) with around 70-percent optical coverage can have surface transfer inductances of about 0.1 or 0.2 nH. Thus from Fig. 2 it can be concluded that, for about the same optical coverage, slotted cables allow a higher percentage of the wave's power to travel outside the coaxial structure; therefore, there is a higher probability of interaction between the wave and the environment.

An interesting conclusion can be taken from the first two figures: in Fig. 1, $L_{ST} = 1$ nH corresponds to an outer transverse wavenumber $h_0 \approx 2.24$ rad $\cdot$ m^{-1}; for the slotted cable this value of h_0 corresponds to a slot of 180°, such that those two cables will be equivalent as far as the rate of decay of the outer fields is concerned; $L_{ST} = 1$ nH, in Fig. 2 corresponds to 0.8 percent of power travelling outside while 180° slot to about 15 percent. In other words, for about the same area to be covered by communication facilities, the slotted cable will be more likely to be affected by the environment than the braided cable. Near the cable the coupling will be higher for the former but the noise level will be reached at about the same radial distance for both types.

3) Characteristic Impedance

The characteristic impedance of the two types of cable, calculated on the approximation of pure TEM modes, varies in an opposite direction when the coverage of the outer conductor decreases (Fig. 3).

For the loose braid cable, as L_{ST} increases (decrease of optical coverage) there is a decrease of the characteristic impedance: taking the analogy of a stationary field, for the same power and a

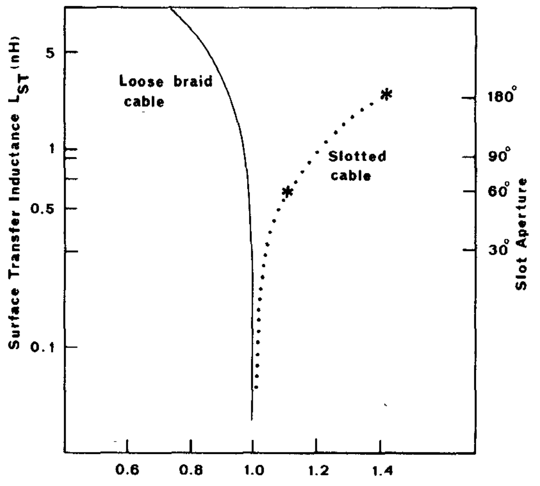

Fig. 3. Dependence of the characteristic impedance with the surface transfer inductance (loose braid cable) and the slot aperture (slotted cable); $r_2/r_1 = 8$; $\epsilon_r = 2.26$; $f = 100$ MHz.

decrease of potential difference between inner conductor and inner part of the outer conductor (which is implied by the increase of L_{ST}), the capacitance increases and, therefore, the characteristic impedance decreases. For the slotted cable, assuming both sides of the outer conductor to be at the same potential, when the aperture opens the field lines will be longer; thus the capacitance decreases and the characteristic impedance increases.

Despite the theoretical significance of this fact, it is not of great importance as, in a real cable, measurements showed [11] that the outer dielectric sleeves attenuate substantially these effects.

4) Conductor Losses

The slotted cable has lower losses than the equivalent coaxial cable as the inner density of power is lower and the current of the outer conductor distributes itself by the inner and outer parts of the outer conductor. The same should apply to the loose braid cable; however, in this instance, the outer conductor has a braid configuration. For a braid of N_s strands, two correction factors can be introduced in order to evaluate this cable outer conductor loss [11]. The first correction factor is due to the fact that the current does not propagate along a straight line but along the perimeter of the meshes and the second is due to the smaller than $2\pi r_2$ real perimeter of the outer conductor; both factors contribute to a loss increase. Also, for the same area to be covered by communication facilities, the braided cable will propagate more energy inside the coaxial structure, which implies a higher density of power, higher current density and, again, higher losses. This fact is significant as far as the number of repeaters is concerned.

Conclusions

Primarily of theoretical importance, this paper compares the characteristics of continuously slotted and loose braid coaxial cables in free space. It is essentially based on the work of Fernandes ([6], [10]) concerning these two types of leaky cables.

Considering, exclusively, the electromagnetic characteristics of the coaxial mode, it was concluded that 1) the radial decay of the outside field is very poorly influenced by the electromagnetic coverage of the outer conductor such that there are not important differences between the two types of cables, 2) the percentage of power that travels outside the coaxial structure is higher for the slotted cable, when comparing this with a loose braid cable with the same optical coverage; therefore, for the same area to be covered by the cable's field, the slotted cable wave will be more likely to be affected by the environment, 3) the characteristic impedance of the slotted cable increases with the slot angle and, for the loose braid cable, decreases with the increase of the mesh dimensions, and 4) the conductor losses are higher for the loose braid cable.

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