FEASIBILITY OF A RADIOCOMMUNICATION IN MINE GALLERIES BY MEANS OF A COAXIAL CABLE HAVING A HIGH COUPLING IMPEDANCE.

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To realize a radiowave communication along mine galleries a few kilometers long without repeater, we show that it is possible to use a coaxial cable bearing an important surface transfer impedance like a transmission line with an inductive coupling to the transmitter and the receiver. We determine the electrical and geometrical constants of the cable and the optimal frequency.

INTRODUCTION

To realize a radiowave communication along mine galleries a few kilometers long, it is possible to use different kinds of transmission lines with an inductive coupling to the transmitter and the receiver.

The communication could be established without line amplifier with a two-wires line for frequencies lower than 1MHz. But such a solution requieres a very good laying which is not always possible in all the galleries.

An other solution consists of a coaxial cable with spaced tuned slots. This process has been developped by Professor DELOGNE in Belgium mines in the 5-10MHz frequency range. This method gives very good results but the cable is quite expensive.

With the classical slotted coaxial cables it is necessary to use very high frequencies to obtain a good radiation. But the losses are important, and the distances between the repeaters has to be smaller than a few hundred meters.

In this paper, we show that it is possible to use a coaxial cable bearing an important surface transfer impedance. By using the coupled transmission line theory, we determine the electrical and geometrical constants of the cable, and the optimal frequency range.

PROBLEM DESCRIPTION

The transmission line is made of an insulated coaxial cable connected to both ends to its characteristic impedance. It is set in a parallel direction to the gallery at a distance h of the wall (fig.1.).

We have two coupled lines. The first consists of a single wire which is made of the braid outer conductor of the coaxial and of the earth-conductor. This line is adapted and coupled to magnetic transmitter and receiver set near the cable at points A and B. The electrical constants of this first line are :

Z_{c1} = characteristic impedance

$\gamma_1=\alpha_1+j\beta_1$ = propagation constant where α_1 is the attenuation factor.

The second line is the coaxial itself with a characteristic impedance Z_{c2} and a propagation constant γ_2.

The coaxial braid has a coupling impedance Z_t per unit length. Z_t has the following form : $Z_T = jL_T\omega$ where L_T is the transfer inductance of the braid. A part of the transmitted energy on the line 1 can excite the coaxial line by means of the coupling impedance. The other part quickly vanishes by propagating on the single wire line presenting important losses.

The energy propagating in the coaxial has a much lower attenuation for $\alpha_2 \ll \alpha_1$ and can re-induce a current on the line.1. If we call A_1 and A_2 the coupling attenuation between line 1 and 2 and reciprocally, expressed in db, $A\ell_1$ and $A\ell_2$ the attenuations along the first and second lines, expressed in db/m, we can find a length of transmission L such as :

$$A_1 + A\ell_2 \cdot L + A_2 < A\ell_1 \cdot L \qquad (1)$$

If so, the communication will get improved by the coupling between the both lines.

On figure.2. we have represented the signal level on the receiver as a function of the distance AB = x. A particular point of this curve is the point C which corresponds to the minimum distance L_{min} to verify the inequality (1). If the receiver sensibility is lower than the level obtained at L_{min} we see on figure.2. that the communication distance is increased.

THEORETICAL ANALYSIS

We study this problem by means of the theory of coupled lines [1][2]. The following equations of telegraphy could be used as starting point :

$$\begin{pmatrix} \frac{d^2}{dx^2} I_1 \\ \frac{d^2}{dx^2} I_2 \end{pmatrix} = \begin{pmatrix} \gamma_1^2 & Y_1 Z_t \\ Y_2 Z_t & \gamma_2^2 \end{pmatrix} \cdot \begin{pmatrix} I_1 \\ I_2 \end{pmatrix} \qquad (2)$$

I_1 and I_2 are the currents along the two lines

Y_1 and Y_2 are the admittances per length unit of lines 1 and 2.

This system solution is :

$$\begin{aligned} I_1 &= k_1(A_1 e^{\Gamma_1 x} + B_1 e^{-\Gamma_1 x}) - k'_1(A_2 e^{\Gamma_2 x} + B_2 e^{-\Gamma_2 x}) \\ I_2 &= -k_2(A_1 e^{\Gamma_1 x} + B_1 e^{-\Gamma_1 x}) + k'_2(A_2 e^{\Gamma_2 x} + B_2 e^{-\Gamma_2 x}) \end{aligned} \qquad (3)$$

with : $k_1 = -Z_t Y_1 \qquad k_2 = -Z_t Y_2$

$k'_1 = \gamma_1^2 - \Gamma_1^2 \qquad k'_2 = \gamma_1^2 - \Gamma_2^2$

The constants A_1, B_1, A_2, B_2 could be determined by using the boundary conditions on the ends of lines.
The boundary conditions are obtained in the form of a four linear complex equations system. The system may be solved by means of a computer.

Γ_1^2 and Γ_2^2 are the eigenvalues of the system (2) :

$$\begin{matrix}\Gamma_1\\ \\ \Gamma_2\end{matrix} = \left[\frac{1}{2}(\gamma_1^2+\gamma_2^2) \pm \frac{1}{2}(\gamma_1^2-\gamma_2^2)\sqrt{1+\frac{4Z_t^2Y_1Y_2}{(\gamma_1^2-\gamma_2^2)^2}}\right]^{1/2} \quad (4)$$

If we suppose that $|\gamma_1| >> |\gamma_2|$ and that the transfer impedance is much smaller than Z_{c1} and Z_{c2}, the expression (4) could be simplified and we finally obtain :

$$\Gamma_1 = \gamma_1 + O(\frac{Z_T^2}{Z_{c1}Z_{c2}}\frac{\gamma_2}{\gamma_1^2})$$

$$\Gamma_2 = \gamma_2 + O(\frac{Z_T^2}{Z_{c1}Z_{c2}}\frac{\gamma_2}{\gamma_1^2}) \quad (5)$$

The previous conditions are always valid for the low coupled lines that we consider.

DETERMINATION OF COAXIAL CABLE CHARACTERISTICS AND OPTIMAL FREQUENCY

We study the effect of each parameter of the transmission line on the receiving level. It is sufficient to determine the current I_1 on the line 1 as a function of x, (distance AB between the two transmitters) the receiving level being a linear function of I_1.

We have represented on fig.3. the distribution current $I_1(x)$ for a given frequency f = 9MHz and for 3 values of Z_T. The other parameters being constant, we observe that the level I_{c1} corresponding to the minimum distance L_{min} is a linear function of Z_T^2.

On fig.4. we have studied I_{c1} as a function of the frequency for different values of the permittivity ε_{r2} on the coaxial cable. In this study we suppose that the parameters α_1, α_2, Z_{c1}, Z_{c2} are constant. In reality it is not quite exact, particularly for α_1 and α_2 which vary respectively according to the frequency and the square root of the frequency. But we can see on the next figures.5. and .6. that if α_1 and α_2 vary, I_{c1} is not affected if α_1 is much larger than α_2. Thus we observe that the current on line 1 is all greater as ε_{r2} is near 1. For classical values of ε_{r2} for braided coaxial cable we observe an optimal frequency of about 7MHz.

On figures.5. and .6. we have represented $I_1(x)$ for different values of α_1 and α_2. I_{c1} keeps constant and we notice a region where they are beats between the waves propagated on both lines.

Figure.6. shows that we must choose a ratio $\alpha_1/\alpha_2 > 5$ to use the coupling effect.

To build a coaxial which has good performances for this type of communication we study the current distribution $I_1(x)$ on line 1 for different values of L_T at frequency f = 7MHz (see fig.7.).

For large values of L_T we take into account an important coupling between both lines. On the curves in fig.7. we can see that there is an optimal transfer inductance $L_T = 40.10^{-9}$H/m for a communication of one kilometer long.

It is quite evident that it is necessary to determine the geometrical and electrical characteristics of cable to obtain a minimum attenuation factor α_2 in spite of the important value of L_T (for a classical TV coaxial, L_T is of about $0.2.10^{-9}$H/m).

Figure.8. shows the structure of a braided shielding. The transfer inductance of such a braid is given by Krügel |3| :

$$L_T = \frac{\sigma}{4} \, tg^2 \psi \qquad (6)$$

where ψ is the angle of braid wire with cable axis
σ is the dispersion factor
$\sigma = 1 - K^2$ where k is the coupling factor of the two half-braids, which behave like two coils winded in the opposite direction. σ is much smaller than 1.
It is very difficult to give an analytical expression for σ. The actual theory of leak transformer is insufficient to take into account all the parameters of the braid in the calculation of σ.
Krügel has shown that σ is an increasing function of ψ and a decreasing function of the coverage ratio for $\psi > 45°$.
R is given by :

$$R = \frac{\text{actual area of braid}}{\text{total surface area}} = 2F - F^2$$

where F is the fill factor, i.e., the ratio of the actual width of one pick to the width of one pick for 100% coverage :

$$F = \frac{a}{b} = \frac{CNd}{2\pi(D+2d)\cos\psi} < 1 \qquad (8)$$

C : number of carriers
N : number of braid wires per carrier
d : braid wire (or strand) diameter
D : diameter over cable core

The attenuation factor α_2 of a braided coaxial cable for copper is given by :

$$\alpha_2 = \frac{2.6 \, . \, 10^{-9} \sqrt{\varepsilon_{r2}}}{\log \frac{D}{D_i}} \left| \frac{K_s}{D_i} + \frac{K_b}{D} \right| \sqrt{f} \text{ db/m} \qquad (9)$$

where D_i is the inner conductor diameter

K_s is a factor larger than 1 if the core wire is made of strands (for example $K_s = 1.06$ for 7 strands)

K_b is the braiding factor. It has the following form : |4|

$$K_b = \frac{1}{F.\cos^2\psi} = \frac{2\pi(D+2d)}{CNd\ \cos\psi} \tag{10}$$

According to equations (6) until (10) we see that for a given value of L_T and ψ it is possible to increase C, N and d to obtain an attenuation factor α_2 not too high.

To determine the best ratio D/D_i we have represented on figure.9. the current I_{c1} as a function of Z_{c2}.

We observe a maximum value of I_{c1} for $Z_{c2} = 75\Omega$. If we build a cable having a classical value for the outer diameter of the braid D+2d = 7,5mm, a characteristic impedance $Z_{c2} = 75\Omega$ with $\varepsilon_{r2} = 1.5$, N = 4, C = 8, d = 0.25mm, some measurements have shown us by extrapolating that we can obtain $L_T = 40.10^{-9}$ H/m for an angle of braid $\psi = 60°$.

Then the attenuation factor α_2 has the following form $\alpha_2 = 8.10^{-6}.\sqrt{f}$ db/m.

With this cable we have made the theoretical study of the communication along galleries of mine between the two magnetic transmitters. On figure.10. we have represented $I_1(x)$ for three values of the frequency : f = 3, 7 and 20MHz.

The attenuation factor of line 1 is evaluated by measurements in coal mine in the South of France. For a single wire line situated at 30cm of the gallery wall, we have :

$$\alpha_1 = 10.4.10^{-9}f + 1.74.10^{-3}\text{db/m} \tag{11}$$

The levels R_s corresponding to the receiver sensibility have been represented on figure.10. R_s is proportional to f^2. We observe on the 3 curves that the communication distance is increased when we use the coaxial cable with a coupling effect. Indeed x_i represents the maximum distance of communication using a single wire line having an attenuation factor α_1. x'_i is the maximum distance when we use the coaxial cable.

For these three frequencies, we have $x'_i > x_i$ but we notice that 7 MHz is an optimal frequency. x_2 = 550m and x'_2=1200m. There is a ratio 2 between these two distances.

CONCLUSION

With this coaxial cable we have studied, we have the possibility to increase the maximum distance of communication in a ratio greater than 2. An other advantage of this system is that the line could be set careless. Indeed the attenuation factor α_1 of the single wire line made of the cable and the gallery could be important without influence on the communication.

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REFERENCES

(1) P.I. KUZNETSOV and R.L. STRATONOVICH, The propagation of electromagnetic waves in multiconductor transmission lines, PERGAMON PRESS, 1964

(2) H. MURATA, S. INAO and H. HONDO, Electromagnetic interference with video transmission cable, 20th International wire and cable symposium proceedings, Atlantic City, N.J., Dec. 2, 1971

(3) Von L. KRUGEL, Abschirmwirkung von Aussenleitern flexiber Koaxialkabel, Telefunken-Zeitung, Jg 29 (Dezember 56), Heft 114

(4) J. SPERGEL, Computer aided design of braid parameters for coaxial cable, 20th Internation wire and cable symposium proceedings, Atlantic City, N.J., Dec.2, 1971

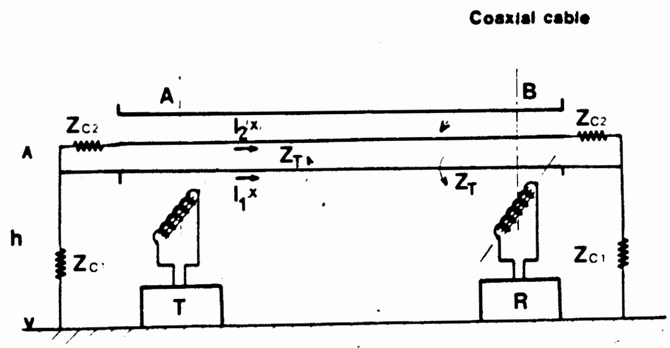


Fig.1

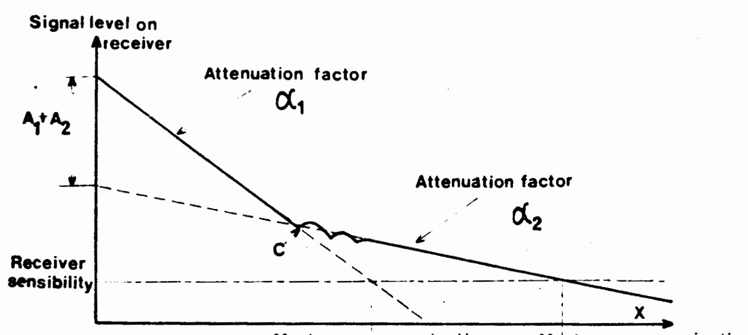


Fig.2

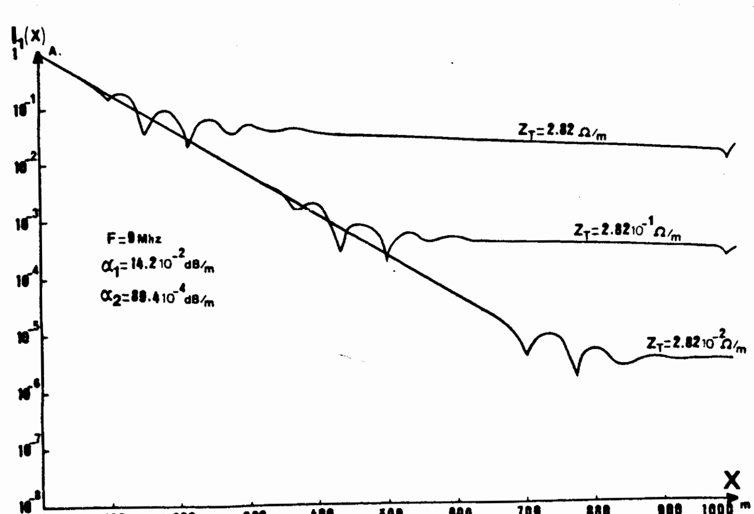
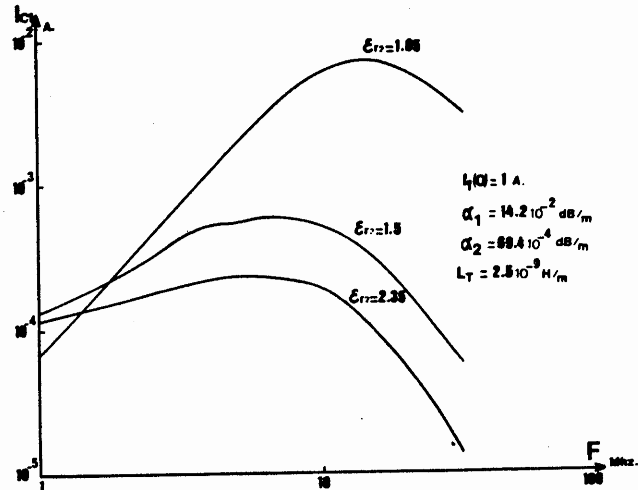


Fig.3



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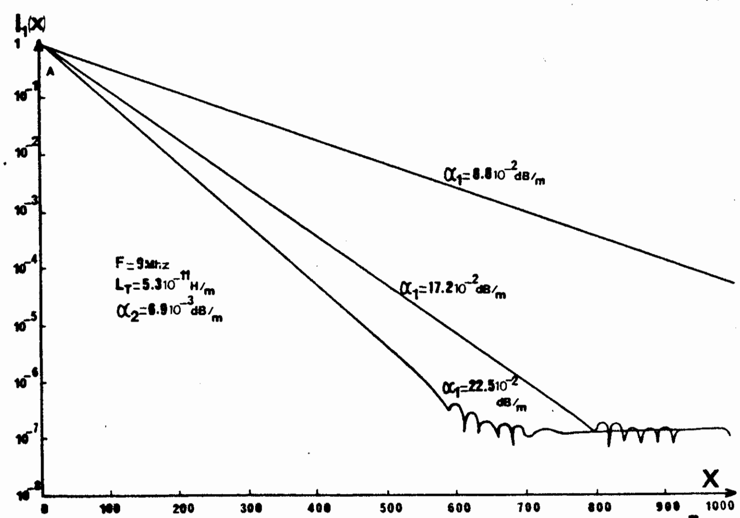

Fig.5

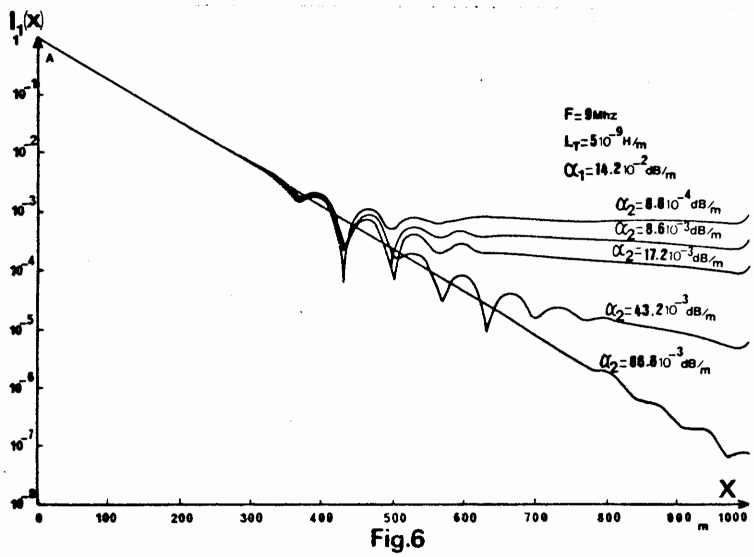

Fig.6

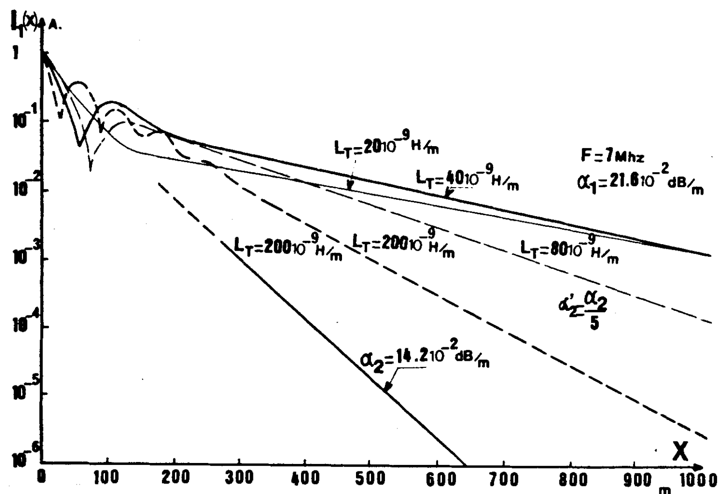
$L_1(x)$ A.
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0 100 200 300 400 500 600 700 800 900 1000
m
X
$L_T = 20\,10^{-9}$ H/m
$L_T = 40\,10^{-9}$ H/m
F = 7 Mhz
$\alpha_1 = 21.6\,10^{-2}$ dB/m
$L_T = 200\,10^{-9}$ H/m
$L_T = 200\,10^{-9}$ H/m
$L_T = 80\,10^{-9}$ H/m
$\alpha_2' = \frac{\alpha_2}{5}$
$\alpha_2 = 14.2\,10^{-2}$ dB/m

Fig.7

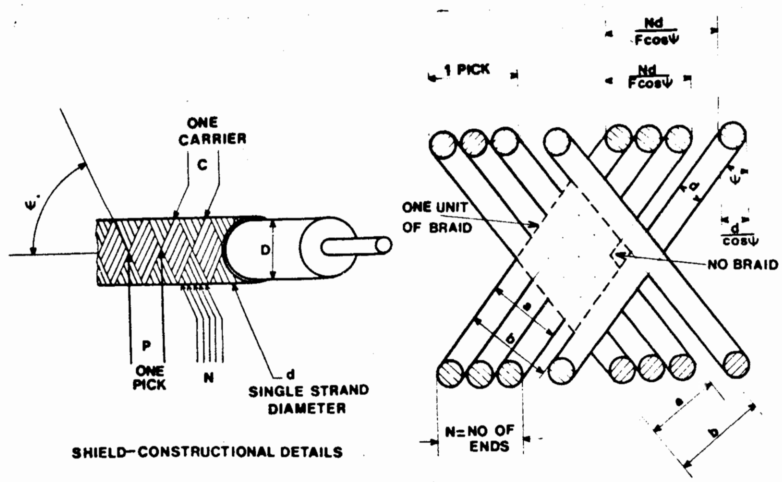

Fig.8

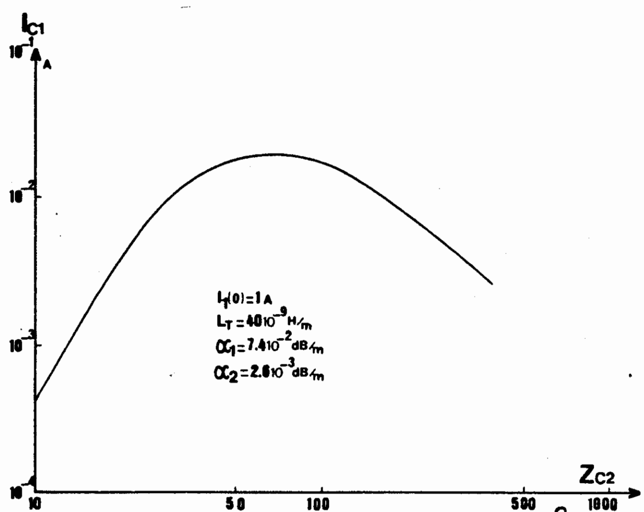

Fig.9

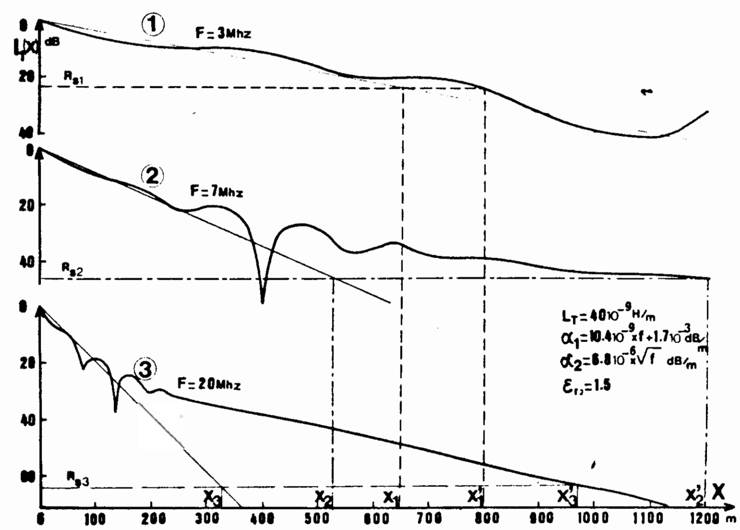

Fig.10