103622-1002

DL/CSE/TM11

LENDING COPY

technical memorandum Daresbury Laboratory

DL/CSE/TM 11

INTERFERENCE IMMUNITY OF SOME COAXIAL CABLES

by

M.M. PRZYBYLSKI, Daresbury Laboratory

MAY, 1981

Science Research Council

Daresbury Laboratory

1. INTRODUCTION

Coaxial cables with a braided screen offer good immunity against interference currents flowing in the screen. An improvement in their screening properties can be achieved by applying a second braid.

However if a layer of ferromagnetic material is sandwiched between the two braids, a further significant improvement in a cable's screening performance can be achieved.

2. IMMUNITY AGAINST INTERFERENCE CURRENT IN THE BRAID

An interference current flowing in the outer conductor of a coaxial cable develops a voltage on the inside surface of that outer screen. This voltage will give rise to an interference signal across any load connected to the cable.

The most important parameter defining a cable's screening performance against currents flowing in its screen, is its surface transfer impedance, Z_T.

The transfer impedance per unit length is the quotient of the voltage, V_s, induced on the inside surface of the screen and the current, i_s, flowing in it;

$$Z_T = \frac{V_s}{i_s} \qquad (1)$$

For electrically short cables, where their lengths $\ell < \lambda/10$, the induced voltage is divided between the cable terminating impedances Z_1 and Z_2, as shown in fig.1. For a cable terminated in its characteristic impedance, $Z_1 = Z_2$ and the voltage developed at the output is given by;

$$V_1 = \frac{1}{2} Z_T \, i_s \, \ell \qquad (2)$$

The transfer impedance of a homogeneous cylindrical screen is a function of skin effect[1] and is given by;

$$Z_T = R_o \frac{u}{\sqrt{\cosh u - \cos u}} \qquad (3)$$

where R_o = d.c. resistance per meter of cable screen

u = twice the number of skin depths in the screen thickness.

Since, u, increases proportionally to the square root of frequency, the transfer impedance of a homogeneous cylindrical screen decreases monotonically with increasing frequency, as shown in fig.2.

It shows that skin effect, which causes current to flow preferentially near the outer surface of the screen, gives rise to low values of surface transfer impedance at high frequencies. Thus providing very effective screening against high frequency interference currents.

If however the screen is not continuous, but has holes, it loses some of its high frequency screening property, since its inductance is no longer fully coupled to the centre conductor. The uncoupled inductance, L_u, gives rise to a voltage induced by a longitudinal current following in the cable screen, given by:

$$V_u = jw \, L_u \, i_s \qquad (4)$$

where w = frequency of the current i_s.

Figure 2 also shows the effect of the uncoupled inductance on transfer impedance.

The "holes" in the mesh of a braided screen cable give rise to an uncoupled inductance, thus degrading the high frequency screening against interference.

The addition of a second braid will improve screening. At low frequencies there will be an approximately twofold improvement, as the d.c. resistance of the outer screen is reduced. Due to the difference in diameters of the braids, the inner braid will have an inductance, L_{12}, which will not be coupled to the outer braid. Figure 3 shows a simplified schematic diagram of the two braids. The current in the inner braid is given by:

$$i_1 = i_s \frac{R_2}{R_1 + R_2} \times \frac{1}{1 + j \frac{\omega L_{12}}{R_1 + R_2}} \qquad (5)$$

The uncoupled inductance is

$$L_{12} = \frac{\mu_o \mu_r}{2\pi} \ln \frac{r_2}{r_1} \qquad (6)$$

where r_1 = outer radius of inner braid

r_2 = inner radius of outer braid

μ_o = permittivity of free space

μ_r = permittivity of material between the braids

R_1, R_2 = resistance per meter of inner and outer braids respectively.

The interference current in the inner braid shows a single pole response, with a rolloff at a rate of 20 db/decade, with a pole at a frequency,

$$f_c = \frac{R_1 + R_2}{2\pi L_{12}} \qquad (7)$$

Since the voltage induced on the inner surface of the inner screen is equal to the product of the current, i_s, flowing in it and that screen's transfer impedance Z_{T1}, it can be shown that the transfer impedance of a double screen cable is,

$$Z_T = \frac{i_1}{i_s} Z_{T1} \qquad (8)$$

From eqns.(5) and (8)

$$Z_T = \frac{R_2}{R_1 + R_2} Z_{T1} \frac{1}{1 + j \frac{\omega L_{12}}{R_1 + R_2}} = \frac{R_1 R_2}{R_1 + R_2} \times \frac{Z_{T1}}{R_1} \times \frac{1}{1 + j \frac{\omega L_{12}}{R_1 + R_2}} \qquad (9)$$

From the above,

$$\frac{Z_{T1}}{R_o} = \frac{Z_{T1}}{R_1} \times \frac{1}{1 + j \frac{\omega L_{12}}{R_1 + R_2}} \qquad (10)$$

where $R_o = \frac{R_1 R_2}{R_1 + R_2}$, is the d.c. resistance of both screens in parallel.

Figure 4 shows $\frac{|Z_T|}{R_o}$ for a typical double braid coaxial cable.

The corner frequency, f_c, can be significantly reduced, if a layer of ferromagnetic material is sandwiched between the two braids. The increased, μ_r, (eqn.(6)) will give rise to a higher value of uncoupled inductance, L_{12}. Figure 4 also shows the effect on transfer impedance of the addition of a mumetal tape to a cable screen consisting of two conducting braids. The significant improvement in interference immunity, has given rise to a term "superscreened" to be used to describe such a cable.

3. MEASUREMENT OF TRANSFER IMPEDANCE

A method of measuring transfer impedance is given in B.S.2316 Part 1 and is based on a special triaxial test jig[2].

The author has found that a simple test jig, shown schematically in fig.5, yielded accurate results. In it a variable frequency voltage source, V_G, injected a longitudinal current, into the braid of a test cable, placed on top of a 10 mm wide copper strip, which provided a return current path.

The transfer impedance was calculated from the following relationship,

$$Z_T = 2 \frac{V_O R}{V_G A} \qquad (11)$$

where R = output impedance of generator

A = gain of preamplifier

V_o = output voltage of preamplifier

The jig was placed away from other conducting structures in the laboratory.

Figure 6 shows the transfer impedance of three single braid cables, one double braid cable and a "superscreened" cable. All three cables are widely used at the Daresbury Laboratory.

Up to approximately 1 MHz the transfer impedance of single braid cables is constant. At higher frequencies their interference immunity degrades due to the "holes" in the braid.

Up to 100 kHz the transfer impedance of the double screened RG223 cable is approximately half that of RG58 type cable, reflecting the higher constructivity of its two screens, compared with one of the RG58. Between 1 MHz and 30 MHz its transfer impedance is between 10 and 30 times smaller than that of RG58.

The "superscreened" MM11/50 cable behaves similarly to the RG223 up to 1 kHz. For frequencies higher than 10 kHz its transfer impedance is between 20 and 2000 times smaller than that of RG58, giving significantly improved immunity to longitudinal interference currents in the braid.

4. CONCLUSIONS

Results shown in this report illustrate the interference immunity properties of some 50 Ω cables widely used at the Daresbury Laboratory.

The superior screening performance of "superscreened" cable over the

1 kHz to 100 MHz frequency range makes it very useful in high intereference immunity channels for transmission of signals from nuclear detector preamplifiers.

In designing systems with high electrical interference immunity, attention must also be paid to the quality of cable connectors and the screening properties of electronic circuit enclosures, otherwise improvements achieved by the use of high interference immunity cable can be forfeited.

5. ACKNOWLEDGEMENTS

My thanks to Mr. E.P. Fowler from the Atomic Energy Establishment Winfrith for many helpful discussions and to Mr. G. Hughes for correcting the manuscript.

6. REFERENCES

1. S.A. Schelkunoff, The electromagnetic theory of coaxial transmission lines and cylindrical shields. Bell System Tech. J. 13, (1934) 532.

2. B.S.2316 (1968): Specification for radio-frequency cables, Part 1 : General requirements and tests.

FIGURE CAPTIONS

Fig.1 Interference voltages V_1 and V_2 generated by current i_s in the cable screen.

Fig.2 Transfer impedance of a solid screen coax.

——— with a continuous solid screen

- - - - - screen with holes

Fig.3 Equivalent circuit of cable with two outer braids.

Fig.4 Typical transfer impedance of coaxial cables

——— single braid cable

--------- double braid cable

-·-·-·-·- "superscreened" cable with two braids and a mumetal tape.

Fig.5 Test jig for measurement of Z_T

Fig.6 Transfer impedance of RG58, RG174, RG223, UR67 and MM11/50 cables.

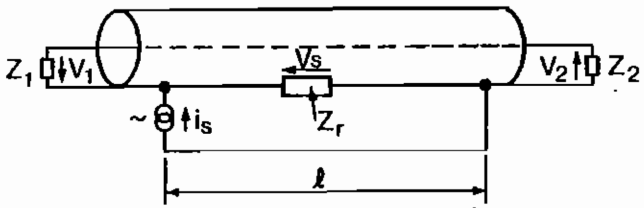

Z1
V1
Vs
V2
Z2
is
Zr
ℓ

Fig. 1

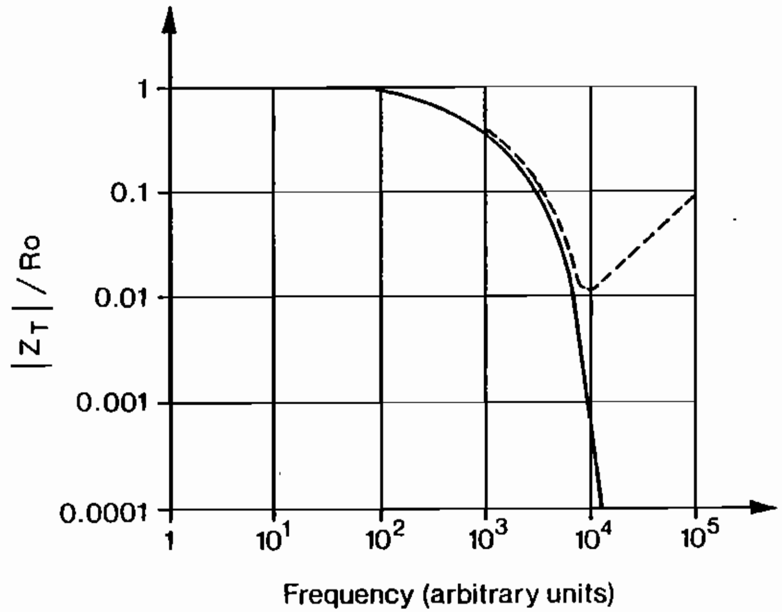
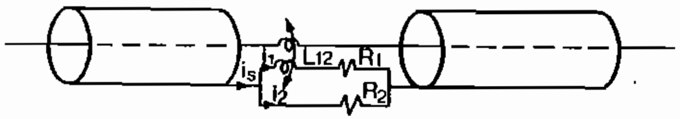
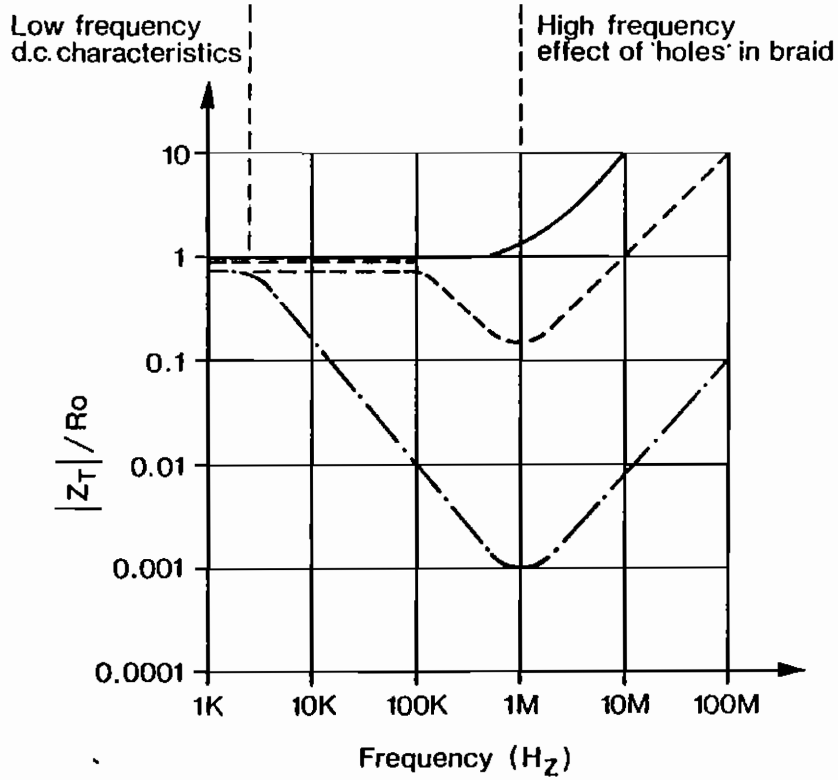

1
0.1
0.01
0.001
0.0001
|ZT| / Ro
1
10^1
10^2
10^3
10^4
10^5
Frequency (arbitrary units)

Fig. 2



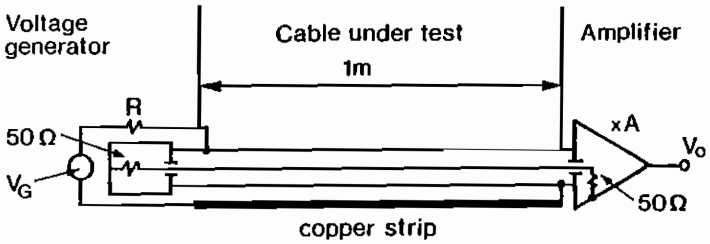
is
i1
i2
L12
R1
R2

Fig. 3



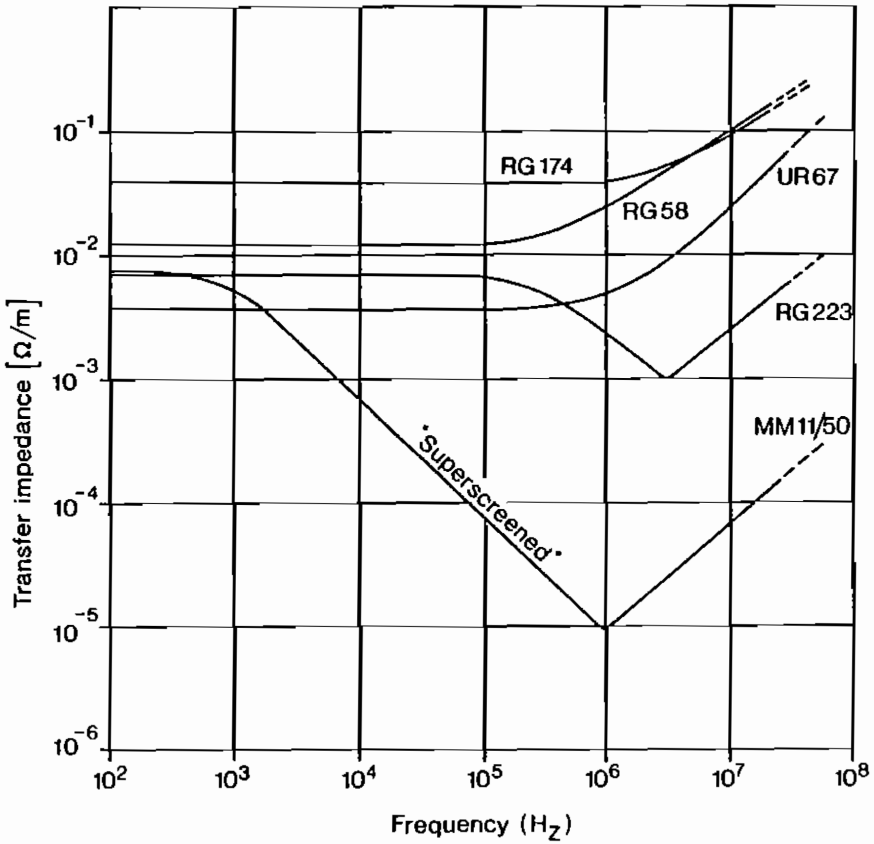
Low frequency
d.c. characteristics
High frequency
effect of 'holes' in braid
10
1
0.1
0.01
0.001
0.0001
|ZT|/Ro
1K
10K
100K
1M
10M
100M
Frequency (HZ)

Fig. 4



Voltage generator
Cable under test
Amplifier
1m
R
50 Ω
V_G
xA
V_o
50Ω
copper strip

Fig. 5



RG 174
UR67
RG 58
RG 223
MM11/50
'Superscreened'
Transfer impedance [Ω/m]
Frequency (Hz)

Fig. 6