Zeitschrift: Technische Mitteilungen / Schweizerische Post-, Telefon- und Telegrafenbetriebe = Bulletin technique / Entreprise des postes, téléphones et télégraphes suisses = Bollettino tecnico / Azienda delle poste, dei telefoni e dei telegrafi svizzeri

Herausgeber: Schweizerische Post-, Telefon- und Telegrafenbetriebe

Band: 59 (1981)

Heft: 9

Artikel: Screening effectiveness of coaxial-connectors and measuring methods at high frequency and microwave

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DOI: https://doi.org/10.5169/seals-874203

Screening Effectiveness of Coaxial-Connectors and Measuring Methods at High Frequency and Microwave

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621.316.541:621.315.212:621.317.341.029.6:621.316.95

1 General

A coaxial cable represents a screened transmission line. The outer metallic shell, generally tubular, consists of woven braids, overlapping tapes, solid tubes or combinations of them. Besides of guiding electromagnetic waves along the line, the outer shell of a cable largely prevents the coupling of unwanted electromagnetic energy from outside into the inner (coaxial) system or vice versa.

To connect equipments together, linking cables and equipments are fitted with convenient connectors, which consist also of outer shells with contacting mating faces, formed by resilient or solid jack or plug parts. These connections have some impedances. Disturbing currents at the outer surface of the shell may produce electromagnetic forces (emf) in the inner circuit. For direct current and low frequencies, this emf generated is related to the current flowing by the resistance of the component involved. At higher frequencies more complex conditions apply and the coupling can best be described in terms of the transfer impedance.

2 Definition of Screening Effectiveness and Transfer Impedance Z_t for the Connector Assembly

Although the screening effectiveness of each significant part of a connector assembly could be specified separately, it will be very difficult in practice to deduce realistic values for a connector pair by summation at high and microwave frequencies. Repetitive connectings and measurements show a wide dispersion of screening values, created by the influence of the instabilities of the many contact points around the outer conductor contact surface and of the fixing nut screening behavior.

The connector screening effectiveness will therefore be defined for a complete connector pair, mounted on appropriate cables or solid lines and connected together, applying specified fixing torques.

The transfer impedance Z_t is the quotient of the electromagnetic force Δe generated across one port by the current i made to flow in the other port in a two port or four terminal network as shown in *Figure 1.*

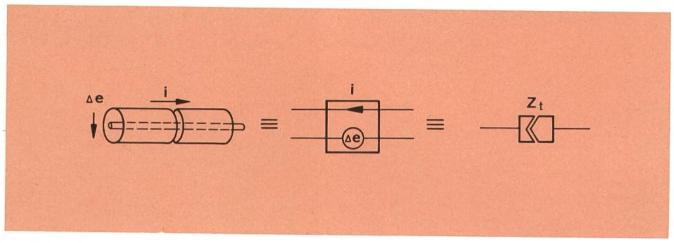

Fig. 1
Screening effectiveness circuit for definition of Z_t

$$Z_t = \frac{\Delta e}{i}$$

Δ e Electromagnetic force
i Current

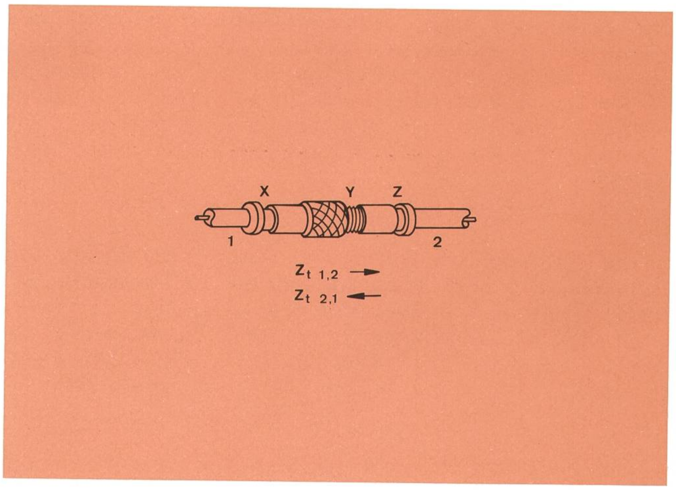

Fig. 2
Real connector assembly with the possibility of $Z_{t1,2} \neq Z_{t2,1}$
x, y, z Interfering points

Real connector assemblies *(Fig. 2)* consist of several parts with the possibility of tiny holes and slots at different places x, y, z along this assembly. Thus, a directional effect can result which may produce two different screening effectiveness values depending on the direction of propagation in the inner system

$$Z_{t\,1,2} \neq Z_{t\,2,1}$$

The larger value shall then be used in the specification.

3 Screening Effectiveness Measuring Method, Proposed by the International Electrotechnical Commission (IEC)

Publication IEC 169-1 Sub. clause 14,8 shows a circuit for the screening effectiveness measurement. This method is based on a triple coaxial setup according to *Figure 3.*

A generator feeds the inner coaxial-line with the input voltage U_1. The voltage U_2 on the outer coaxial-system allows the computation of the transfer impedance

$$Z_T = Z_0 \frac{U_2}{U_1}$$

This triaxial test-method has several principal drawbacks such as: limited frequency range, tedious calibra-

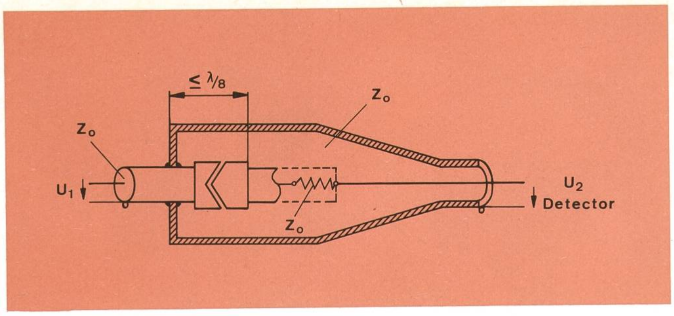

Fig. 3
IEC triple coaxial circuit

tion, critical mounting (especially of the shielded termination) and no direct possibility to measure directional effects.

4 New Matched Triaxial Broadband Test Setup

A new measuring setup allows to overcome the above mentioned difficulties. It consists of a *matched* triaxial-system and can be used on a wide frequency range (this method has been proposed as a modification to the existing IEC triaxial test method).

The matched triaxial arrangement is usable to several GHz, limited only by the higher order modes of the outer coaxial system as well as the dimensions of the connector under test. *Figure 4* shows the principle arrangement.

The incoming signal P_1 is divided at T and flows in both directions TB and TC. Because the connector pair outer conductors are parts of the inner conductor of the outer coaxial system, an inductive transparency of the connection couples power into the inner system. This power flows in both directions B and C. The backward part of the energy is absorbed in the step attenuator, the forward power P_3 is measured by the spectrum analyzer. Calibration is made by comparing P_3 with the power P_1 fed through the calibrated step attenuator into the spectrum analyzer receiver, using the spectrum analyzer as a comparator.

The combination tracking generator — spectrum analyzer — low noise amplifier — power amplifier allows broadband sweep measurements. The equivalent electrical circuit is shown in *Figure 5.*

$$P_2 \approx i_2^2 \cdot Z_{02} \;:\; i_2 \approx \sqrt{\frac{P_2}{Z_{02}}}$$

$$\Delta\, V = i_2 \cdot Z_t \approx Z_t \sqrt{\frac{P_2}{Z_{02}}}$$

$$i \approx \frac{\Delta V}{2 \cdot Z_{01}}$$

$$P_3 = i^2 \cdot Z_{01} \approx \left(\frac{\Delta V}{2 \cdot Z_{01}}\right)^2 \cdot Z_{01}$$

$$P_3 \approx \left(\frac{Z_t \cdot \sqrt{\frac{P_2}{Z_{02}}}}{2 \cdot Z_{01}}\right)^2 \cdot Z_{01} \approx \frac{Z_t^2 \cdot P_2}{4 \cdot Z_{01} \cdot Z_{02}}$$

$$\frac{P_3}{P_2} \approx \frac{Z_t^2}{4 \cdot Z_{01} \cdot Z_{02}}$$

$$\boxed{Z_t \approx 2 \cdot \sqrt{Z_{01} \cdot Z_{02} \cdot \frac{P_3}{P_2}}}$$

For resistive matching and $Z_{01} = Z_{02}$: $P_2 = \frac{1}{4} \cdot P_1$

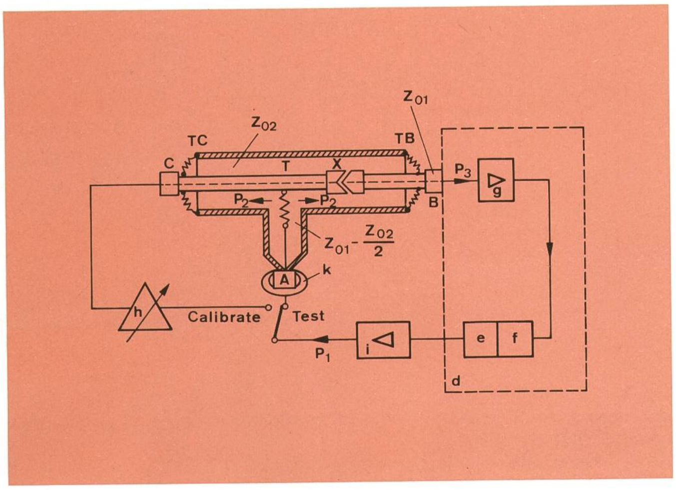

Fig. 4
Triaxial arrangement with matched T-feed

A	Power feed connection
B, C	Measuring ports
X	Connector pair under test
d	Screened room
e	Tracking generator
f	Spectrum analyser
g	Low noise preamplifier
h	Calibrated variable attenuator
i	Power amplifier
k	Ferrite rings
TB, TC	Outer system terminating devices with impedance Z_{02}
T	Well matched power dividing T-connection
P_1	Input power
P_2	Power parts in outer system
P_3	Inner system coupled power

The triaxial setup is usable from a low frequency limit of about 10 MHz to a highest frequency at which only a TEM (transverse-electro-magnetic) propagation mode is possible. This upper limit depends primarely on the diameter of the bulge in the outer coaxial shell, which surrounds the connector under test. As an example, a N-type connector can be measured with a well matched triaxial arrangement up to about 6 GHz.

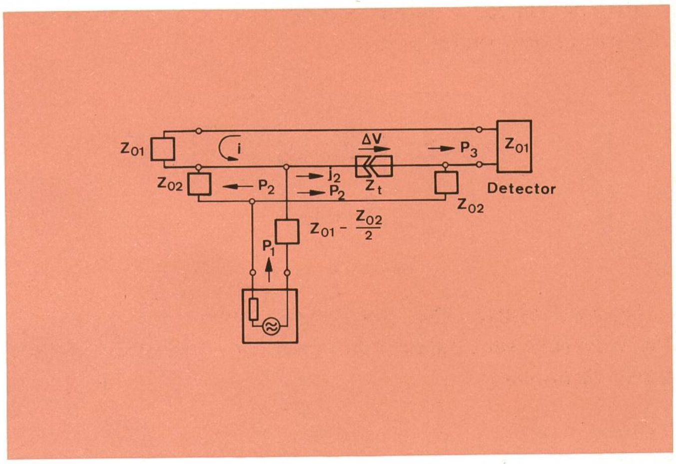

Fig. 5
Electrical equivalent circuit for the matched triaxial test setup for $Z_{01} = Z_{02}$ $P_2 = {}^1/_4 \cdot P_1$
$Z_t \ll Z_{01}$; Z_{02}

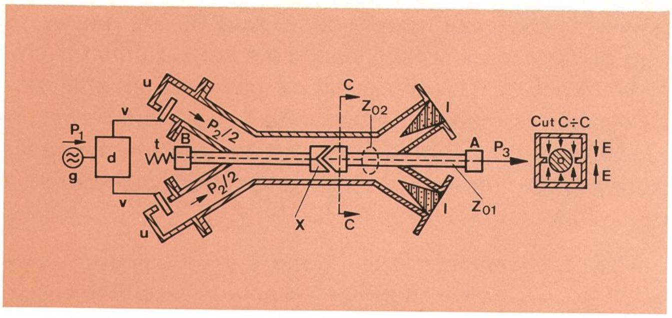

Fig. 6
Waveguide setup

A	Receiving side connector
B	With Z_{01} terminated connector for inner system
d	In phase power divider
E	Electrical field within test area
g	Generator
I	Waveguide load
X	Connector pair under test
t	Coaxial termination of inner system Z_{01}
u	Coaxial to waveguide transition
v	Semirigid coaxial cable with equal electrical length
Z_{01}	Impedance of inner system
Z_{02}	Quasi TEM-impedance of outer system
P_1	Feeding power
P_2	Total power in outer system with a quasi TEM-mode
P_3	Receiving power in inner coaxial system

5 The Matched Waveguide Assembly

To overcome the frequency limitation of the triaxial assembly, a very simple waveguide setup has been realised which allows to increase the measuring frequency range to about 3/4 of the connector upper frequency limit.

In *Figure 6,* the input signal is split in a 3 dB in phase power-divider and then launched in phase-opposition to the two waveguide arms. If the arms are of equal lengths, the field at the connector under test is quite similar to the TEM-mode in the coaxial arrangement.
The measuring conditions in this setup are similar to those in the matched triaxial configuration.

The quasi TEM-mode impedance of the outer system at the connector pair under test Z_{02} depends on the connector size and the waveguide dimensions and may vary from $\frac{Z_{01}}{3}$ to $3 \cdot Z_{01}$, which affects the overall accuracy still less than the wide dispersion of practically measured screening values, caused by repetitive connecting and disconnecting the devices under test.

The practical results with the waveguide arrangements correspond within ±3 dB to those obtained with the matched triaxial setup.

$$Z_t \approx \sqrt{Z_{01} \cdot Z_{02}^{*} \cdot \frac{P_3}{P_2}}$$

*quasi TEM

Figure 7 shows the frequency application ranges of the different test assemblies as a function of connector outer dimension.

6 Practical Considerations

In accordance with Figure 4 the 10 MHz to 2 GHz frequency range setup is shown in *Figure 8.* For higher frequencies (1 to 9 GHz) two modifications have been made *(Fig. 9a* and *9b).* The input feeder line is matched by introducing a lossless multistep impedance transformer section on the inner feeding conductor (1 to 10 GHz). The terminations TB and TC consist of horn-an-

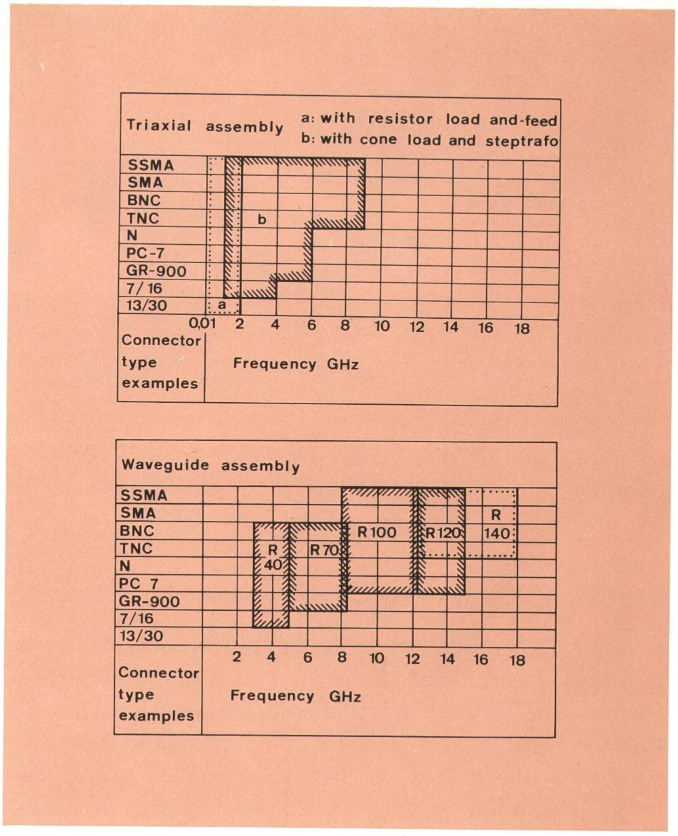

Fig. 7
Triaxial- and waveguide assembly application charts

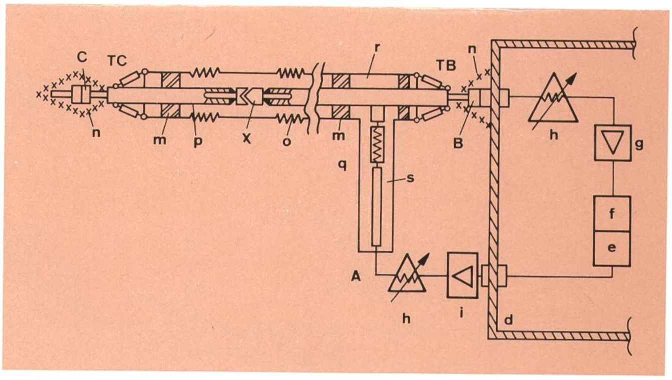

Fig. 8
Matched triaxial setup for screening measurements of connectors from 10 MHz to 2 GHz

A	Power feed connection
B	Measuring port
C	Inner coaxial termination
X	Connector pair under test
TB, TC	Outer coaxial system terminations (4 parallel 200 Ω)
d	Screened room
e	Tracking generator
f	Spectrum analyser
g	Low noise preamplifier
h	Variable attenuator
i	Power amplifier, 10 MHz to 1 GHz transistor amplifier; 1 to 2 GHz TWTA
m	Dielectric foam beads
n	Additional screening braid
o	Corrugated copper tube for elastic deformation
p	Solid brass tube 6/4 mm ∅
q	25 Ω serie resistor feed point to power splitter
r	Outer system outer tube brass 16/14 mm ∅
s	Feeding coaxial system with outer ∅ 7 mm, inner ∅ 3 mm

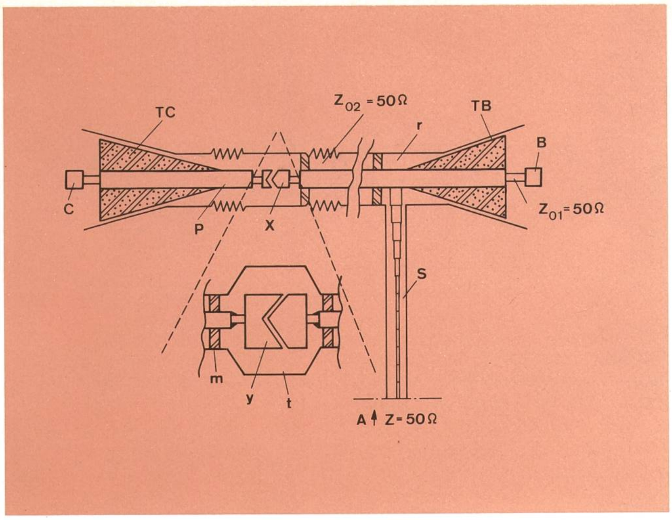

Fig. 9a
Matched triaxial setup for screening measurements of connectors from 1 to 9 GHz

A	Power feed connection
B, c	Measurement port (other port terminated)
X	Connector pair under test
Y	Large connector pair under test with bulge t of outer shell
m	Dielectric foam bead
p	Solid brass tube 6/4 mm ∅
r	Outer system outer tube brass 16/14 mm ∅
s	Feeding coaxial system with multistep 50 to 25 Ω transformer, outer tube inner ∅ 7 mm, inner conductor ∅ 3 mm at A
TB, TC	Horn filled with absorber cone terminations

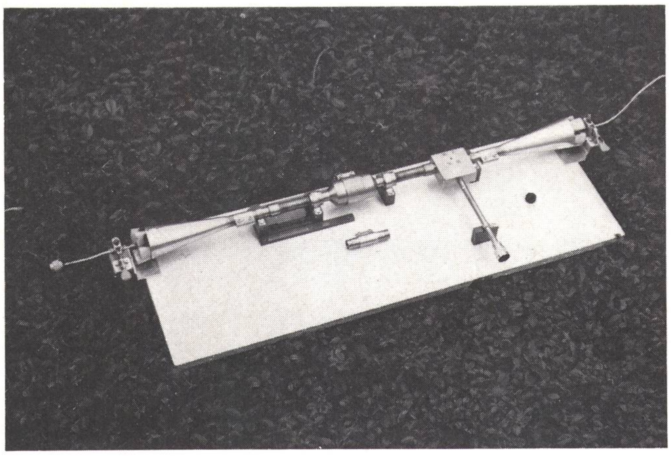

Fig. 9b
Matched triaxial setup 1...9 GHz ready for measurement

tenna like outer conductor lines, filled with grafite coated dielectric foam cones.

The outer coaxial system has a diameter of 14 mm. Thus, SMA, APC-3,5 and similar sized connectors can be measured without the necessity of changing this diameter in the region of the connector pair under test. The reflections, resulting from the impedance changes at the coupling elements, are therefore negligible. The semirigid copper cable of the inner system is surrounded by a brass tube to the proximity of the connector under test, and soldered to the semirigid cable at these ends. This tube has about the same outer diameter as the SMA connector outer shell and maintains therefore the Z_{02} condition of about 50 Ω.

For the measurement of larger size connectors, APC-7 or N types for example, the diameter of the outer coaxial system has to be increased over the length of the connector pair under test. The dimensions are not critical, reflection factors of about 0.5 are allowed (mismatch loss < 1.2 dB).

The ferrite rings at A (Fig. 4) are not necessary for frequencies above 10 MHz. The physical lengths of the cables between power amplifier output and screened room feed-through point are sufficiently long to create a high impedance between outer conductor of the outer system and outer conductor of the inner system of the triaxial assembly.

Figure 10a shows an exploded view of the waveguide assembly. The residual leakage and the mismatch of the

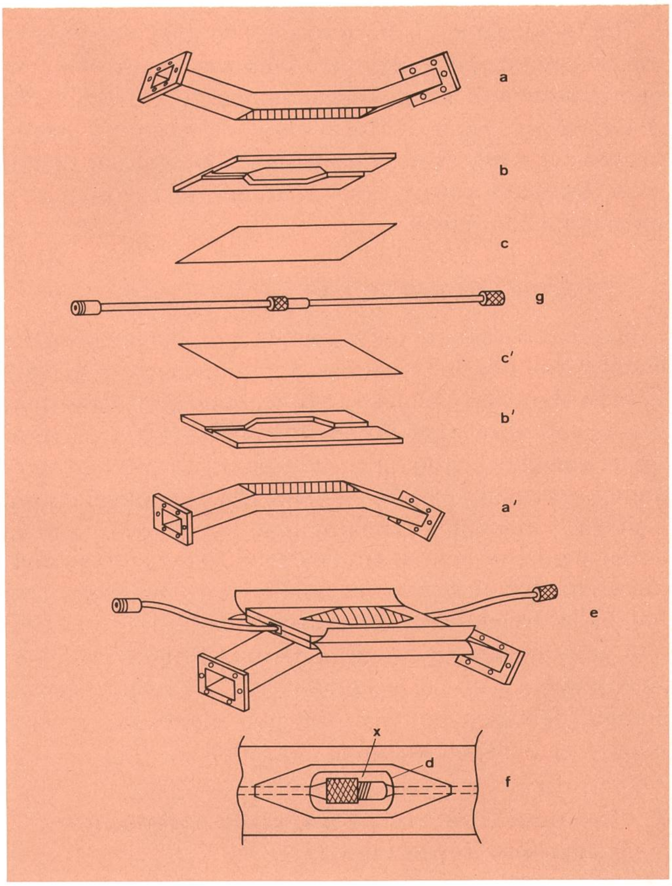

Fig. 10a
Waveguide assembly exploded view

a,a'	Upper, lower waveguide
b,b'	Upper, lower diaphragm plate
c,c'	Upper, lower tin sheet ~ 0.05 mm
g	Connector-cable-assembly under test (X)
e	Completely closed assembly for leakage and mismatch test (upper waveguide removed)
f	View of diaphragm ready for test

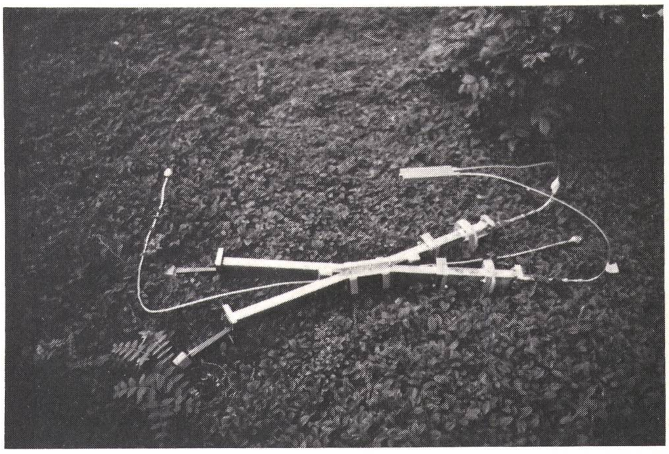

Fig. 10b
Waveguide setup R70 ready for measurement

setup can be tested before opening the two tin sheets (c) at the connector under test area (d) by a knife. This aperture cut with a 1 mm spacing between the tin sheet edge and the connector surface is needed to enable the main longitudinal current to flow at the surface of the connector's outer body. *Figure 10b* shows the waveguide setup ready for measurement.

At the area of the connector under test, each half of the assembly works more or less equivalent to a single ridge guide (Fig. 6 on the right) with the field- and current-maximas at the outer surface of the connector. This results in a quasi TEM mode operation of the whole assembly.

The dimensions of the trapezoid formed openings in the two metal plates depend on the waveguide and connector sizes and are therefore expressed in fractions of these values *(Fig. 11)*. The waveguide assembly has to be mechanically fixed by clamps. The coaxial cables must be fixed against torsion forces to assure stable measuring conditions.

7 Artificial Connector Pair

Practical screening measurements on connector pairs show the impossibility of using real connectors as calibration standard, because their screening effectiveness values vary very much depending on fixing torque, rotational position, changing surface contacts and mechanical tolerances. In *Figures 12a* and *12b* a simple and rigid artificial connector construction is shown, whose screening behaviour resembles very close to the screening character of a medium quality real connector. This has been proved with the triaxial method up to 10 GHz and with the waveguide arrangement R 100 from 6.6 to 12 GHz with close correspondence of the two measured curves (deviation between the two measuring assemblies < ± 2 dB) as shown in *Figure 13.*

8 Practical Limits on Measurable Attenuation Range and Repeatability

The measurable attenuation range P_3/P_2, obtainable by swept methods, depends on the specifications of the

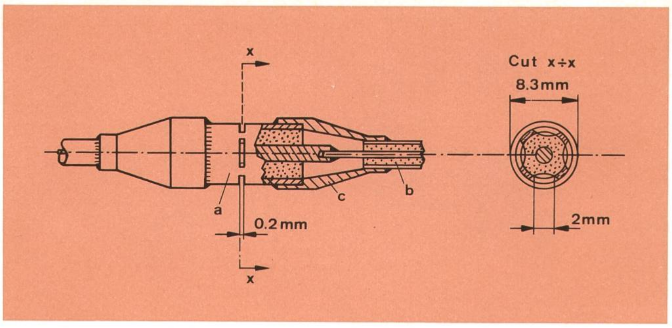

Fig. 12a
Artificial connector pair, made by a short piece of semi rigid coaxial cable 50 Ω SR-7 Huber & Suhner
a SR-7 cable piece
b RG 402/U semi rigid cable
c Solder adaptor

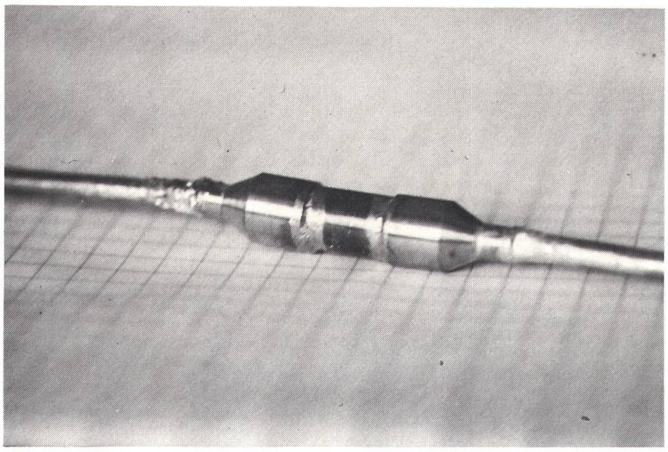

Fig. 12b
Artificial connector pair, soldered on two semirigid coaxial cables RG 402/U

low noise amplifier, the power amplifier and the spectrum analyzer. The practical limits with a usual equipment are:

- 155 dB from 10 MHz to 3 GHz which corresponds to a transfer impedance of $Z_t = 2\ \mu\Omega$
- 140 dB from 3 GHz to 8 GHz, $Z_t = 10\ \mu\Omega$
- 125 dB from 8 GHz to 12 GHz $Z_t = \sim 55\ \mu\Omega$

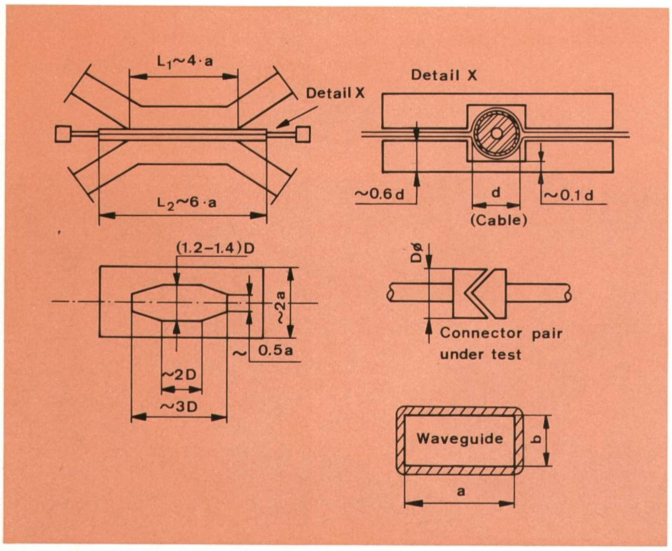

Fig. 11
Waveguide assembly dimensions
Range of D (outer Ø of connector under test) ≈ (0.25 ... 0.9)·a
a,b Inner sizes of waveguide
d Cable outer diameter

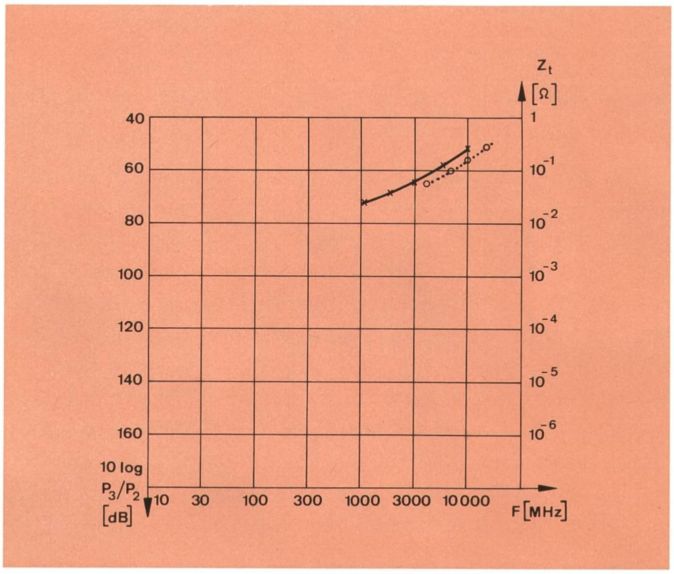

Fig. 13
Screening effectiveness artificial connector
——* Triaxial assembly
o...o...o Waveguide assembly

These low transfer impedance values *(Fig. 14)* are obtainable by using a good screened room at the receiving side. Additional screening at the inner system terminations and at the feed through point of the screened room are indispensable.

The measuring inaccuracy of about ± 3 dB depends on the calibration attenuator-quality, the instruments stability and the reflection factors at several points of the setup. Practical measurements indicate that the mechanical handling problems of the connections results in a wide dispersion of screening attenuation values, which exceed the measuring inaccuracies very much.

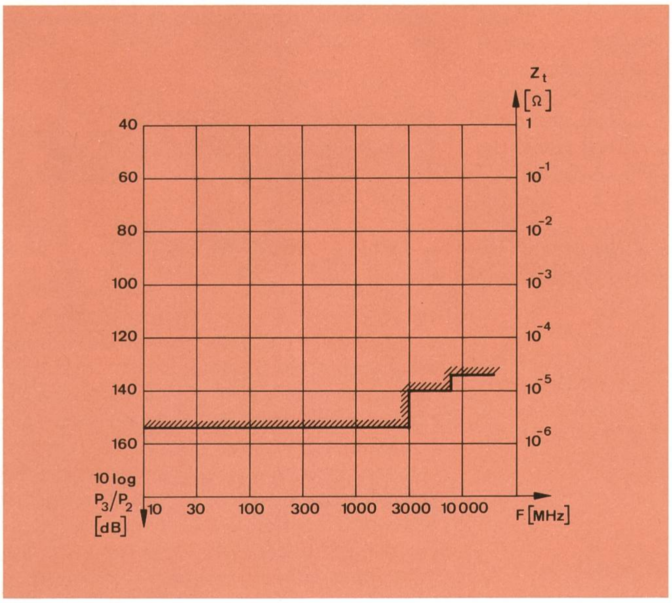

Fig. 14
Measurement sensitivity limit of existing setup

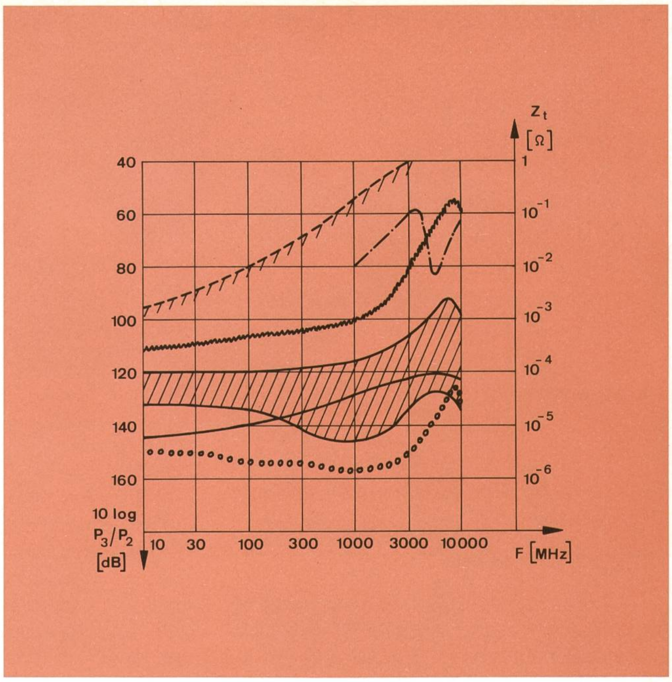

Fig. 15
Screening effectiveness values Z_t of different connector type pairs

– – – –	BNC 50 Ω worst case, depends on rotational angle between plug and jack; best to worst range ~ 40 dB
—·—·—	C-connector pair (single measurement)
∿∿∿∿∿	Standard N-connector, fixed with 7 cmkp torque
oooooooo	Same standard N-connector, fixed with 11.5 cmkp torque
———	SMA-connector pair, fixed with 10 cmkp torque
//////	N-precision connector pair, fixed several times with different fixing torques

9 Test Results

In *Figure 15* screening effectiveness curves with comments are presented.