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Passive RF and microwave devices, intermodulation level measurement – Part 1: General requirements and measuring methods

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PASSIVE RF AND MICROWAVE DEVICES, INTERMODULATION LEVEL MEASUREMENT –

Part 1: General requirements and measuring methods

FOREWORD

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International Standard IEC 62037-1 has been prepared by technical committee 46: Cables, wires, waveguides, R.F. connectors, R.F. and microwave passive components and accessories.

This first edition of IEC 62037-1 replaces IEC 62037, published in 1999. It constitutes a technical revision.

The text of this standard is based on the following documents:

FDIS	Report on voting
46/402/FDIS	46/416/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all the parts in the IEC 62037 series, published under the general title *Passive RF and microwave devices intermodulation level measurement*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this standard may be issued at a later date.

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PASSIVE RF AND MICROWAVE DEVICES, INTERMODULATION LEVEL MEASUREMENT –

Part 1: General requirements and measuring methods

1 Scope

This part of IEC 62037 deals with the general requirements and measuring methods for intermodulation (IM) level measurement of passive RF and microwave components, which can be caused by the presence of two or more transmitting signals.

The test procedures given in this standard give the general requirements and measurement methods required to characterize the level of unwanted IM signals using two transmitting signals.

The standards in this series address the measurement of PIM, but do not cover the long term reliability of a product with reference to its performance.

This standard is to be used in conjunction with other appropriate part(s) of IEC 62037.

2 Normative references

None.

3 Abbreviations

CATV	Community antenna television
DUT	Device under test
IM	Intermodulation
PIM	Passive intermodulation

4 Characteristics of intermodulation products

PIM interference is caused by sources of non-linearity of mostly unknown nature, location and behaviour. A few examples are inter-metallic contacts, choice of materials, corrosion products, dirt, etc. Most of these effects are subject to changes over time due to mechanical stress, temperature changes, variations in material characteristics (cold flow, etc.) and climatic changes, etc.

The generation of intermodulation products originates from point-sources inside a DUT and propagate equally in all available directions.

The generation of passive intermodulation products (PIM) does not necessarily follow the law of the usual non-linear equation of quadratic form. Therefore, accurate calculation to other power levels causing the intermodulation is not possible and PIM comparisons should be made at the same power level.

Furthermore, PIM generation can be frequency-dependent. When PIM generation is frequency-dependant, the PIM performance shall be investigated over the specified frequency band.

5 Principle of test procedure

Test signals of frequencies f_1 and f_2 with equal specified test port power levels are combined and fed to the DUT. The test signals should contain at least 10 dB less harmonic or self-intermodulation signal level than the expected level generated in the DUT.

The PIM is measured over the specified frequency range. The intermodulation products of order $(2f_1 \pm f_2)$, $(2f_2 \pm f_1)$ etc. are measured.

In most cases, the third order intermodulation signals represent the worst case condition of unwanted signals generated; therefore, the measurement of these signals characterizes the DUT in a sufficient way. However, the test set-ups given in Clause 6 are suitable for measuring other intermodulation products.

In other systems (such as CATV), the 3rd order may not be as applicable in characterizing the DUT.

Intermodulation can be measured in reverse and forward direction. Reverse and forward is referred to the direction of propagation of the most powerful carrier.

6 Test set-up

6.1 General

Experience shows that the generation of intermodulation products originates from point-sources inside a device under test (DUT) and propagates equally in all available directions. Therefore, either the reverse (reflected) or the forward (transmitted) intermodulation signal can be measured.

Two different test set-ups are described in Figure 1 and Figure 2 and are for reference only. Other topologies are possible.

Set-up 1 is for measuring the reverse (reflected) intermodulation signal only, and set-up 2 is for measuring the forward (transmitted) intermodulation signal. The measurement method (reverse or forward) is dependent upon the DUT. The set-ups may be assembled from standard microwave or radio link hardware selected for this particular application. All components shall be checked for lowest self-intermodulation generation.

Experience shows that devices containing magnetic materials (circulators, isolators, etc.) can be prominent sources of intermodulation signal generation.

See Annex B for additional set-up considerations.

6.2 Test equipment

6.2.1 General

Two signal sources or signal generators with power amplifiers are required to reach the specified test port power. The combining and diplexing device may comprise a circulator, hybrid junction, coupler or filter network.

The test set-up self-intermodulation generated (including contribution of the load) should be at least 10 dB below the level to be measured on the DUT. The associated error may be obtained from the graph in Figure 3.

The DUT shall be terminated by a load for the specified power if necessary. The receiving bandpass filter, tuned for the desired intermodulation signal, is followed by a low noise amplifier (if required) and a receiver.

See Annex B for additional set-up considerations.

6.2.2 Set-up 1

This set-up is to measure the reverse (reflected) IM-product and is therefore suitable for 1-port and multi-port DUTs. On multi-port DUTs, the unused ports shall be connected to a linear termination.

a) Generators

The generators shall provide continuous wave (CW) signals of the specified test port power. They shall have sufficient frequency stability to make sure that the IM-product can be detected properly by the receiver.

b) Transmit-filters

The filters are bandpass-filters tuned to the particular frequencies. They isolate the generators from each other and filter out the harmonics of f_1 and f_2.

c) Combining and diplexing device

This device is used for combining the signals f_1 and f_2, delivering them to the test port and provides a port for the extraction of the reverse (reflected) signal f_{IM}.

d) Receive-filter

This filter is used for isolating the input of the receiver from the signals f_1 and f_2 to the extent that IM-products are not generated within the receiver.

e) Test port

The DUT is connected to P4. The specified input power shall be at the DUT, with any set-up loss between the receiver and the DUT compensated for.

f) Termination

When a multi-port DUT is measured, the DUT shall be connected to a sufficiently linear termination (low intermodulation) of suitable power handling capability.

g) Receiver

The receiver shall be sensitive enough to detect a signal of the expected power level.

The receiver response time shall be sufficiently short to allow acquisition of rapid changes in amplitude. Sensitivity can be increased by a low noise preamplifier. Frequency stability shall be sufficient for the proper detection of the IM-signal.

When the PIM measurement result is close to the thermal noise floor of the receiver, the receiver sensitivity can be improved by reducing the resolution bandwidth (RBW). Furthermore, by using the averaging mode rather than the max-hold mode, a further improvement can be achieved, since the max-hold mode essentially measures the maximum thermal noise peak, while the averaging mode results in a measurement that is closer to the r.m.s. value.

6.2.3 Set-up 2

This set-up is to measure the forward (transmitted) IM-product and is therefore suitable only for two- or multi-port DUTs.

All components are the same as those of set-up 1, except for those as noted below:

a) Combining and diplexing device

   The extraction-port P3 on this device shall be terminated to prevent reflection of the IM-signals.

b) Diplexing device

   The signals f_1, f_2 and f_{IM} are split to P6 and P7. This device, together with an additional receive-filter, is used for the extraction of the intermodulation signals.

7 Preparation of DUT and test equipment

7.1 General

The DUT and test equipment shall be carefully checked for proper power handling range, frequency range, cleanliness and correct interconnection dimensions. All connector interfaces shall be tightened to the applicable IEC specification or, if none exists, to the manufacturer's recommended specification.

See Annex B for additional set-up considerations.

7.2 Guidelines for minimizing generation of passive intermodulation

The following guidelines and Table 1 should be considered and adhered to wherever possible.

a) Non-linear materials should not be used in or near the current paths.

b) Current densities should be minimized in the conduction paths (e.g. Tx channel), by using larger conductors.

c) Minimize metallic junctions, avoid loose contacts and rotating joints.

d) Minimize the exposure of loose contacts, rough surfaces and sharp edges to RF power.

e) Keep thermal variations to a minimum, as the expansion and contraction of metals can create non-linear contacts.

f) Use brazed, soldered or welded joints if possible – but ensure these joints are good and have no non-linear materials, cracks, contamination or corrosion.

g) Avoid having tuning screws or moving parts in the high current paths – if necessary, then ensure all joints are tight and clean, and preferably, free from vibration.

h) Cable lengths in general should be minimized and the use of high quality, low-IM cable is essential.

i) Minimize the use of non-linear components such as high-PIM loads, circulators, isolators and semiconductor devices.

j) Achieve good isolation between the high-power transmit signals and the low-power receive signals by filtering and physical separation.

Table 1 – Guide for the design, selection of materials and handling of components that may be susceptive to PIM generation

Part, material or procedure	Recommendations
Interfaces	Minimize the total number.
Connectors	Minimize the number of connectors used. Use high quality, low-PIM connectors mated with proper torque.
Inter-metallic connections	Each inter-metallic connection should be evaluated in terms of criticality for the total PIM level. Methods of controlling the performance are high contact pressure, insulation, soldering, brazing, etc.
Ferromagnetic materials	Not recommended (non-linear).
Non-magnetic stainless steel	Not recommended (contains iron).
Circulators, isolators and other ferrite devices	Not recommended.
Sharp edges	Avoid if it results in high current density.
Terminations or attenuators	Should be evaluated before use.
Hermetic seals / gaskets	Evaluate before use and avoid ferromagnetic materials.
Printed circuit boards (PCB)	Materials, processes and design should all be considered and evaluated. Use low-PIM materials; be careful with material impurities, contamination and etching residuals. The copper trace should be finished to prevent corrosion.
Dissimilar metals	Not recommended (risk of galvanic corrosion).
Dielectric material	Use clean, high quality material. Ensure it does not contain electrically conductive particles.
Machined dielectric materials	Use clean non-contaminated tools for machining.
Welded, soldered or brazed joint	Well executed and thoroughly cleaned, they provide satisfactory results. Shall be carefully inspected.
Carbon fibre epoxy composite (CFEC)	Generally acceptable for use in reflector and support structures, provided the fibres are not damaged. Should be evaluated if high flux density (e.g. >10 mW/cm^2 is expected.
Standard multilayer thermal blankets made of Vacuum Deposited Aluminium (VDA) on biaxially-oriented polyethylene terephthalate film or Polyimide film	Special design required.
Cleanliness	Maintain clean and dry surfaces.
Plating	The thickness of the plating should be at least three times greater than the skin depth of the wave resulting from the skin effect at the lowest relevant frequency.

8 Test procedure

Table 2 gives certain conditions for test set-up 1 and test set-up 2.

Table 2 – Test set-up conditions

Test set-up 1	Test set-up 2
The set-up shall be verified for correct signal levels applied to the DUT. For mobile communication systems, it is generally recommended to use 2 × 20 W (43 dBm) at the test port of the DUT, unless otherwise specified. Other systems may require different power levels.	
The minimum number of test frequencies and/or frequency spacing shall be specified.	
For lowest measurement uncertainty, the receiver shall be calibrated at the expected IM-level with a calibrated signal-source as indicated in Figure 1 and Figure 2.	
The termination shall be connected directly to the test port P4 and the self-intermodulation level of the set-up recorded.	P5 of diplexing device shall be connected directly to P4 of combining and summing device and the self-intermodulation level of the set-up recorded.
For low measurement uncertainties, the level of self-intermodulation should be at least 10 dB below the specified value for the DUT.	
Test the DUT as given in the specific set-up and procedure in the appropriate test set-up.	
An additional mechanical shock test may be carried out during the test sequence.	

9 Reporting

9.1 Results

The input power at individual frequencies should be specified.

The values of f_1 and f_2 should be specified.

The PIM level and frequency should be specified.

9.2 Example of results

The result is expressed as an absolute magnitude in dBm or relative magnitude in dBc, referenced to the power of a single carrier.

The relationship between a measured IM_3-value of –120 dBm can be converted to dBc as follows:

EXAMPLE:

$$f_1 = 936 \text{ MHz},\ f_2 = 958 \text{ MHz},\ f_{IM_3} = 914 \text{ MHz}$$

$$P(f_1) = P(f_2) = 20 \text{ W } (+43 \text{ dBm})$$

$$IM_3 = -163 \text{ dBc } (-120 \text{ dBm})$$

10 Measurement error

The measurement uncertainty can be calculated by the following formula:

$$RSS = \sqrt{[(\delta A)^2 + (\delta Pm)^2 + (\delta Pg)^2 + (\delta D)^2]}$$

where

δA is the uncertainty of attenuator;

δPm is the uncertainty of power meter;

δPg is the uncertainty of generator 3;

δD is the uncertainty due to the difference between self-intermodulation of the test bench and intermodulation of the DUT (taken from Figure 3).

Mismatch errors are not included in the given formula.

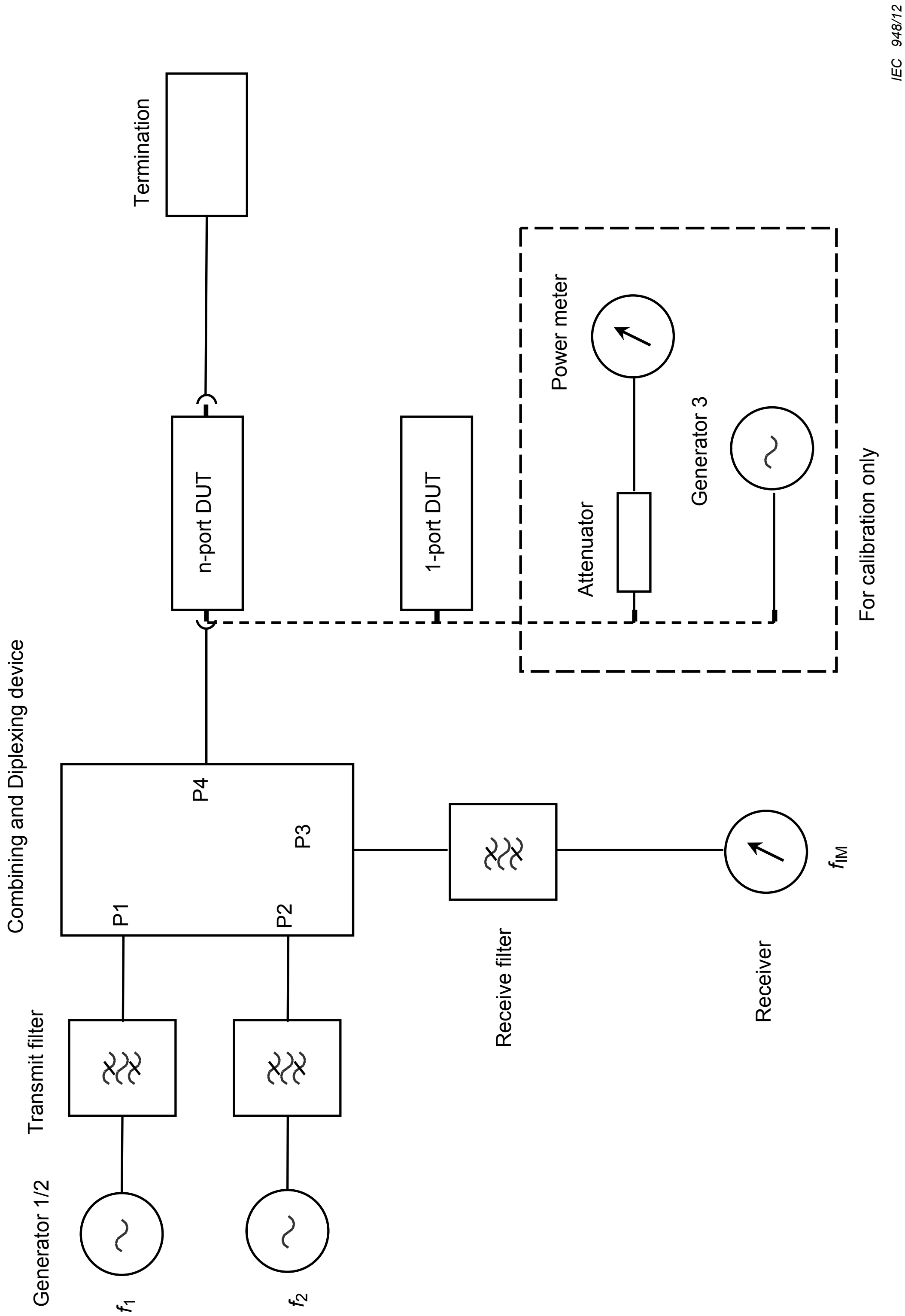

Figure 1 – Set-up 1; reverse IM-test set-up

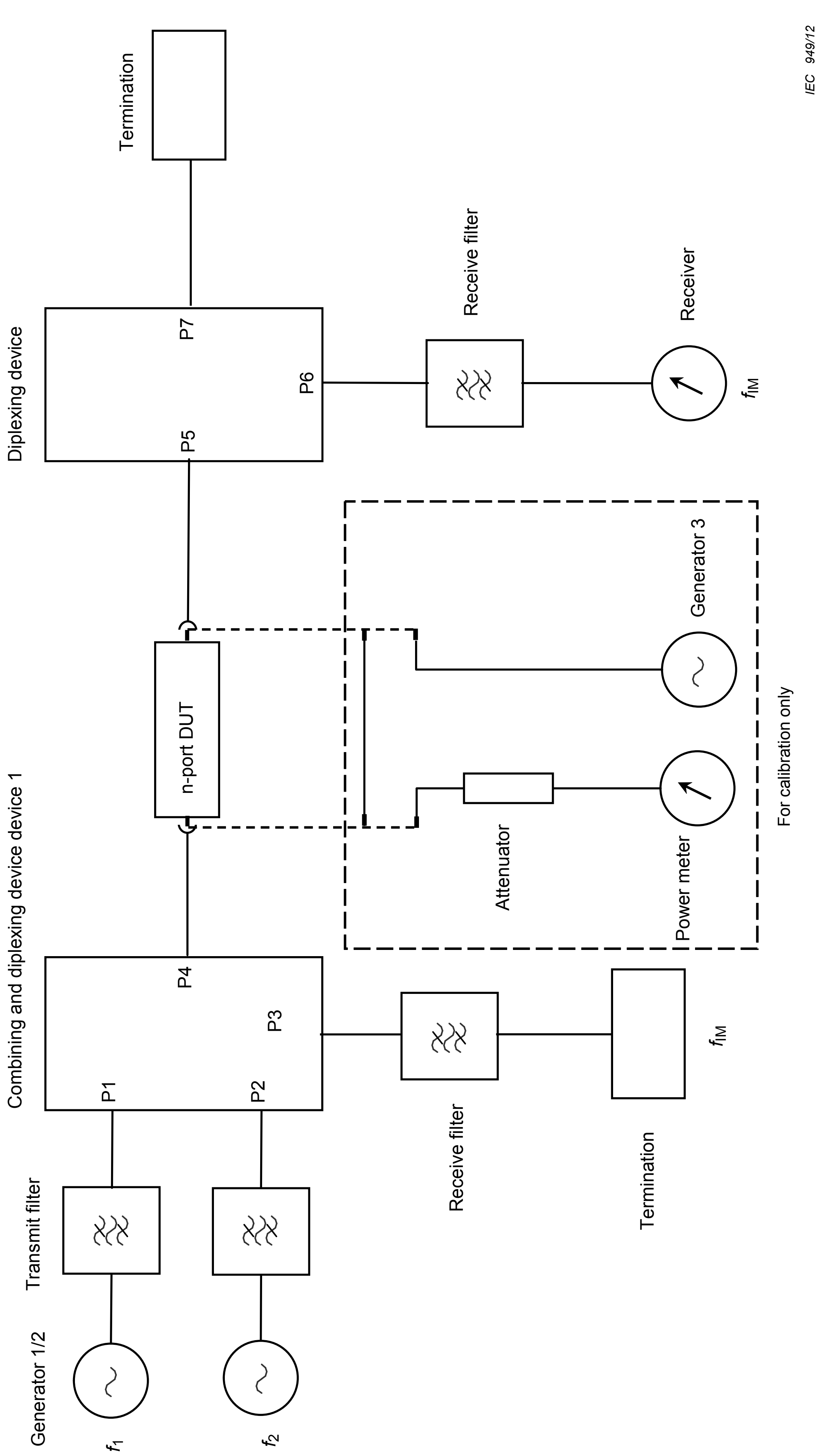

Figure 2 – Set-up 2; forward IM-test set-up

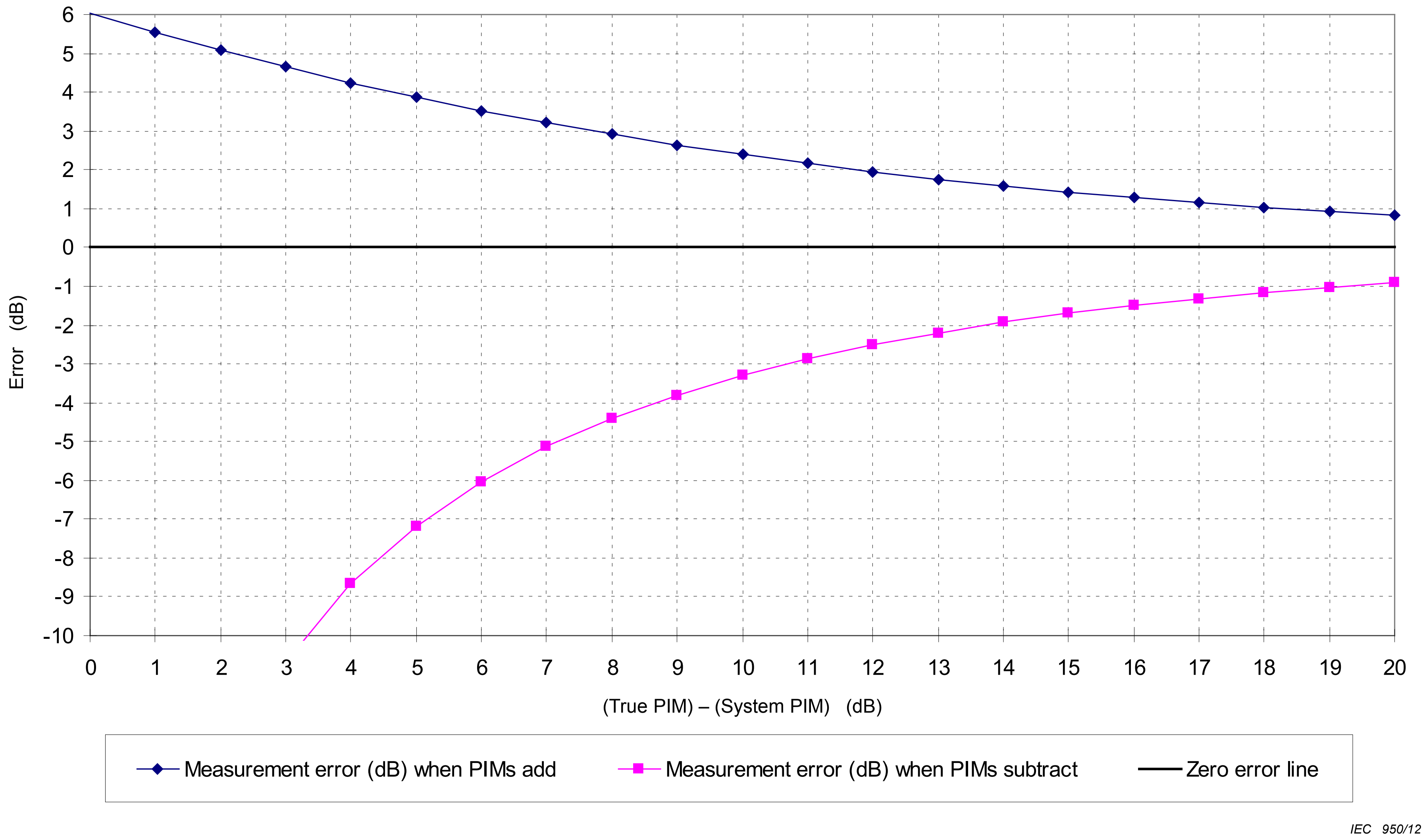

Figure 3 – Passive intermodulation (PIM) measurement error caused by residual system error

Annex A
(informative)

Configuration of low-PIM termination

A.1 General

This annex provides information on low-PIM terminations.

A.2 Configuration of low-PIM terminations

A.2.1 Long cable termination

High-PIM terminations may often consist of resistive materials. Therefore, long coaxial cables are used as a low-PIM termination (see Figure A.1). The following guidelines are in no particular order of significance, but should be considered and adhered to wherever possible.

a) Avoid braided cables. Cables with a single centre conductor should be used. Semi-rigid cables would be a good choice from the practical viewpoint.

b) Avoid using cables with high-PIM materials and high-PIM plating. Plating with silver and tin would be a good choice. Plating should be sufficiently thicker than the skin depth at the lowest fundamental frequency.

c) A seamless cable configuration is the best for terminations because minimizing cable-connection is essential to achieve low-PIM. When the termination is composed of several short cables, the longest one should be used at the nearest side to the DUT.

d) Choose the cable with sufficient power-handling capability.

e) Choose the cable length sufficient for power absorption at the lowest fundamental frequency considering the isolation performance between the receive signals and transmit signals.

f) Use a connector with low-PIM characteristics.

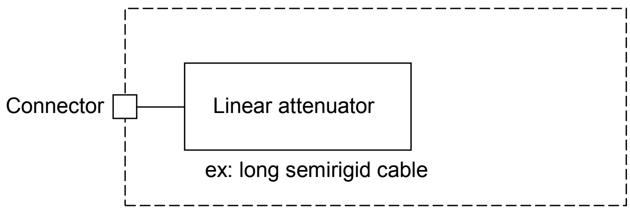

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Figure A.1 – Long cable termination

A.2.2 Lumped termination with a linear attenuator

Low-PIM cable can be considered as a linear attenuator. The combination of the linear attenuator and a high-PIM lumped load as shown in Figure A.2 may be used as a low-PIM termination. The following procedure is presented for designing a low-PIM termination.

1) Measure the PIM characteristics of the lumped termination as a function of the fundamental power, and determine the PIM-increase ratio X[dB].

2) Determine the required attenuation of the linear attenuator X_c[dB] using the formula:

$$PIM_{term} = PIM_{RDL} - (X + 1)X_c$$

3) Design the required length of the cable for the linear attenuator using the following formula:

$$X_c = \alpha \times l_m$$

where

PIM_{RDL} is the PIM of the lumped termination for P_{in}, in dBm;

PIM_{term} is the PIM level required for the low-PIM termination in dBm;

X is the PIM increase against the 1 dB-increase of each input tone, in dB;

X_c is the attenuation of the linear attenuator, in dB;

α is the attenuation ratio of the cable, in dB/m;

l_m is the cable length, in m.

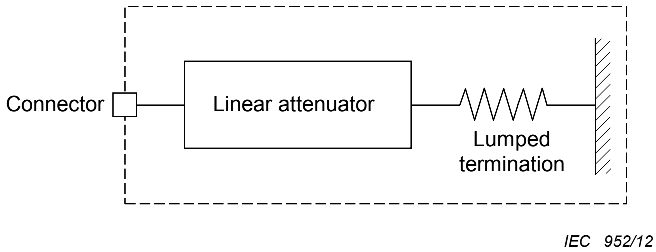

Figure A.2 – Lumped termination with a linear attenuator

Annex B
(informative)

Test procedure considerations

B.1 General

Due to the phase interaction of the connectors and the length of the transmission line when measured in the reverse (reflected) mode, the frequency at which maximum PIM occurs within the band can vary and shall be determined.

B.2 Stepped frequency sweep

An accepted method of sweeping is to fix F1 at the low end of the transmit band and step F2 down, starting at the top of the band for all combination of frequencies that result in IM in the receive band. If desired, this procedure can be reversed by fixing F1 at the highest frequency in the transmit band and then stepping F2 up, starting at the bottom of the band.

B.3 Fixed frequency

Assemblies of varying lengths shall be made to ensure that the PIM adds in-phase. Assemble 2 additional DUTs. The first one is to be $\lambda/6$ longer and the second one is to be $\lambda/3$ longer at the receive frequency of test. The PIM of the three assemblies is measured to determine which DUT exhibits maximum PIM. The impact test is to be performed on this DUT.

Multiple fixed frequency may be used in lieu of varying the cable length.

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