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Radiocommunication Sector of ITU

Recommendation ITU-R SM.1446-0

(04/2000)

Definition and measurement of intermodulation products in transmitter using frequency, phase, or complex modulation techniques

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***Note**: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
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RECOMMENDATION ITU-R SM.1446-0*

Definition and measurement of intermodulation products in transmitter using frequency, phase, or complex modulation techniques

(2000)

Scope

This Recommendation serves as a basis for the definitions of the different intermodulation types in the transmitter and diverse types of measurement techniques.

Keywords

Intermodulation (IM) products, measurement techniques, unwanted emissions

The ITU Radiocommunication Assembly,

considering

a) that intermodulation (IM) products are part of the unwanted emissions (RR No. 1.146);

b) that IM products are generated either in the radio transmission system itself and/or by interaction between different radiating elements at the same radio site;

c) that the limits of unwanted emissions in the spurious domain cover only single- or multichannel IM products, and are prescribed by Appendix 3 of the RR and Recommendation ITU-R SM.329;

d) that the limits of out-of-band emissions cover only single- or multichannel IM products, and are under study;

e) that no limits are defined for inter-transmitter IM between different systems;

f) that there is a rapid increase of shared radio sites, and that each site can potentially radiate passive and active IM products in an anomalous and uncontrolled way, and these will all add together at receivers;

g) that the IM products due to amplitude-modulated radio transmitter are considered in Recommendation ITU-R SM.326;

h) that there is a need to define methods of measurements of IM products, particularly for digital modulation techniques,

noting

a) that Report ITU-R SM.2021 contains general principles on generation of IM products and the relevant mitigation techniques to minimize IM,

recommends

1 that when considering the types of mechanisms which generate IM products in the transmission system the definitions and the relevant measurement techniques for each type of IM given in Annex 1 should be used.

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[*] Radiocommunication Study Group 1 made editorial amendments to this Recommendation in the years 2016 and 2019 in accordance with Resolution ITU-R 1.

ANNEX 1

IM products in the transmitter

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Page

1 Definitions of the different IM types in the transmitter

IM products are generated at non-linearities in the transmitter output amplifier, e.g. at semiconductors, klystrons, etc., and in passive devices like combiners, circulators, connectors, etc.

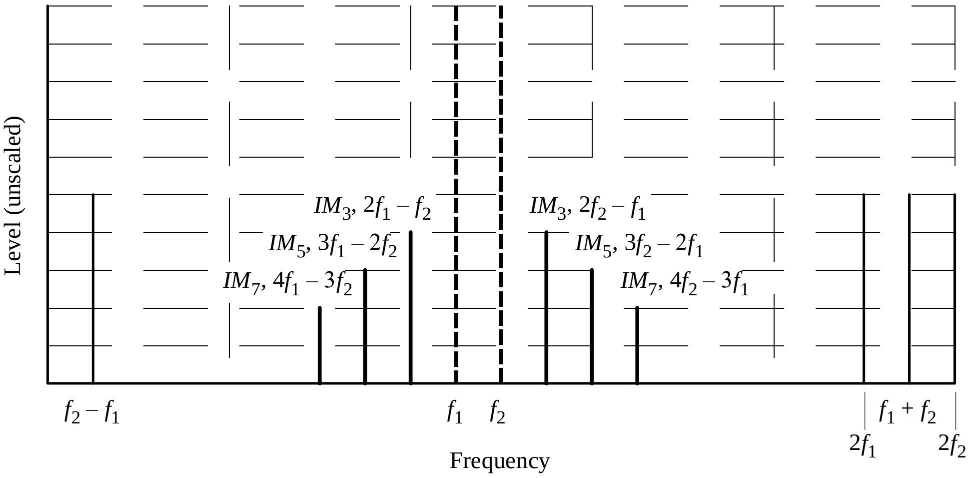
IM products at the frequency f_{IM} are generated by two or more unwanted signals at the frequencies f_1, f_2, … at non-linearities in the output of a transmitter. The relation between f_{IM} and f_1, f_2, … can be expressed very general:

$$f_{IM} = | \, m_1 f_1 + m_2 f_2 + \ldots \, | \qquad \text{with} \qquad m_\upsilon = 0, \pm 1, \pm 2, \ldots$$

The order of the IM product is given by $n = m_1 + m_2 + \ldots$. This means that the frequency for 2nd order IM products, IM_2 with $n = 2$, $m_1 = m_2 = 1$ results in $f_{IM} = | \, f_1 \pm f_2 \, |$ and of the 3rd order IM_3 ($n = 3$, $m_1 = 2$, $m_2 = 1$) in $f_{IM} = | \, 2 f_1 \pm f_2 \, |$ or in $f_{IM} = | \, 2 f_2 \pm f_1 \, |$ with $m_1 = 1$, $m_2 = 2$. The $2 f_1 - f_2$ and $2 f_2 - f_1$ products are of most concern to designers since these are often specified in standards, although the $f_1 + f_2 - f_3$ products are of greater magnitude and more numerous if there are more than two interfering signals. For some applications the 5th order IM products IM_5 occurring at $3 f_1 - 2 f_2$ or $3 f_2 - 2 f_1$, respectively, have also to be considered. The relation of the different IM products is illustrated in Fig. 1.

FIGURE 1

Unscaled IM products (bold lines) related to the fundamentals (bold dashed lines)



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Five different types of IM are defined.

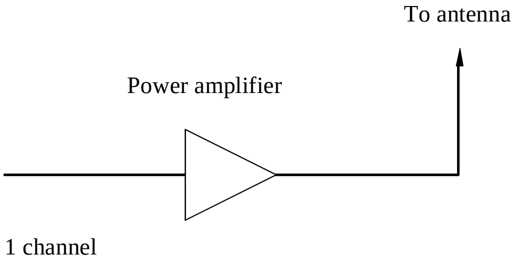
1.1 Type 1 – Single-channel IM

Single-channel IM is defined as distortion of the wanted signal by virtue of non-linearity in the transmitter circuits including all passive devices like combiners, etc.

Figure 2 illustrates this type of IM.

FIGURE 2

Type 1 – Single-channel IM



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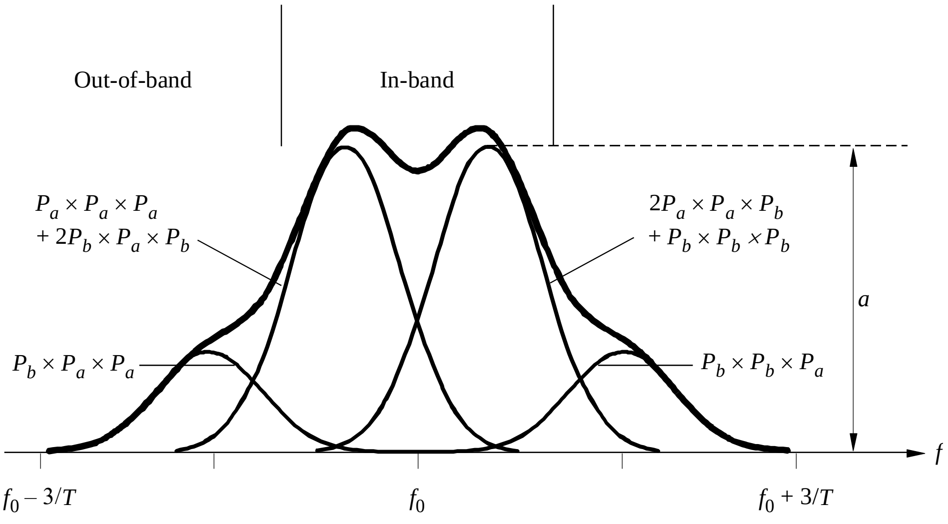
In addition to producing IM distortion products by the mixing of two or more RF transmission signals, in-band and out-of-band emissions can be observed from a single baseband modulation signal due to mixing of discrete component frequencies of a complex transmitter input waveform. This can occur with an analogue signal such as speech which generally is comprised of several time variant frequency components. It also occurs with digital signals due to Fourier series component frequencies mixing to produce new frequency components. This leads to transmitted digital waveform distortion and an increase in the amplitude in a portion of the original signal spectrum. A truly random digital signal will contain an infinite number of these spectral components resulting in a noise-like continuous spectrum shaped by the passband filter. The effect of IM distortion is to increase the energy in sub-bands of the noise-like spectrum, especially those due to 3rd order IM. This increase in the noise-like spectrum has been referred to both as IM noise and spectral growth and often appears in digital modulation spectral plots as bumps or shoulders near the edges of the passband filter which contribute excess noise power to the adjacent band and potential interference as illustrated in Fig. 3.

FIGURE 3

Example of 3rd order IM noise in the used frequency bands $BO = 0.82\ (BI - 4.5)$ and $f_0 < f < f_0 + 1/T$ where T is the symbol length, f_0 is the carrier frequency and P are the unscaled signal powers



BO: output back-off
BI: input back-off

1446-03

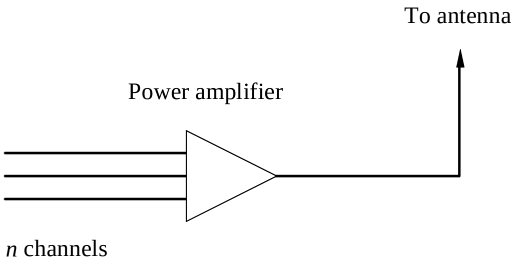
1.2 Type 2 – Multichannel IM

Multichannel IM is defined as the situation where the wanted signals of several channels are distorted by virtue of non-linearity in the same transmitter circuits.

The signals in the different channels may have different modulations, bandwidths or different spacings within the whole band.

FIGURE 4

Type 2 – Multichannel IM



1446-04

1.3 Type 3 – Inter-transmitter IM

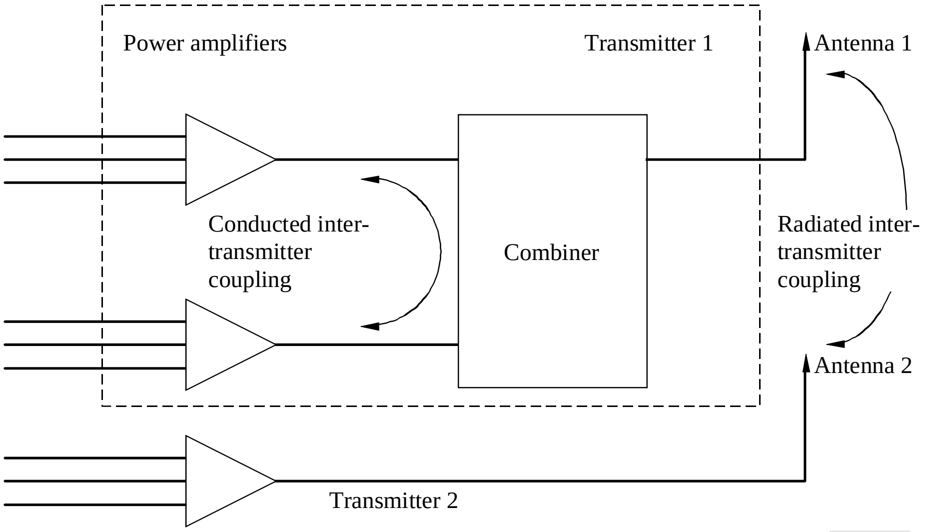
Inter-transmitter IM, where one or more transmitters on a site intermodulate, either within the transmitters themselves, or within a non-linear component on site to produce IM products at frequencies possibly far removed from actual transmit frequencies. This is often known as the rusty bolt effect and is a function of the various problems of mainly co-site engineering, although certain tests may be called upon to be made on the transmitters themselves.

The IM products described by type 3 are induced by interfering signals entering the transmitter via its antenna. If they are near the nominal frequency of the transmitter, they may generate considerable IM products in the transmitter output. If they are far from the nominal frequency, i.e. outside the wanted operating bandwidth, the frequency selectivity of the system has also to be taken into account.

Figure 5 illustrates this type of IM.

FIGURE 5

Type 3 – Inter-transmitter IM



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1.4 Type 4 – IM due to active antennas

An example of an active antenna structure used at a satellite is given in Fig. 6 for illustration.

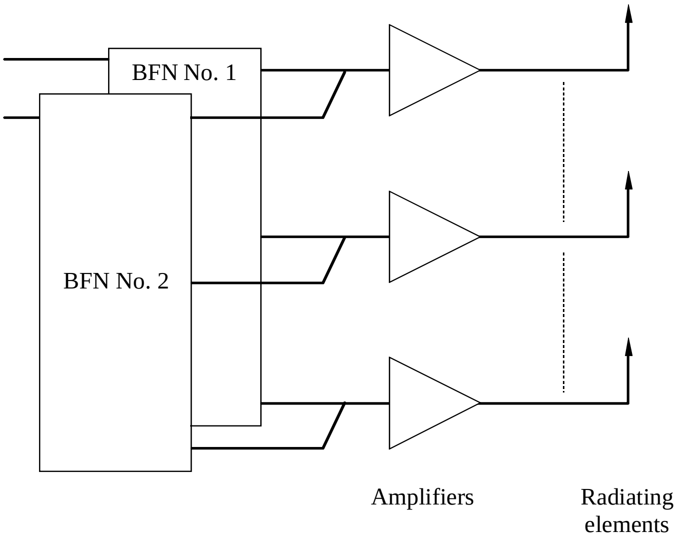
Beam-forming upstream from power amplifiers permits the RF power losses to be limited, but imposes a multicarrier operating mode to the amplifiers: each amplifier receives all the signals to be transmitted and operates therefore on the whole system bandwidth. This distribution of the signal power over the different antenna paths permits power exchanges between the beams as well as their reconfiguration through the simple transmission of a telecommand signal.

The multicarrier operating mode of an active antenna, along with the non-linearity of amplifiers, originates spurious emissions under the form of IM signals. The analysis of these IM signals is made very complex by the active architecture of the antenna.

NOTE 1 – Active antennas are now under development and varieties of the system are now widening in the working technology and applications of communication services. These systems are envisaged to be widely used in many fields in the future, e.g. for very high-speed communication with more than 1 Gbit/s for imaging, radar, etc. Therefore, the IM from active antennas and its measurement method should be studied further.

FIGURE 6

Type 4 – Active antenna architecture including amplifiers



BFN: beam-forming networks

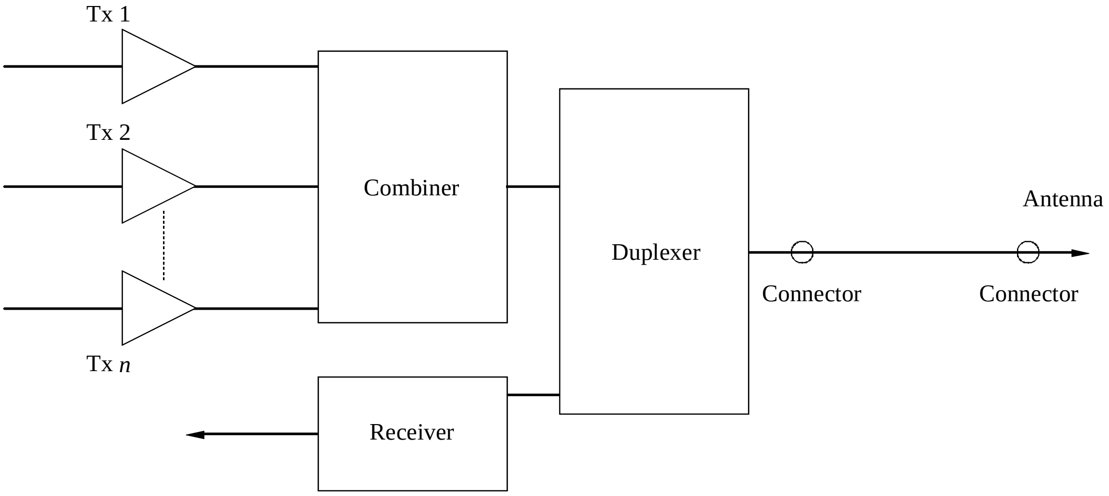
1446-06

1.5 Type 5 – IM due to passive circuits

An example of a radio station is illustrated in Fig. 7 where many transmitters and receivers share a common antenna. Usually passive circuits such as waveguides, cables and connectors may be considered not to produce any IM products, because they are considered to be linear circuits. However, when their performance is degraded due to ageing or loose contact, some amount of non-linearity may appear. If a number of transmitters are operating, IM products due to a combination of transmitting frequencies may be generated. In an extreme case, 9th order IM products seriously degraded receiver performance.

FIGURE 7

Type 5 – IM due to passive circuits



1446-07

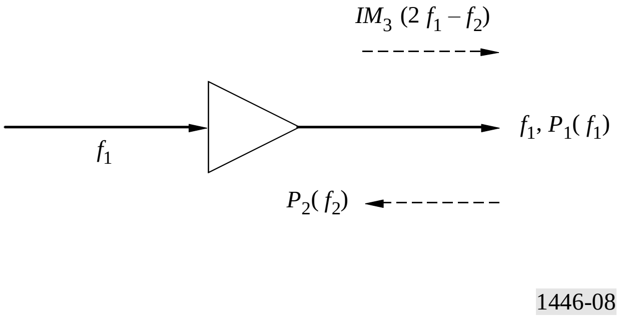
Therefore, it is important to maintain the linearity of passive circuits such as waveguides, cables and connectors.

1.6 Transmitter IM attenuation

The transmitter IM attenuation is a measure of the capability of a transmitter to inhibit the generation of signals in its non-linear elements caused by the presence of the carrier. This definition is indicated in Fig. 8 with f_1 as the carrier frequency having the output power $P_1(f_1)$ and f_2 as the interfering signal having the power P_2.

FIGURE 8

Definitions of transmitter IM attenuation and reverse IM factor



The transmitter IM attenuation, A_{IM}, is then defined by:

$$IM_3 < P_1 - A_{IM} \qquad \text{dB}$$

Another definition, appropriated particularly for Type 3 and called reverse IM factor, A_{RIM}, defines the IM suppression of external signal sources:

$$IM_3 < P_2 - A_{RIM} \qquad \text{dB}$$

These definitions used for transmitters should not be mixed up with receiver IM rejection which is a measure of the capability of a receiver to receive a wanted modulated signal without exceeding a given degradation due to the presence of IM products.

2 Radiocommunication services considerations

Some examples for IM products and performance occurring in fixed-satellite, mobile-satellite and broadcasting services are listed in Appendix 1 to Annex 1. In general, the IM performance depends on a huge variety of different factors, e.g., like modulation and access schemes, hardware components and cost for equipment. The selected examples are aimed only to illustrate which ranges of IM suppressions are achievable in real systems. They are not intended to define any limits for IM products.

3 Measurement techniques

For the measurements of IM products or noise, in general, the same techniques as are used for the measurements of out-of-band and spurious emissions are applicable. There are some rules to be followed: e.g. the IM levels should be not affected by the presence of the transmitter output signal, and an adequate dynamic range has to be provided in the measuring equipment to allow detection of low level IM signals in the presence of wanted signals.

In this section, some specific procedures for IM measurements are described.

3.1 Generic measurement methods for single-channel IM measurement (Type 1)

In general, these methods are broken down into classical analogue, and digital transmitter requirements.

3.1.1 Analogue modulation

In all the methods, it is important to ensure that the input signals neither intermodulate prior to application to the transmitter under test, or are affected by the RF output of the transmitter. Various methods of combining signals exist.

3.1.1.1 Two tone testing

The classical case here is of the single-sideband or independent sideband (ISB) transmitter. The application of two equal amplitude, sinusoidal, non-harmonically related tones to the input is well known, and the 3rd and 5th order products are measured, usually by means of a spectrum analyser, although other methods exist. Some differences occur in specifications; the attenuation of the IM products may be specified either with respect to one tone of the two tone signal, or with respect to the peak envelope power (PEP) of the signal, and there is a 6 dB difference between these levels. Thus a signal 24 dB below the level of one tone of the two tone signal is 30 dB below PEP.

Although this method has been used for many years, and has the advantage of simplicity, it does fail to deal adequately with modulation such as speech. In speech, although the bandwidth can be limited to 300-2 400 Hz, variation at the syllabic rate down to 10 Hz or 15 Hz still occurs. As a result, a transmitter which performs adequately on a two tone test with a tone spacing of 700 Hz may perform poorly with respect to IM products and thus out-of-band emissions on speech, especially where large amounts of speech processing to reduce the peak to average ratio is in use. Some transmitter specifications have attempted to address this by requiring testing with tone spacings as low as 30 Hz, but measurement difficulties can then exist.

3.1.1.2 Three tone testing

Another approach is to use, as in the cable TV industry, a three tone test. (The test procedure is different to that used in cable TV, however.) Here, three equal amplitude, sinusoidal, non-harmonically related tones are used, with two of them spaced by some 30 Hz or so. Interpretation of the resultant spectrum analyser display becomes more complex, in that there are now six of the 3rd order IM products, whereas in the two tone test, there were only two. Similarly, there will also be six of the 5th order IM products, and so on. Nevertheless, this test is very good at showing deficiencies in the final amplifier power supply dynamic regulation.

3.1.1.3 Noise testing

3.1.1.3.1 Non-continuous frequency domain noise

Another method that has been used is noise loading of the transmitter input. This technique has been used for many years in analogue FDM systems, wherein the equipment is loaded with a noise spectrum that includes a slot or hole in the input frequency domain. The effects of IM distortion can then be measured by the amount of signal appearing in the equivalent slot or hole at the output. However, unless the input noise is modulated at the syllabic rate, this method offers little real advantage in the single channel case. For multichannel equipment, such as an ISB transmitter carrying two voice channels and 12 voice frequency telegraph signals, it provides a better approximation than that of a two tone test. The biggest advantage of this method is that it can provide a more realistic peak-to-average ratio than the continuous tone methods.

3.1.1.3.2 Continuous frequency domain noise

An alternative to providing a slot or hole in the frequency domain of the input signal is to examine the spectral regrowth of the noise modulated signal compared with the spectrum produced by the transmitter without IM products. This is harder to interpret, but its applicability is dependent upon the application. In those applications where in channel IM product is important for the system function, this method has no applicability: where the IM product is of importance because of its effect on out-of-band emissions, however, it is a realistic guide to the transmitter performance.

3.1.2 Digital modulations

IM products in these transmitters are usually measured in terms of the adjacent channel protection ratio. A suitable pseudo-random bit stream is used to modulate the transmitter and the power in the adjacent or alternate (i.e. adjacent + one channel) is measured using a suitable spectrum analyser or measuring receiver. Otherwise, the technique is similar to the single channel technique in § 3.1.1.3.2. This applies to a number of digital modulation methods, including orthogonal frequency division multiplex.

3.2 Generic measurement methods for multicarrier IM measurement (Type 2)

High power amplifiers, e.g. used in satellite systems, are operated as close as possible to their maximum (saturation) output powers causing IM products degrading the signal-to-noise ratio where the same amplifier is used to transmit more than one carrier. In digital systems the BER is determined by the ratio of energy per bit to noise spectral density, E_b/N_0 where E_b is the carrier power divided by the bit rate and N_0 is the single-sided noise power per Hz of bandwidth. Noise and interference contributions from the uplink and downlink must be combined with the IM noise in such a way that all contributions are normalized to the carrier power. A convenient characterization of the IM noise is the equivalent noise temperature, T_{im}. A rule-of-thumb for the expected value of C/T_{im} is:

$$C/T_{im} = -150 - 10\log(N) + 2BO \qquad \text{dB}$$

where N is the number of carriers and BO is the output back-off, given depending on the input back-off BI by:

$$BO = 0.82(BI - 4.5) \qquad \text{dB}$$

Assuming all carriers have equal power:

$$C = P_s - 10\log(N) - BO \qquad \text{dBW}$$

where P_s is the saturation output power. Thus:

$$T_{im} = P_s + 150 - 3BO \qquad \text{dB(K)}$$

and

$$N_0 = P_s - 78.6 - 3BO \qquad \text{dB(W/Hz)}$$

Thus, when the input power is increased by 1 dB, the output power is increased by 0.82 dB. On the other hand, the IM noise increases by 2.46 dB and the C/T ratio is reduced by 1.64 dB. This rule-of-thumb is valid over a narrow range close to 4.5 dB to the saturation for all travelling wave tube amplifiers without linearization. This method is sometimes referred to as the no-carrier test method.

3.2.1 Descriptions of measurement methods

The principles and test methods of seven different measurement procedures are listed briefly in the following:

– *Single carrier test*

The multicarrier signal and the IM products of the 2nd and 3rd order are modelled by a Bessel function depending on the output power and the phase shift of the amplifier. A single CW carrier is fed into the amplifier. The amplitude of the test signal is varied from zero until the amplifier is saturated. The output power and phase shift are measured as functions of the input power.

– *Two carrier test with intercept analysis*

The non-linear transfer characteristic is represented by a Taylor series expansion. The performance under multicarrier loading can be predicted from the Taylor series model. The outputs from two signal generators operating at f_1 and f_2 are combined and applied to the input of the amplifier. The output powers at these fundamentals and at the 3rd order IM products at $2f_1 - f_2$ and $f_2 - f_1$ etc., are recorded and used for the determination of the intercept points. These points are used then for the determination of the Taylor series coefficients.

– *Multiple carrier test*

This test is based on the assumption that the sum of the IM noise power density becomes asymptotic to the same fixed value as the number of carriers increases. It was shown that the sum of IM products up to the 7th order accounts for about 82.2% of the IM power, i.e. if higher products can be neglected, a minimum of 7 to 15 carriers is sufficient. A number of independent CW carriers, roughly equally spaced with a gap near the expected IM products and individually modulated by both FM and AM signals, are combined in the input of the amplifier. At the output, in the gap left, the IM products are measured directly by a spectrum analyser.

- *2/3/4 carrier test with rule-of-thumb*

  If a sufficient number of sources is not available for the multicarrier test, then a test may be performed using a smaller number of carriers and the multicarrier performance may be predicted using a rule-of-thumb. The asymptotic result for a large number of carriers is:

$$\left(\frac{C}{IM}\right)_{\infty} = \frac{1}{6}\left[\sqrt{\left(\frac{C}{IM}\right)_{2}} + 1\right]^{2}$$

  where $(C/IM)_2$ is measured with two carriers.

  The basis of this test is to make direct measurements of the IM products generated by 2, 3 or 4 independent carriers in a similar way as described before.

  For the measurements a noise generator and a filter having different notch bandwidths are used. This notch filter removes the noise from a single channel known as quiet channel. At the output a spectrum analyser measures the IM products in this quiet channel. It should be remarked that the analogue noise power ratio (NPR) notch filter should be 20 dB deeper than the level of NPR to be measured, and have a bandwidth of about 10% of the amplifier bandwidth.

- *Frequency agile signal simulator (FASS) test*

  The FASS is capable of synthesizing any arbitrary waveforms including multiple carriers modulated at a variety of data rates using different modulation formats. This exciting signal is much closer to the actual signal than the white Gaussian noise but due to the finite memory the signal must be repeated at certain frequencies. The IM noise can be measured directly in a variety of different combinations of carrier, modulation formats and bandwidths.

  A digital synthesis technique is utilized in this method to generate a waveform by means of computer software. The waveform consists of digital data downloaded to a synthesizer that then generates a waveform via digital/analogue (D/A) converter. Such commercially available FASS are able to synthesize waveforms directly to microwave frequencies in a digital way.

- *BER test*

  The BER is the ultimate measure of acceptability for digital transmission systems. A direct BER measurement would be more appropriate than a test which tries to isolate the contribution of IM noise to the total power.

  BER tests are commonly used to measure the performance of digital systems in the presence of co-channel and adjacent channel interference, but are rarely used for measuring the effects of amplifier non-linearities. Such tests are rather cost and time consuming due to additional equipment and measurement time required for the very low BER, e.g. 1×10^{-10}. However, this is exactly the range where IM noise is likely to occur and to impair the system performance.

3.2.2 Comparison of the methods

For the measurement of the IM products or noise, respectively, all methods are appropriate. The main features are summarized in the following items and Table 1 with appreciation of each method. The BER test is practically not used for IM measurements because of its large expenditure of equipment and time.

- The single carrier and two carrier with intercept analysis test methods are simple, quick and popular but are limited by the indirect prediction of multicarrier performance via a mathematical model which assumes the amplifier is memory-less.

- The multicarrier, NPR and FASS methods can produce accurate results because they generate direct measurements of performance under realistic load conditions.

- The 2/3/4 carrier test with rule-of-thumb is quick and simple but suffers from the limitation that the rule-of-thumb is only valid in the region where 3rd order products are dominant.

- The FASS test method is very flexible and can produce accurate results but its testing bandwidth is limited by D/A converter speed and its frequency resolution by memory capacity, although its testing frequency can vary over a very large range.

TABLE 1

Rating of the methods

Criterion	Single carrier	Multicarrier	2/3 carrier	Analogue NPR	FASS
Carrier:					
Large number	2	2	1	3	3
Mixed level	2	3	1	1	3
Non-uniform	2	3	1	1	3
Accuracy	2	3	1	3	3
Reproducibility	3	3	1	2	3
Cost	3	2	3	2	1
Simplicity	3	1	3	3	3
Time	2 ≈ 0.5 h	1 ≈ 1.5 h	3 ≈ 5 min	3 ≈ 5 min	3 < 5 min
Frequency	3	3	3	2	3
Bandwidth	1	3	3	2	2

Key: 1: poor, 2: acceptable, 3: good.

NOTE 1 – The single carrier test assumes that the amplifier is memory-less.

The relative importance of the criteria in Table 1 depends, of course, on the application. For example, in an SCPC MSS application the ability to predict performance for large numbers of carriers is important but the applicability to mixed levels and non-uniform spacing is less important. Also, frequency and bandwidth are less important so long as the MSS band is covered. This suggests that the analogue NPR test may prove to be a good choice for this application.

On the other hand, for an FDMA/FSS application, the ability to handle mixed carrier levels and non-uniform spacing assumes greater importance and the availability of equipment covering the higher FSS bands may be a problem. In this case, the balance shifts in favour of the multicarrier test.

In both cases, if cost, simplicity and time are more important than absolute accuracy and reproducibility, then the single carrier test is still a serious contender.

3.3 Generic measurement methods for inter-transmitter IM measurement (Type 3)

These classical, generic approaches are used to measure the 3rd order IM product considered as the most important one.

3.3.1 Principle

IM products in the transmitter cause unwanted emissions, which are induced by some interfering signal near the nominal frequency of the transmitter. It is assumed a transmitter with the wanted transmitted signal power L_w at the nominal frequency $f_0 = f_1$ and an incoming signal power L_1 at frequency $f_2 = f_0 \pm \Delta f$. This produces a 3rd IM product $IM_3 = L_{IM}$ at frequency f_{IM}:

$$f_{IM} = 2f_0 - (f_0 \pm \Delta f) = f_0 \pm \Delta f$$

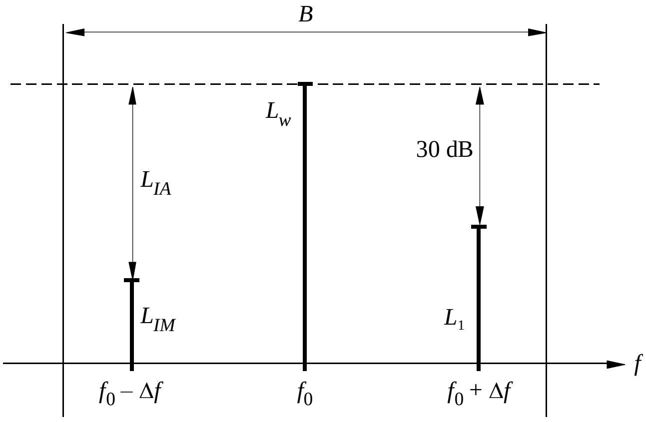
In order to take account only of the main mechanisms neglecting effects of higher order, the frequency separation of Δf should be chosen inside the bandwidth B of the system so that the IM component L_{IM} is not subjected to additional severe attenuation in the victim receiver. The signal level of the IM component is defined as:

$$L_{IM} = 2L_w + L_1 + 20 \log k$$

where k is an arbitrary constant and introduced only for deriving the IM product from the measurement. In Fig. 9 the IM attenuation L_{IA} is defined as the attenuation of the IM product L_{IM} relative to the wanted signal level L_w for an interferer 30 dB below L_w.

FIGURE 9

Determination of IM products by a two-tone method



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Introducing the relations of Fig. 9 into equation (10), 20 log k can be determined by 20 log $k = 30 - 2L_w - L_{IA}$ and the IM product L_{IM} becomes:

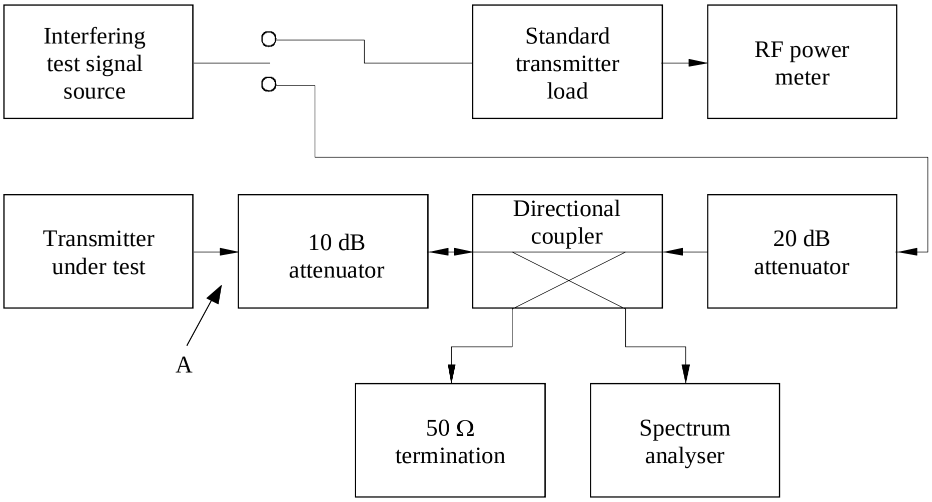
$$IM_3 = L_{IM} = L_1 - L_{IA} + 30 \qquad \text{dB}$$

3.3.2 Measurement set-up

Step 1: Connect the equipment as illustrated in Fig. 10. In order to reduce the influence of mismatch errors it is important that the 10 dB power attenuator is coupled to the transmitter under test with the shortest possible connection. The interfering test signal source is an unmodulated RF carrier providing the same power output as the transmitter under test. The transmitter under test and the interfering test signal source shall be physically separated in such a way that the measurement is not influenced by direct radiation.

FIGURE 10

Measurement set-up



1446-10

Step 2: Adjust the spectrum analyser to give a maximum indication with a frequency scan width of 500 kHz.

Step 3: Set the frequency of the interfering test signal source to within 50 kHz to 100 kHz above the frequency of the transmitter under test. The frequency shall be chosen in such a way that the IM components to be measured do not coincide with other spurious components.

Step 4: Record (dBm) the largest 3rd order IM component from the spectrum analyser as IM_3.

Step 5: Record (dBm) the transmitter under test RF output power level from the spectrum analyser as P_1.

Step 6: Calculate the IM ratio as:

IM Attenuation (referred to point A)

$$A_{IM} = P_1 - IM_3$$

Step 7: Set the frequency of the interfering test signal source to within 50 kHz to 100 kHz below the frequency of the transmitter under test. The frequency shall be chosen in such a way that the IM components to be measured do not coincide with other spurious components.

Step 8: Repeat steps 4 through 6.

Step 9: The lower of the two readings obtained in steps 6 and 8 is the IM attenuation.

NOTE 1 – Variations in the attenuator characteristics may be required for transmit power levels > 25 W.

APPENDIX 1

TO ANNEX 1

Examples of IM performance

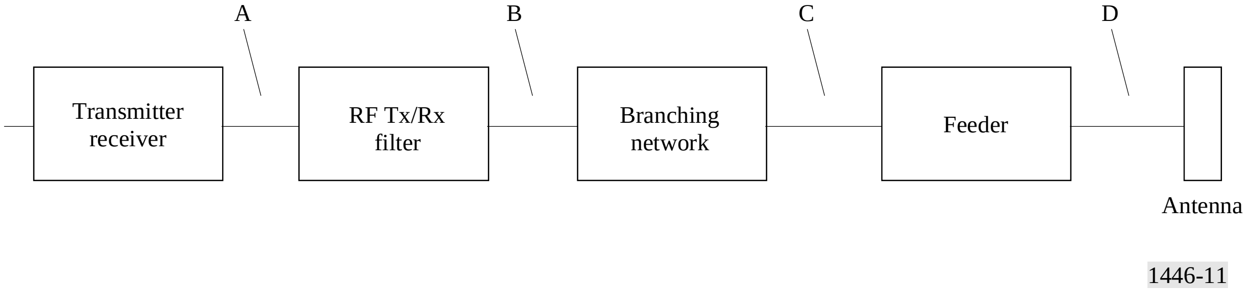
In general, the IM performance depends on a huge variety of different factors, e.g. like modulation and access schemes, hardware components and cost for equipment. The following examples are aimed only to illustrate which ranges of IM suppressions are achievable in real systems. They are not intended to define any limits for IM products.

1 Fixed service

IM limits in current European standards for microwave radio-relay links are listed only for information (see Fig. 11). They only make reference to the inter-transmitter IM problem (Type 3), i.e. there are no specific values available for IM attenuation in European standards.

FIGURE 11

Typical block diagram for fixed service



Conformance to the fixed link IM limit is to be declared by the equipment manufacturer during installation. The maximum permitted IM level is quoted referenced to point B in the receive chain. All fixed link installations are to meet the given criteria when wanted power levels at point C equal 28 dBm.

2 Mobile service

Many mobile standards do not contain any specific values for IM attenuation. The values for IM emissions are included in the limits for spurious emissions. Some examples of available IM attenuation are listed in Table 2. The values required range from 40-70 dB. The interfering signal is usually assumed as CW with power 30-50 dB below the wanted signal.

TABLE 2

Examples of IM attenuation in mobile radio

Service	IM attenuation
GSM900	
Base transceiver station and mobile private branch exchange (PBX)	> 70 dB
GSM1800	
Between mobile stations	> 50 dB
TETRA	
Base station, only one channel	> 40 dB
more channels	> 70 dB
several transmitters	> 60 dB
Mobile station	> 60 dB, measured at the antenna connector
PMR	
For all components	> 40 dB
Several base stations at the same site	> 70 dB

3 Satellite service

The IM products in satellite services are generated by multicarrier operation through common amplifiers in the RF transmit subsystem (IM Type 2). Examples for the performance requirements of INTELSAT earth stations are given in Table 3.

TABLE 3

Examples of the performance requirements for IM products transmitted from INTELSAT earth stations

Uplink transponder	e.i.r.p. density limits at 10° elevation angle and beam edge
4/6 GHz:	Any combination of INTELSAT carrier types except those formed exclusively by interaction among SCPC carrier:
Hemispheric and zone beams	21 dB(W/4 kHz)
Global beams and C-spot	24 dB(W/4 kHz)
4/6 GHz:	Formed exclusively by interaction among pre-assigned SCPC carrier:
Global, hemispheric and zone beams	31.5 dBW for $2 \leq N \leq 7$ SCPC channels
	$48.1 - 20 \log_{10} N$ for $N > 7$
11/14 GHz:	Any combination of INTELSAT carrier types:
	10 dB(W/4 kHz) for INTELSAT V-VI
Spot	16 dB(W/4 kHz) for INTELSAT VII-VIII

Examples for typical values of IM attenuation for land earth stations/coast earth station (LES/CES) and attenuation of IM products due to multiple carriers for Inmarsat-2 and Inmarsat-3 satellites are depicted in Table 4.

TABLE 4

Examples of the IM attenuation from Inmarsat earth and space stations

System component	IM attenuation
Inmarsat LES/CES	3rd order IM products: > 30 dB below the e.i.r.p. of each of two test carriers each having an amplitude of $e.i.r.p._{max}$ –3 dB where $e.i.r.p._{max}$ is the maximum e.i.r.p.
Inmarsat-2 space station Forward direction transponder Return direction transponder	Due to multiple carriers: > 13.5 dB > 22.0 dB
Inmarsat-3 space station Forward direction transponder Return direction transponder	Due to multiple carriers: > 14.0 dB > 21.5 dB

4 Broadcasting services

For broadcasting transmitters installed at the same site, the reverse IM factor is often used to characterize the inter-transmitter IM, A_{RIM} (Type 3).

For illustration, the following example is picked up: the wanted FM sound broadcasting transmitter operates at $f_1 = 98$ MHz, having power 300 W, and is interfered by a signal of 300 mW generated by a second transmitter. The frequency f_2 is varied between 87.5 MHz and 108 MHz (Band II) with a frequency separation of $| f_1 - f_2 | > 300$ kHz. The results are given in Table 5.

TABLE 5

Examples of the reverse IM factor at FM transmitter sites

Frequency	f_1	f_2	$2 f_1 - f_2$	$2 f_2 - f_1$	$3 f_1 - f_2$
Absolute power (dBm)	55	25	15	–5	–20
A_{RIM} (dB)	–	–	10	30	45

Typical values of the reverse IM factor for FM transmitters are 10 dB or larger. The use of isolators may increase the protection.