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SPECIFICATIONS FOR MEASURING EQUIPMENT

EQUIPMENT TO MEASURE NONLINEAR DISTORTION USING THE 4-TONE INTERMODULATION METHOD

ITU-T Recommendation 0.42

(Extract from the *Blue Book*)

NOTES

1 ITU-T Recommendation O.42 was published in Fascicle IV.4 of the *Blue Book*. This file is an extract from the *Blue Book*. While the presentation and layout of the text might be slightly different from the *Blue Book* version, the contents of the file are identical to the *Blue Book* version and copyright conditions remain unchanged (see below).

2 In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Recommendation O.42

EQUIPMENT TO MEASURE NONLINEAR DISTORTION USING THE 4-TONE INTERMODULATION METHOD

(Malaga-Torremolinos, 1984)

1 Introduction

Nonlinear distortion impairments on analogue circuits are normally evaluated be measuring the harmonic frequency signals resulting from a sinusoidal test signal, or by measuring intermodulation frequency signals resulting from the interaction of a multitone test signal. Studies and experience have shown that the harmonic distortion method may severely underevaluate the amount of nonlinearity present on a circuit under certain circumstances. When multiple sources of nonlinearity are present on a circuit, harmonic products may tend to cancel each other, whereas the intermodulation products generated by a complex data signal may not cancel and may significantly impair the transmitted message. This effect has become increasingly important with the advent of higher bit rates and with multilevel/multiphase encoded data signals.

The following intermodulation method of testing for nonlinear distortion using a 4-tone test signal is recommended in order to achieve improved accuracy. This method measures certain 2nd and 3rd order distortion products resulting from the intermodulation of the tones in the prescribed test signal. The frequencies of the four test signal tones are selected to generate 2nd and 3rd order intermodulation products that occur in the passband of an analogue circuit and are easily separated from the applied test signal and measured. Four tones are used in order to achieve a test signal whose amplitude distribution is approximately Gaussian.

2 Principle of operation

Intermodulation distortion can be broadly defined as the modulation of the components of a complex wave with each other, as a result of which new components are produced that have frequencies equal to the sums and differences of integral multiples of those of the components of the original complex wave. Normally the 2nd and 3rd order intermodulation components are sufficient to evaluate the circuit nonlinearity.

A test signal is used which consists of four equal-level tones. Two of the tones are nominally 6 Hz apart centred at 860 Hz and the other two are nominally 16 Hz apart centred at 1380 Hz. To evaluate 3rd order distortion, the total power due to the six 3rd order intermodulation products in a narrow band centred at 1.9 kHz is measured and expressed in dB below the received signal. For 2nd order distortion, the power due to the four 2nd order intermodulation products in a narrow band centred at 520 Hz and the power nominally due to the four 2nd order intermodulation products in a narrow band centred at 2240 Hz are also measured. These two 2nd order distortion product powers are then averaged and the result expressed in dB below the received signal.

Second order intermodulation distortion is defined as follows:

$$\text{Intermod}_{2nd} = 20 \log_{10} (V_{4T}/V_{2nd}) \text{ dB}$$

where:

V_{4T} is the r.m.s. voltage of the 4-tone signal, and

$$V_{2nd} = \sqrt{\frac{(V_5)^2 + (V_{22})^2}{2}}$$

where:

V_5 is the r.m.s. voltage in the frequency band centred at 520 Hz, and

V_{22} is the r.m.s. voltage in the frequency band centred at 2240 Hz.

Third order intermodulation distortion is defined as follows:

$$\text{Intermod}_{3rd} = 20 \log_{10} (V_{4T}/V_{19}) \text{ dB}$$

where:

V_{4T} is the r.m.s. voltage in the 4-tone signal, and

V_{19} is the r.m.s. voltage in the frequency band centred at 1900 Hz.

Depending on the relative levels of the intermodulation distortion products and noise on the circuit, the level of the signals measured in the receiver with the 4-tone test signal may be due in part or entirely to circuit noise. To determine the contribution of this noise, an additional measurement is made using a 2-tone signal consisting of the high pair or low pair of tones at the same power level as the 4-tone signal. The resulting signal-to-noise level readings are used to correct the observed distortion readings. The correction may be accomplished automatically in the test set or by the operator.

3 Specific requirements

The following provides a minimum set of requirements that should be met by an instrument used to measure nonlinear distortion using the "4-tone" intermodulation method.

3.1 *Transmitter*

3.1.1 *Level accuracy*

The r.m.s. signal output level error shall be less than ± 1 dB.

3.1.2 *Level range*

The output level range shall be at least 0 to – 40 dBm. Calibrated attenuator increments of 1 dB or smaller shall be provided unless a level indicator is part of the test set, in which case a vernier control is acceptable.

3.1.3 *Spectrum*

The transmitted signal shall consist of four equal-level tones. Two of the tones shall be 6 ± 1 Hz apart centred at 860 ± 1 Hz and two of the tones shall be 16 ± 1 Hz apart centred at 1380 ± 1 Hz. The tones shall be of equal level within ± 0.25 dB.

3.1.4 *Harmonic distortion*

Any harmonic of any of the four tones shall be at least 35 dB below the tone.

3.1.5 *Background interference*

Any noise, distortion or interference falling within the distortion filter passbands as specified in § 3.2.4, shall be at least 80 dB below the signal.

3.1.6 *Probability density function*

The probability density function of the transmitted signal shall be approximately that of four independent sinusoidal oscillators even if the tones are synthesized from a single source.

3.1.7 *Signal-to-noise check signal*

It shall be possible to disable either the two tones centred at 1380 Hz or the two tones centred at 860 Hz and increase the other two tones by 3 ± 0.25 dB. This signal-to-noise check signal is used to determine the interference of the noise on the circuit under test to the measurement.

3.2 *Receiver*

3.2.1 *Accuracy*

The measurement error shall be less than ± 1 dB.

3.2.2 *Input level range*

The receiver shall meet the accuracy and measurement range requirements for an input level range of 0 to – 40 dBm.

3.2.3 *Measurement and display range*

The test set shall be capable of measuring and displaying the ratio of the signal level to the 2nd and 3rd order distortion products over a range of 10 to 70 dB.

3.2.4 *Filter specifications*

The six 3rd order products to be measured fall in the range 1877 to 1923 Hz, the lower four 2nd order products in the range 503 to 537 Hz and the four upper 2nd order products in the range 2223 to 2257 Hz. (This allows for frequency shift in the channel and transmit signal frequency drift.)

Filters used to recover the products must be wide enough to measure the total power within the overall accuracy requirement of ± 1 dB and must be narrow enough to reject out-of-band noise. The filter bandwidths may be checked by adding a 3.5 kHz band-limited white noise signal at a level of – 40 dBm to the input of the set in addition to the 4-tone signal at –10 dBm. The 2nd and 3rd order intermodulation levels displayed must each be at least 46 dB lower than the power of the –10 dBm tone signal.

Additionally with the 4-tone signal at –10 dBm applied to the input of the set, a test sinusoidal signal at a level of –25 dBm shall be added. The 3rd order distortion reading shall be at least 55 dB below the signal level for all test frequencies below 1600 Hz and above 2200 Hz. The 2nd order distortion reading shall be at least 55 dB below the signal level for all test frequencies below 220 Hz, between 820 and 1940 Hz, and above 2540 Hz. At 180 Hz and lower frequencies, the rejection must be at least 25 dB greater than the above requirement.

3.2.5 *Detectors*

The test signal and intermodulation distortion levels shall be measured with an average or an r.m.s. detector.

3.2.6 *Crosstalk with associated transmitter*

The receiver shall meet overall accuracy requirements when its associated transmitter (if provided) is set to its highest output level and terminated in 600 ohms, and a second transmitter, set 40 dB below this level, is used as a signal source for intermodulation measurement.

3.2.7 *Self-check capability*

A self-contained means should be provided to ensure that the receiver is calibrated within ± 1 dB for 2nd and 3rd order distortion measurements.

3.2.8 *Improper received signal level*

An indication shall be provided for received test signals that are not within the input level range of 0 to – 40 dBm.

3.2.9 *Signal-to-noise check signal indicator*

An indication shall be provided to indicate the presence or absence of the signal-to-noise check signal.

3.2.10 *Correction for signal-to-noise*

Generally the correct signal-to-intermodulation distortion ratio is greater than the observed distortion reading due to the presence of circuit noise. The operating instructions shall include a suitable correction curve or correction table, unless the test set automatically makes the correction in the observed reading after the signal-to-noise check transmission.

3.2.11 *Spurious tone monitor*

A means should be provided to determine if a spurious tone or noise equal to or greater than the test tone is being received. Frequencies closer than ± 100 Hz about 860 Hz and 1380 Hz are excluded from this requirement.

3.3 *Input and output impedances*

All given impedances are for a balanced (earth free) connection.

3.3.1 *Terminating mode (transmit or receive)*

When used in a terminating mode, the input/output impedance shall be 600 ohms with a return loss of ≥ 30 dB from 300 to 4000 Hz.

3.3.2 *Bridging mode (receive)*

When used in a bridging mode, the tapping loss across 300 Ω shall be ≤ 0.15 dB from 300 to 4000 Hz.

3.4 *Longitudinal losses*

The transmitter/receiver inputs and outputs should meet the following requirements. Measurements should be made in accordance with Recommendation O.121.

3.4.1 *Longitudinal conversion loss*

The longitudinal conversion loss should be ≥ 46 dB between 300 to 4000 Hz.

3.4.2 *Input longitudinal interference loss*

The input longitudinal interference loss should be ≥ 110 dB at 50 Hz. This requirement decreases 20 dB per decade to 5000 Hz. The impressed longitudinal voltage shall not exceed 42 volts r.m.s.

3.5 *Output indicators*

3.5.1 *Analogue*

If an analogue meter is used, the spacing of the meter markings shall be 1 dB or less over the normally used portion of the meter scale.

3.5.2 *Digital*

If a digital indicator is used, the result shall be displayed to the nearest 1 dB. The result shall be rounded rather than truncated. The instrument shall indicate within 1 dB of the final reading within 10 seconds after application of a test signal. After this initial period, the display shall be updated at least once every 5 seconds on the basis of continuing measurements of both the received 4-tone level and the intermodulation products. An update period of two or three seconds is recommended.

3.6 *Operating environment*

The electrical performance requirements shall be met when operating at the climatic conditions as specified in Recommendation O.3, § 2.1.