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Intermodulation Distortion Performance and Measurement Issues

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Intermodulation distortion performance and measurement is a critical part of modern communication system and circuit design

Intermodulation distortion (IMD) is a part of all communications systems, with each component—including passive components, connectors, cables and antennas—capable of adding significantly to the total distortion. This tutorial will present some of the issues regarding the effects of IMD on system performance and in the accurate and repeatable measurement of IMD in various circuits and systems.

Third Order IMD

IMD testing is usually done by delivering multiple signals to the device under test, then measuring energy at the output at frequencies other than those signals—the new spurious signals generated by the non-linearities of the DUT. By far, the most common IMD measurement is third order IMD. It is a convenient measurement because it requires only two test signals, and if the test signals are close in frequency to one another, third order products fall close enough to the test signals to be within the passband of the DUT.

The figure of merit associated with third order IMD is the third order intercept point (IP_3), which is the amplitude at which the third order distortion products are equal to the input signals. This is an imaginary point, because the DUT will go into saturation before that amplitude is reached. For more information, see the References. With this basic overview, we can now look at some specific issues.

Second Order IMD

In the not-too-distance past, most communications systems were relatively narrowband, including bandpass filtering early in the signal chain. Since second order IMD products involve the sum or difference of two signals, or the second harmonic of a single signal, the bandpass filters effectively removed the signals that could generate second order IMD products.

Many modern systems are broadband, and this preselection filtering is not present. Thus, second order IMD is a “new” issue for many engineers. As pointed out by Hart [1], second order IMD is potentially more troublesome than third order, because second order products increase more rapidly with increased signal levels than third order products (by a factor of 4/3).

Test Signal Quality

To achieve reliable test results, the test signals must be equal in amplitude, and having low sideband noise. Some years ago, it was not possible to make accurate IMD measurements using spectrum analyzers, because the sideband noise of the sweep generators and early synthesizers affected the measurement.

For third order testing, two quality signal generators and a modern spectrum analyzer are quite sufficient, but attention must also be paid to the accuracy of the network that combines the two signals for presentation to the DUT [2]. Any imbalance will result in unequal amplitudes of the various third order products.

Full-System Concerns

Each individual circuit element has an associated IMD performance, which must be combined with the rest of circuit to obtain the required overall performance [3]. Conversely, when overall system testing does not meet specifications, the contributions of individual parts must be evaluated to identify the source of the problem.

Cascaded performance is well-understood, and was one of the first RF applications of computer-aided design. Today, the performance of individual circuits can be simulated, then incorporated into the high-level "block diagram," where its effects on the full system gain, noise, IMD etc. can be evaluated.

Linearity

Modern complex modulation schemes require highly linear transmission and reception systems for reliable communications, both to achieve low bit-error rate (BER) and to minimize interference. Although noise, compression and harmonic distortion are also contributors to linearity performance, IMD remains the most critical metric since it (and its measurement) is, in part, dependent on these other non-linear functions.

While linearity can be defined mathematically [4], there are sufficient unknown variables, such as the degree of non-linearity of a given device, that mathematical simulation can be complex (and computationally intensive). Measurement remains important to verify the accuracy of simulation, especially at maximum performance (lowest levels of IMD).

High-Order IMD

High-order IMD is a significant factor in today's wireless communications systems. With each cell site having multiple transmitters and receivers, system IMD performance must be evaluated in the laboratory using multiple signal sources.

Complex modulation can approximate the randomness of noise, which has a higher peak-to-average ratio than multiple sine waves. Standard IMD testing must be replaced with noise power testing, using a noise source with a notched-out region, with a measurement of how much that region is "filled" with IMD products.

Transmitter IMD

In today's critical performance systems, the high order distortion products generated in the transmitter are especially important. These products can affect other receivers (and transmitters) operating near the transmitter frequency. Most wireless standards include a spectral "mask" showing the maximum allowable power in transmitter sidebands at various frequency offsets.

Theoretical analysis and design techniques to reduce transmitter IMD is complicated by the relatively strong non-linear performance of power devices. This has resulted in development of distortion-reducing feed-forward and predistortion signal processing techniques.

References

1. W. E. Sabin and E. O. Schoenike, editors, *Single Sideband Systems & Circuits*, 2nd ed., Mc-Graw-Hill, 1995. Ch. 9, "Preselectors and Postselectors," by Bill D. Hart.

2. W. Hayward, *Introduction to Radio Frequency Design*, American Radio Relay League, 1994, Sec. 8.2.

3. U. L. Rohde and T. T. N. Bucher, *Communications Receivers: Principles & Design*, McGraw-Hill, 1988, Ch. 3.

4. K. McClaning and T. Vito, *Radio Receiver Design*, Noble Publishing Corp., 2000, Chs. 6 and 7.