Intermodulation Distortion Measurements of Ferrites

Introduction

Intermodulation Distortion (IMD) measurements are used to characterize the non-linearity of RF components, including ferrite circulators and isolators. Two Continuous Wave (CW) tones (f1 and f2) are combined and input to the Device Under Test (DUT). The output results are measured on a spectrum analyzer.

The third order, and occasionally the fifth order, products are the critical unwanted frequency IMD products that are measured:

3rd order products at: $(2 \times f1) - f2$ and $(2 \times f1) - f1$

5th order products at: $(3 \times f1) - (2 \times f2)$ and $(3 \times f2) - (2 \times f1)$

These relationships are illustrated in Figure 1.

Forward IMD Test Setup

The block diagram shown in Figure 2 illustrates a typical forward IMD test stand. Measurements are taken using Agilent 83712B signal generators and Amplifier Research 100W1000M1 amplifiers. The dual isolators provide >50 dB of isolation and K&L's six-cavity tunable Low-Pass Filters (LPFs) remove system harmonics. A quad hybrid (the M/A-COM Tech QH32-0018-N) provides a further 18 dB of isolation between the tones.

The directional couplers (the M/A-COM Tech CH25-0014-10N) must be terminated with a broadband cable load with superior VSWR (<1.1:1). A six-cavity notch filter (the M/A-COM Tech WRCD800/960 0.2/40-6EEK) attenuates the fundamental frequencies (f1 and f2) to provide greater dynamic range.

It is important not to overdrive the internal mixer of the spectrum analyzer (Agilent 8561E). Overdriving the mixer can cause clipping, so the input level into the analyzer should be ≤+23 dBm. Typical analyzer settings are:

    Span = 2 kHz
    RBW = 3 Hz
    VBW = 3 Hz

Cables, connectors, and test fixtures can also affect the IMD measurement. N-type connectors should be used, and they must be clean and correctly torqued. Avoid nickel plating. The test fixture must fully enclose the DUT to ensure adequate shielding from stray radiation.

Harmonics must be filtered before measuring power. Spectrum analyzers should be used to measure relative power only (dBc), not absolute power (dBm). Power meters are only accurate at their characteristic impedance (50 Ω), so poorly matched DUTs introduce inaccuracies.
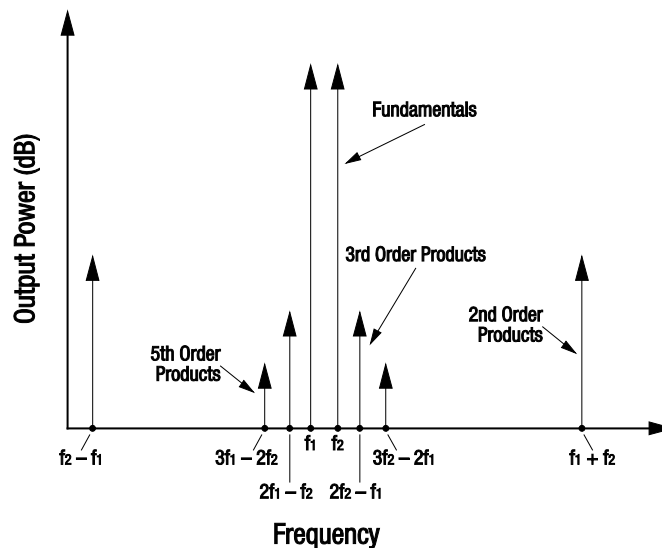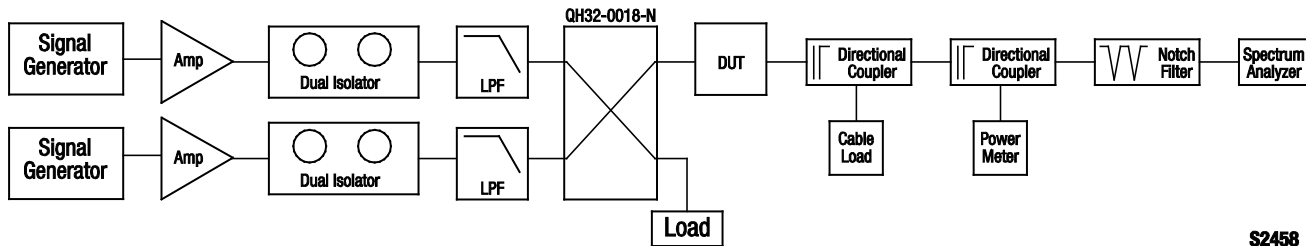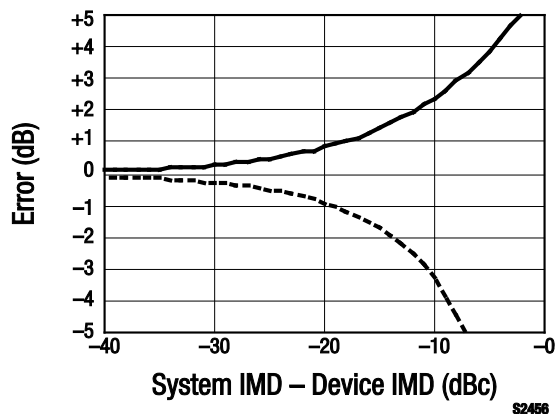

Figure 1. Third and Fifth Order Products

Figure 2. Forward IMD Test Setup

Figure 3. Measurement Error

Measurement Error

Every system exhibits some amount of measurement error that can be calculated as follows (and illustrated in Figure 3):

$$\text{Positive Error} = 20\log (1 + 10^{(IMD_{system} - IMD_{device})/20})$$

$$\text{Negative Error} = 20\log (1 - 10^{(IMD_{system} - IMD_{device})/20})$$

For a typical system ($IMD_{system} - IMD_{device} = -15$ dB), the measurement error is +1.4 dB/−1.7 dB.

To minimize measurement error, the value for IMD_{system} should be 30 dB or more than the IMD_{device}.

Phase Cancellation Reverse IMD Test Setup

Figure 4 shows the configuration used for reverse IMD measurements with cancellation. High forward power is applied to the input of the DUT at frequency f2, while reverse power at a lower level is applied to the output of the DUT at frequency f1. The output signals, including the IMD products, are coupled through the directional coupler to the quadrature hybrid and then to the spectrum analyzer.

High signal levels at the spectrum analyzer input lead to the generation of IMD products in the instrument, which produce errors in the measurement. To protect the spectrum analyzer from these levels, a cancellation process is used to significantly reduce the level of the signal at f2 without affecting the IMD products generated in the DUT.

As shown in Figure 4, a third signal source is set to the same frequency (f2) and a signal is applied to the other input of the quad hybrid. The amplitude of the signal is adjusted to match that of the signal to be cancelled. The phase of the third signal is adjusted in small steps until f2 is nullified, after which the phase stepping stops. Null depths of >40 dB are routinely achieved.

The levels of third and fifth order IMD products can then be accurately measured in the spectrum analyzer after optimally setting resolution bandwidth, video bandwidth, attenuation, and frequency span. Cancellation of the f1 signal is not necessary because its level is already much lower than the f2 signal.

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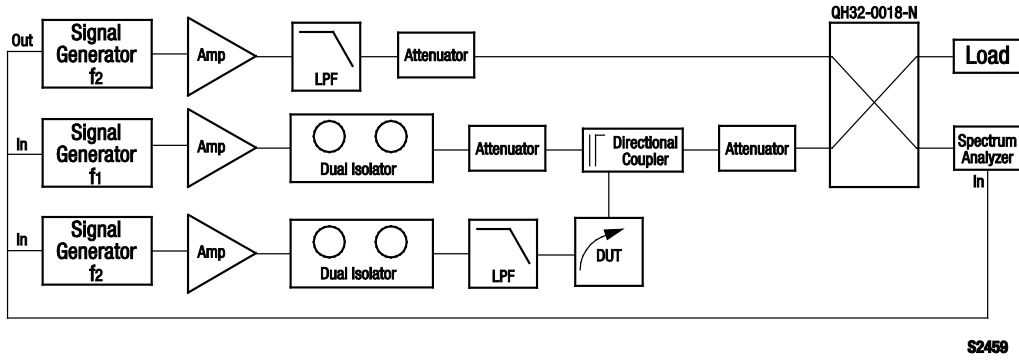
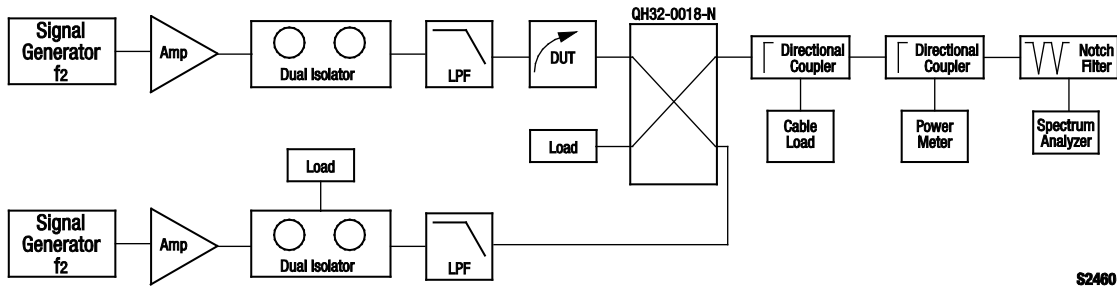Figure 4. Phase Cancellation Reverse IMD Test Setup

Figure 5. Reverse IMD Test Setup

This technique allows the spectrum analyzer to use sensitive settings (e.g., no attenuation) with little distortion being added. The added benefit is that a lower noise floor is achieved.

The system illustrated in Figure 4 also measures harmonics generated in the DUT. The three signal generators and the spectrum analyzer are phase-locked with the signal source of one generator acting as a reference source for the other two. While operation of this system can be done manually, it is most efficiently performed by software and the entire measurement can be automated, controlling the instruments through the General Purpose Interface Bus (GPIB) ports.

Reverse IMD Test Setup

Figure 5 illustrates the typical setup for a reverse IMD test stand. This is similar to the forward IMD test setup, except the second signal is input into the output of the DUT.

Second and Third Harmonic Test Setup

The second and third harmonics test setup is incorporated into the reverse IMD test setup. A test tone (f2) at known power level (p2) is injected into the DUT and the second and third harmonics are measured at frequencies derived from twice and three times the f2 frequency. The measurement is relative to fundamental frequency f2 (i.e., the delta, measured in dBc).

Conclusion

It can be difficult to measure the IMD products of a ferrite circulator or isolator. Care must be taken that unwanted IMD products are not introduced.

Good filtering and the correct spectrum analyzer settings are critical to ensure accurate IMD measurements. Contact a local Skyworks office for any questions or assistance.

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