Two-tone Measurement Technique for Optoelectronic Trans-impedance Amplifier Characterisation

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Abstract

Low distortion (in addition to high sensitivity and high gain) is becoming an important requirement for the Trans-Impedance Amplifier (TIA) within the optical communications receive chain. Electronic dispersion compensation can be used to extend the use of legacy multimode fibre at 10 Gb/s. Existing measurement techniques do not partition distortion components between the source and receiver. This paper outlines a measurement technique that was applied to a high gain TIA with Automatic Gain Control to accurately determine the distortion over the entire input dynamic range. The technique can be operated over the full frequency range of the TIA and is tolerant of source harmonic distortion.

Introduction

XFP/SFP & SFP+ are transceiver module standards that are used for 10G Ethernet optical interconnections. For Ethernet Long-Reach Modules, defined in IEEE 802.3aq[1], the requirement extends the multi-mode fibre-interconnect lengths from 10's of meters up to 300 m. Over the maximum distance currently deployed, the multi-mode fibre broadens the system impulse response so much that Electronic Dispersion Compensation (EDC) is required within the receive path. The photodiode and Trans-Impedance Amplifier (TIA) convert the signal from optical to electrical prior to the EDC circuitry. The bandwidth of the TIA component is >10 GHz, and the optical conversion gain of the component compensates for different signal levels by means of automatic gain control (AGC). The Total Harmonic Distortion (THD) performance of the TIA with Optical Modulation Amplitude (OMA) is a key parameter for the quality of the receive path and for determining the receiver dynamic range. To work optimally, the EDC circuit, which acts to compensate the filtering due to the optical fibre dispersion, requires that the TIA have minimal distortion.

Typically, the measurement of THD is determined by measuring the power in the harmonics of a sinusoidally modulated source. The response from the TIA is measured using a spectrum analyser and the RF powers in the fundamental and harmonic components are combined to calculate the THD. A key issue for this measurement is that different sources will add distortion components of their own, giving rise to uncertainty in the result, as the relative phases of the two signals are unknown. These discrepancies can lead to inconsistent measurements and disagreements between vendors and suppliers.

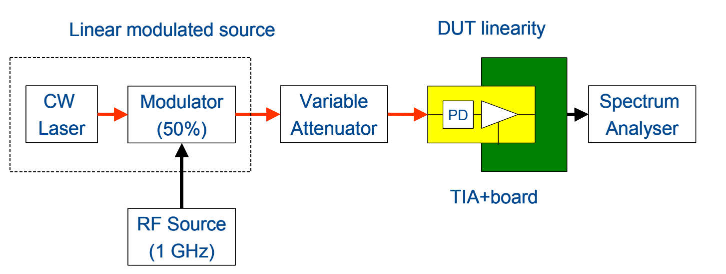

Figure 1 Original measurement system

Original Measurement system

In the original approach (Fig. 1), a CW optical signal was modulated with a single frequency (e.g 100 MHz to 1 GHz) RF signal. The response from the TIA was measured using a spectrum analyser. The RF powers in the fundamental and harmonic components were combined to calculate the THD. An integrated laser and semiconductor Mach-Zehnder (MZ) modulator was used as the optical source to generate the modulated signal. This approach was chosen because the semiconductor MZ modulator will contribute a lower level of harmonic distortion to the result than direct modulation of the laser source.

Theory

The nonlinearity of the TIA is treated as a simple time-independent series and considering only the first five terms:

$$V_{out} = \sum_{i=1}^{5} b_i \cdot Iopt_{in}^{i}$$

where $Iopt_{in}$ is the modulated optical input and V_{out} is the response. b_i is the ith term of the transfer function. The linear term will be dominant. The THD will be given by:

$$THD\,(\%) = \sqrt{\frac{\sum_{i=2}^{5} b_i^2}{\sum_{i=1}^{5} b_i^2}} \times 100$$

However, the optical source will contain harmonic components,

$$Iopt_{out} = \sum_{i=1}^{5} a_i \cdot V_{in}^{i}$$

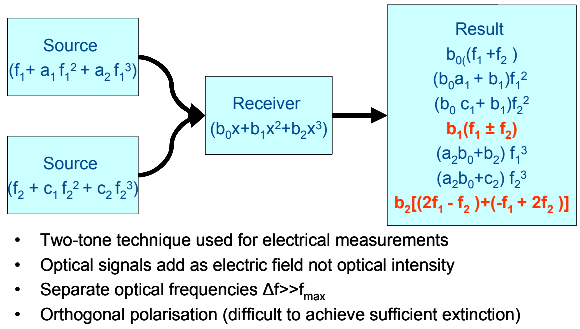

Figure 2 Using two modulated sources and selecting intermodulation components mitigates source distortion

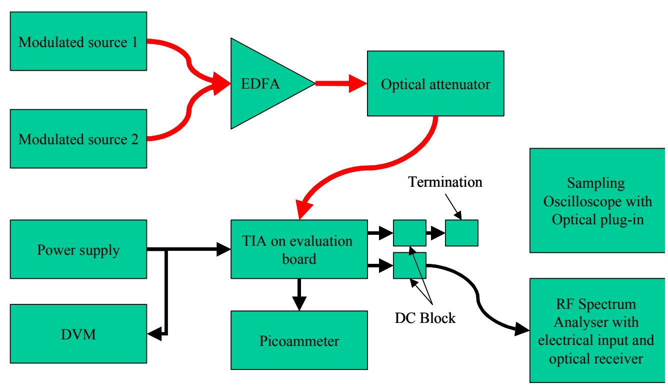

Figure 3 Measurement system

where V_{in} is the modulating signal, which is assumed to be free of distortion components and $Iopt_{out}$ is the optical output from the source. Clearly, there will be cross-product terms in the overall result. The distortion components arising from a Mach-Zehnder modulator can be calculated and techniques such as low modulation-index and bias stabilisation can be used to minimise distortion.

We use two separate optically modulated sources and identify the cross-modulation signal components that are solely due to distortion arising within the TIA. It is important to remember that a modulated optical signal is an amplitude modulated carrier and so the wavelengths of the two optical signals should be separated sufficiently that any heterodyne beat signals will fall outside the detection response of the component (>0.2 nm separation at 1550 nm will be sufficient for a 10 Gb/s component).

Test measurement system

The system used two $LiNbO_3$ Mach-Zehnder modulators driven by separate RF synthesizers. The modulator bias was either manually adjusted or locked at the extinction-point using an integrating feedback system[2]. The RF signals were measured using an RF spectrum analyser. An amplified wideband O/E module was used with the spectrum analyser to measure the performance of the optical source.

The sampling oscilloscope measures the modulation and average optical power. The TIA contains an automatic gain control network that stabilises the RF output level.

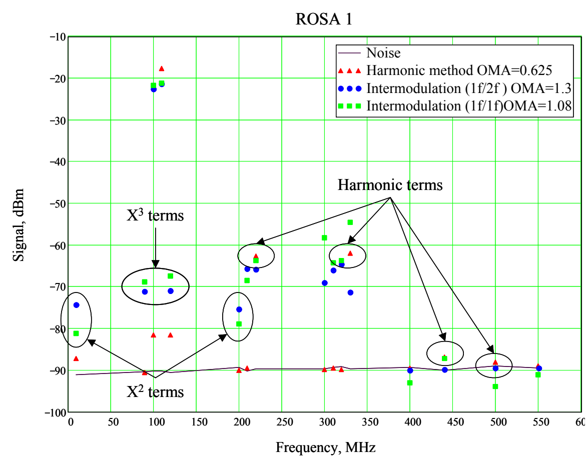

Figure 4 Harmonic and modulation terms present in the RF signal

The modulators contain polarising elements, so the optical output was manually adjusted using the input polarisation controllers. When the modulated sources were used at quadrature, turning off the RF power does not affect the average light level. However, when one of the modulated optical sources was stabilised at extinction, turning off the RF power to this modulated source changed the average optical power.

Results

As this is a classic two-tone measurement technique, each modulated optical source gives rise to additional harmonic terms, which have contributions from both the TIA and from the source. However, the cross-modulation terms are much less sensitive to distortion (see Fig.4). The mean THD calculated from these results is 0.73% and the standard deviation of the values is 0.07%.

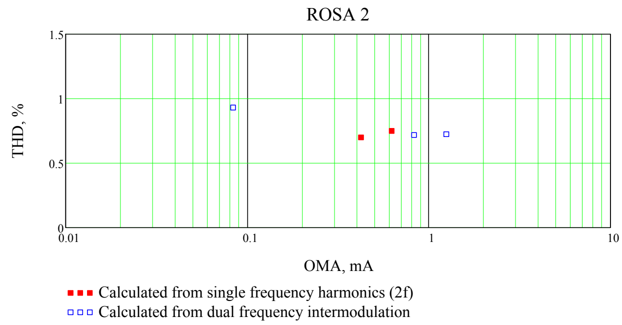

Figure 5 Equivalence of harmonic and intermodulation techniques

We have compared the existing harmonic technique (at an extinction Ratio of 1.9 dB) with the intermodulation technique (at an extinction Ratio of 3.9 dB). For the harmonic measurement the modulator was stabilised at extinction. The results show good agreement and demonstrate equivalence between the methods (see Fig. 5).

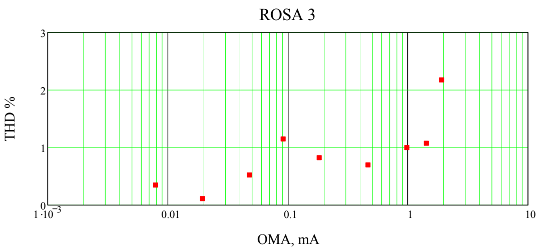

Figure 6 Variation of the THD with OMA

The behaviour of one of the devices (ROSA 3) was investigated as a function of OMA at an extinction ratio of 5.3 dB (Fig. 6). At low OMA levels the distortion terms were comparable to the noise floor. In all the analyses a correction has been made for the noise floor, but in this case the estimate for the noise was too high. Removing the noise correction does not significantly alter the results (see Table 1).

Conclusions

The intermodulation technique shows equivalence to the existing measurement method but is much less sensitive to distortion products from the optical modulated source. The system is more complex, as two optical and two RF sources are required, but the test system used here could be greatly simplified for routine measurements.

RF parameters, such as impedance match and the linearity of the RF spectrum analyser power scale are expected to be contributing factors in the overall uncertainty budget.

An additional advantage of the intermodulation system is that the main signal components arise at frequencies that are close to, or below, the modulation frequency. This means that the distortion can be investigated over the full operating frequency range of the component, revealing any memory effects.

Table 1 Variation of THD with OMA - noise floor correction

OMA, mA	THD (%) with noise correction	THD (%) without noise correction
1.91	2.16	2.16
1.44	1.07	1.08
0.99	0.99	1.00
0.47	0.70	0.70
0.18	0.82	0.82
0.09	1.15	1.15
0.05	0.52	0.53
0.02	0.10	0.16
0.01	0.34	0.28

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