know your response

Measuring frequency response of high-speed optical receivers requires microwave measurements.

By Paul D. Hale, Tracy S. Clement, and Dylan F. Williams, National Institute of Standards and Technology

Measuring the frequency response of an optical receiver is easy if you have a standard reference receiver, a simple test setup, and a network analyzer to perform electrical mismatch corrections.

Your test setup consists of the receiver you want to test, a power meter, and a diode laser modulated by an electrical signal generator (see figure). Start by regulating the test setup with a calibrated reference receiver. Then replace the reference receiver with the receiver you wish to characterize and take another measurement. The ratio of the two measurements is almost all you need.

Taking a closer look, the total response T_x measured by the test setup (where x is C for the calibrated reference receiver and U for the unknown receiver) is given by:

$$T_x = (A_G M_{GL} R_L)(R_x M_{xM} R_M)$$

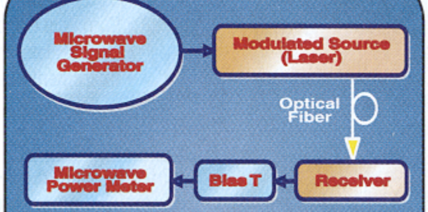
A_G is the voltage the signal generator would deliver to a 50 Ω load. R_L is the response of the laser and relates the laser's input voltage to its optical output. R_x is the response of the receiver. It relates the receiver's electrical voltage across a 50 Ω load to its optical input power. Finally, R_M is the response of the power meter to a source with 50 Ω impedance.

But what are M_{GL} and M_{xM}? These are "mismatch" terms that account for electrical reflections between the laser and the signal generator, and the receiver and power meter. The problem is that at high frequencies, electrical sources and loads are rarely perfectly matched to 50 Ω. When you connect an electrical source to a load, the actual power transferred is rarely that which the source would deliver to a 50 Ω load. Thus, the result of the measurement depends on both the source and load impedance.

The terms A_G, R_L, M_{GL}, and R_M don't change from measurement to measurement. To find the response R_U of an unknown receiver, divide the total measured response T_U of the test setup with the unknown receiver by the total measured response T_C with the calibrated reference receiver (with response R_C). After rearranging the ratio, you get

$$R_U = \frac{T_U}{T_C}\frac{M_{CM}}{M_{UM}} R_C$$

The mismatch terms M_{UM} for the unknown receiver and M_{CM} for the calibrated receiver are different and don't cancel.



A system for measuring frequency response of an optical receiver uses a microwave-modulated laser source, a power meter, and a calibrated photoreceiver.

How do you calculate M_{CM} and M_{UM}? If you connect the receiver directly to the power meter, M_{xM} is given by

$$M_{xM} = | 1 - \Gamma_{xR}\Gamma_M |^{-2}$$

where Γ_{xR} and Γ_M are the complex electrical reflection coefficients of the receiver and power meter.[1] If the receiver is connected to the meter via an interconnecting network (such as a bias tee) with scattering parameters S_{ij} (port 1 on the receiver side), M_{xM} is given by:[2]

$$M_{xM} = \left| \frac{1 - S_{11}\Gamma_x - S_{22}\Gamma_M - \Gamma_x\Gamma_M(S_{21}S_{12} - S_{11}S_{22})}{S_{21}} \right|^{-2}$$

Either way, the procedure is straightforward. You use a calibrated vector network analyzer to measure Γ_U, Γ_C, and Γ_M (and S_{ij} if needed) and plug them into the formulas. The interconnecting network for the standard and unknown receivers can be different. For example, the standard receiver can have a coaxial connector, while the unknown is an on-wafer photodiode with coplanar waveguide wafer probe output. The uncertainty in R_U is limited by system noise and the uncertainty in M_{RM}.

You might wonder how a standards laboratory calibrates your standard reference receiver. We use the heterodyne beat between two single-frequency lasers as a standard source, a calibrated microwave power meter, and a procedure similar to that outlined above.[3] The heterodyne signal provides an optical modulation that can be calculated with low uncertainty from basic physical principles. The National Institute of Standards and Technology offers heterodyne measurement of the response magnitude of a photodiode with precision microwave connectors at 1319 and 850 nm. **oe**

The authors are in the Optoelectronics Division at the National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305. Phone: 303-497-5367; e-mail: hale@boulder.nist.gov.

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