# Stressing 1 GbE Receivers on the Physical Layer

## More efficient and effective tests with a new generation of test instruments

Application Note

## 1000Base-T Ethernet, and the technical challenges it creates for design and test

The standard for the 1000Base-T Ethernet (IEEE 802.3ab) describes data rates of 1 Gb/s over a star topology, over up to 100 meters of Category 5 (or better), unshielded, balanced, twisted-pair, copper cable.

To make the 1000BASE-T physical layer standard as compatible as possible with existing standards, it reuses aspects of the existing IEEE 100BASE-TX, 100BASE-T4, and 100BASE-T2 standards. In particular, the 125 Mbaud baseband signaling from 100BASE-TX, the use of all four twisted pairs simultaneously for full duplex transmission from 100BASE-T4, and the 5-level pulse amplitude modulation (PAM5) from 100BASE-T2. This enables dual-speed 100/1000 Ethernet physical layer implementations to reuse existing infrastructures. Cherry-picking elements from existing standards also helped reduce the time taken to develop the newer standard.

Baseband signaling at a modulation rate of 125 Mbaud over each twisted pair matches the GMII clock rate of 125 MHz, as used for 100BASE-TX, and results in a symbol period of 8 ns. Each twisted pair also uses five-level (-2, -1, 0, +1, +2), Pulse Amplitude Modulation (PAM5) to transmit 2-bits per symbol. The resulting data rate of 250 Mb/s in one direction over each twisted pair achieves a combined data rate of 1000 Mb/s. Furthermore, by using canceller symbols and magnetic hybrids (for echo cancellation), 1000BASE-T can optionally transmit and receive simultaneously on each twisted pair, to achieve full-duplex transmission at 2000 Mb/s.

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## The design implications for 1000BASE-T receivers

Gigabit Ethernet promises a cost effective migration to 1000BASE-T for installations that are already running 10/100Base-T over Category 5 cabling. However, because these installations were originally only specified to 10Base-T or 100Base-T, this is also a potential weakness. Inadequate cabling can introduce distortions, attenuation, noise (including cross-talk and echoes that have not been properly removed by the hybrids), and propagation delay, and delay skew between the different twisted pairs.

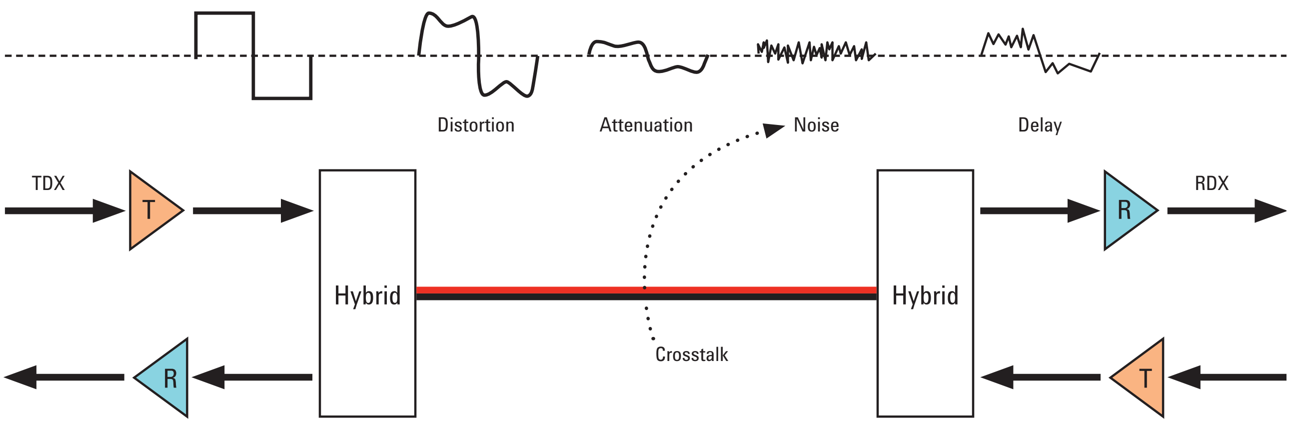


*Figure 1: Effects of attenuation, distortion, noise and delays on transmission*

## Noise sources

The noise with which a receiver has to contend comes from a number of sources.

- Inter-symbol interference, because of the non-linear phase response of the twisted pair.
- Echo from the transmitter in the transceiver. This is related to two factors.
  - The finite isolation of the hybrid
  - The return loss of the twisted pair
- Near-end cross-talk from the three other local transmitters.
- Far end cross-talk from the three other remote transmitters.
- Alien cross-talk, because of the coupling of signals from other cables in the bundle.

On top of all this, there are external noise sources.

The goal is to maintain a signal-to-noise (SNR) margin that achieves a BER of 10-10 or better. For the design of the receiver this means adaptive filtering using digital signal processing to:

- Cancel inter-symbol interference – this can be based on the ISI canceller or adaptive equalizers already in use in 100BASE-TX applications.
- Use the known source symbols to cancel echo – this can be based on the adaptive filters developed for 100BASE-T2.
- Use the known source symbols from the other three transmitters to cancel near-end cross-talk – this again can be based on the adaptive filters developed for 100BASE-T2.

### Further noise environment specifications

Return loss

$$ReturnLoss\ (\mathrm{fMHz})\ (\mathrm{dB}) = \left\{ \begin{array}{ll} 15 & 1 < f < 20 \\ 15 - 10log_{10}(f/20) & 20 < f < 100 \end{array} \right\}$$

Cross-talk
Differential Near End Cross-talk Loss (dB)
$> 27.1 - 16.8log_{10}(f/100)$

Equal Level Far End Cross-talk Loss (dB)
$> 17 - 20log_{10}(f/100)$

Multiple Disturber Far End Cross-talk Loss (dB)
$> 17 - 20log_{10}(f/100)$
$> 19.5 - 20log_{10}(f/100)$
$> 23.0 - 20log_{10}(f/100)$

Power Sum Equal Level Far End Cross-talk Loss (dB)
$> 14.4 - 20log_{10}(f/100)$

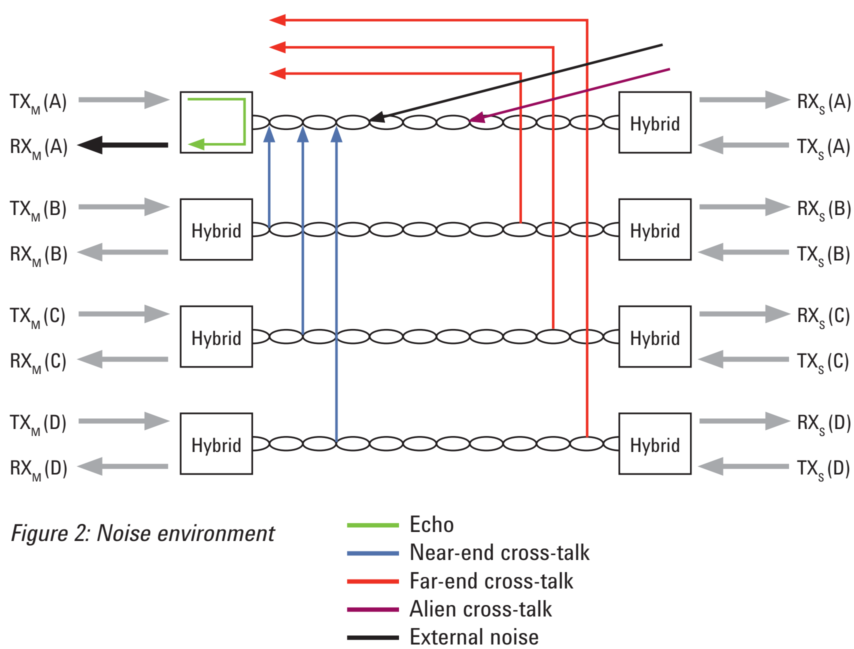


*Figure 2: Noise environment*

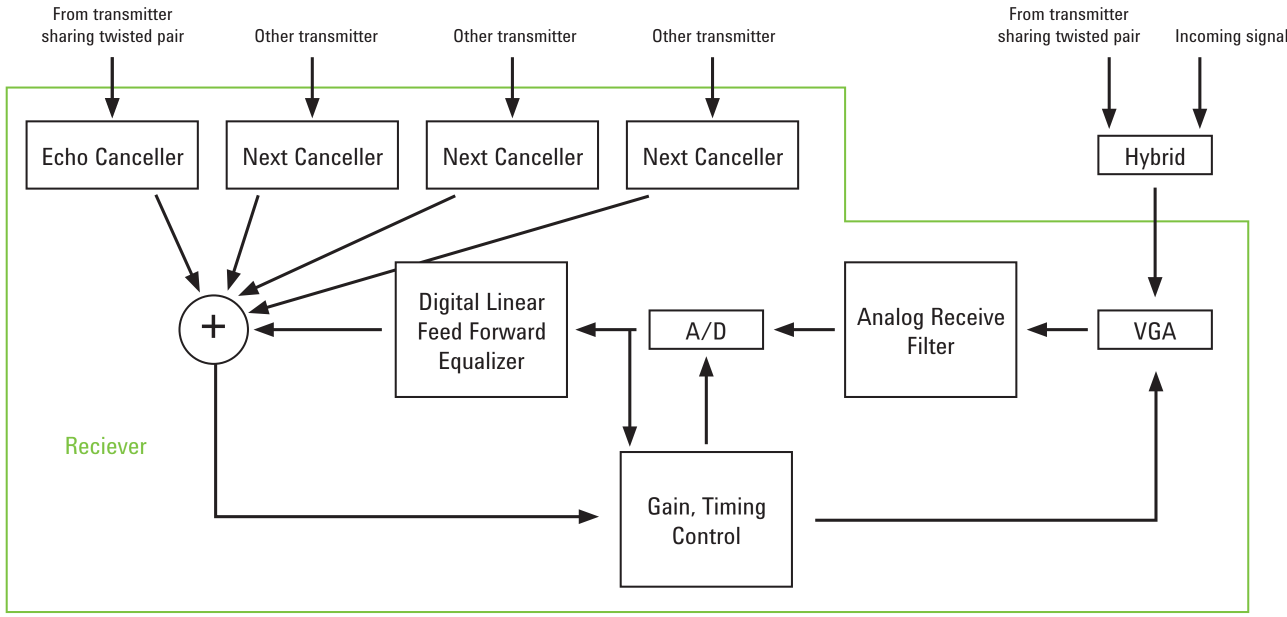


*Figure 3. Receiver Block Diagram*

## Delay skew

For the reception buffers to re-synchronize the four incoming signals, the delay between the fastest and slowest twisted pair over 100m needs to be <50 ns.

## Key challenges

The standard has been around for some time, but the external conditions (distortion, attenuation, noise, delay) make testing complicated such as

- Distortion
- Attenuation
- Noise
- Delay on transmission

## Characterizing a receiver

Characterizing a receiver verifies the condition under which it reliably recovers the transmitted data, as the quality of the input signal deteriorates. This requires four things:

- A source capable of producing controllable deterioration of the signal
- A connection to the device under test. We recommend a short length of cable (< 0.5m), of category 5 (or better) quality, and an adapter to convert the SMA or BNC connectors on the front of the test equipment to the RJ45 connector used by the Ethernet cable.
- A device to read the received data
- An oscilloscope to monitor the input signal to the device under test

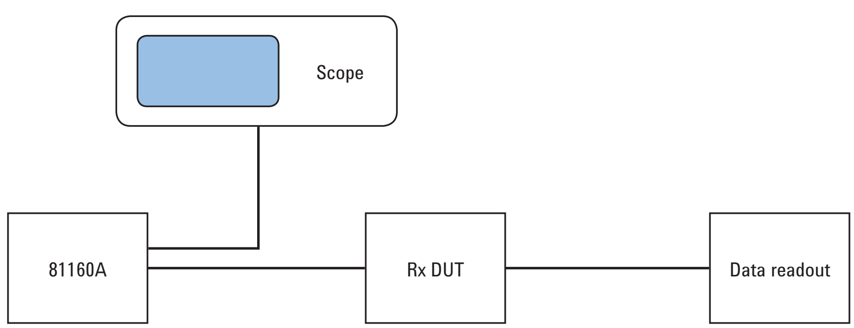


*Figure 4. General receiver characterization test setup*

In this document, we show how this can be done using the Agilent 81160A Pulse Function Arbitrary Noise Generator with the optional second channel. An ideal counterpart for monitoring the signals is any member of the Agilent 7000 or 9000 series oscilloscopes.

The Agilent 81160A Pulse function Arbitrary Noise Generator is the only pulse arbitrary function generator combining precise pulse pattern with versatile arbitrary waveform or distortions, such as adding noise or inter-symbol interference (ISI), and the speed to produce signals for 1000Base-T. Using it to characterize a receiver offers a number of advantages over the traditional method using a 1000Base-T transmitter as a source and a cable plant to degrade the signal.

Stress your device to its limits with:

- Full control over the probing signal, to alter the parameters and explore borderline conditions, or trouble-shoot areas where a device fails to meet the specifications.
- Adjustable noise (with a variety of crest factors) makes it easy to emulate real world conditions, in a controllable and repeatable way.
- The ability to change timing parameters smoothly saves the time and effort of having to resynchronize with the clock signal.

The signal is setup as an arbitrary waveform. This can be either done on the instrument, using the Benchlink Waveform Builder Pro software, or with a Matlab script.

Stress can be easily achieved by adapting the rise time from 5.12 s to 4.61 ns.

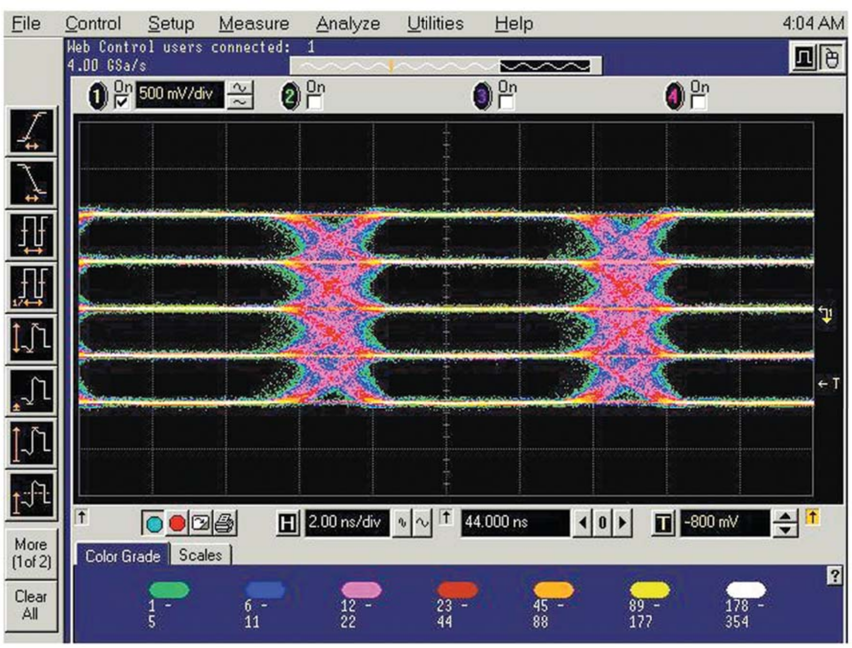


*Figure 5. A typical test signal in the specification is a PAM5 signals*

The waveforms and the adjustable noise (with a variety of crest factors) make it easy to emulate real world conditions, in a controllable and repeatable way. Gaussian white noise is a good approximation to many real-world scenarios. The crest factor is an indicator of signal quality. The higher the crest factor is the more noise is used. If you conduct a jitter tolerance test of your receiver using a noise source with too low a crest factor, it could pass the test even if the device is substandard. The 1000Base-T standards require a BER of 10-10 or better. A crest factor of seven corresponds to a BER of 10-12. So switching between crest factors of 3.1, 4.8, 6 and 7 can help you identify problems quickly. The 81160A generates noise digitally, which makes it repeatable – although the noise remains random for the test, because it has a repeat period of over 20 days.

Stress your device to its limits – defi ne your own arbitrary signal

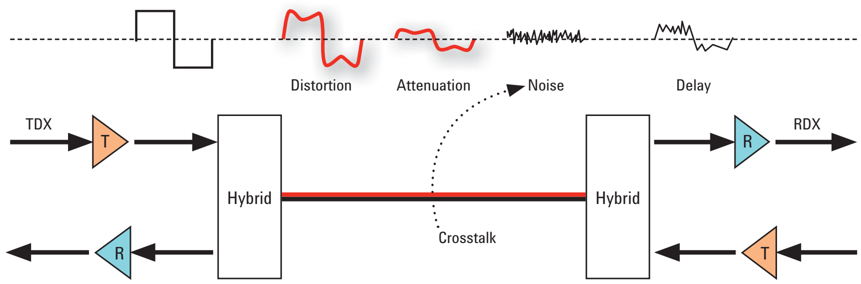


*Figure 6. Distortion and attenuation can be added to the test signal*

Stress your device to its limits – defi ne random and repeatable noise

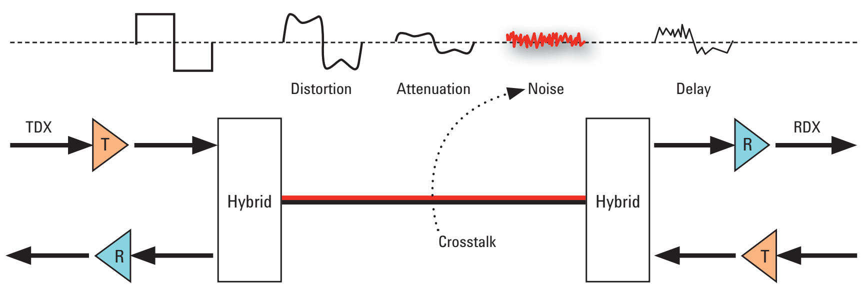


*Figure 7. Noise, with different crest factors, can be added to emulate real conditions*

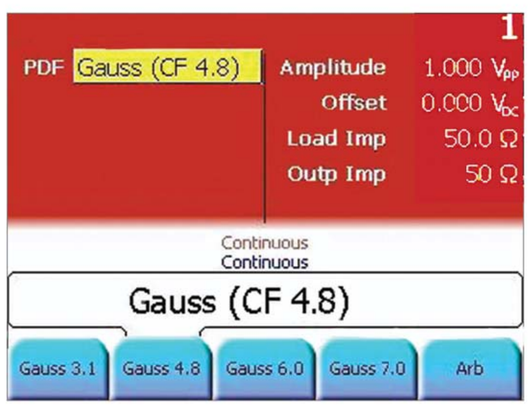


*Figure 8. Push button selection of the noise crest factor*

To further stress your receiver, you can increase the crest factor of the noise and reset the noise amplitude.

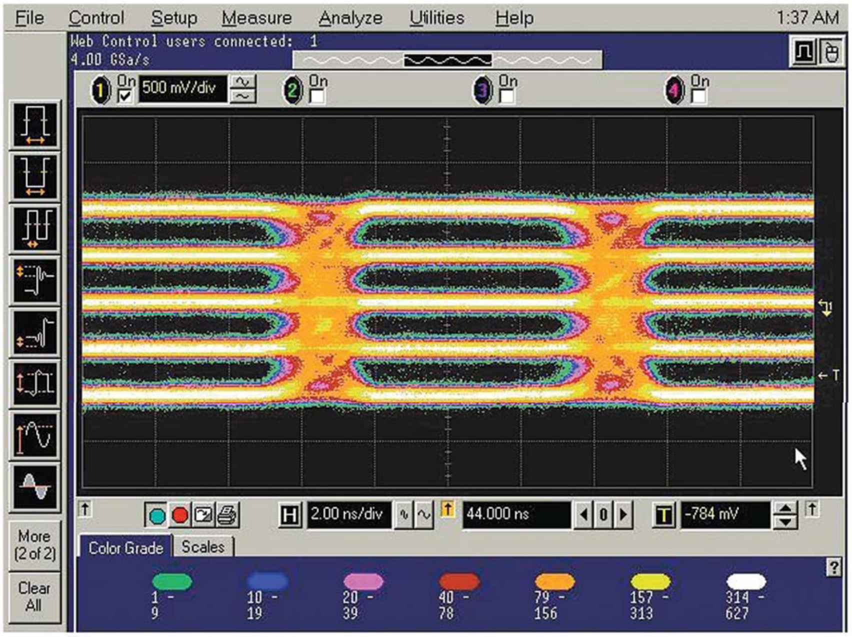


*Figure 9. PAM5 signal with 0.1Vpp noise*

**Glitch free changes of timing parameters** saves the time and effort of having to resynchronize the clock signal. This industry leading feature enables continuous operation without rebooting or resetting the device under test.

An important measurement is the characterization of the delay skew.

Compliant devices need to handle a delay up to 50 ns. Especially for characterization it is important to identify where problems happen.

With the Agilent 81160A you just need to rotate the knob to do on the fly timing changes for more efficient testing. No drop outs or glitches will be visible.

## Stress your device to the limits – change of timing parameters

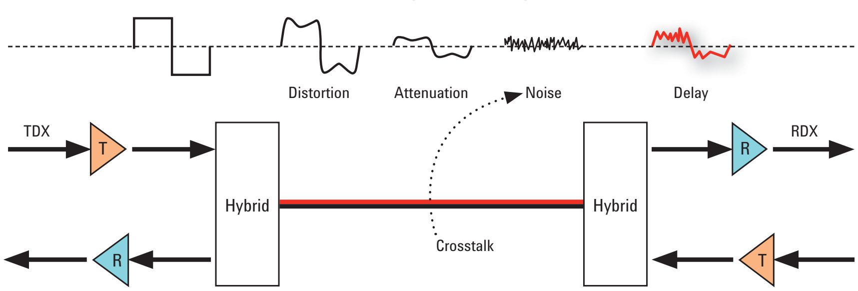


*Figure 10. Changing timing parameters without glitches lets you simulate real problems effi ciently*

## Summary

1000 Base T Ethernet is an established specification and used in many devices. Its great advantage – that it can reuse existing 10/100Base-T infrastructures – is also its greatest potential weakness. Disturbing side effects can threaten signal integrity. It is crucial to be able to quantify effects like noise, delays, and distortion to characterize receivers. At these speeds, the traditional ways of examining these are expensive, time-consuming, and may even be unreliable.

By comparison, the Agilent 81160A is an affordable way of characterizing receivers quickly and reliably because it offers:

- A pulse pattern generator combined with an arbitrary waveform generator, to generate the needed signals such a PAM 5 signal.
- An integrated noise generator, which generates random and repeatable noise.
- Glitch free changes of timing parameters, such as delay, for efficient testing.

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