Technical Note

Selecting Tools at Measurement of High-Speed Digital Signals

Signal Quality Analyzer-R MP1900A
Signal Quality Analyzer MP1800A
MP2110A/MP2100B BERTWave Series

1. Introduction

The recent rapid increases in data volumes at network equipment, servers, and storage due to increasing use of smartphones, cloud computing, FTTx rollout, video streaming, etc., seem likely to increase even further in future. To cope with demand, many appliances and facilities are using digital signals exceeding the Gbit/s band.Dealing with these high-speed signals requires paying attention not only to the digital aspects but also to analog-type behavior, and care is required in choosing tools for monitoring these signals. This document discusses the key points when handling digital signals exceeding 10 Gbit/s from the perspective of measurement tools.

2. Digital Signal Features

Generally, rectangular-wave signals with a duty of 50%, that is to say the reference digital signal, are composed of multiple odd-number integer harmonic frequencies, such as the 3rd, 5th, 7th … harmonics, superimposed on the reference frequency.

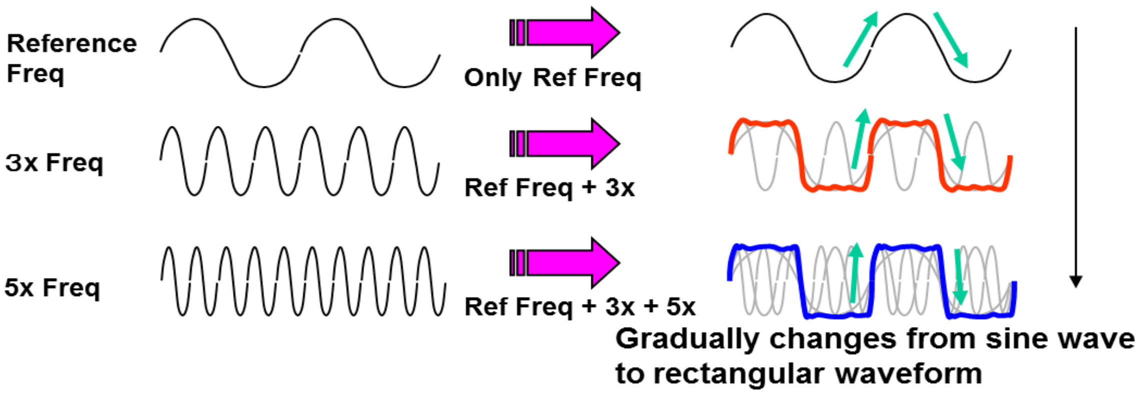

Figure 2.1: Compositions of Rectangular Waveforms

However, in actual signals, if the duty is not 50% for some reason, since jitter may occur as a result of reflections, etc., instead of a multiple odd-number integer harmonic of the reference frequency, a multiple even-number harmonic may be superimposed, but this document deals only with rectangular waveforms with an ideal 50% duty. Moreover, Fourier-series development of the rectangular wave produces the following equation and decreases the power of the harmonics, but for the purpose of simplification, here we assume a constant power as shown in Figure2.1.

$$\mathrm{f(x)} = \frac{\pi}{4}\left(\sin(x) + \frac{1}{3}\sin(3x) + \frac{1}{5}\sin(5x) + \frac{1}{7}\sin(7x) + \cdots\right)$$

On a general PC board, digital signals pass from the Tx circuits to the next stage of the Rx circuits. At this time, generally, the higher harmonic components suffer more loss in the transmission path relative to the lower-frequency components.

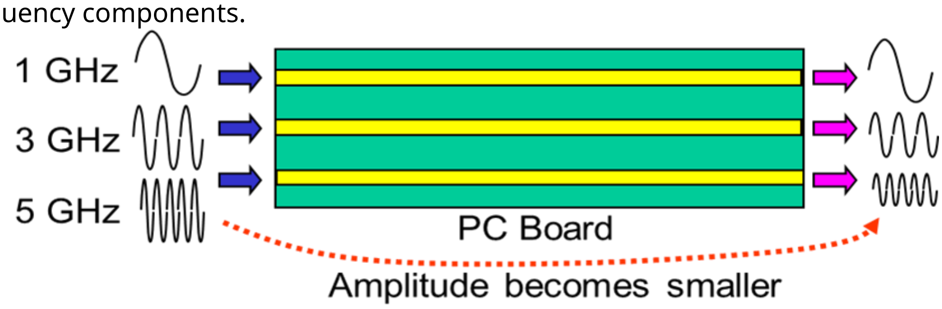

Figure 2.2: Transmission Path Loss

Measuring the S21 parameter using a network analyzer makes it possible to determine the details of these characteristics.

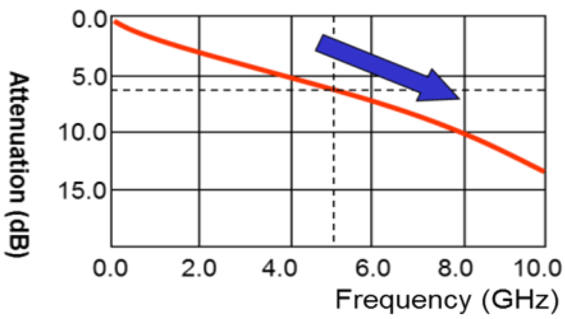

Figure 2.3: Frequencies and Attenuation

The rest of this document explains systems for measuring the characteristics of digital signals composed of multiple frequency components and the effect of the measurement system on the measurement results.

3. Waveform Differences due to Sampling Scope Performance

This section describes differences in sampling scope performance and the impact on measurement results when measuring Gbit/s-band digital signals.

3.1 Waveform Differences due to Band

Normally a sampling scope is used to measure Gbit/s-band signals but considering the basic characteristics described in section 2, the sampling scope band must match the measured signal speed. For example, when measuring a NRZ 10-Gbit/s electrical signal, the required sampling scope band must be considered. With a NRZ 10-Gbit/s digital signal, the reference signal is 5 GHz, so when measuring the rising and falling edges of a rectangular signal transmission, a 5-GHz band sampling scope has insufficient bandwidth because it does not allow passage of the third and fifth harmonics. The fifth harmonic validates the equation when the rectangular waveform is Fourier series developed again.

$$\mathrm{f(x)} = \frac{\pi}{4}\left(\sin(x) + \frac{1}{3}\sin(3x) + \frac{1}{5}\sin(5x) + \frac{1}{7}\sin(7x) + \cdots\right)$$

The above equation shows that the power of the harmonics decreases but the overall impact on the waveform is small. Looking at an ideal waveform, it is necessary to observe the higher harmonics. However, from an engineering perspective, when observing a 28-Gbits/s signal, there are few measuring instruments realistically capable of achieving 98 GHz for the 7th harmonic and 126 GHz for the 9th harmonic. Consequently, it is necessary to evaluate whether it is cost effective to commit resources to evaluation of areas known mathematically to have little impact.

Based on the above, quality measurements of rectangular waveforms generally only need a sampling scope with performance sufficient to cover the 5th harmonic. In other words, for a 10-Gbit/s signal, the sampling scope must be able to cover the 5th harmonic of 5 GHz, or in other words 25 GHz. Similarly, when measuring the 28-Gbit/s signals used by 100G PHY now being actively developed, it is necessary to cover 70 GHz, considering the 5th harmonic of the 14 GHz reference frequency. However, evaluation of devices used commonly in optical communications requires a different band compared to measurement of electrical signals because the standard specifies measurement after passage through a filter at 75% of the bit rate (7.5 GHz LPF at 10 Gbit/s).

The following figures show the waveforms for a 28-Gbit/s signal observed using a 50 and 75-GHz band sampling scope. The rising and falling edges (10% to 90%) observed by the 70-GHz band scope are about 14.2 ps, whereas the edges observed with the 50-GHz band scope are 20% to 30% greater at 17 to 18 ps. As a result, a waveform observed in the 50-GHz band seems delayed compared to the same waveform observed in the 70-GHz band because the 5th harmonic is not passed by the scope.

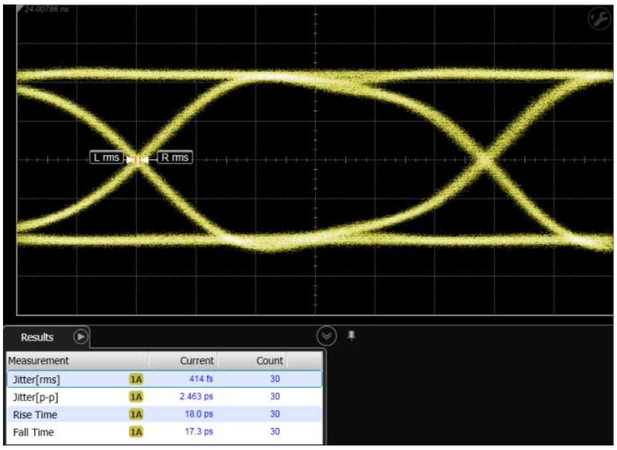

Figure 3.1.1: Waveform Measured with 50-GHz Scope

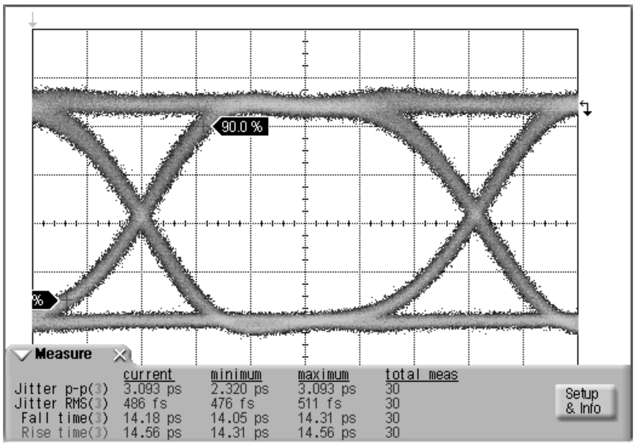

Figure 3.1.2: Waveform Measured with 70-GHz Scope

3.2 Differences in Waveform due to Trigger

When monitoring Gbit/s-band signals using a sampling scope, the trigger precision is an important point requiring some care. Using a sampling scope, to draw the waveform the input signal is sampled at a fixed interval based on the input signal and the asynchronous trigger signal. If there is a lot of jitter in this trigger signal acting as a reference for the waveform, the jitter in the drawn waveform signal appears greater than the actual jitter in the input signal.

When the signal is high speed, when observing a high-speed signal at 20 Gbit/s like this, since the time for 1 bit becomes shorter, the amount of jitter in the measurement system cannot be ignored. The following figures show examples of 28-Gbit/s waveforms monitored using a 70-GHz sampling scope with and without a precision trigger. In the waveform using a precision trigger, the jitter was 486 fs (rms) compared to an increased value of 1.062 ps (rms) without a precision trigger.

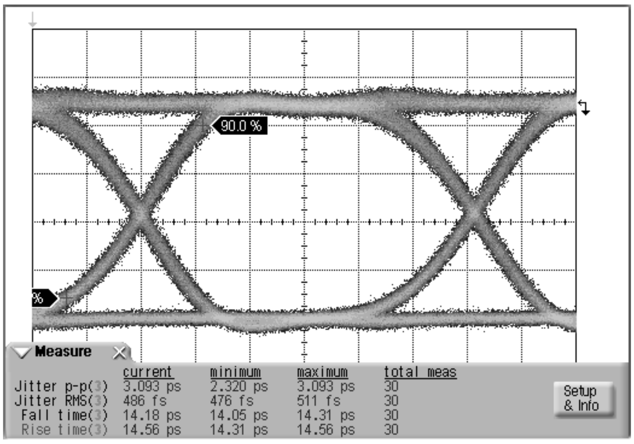

Figure 3.2.1: Waveform with Precision Trigger

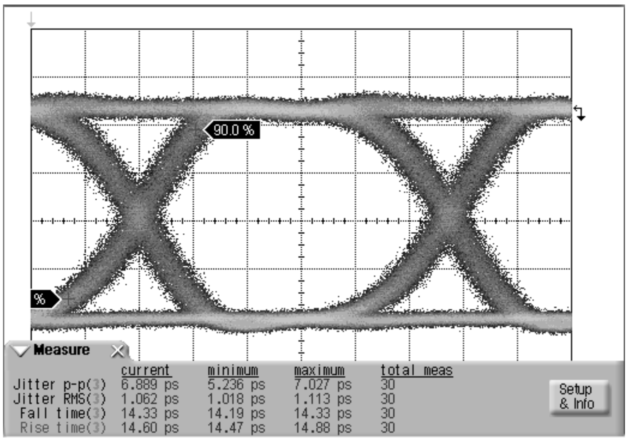

Figure 3.2.2: Waveform without Precision Trigger

In these circumstances, the monitored waveforms are different depending on the scope trigger precision and band even when inputting the same signal; since this risks mistake in signal evaluations, it is important to select the correct measurement tool matching the characteristics of the measurement target.

4. Characteristics of Peripheral Devices

This section explains the effects of the characteristics of peripherals used at waveform quality evaluation, such as filters, connectors, cables, etc., on the observed waveform.

The following shows the measurement results for two 10-Gbit/s signals with different waveform qualities. In both cases, a 2 Vp-p signal was monitored via an 80-cm cable using a 50-GHz sampling scope with precision trigger.

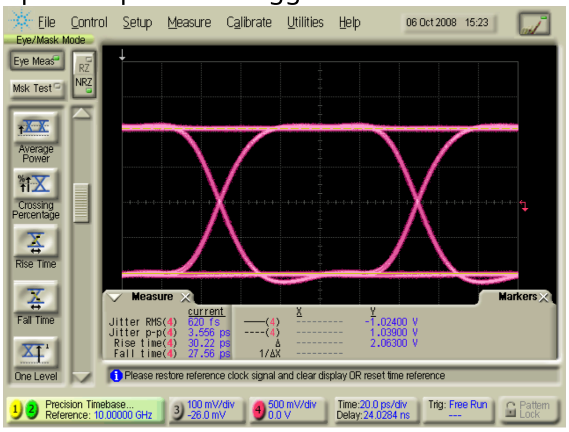

Figure 4.1: MU181020A-011 Waveform

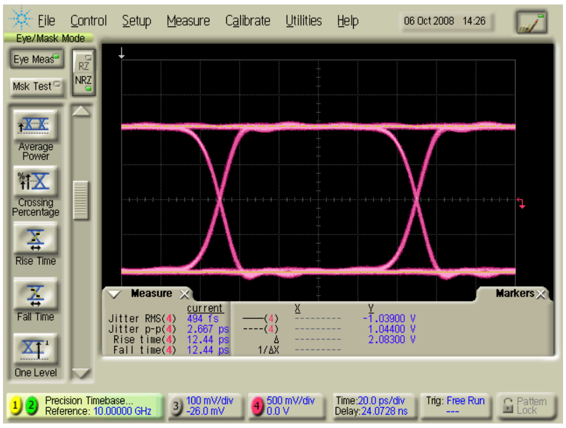

Figure 4.2: MU181020A-012 Waveform

The MU181020A-011 rising and falling edges are about 28 ps, while the MU181020A-012 are about 12.5 ps. The spectrums of these two waveforms are shown below.

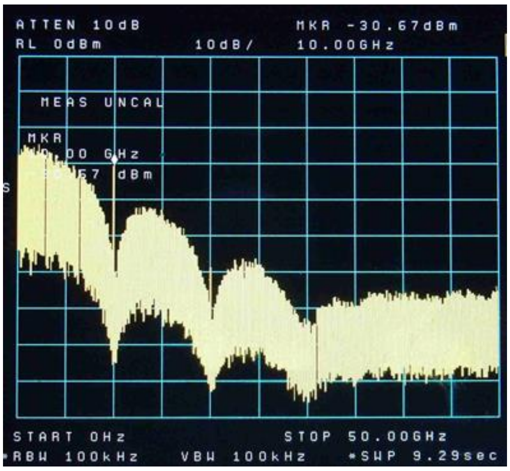

Figure 4.3: MU181020A-011 Spectrum

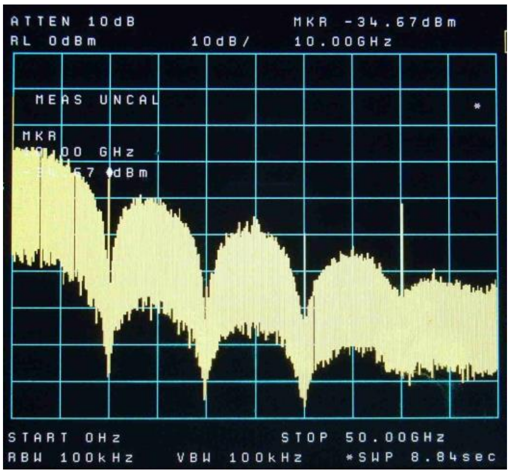

Figure 4.4: MU181020A-012 Spectrum

Although both spectrums are broadly similar in the low range, in the case of the MU181020A-012, the spectrum increases near 35 GHz. With the MU181020A-012, the rising and falling edges are fast and the waveform is very close to a rectangular waveform, meaning that the 7th harmonic is mostly included. To understand this, the following section describes the behavior when the signal passes through connectors and filters.

First, the behavior is shown when the signal described below is passed through a male/female SMP-SMA adapter with adequate bandwidth.

Figure 4.5: SMA-SMP Adapter

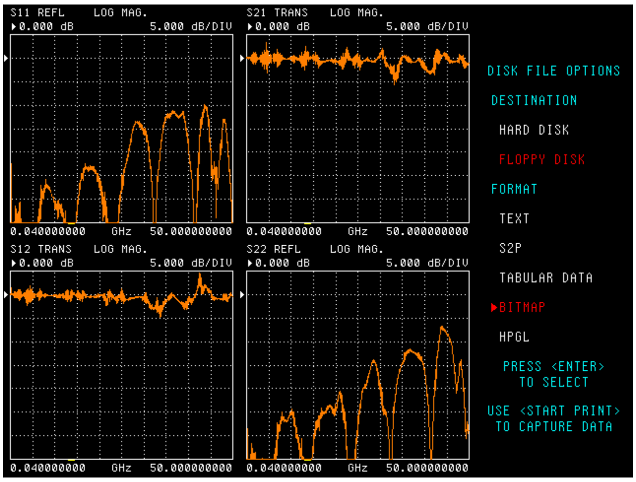

Figure 4.6: S-parameter

The S-parameter captured using a vector network analyzer is described. The S21 frequency characteristic shows level fluctuations, but we see that the band is extended close to 50 GHz. Even at passage through this type of device, the observed waveform is basically unaffected.

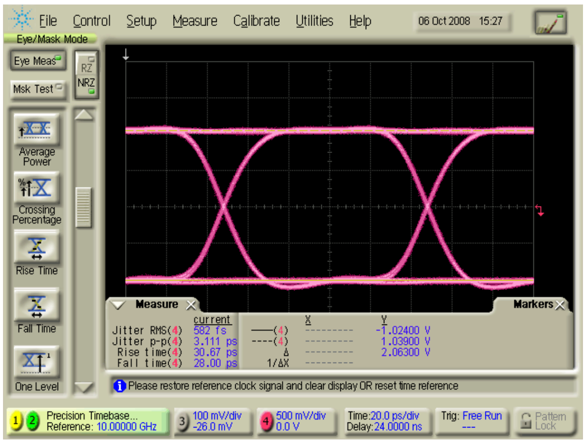

Figure 4.7: MU181020A-011 Waveform with SMP

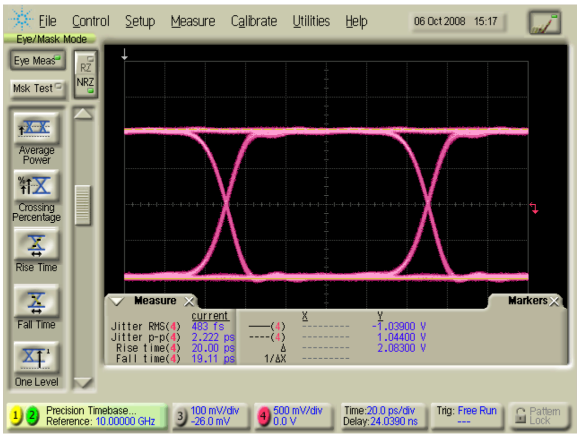

Figure 4.8: MU181020A-012 Waveform with SMP

Next, we describe the behavior of a BNC-SMA male/female adapter.

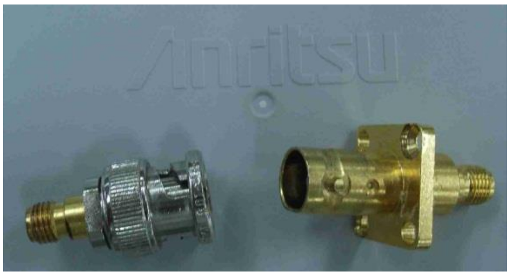

Figure 4.9: BNC Adapter

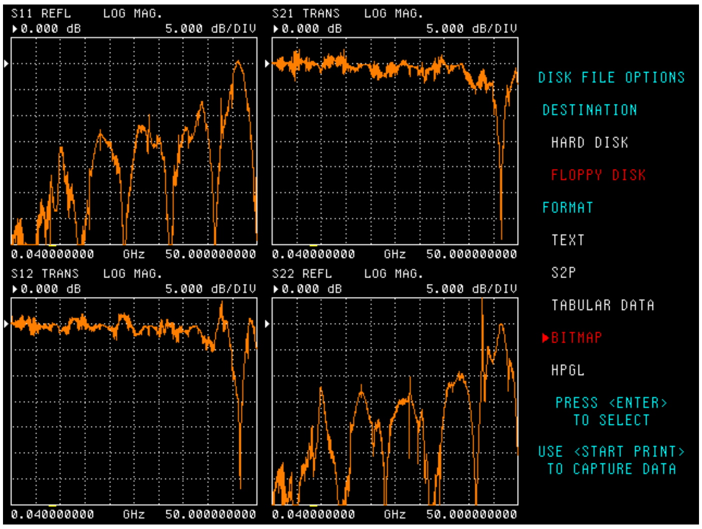

Figure 4.10: S-parameter

Similarly, let's look at the S-parameter measurement results. From S21, the loss close to 40 GHz is larger but from S11 we can see that the reflection is larger beyond 35 GHz. The following figures show the effect of the BNC adapter characteristics on the waveforms.

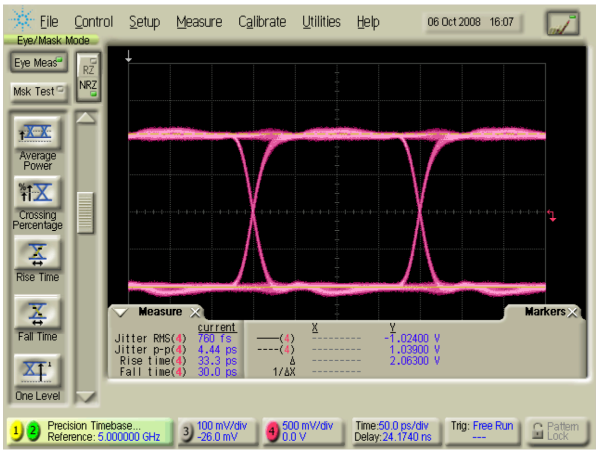

Figure 4.11: MU181020A-011 Waveform with BNC

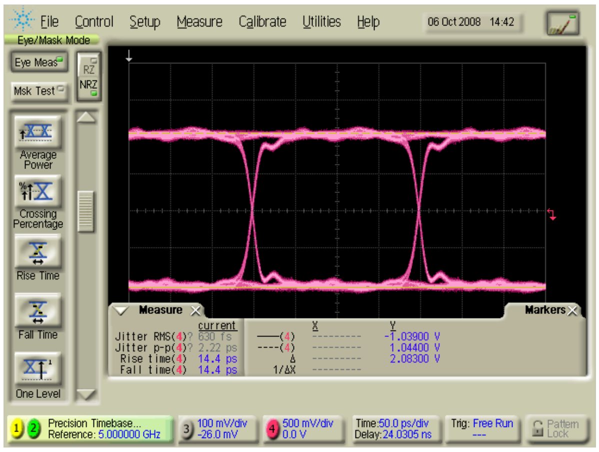

Figure 4.12: MU181020A-012 Waveform with BNC

Waveform distortion is observed in the waveform in both cases. This is thought to be mainly due to reflection but the components above 30 GHz show a more striking effect for the MU181020A-012. If the transmission characteristics are inadequate compared to the signal characteristics, when inputting a signal with fast rising and falling edges like this, instead sometimes it invites a degraded waveform as a result. In these cases, it is clear that the input signal waveform must match the transmission path characteristics.

The following figure shows examples when a signal with fast rising and falling edges is passed through an LPF matching the transmission path. This is explained with an example using an LPF with 6.8-GHz cutoff. The measured S-parameter results using this LPF are shown below.

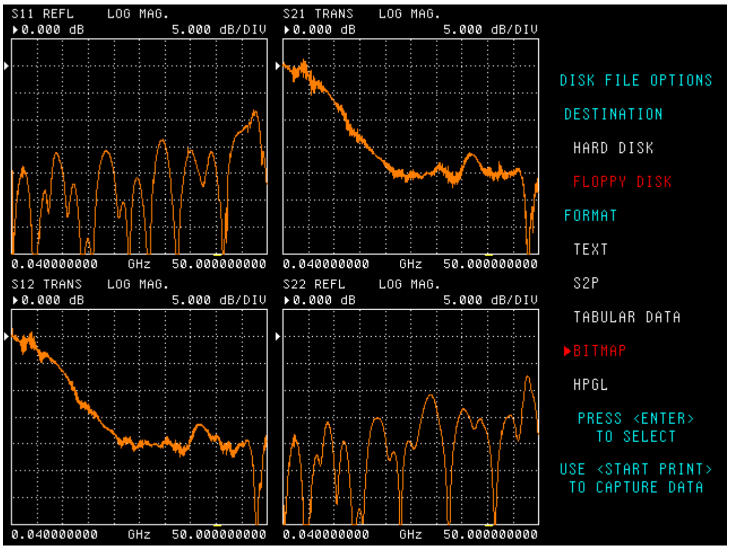

Figure 4.13: LF S-parameters

Looking at S21, there is attenuation of about 10 dB/decade from above 6.8 GHz up to 20 GHz but beyond 20 GHz the attenuation is fixed. Moreover, S11 shows that reflection clearly increases above 40 GHz. The waveforms after passage through this LPF are shown below.

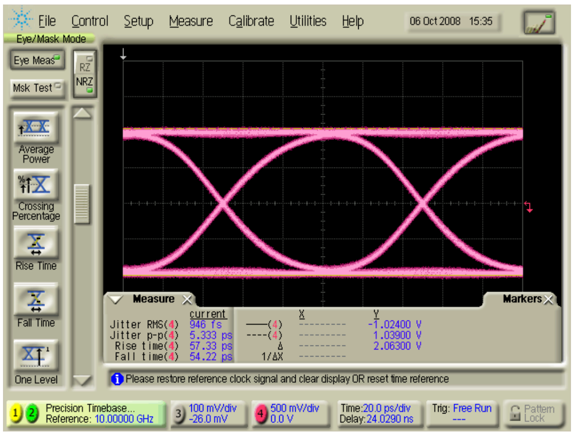

Figure 4.14: MU181020A-011 Waveform with LPF

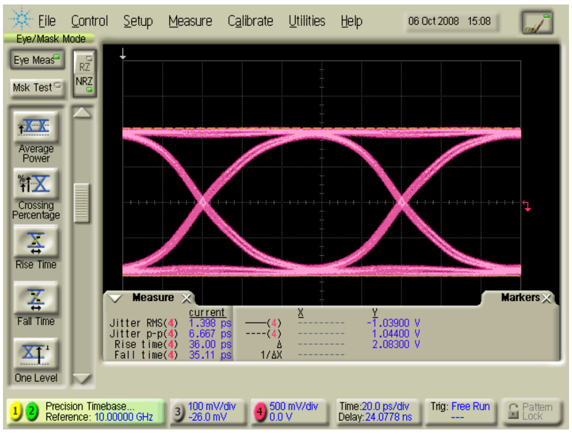

Figure 4.15: MU181020A-012 Waveform with LFP

Since the band is limited by the LPF, both waveforms have increased jitter due to ISI but there is more jitter with the MU181020A-012 with faster rising and falling edges. This occurs because the MU181020A-012 includes more harmonic components that are easily affected by ISI and this LPF does not adequately attenuate components in the range above 20 GHz, so the effect of reflections appears near 40 GHz.

Like the BNC adapter, the band and reflection characteristics are inadequate, so the signal includes more harmonic components and—in other words—the fast rising and falling signal is easily affected. To measure Gbit/s-band signals accurately, it is critically important to take care in selecting cables, adapters, filters, etc., with the appropriate characteristics for use in the measurement system.

Last, this section describes the waveforms observed when measuring a 32-Gbit/s signal with an 80-cm coaxial cable in the 27.5 and 40-GHz bands. The results for the 27.5-GHz band cable show an undershoot in the lower part of the waveform and this is due to waveform distortion generated because the cable bandwidth is inadequate for the input signal.

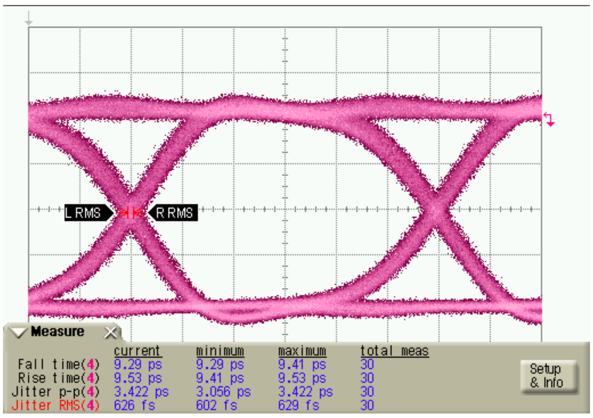

Figure 4.16: 27.5-GHz Band Cable

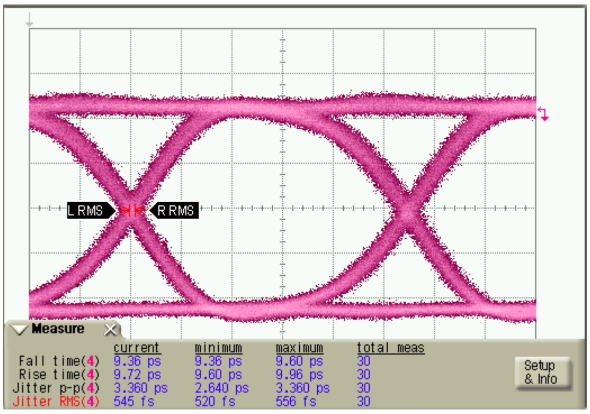

Figure 4.17: 40-GHz Band Cable

Consequently, to measure Gbit/s-band harmonic signals accurately, care must be taken to ensure that the entire system composed of the signal source, cables, adapters, measuring instruments used for observation, etc., satisfies the conditions for measuring the target signal.

5. Summary

We have described the differences in observed waveforms due to the digital signal structure, sampling scope band, and trigger, as well as the effect of the characteristics of peripheral devices used for measurement, such as adapter and filters, on monitored waveforms.

In future, Anritsu will continue to offer its customers even better measurement methods for high value-added quality evaluation of their appliances and devices.

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