Application Note:

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Generating Jitter for Fibre Channel Compliance Testing

MAXIM High-Frequency/Fiber Communications Group

MAXIM

Maxim Integrated Products

Generating Jitter for Fibre Channel Compliance Testing

1 Introduction

Fibre Channel has defined several interoperability points at which total and deterministic jitter (DJ) are specified. Fibre Channel jitter tolerance and jitter output tests require jitter to be applied to the input of the device under test. For example, when operating at 2.125Gb/s, interoperability point α_R (alpha-R) requires 0.6 unit interval (UI) of total jitter and 0.4UI of deterministic jitter to be applied to the input of a device for the jitter output tests. The balance of the total jitter, 0.2UI, is left for random jitter. Attempting to generate this jitter and verifying it can be a daunting task for the novice and expert alike.

The simple apparatus described here generates the random and deterministic jitter needed when evaluating jitter tolerance and jitter output for Fibre Channel components and subassemblies. This technique can be applied to other data rates and standards without much effort. The jitter-generating apparatus is constructed from "off-the-shelf" Maxim product evaluation kits (EV kits) for the MAX3752 port bypass, the MAX3866 transimpedance amplifier, and the MAX3265 limiting amplifier.

Before discussing how to generate jitter, a few definitions are needed. Deterministic jitter is predictable and can be generated consistently given known circumstances. It consists of timing errors that are correlated to the data. The most significant components of DJ are intersymbol interference (ISI) and pulse-width distortion (PWD). ISI is caused by dispersion (i.e., frequency-dependent amplitude loss and phase shift). PWD can be caused by amplitude offset errors, turn-on delays, and saturation.

For the most part, total jitter is the sum of periodic, random, and deterministic jitter. Periodic jitter repeats, yet is not correlated to the data, such as sinusoidal jitter. Random jitter is nonperiodic and not correlated to the data. Ideally, random jitter is caused by Gaussian noise with a broad spectrum. As random jitter is not correlated to the data, its effect on total jitter requires that the probability of infrequent timing errors be combined with the frequent data-dependent effect of deterministic jitter. To that end, the cumulative distribution of the normal probability is calculated for the population that is one minus the bit error rate (1-BER). See Table 1. When expressed in the number of standard deviations from the mean, it lends itself to being estimated easily.

A very simple model of how DJ and RJ can be combined assumes that the normal distribution of RJ has its mean value located at the extremes of DJ timing errors. A more realistic model would superimpose RJ with each DJ edge and then calculate the contribution of all of the cumulative distributions of RJ that are located at each DJ edge. As this can get to be fairly complicated, the simpler model is used.

Random jitter is easily measured at an isolated edge of a repeating pattern. A high-speed digital oscilloscope equipped with a time-histogram capability can easily report the standard deviation of RJ.

The total jitter at a given BER can be estimated as:

$$TJ = PJ + DJ + n*RJ_\sigma$$

Where:

PJ = Periodic jitter, such as sinusoidal
DJ = Deterministic jitter
RJ_σ = Standard deviation (σ) of the random jitter
n = The number of σ within which {(1 - cumulative probability) = BER}.

Table 1. Relationship of n (Number of σ) to BER

Bit Error Rate (BER)	Number of σ (n)
10^{-10}	12.7
10^{-11}	13.4
10^{-12}	14.1
10^{-13}	14.7
10^{-14}	15.3

2 Test Setup

Figure 1 shows the setup that was used to calibrate and verify a deterministic-jitter generator circuit and a random-jitter generator circuit. Note the use of the MAX3265 limiting amplifier. This is an important element, because it opens the eye vertically and minimizes the PWD that can result from creating large amounts of ISI in the deterministic-jitter generator. Without this limiting amplifier, it is possible that differential and single-ended measurements of total jitter will differ substantially. This is especially important, because the error detector is single-ended, yet it is often the final word in quality when it comes to measuring total jitter and eye opening.

A few simple modifications to the MAX3752 EV kit are required to generate and select deterministic jitter. See the discussion under "3 Deterministic-Jitter Generator," at the end of this application note for further details. Also, refer to the data sheet for the MAX3752 EV kit.

2.1 Jitter Calibration

Before making any measurements, connect all of the EV kits, as shown in Figure 1. It is critical that these connections not change during calibration and use. As needed, both DJ and RJ sources can be disabled by jumper selection or power supply. The deterministic jitter and the standard deviation of the random jitter are measured with a high-bandwidth oscilloscope such as the Tektronix 11801C or CSA8000. It is recommended that the eye pattern be acquired using the pattern-generator clock output as the trigger to the oscilloscope. If it is necessary to use the trigger output of the pattern generator as the trigger source, some additional care is needed. Although the trigger output offers a clock selection, it is really a divided-rate clock, either 1/8 or 1/32. This makes it possible to synchronize the oscilloscope to the pattern in such a way that some transitions will not be acquired. When using the trigger output of the pattern generator, extend the pattern length such that it is a noninteger multiple of the divisor. This will reduce the chance of incorrectly measuring the deterministic jitter.

2.2 Setting the Deterministic Jitter

Disable the random-jitter generator by removing the power to the MAX3866 EV kit. Use the oscilloscope to calibrate the deterministic jitter while adjusting the capacitor on the modified MAX3752 EV kit. With little random jitter, the deterministic jitter can be measured using the cursors and an eye pattern. If the RJ is interfering with the DJ measurement, averaging techniques such as Agilent's EyeLine® or Tektronix' FrameScan® can be used to reduce the random jitter.

2.3 Setting the Random Jitter

With the DJ set to the desired value, enable the RJ generator by applying power to the MAX3866 EV kit. Set the supply voltage between 2.5V and 3.0V. Set the oscilloscope to trigger on the pattern synchronization, and set the pattern generator to a short pattern such as 00001111 or a similar pattern. Use the time histogram of the oscilloscope to measure the standard deviation of the RJ. Typically, this is displayed as the RMS value of the histogram. Adjust the RJ by varying the supply voltage to the MAX3866 EV kit until it meets the value needed to reach the total jitter required for the test. In the range of 2.4V to 3.0V, a 200mV change in supply voltage adds about 1ps of RMS random jitter.

2.4 *Verifying the Total Jitter*

The actual total jitter must be confirmed. A so-called BER-scan is used to measure the horizontal eye opening where the BER is at or below the specified value. Do not adjust the DJ. Adjust only the RJ until the total jitter is correct. Remember that the RJ was initially set based upon an estimate of its contribution to the total jitter.

Try to keep acquisition time to a few minutes. Excessively long data-acquisition times will expose the measurement equipment to environmental influences that can introduce drift in trigger levels, time bases, and other interfacing devices.

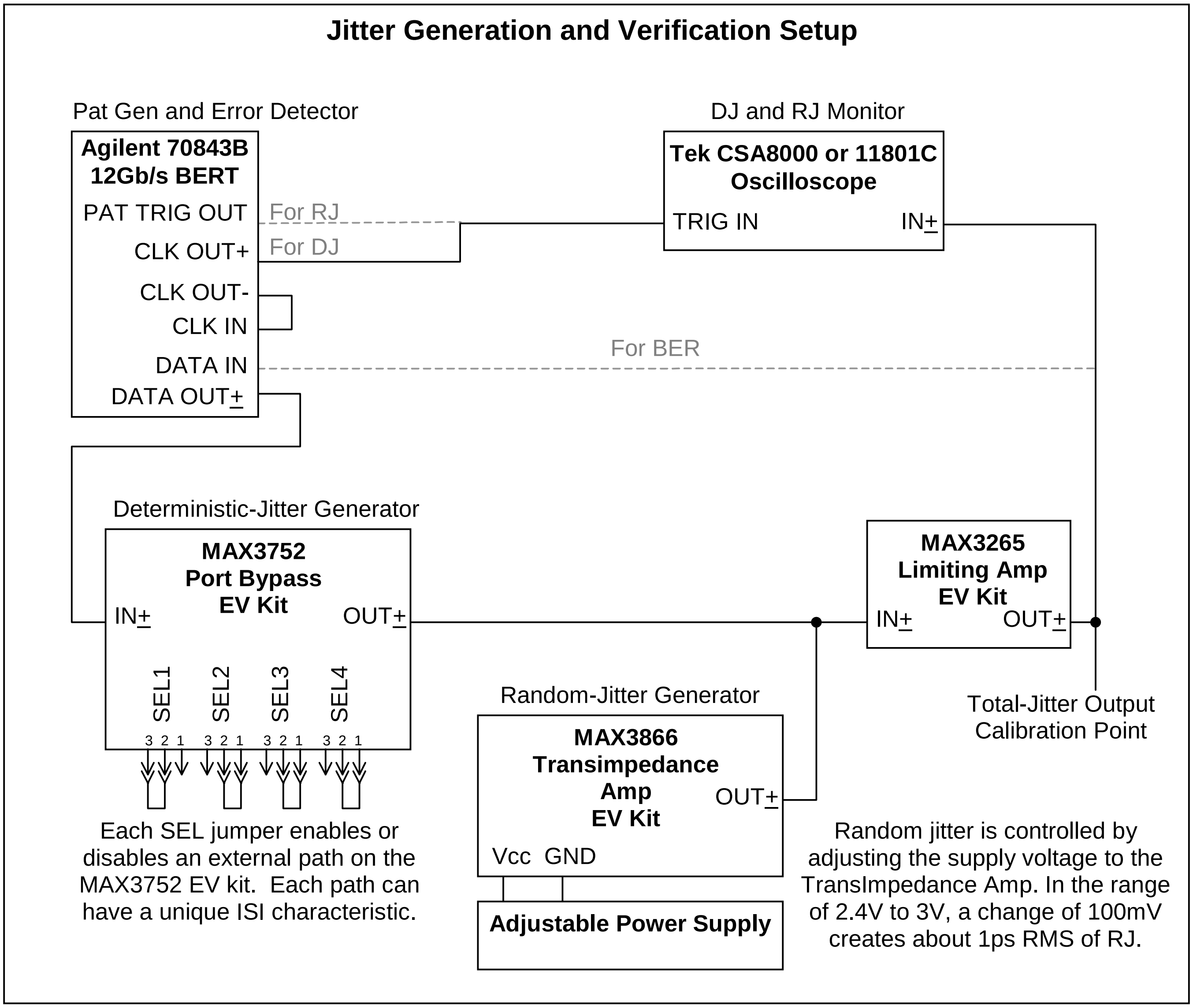
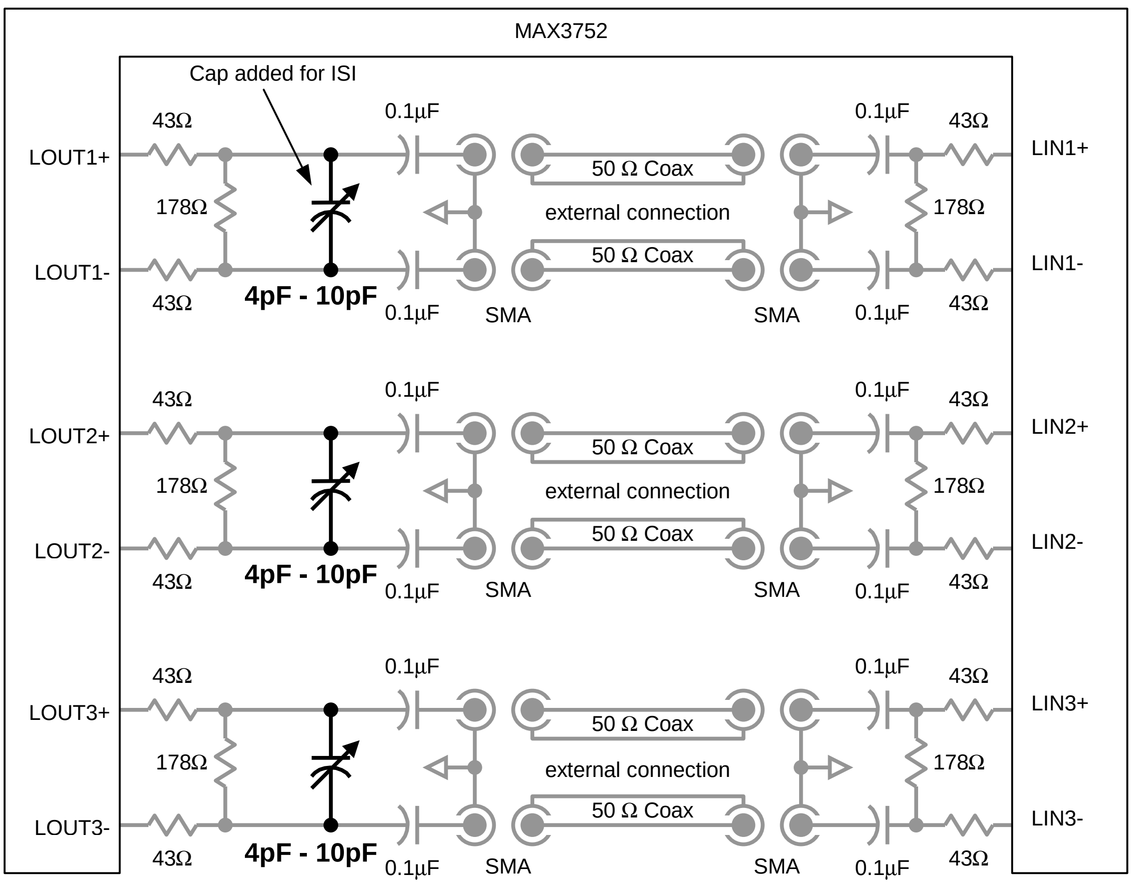


Figure 1. Recommended setup for generating, calibrating, and verifying deterministic and random jitter. Jitter generation is accomplished with "off-the-shelf" product evaluation kits from Maxim.

3 Deterministic-Jitter Generator

The MAX3752 EV kit consists of a quad port bypass circuit, input and output connectors, and jumpers to control the port bypassing function. The MAX3752 allows the daisy-chaining of four external signal paths that can be individually bypassed using jumpers SEL1, 2, 3, and 4. Figure 2 indicates how these paths can be altered to add dispersion resulting in different levels of intersymbol interference (ISI). The ISI is produced by the addition of a capacitor across the differential transmission line of the output of a MAX3752 EV kit. The capacitors used in this example are variable trimmer capacitors located across the end of the coupled 100-ohm transmission line near the SMA output connectors. Alternately, voltage-variable capacitors (varactor diodes) or fixed-value capacitors can be used. The deterministic jitter is chosen by setting the appropriate jumpers (SEL1, 2, or 3) that correspond to the desired jittery path. External path number four can be used; but with this being the last buffer in the chain, there is less overall gain. This can result in an undesirable amount of vertical eye closure. The deterministic jitter (DJ) will vary slightly with supply voltage to the jitter board. The change in DJ is approximately -20%/volt. For example, at Vcc = 3.3V, the DJ = 175ps. When Vcc = 3.0V, the DJ = 185ps. Alternately, when Vcc = 3.6V, the DJ = 165ps. Changing the coax cable lengths will vary the DJ.

Output/Input Network of the MAX3752 EV Kit with Deterministic-Jitter Modifications



Capacitor values of 5pF to 6pF create about 150ps to 200ps of deterministic jitter.

Figure 2. Modifications to the MAX3752 EV kit are shown in black. The variable capacitors can be replaced with fixed-value or voltage-variable (varactors) capacitors. Except for the coaxial cables, all of the other components are part of the EV kit.