Application Note

Overcoming TXB-Type Translators Design Challenges

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ABSTRACT

The TXB010x and the TXB030x are categorized under the TXB-Type translators supporting level shifting of auto-bidirectional signals. While both devices share similar architecture, the differences in one-shot architecture and buffering circuitry enable them to support different use cases. To achieve optimized signal integrity, system designers need to be mindful of the output loading considerations, as well as other guidelines documented in this application note.

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1 Introduction

TI's level translation portfolio includes Auto Bi-Directional, Direction Controlled, and Fixed Direction translators. The TXB-Type level shifters fall under the Auto Bi-Directional translators and can support push-pull driver signals capable of direction change per channel (for example, QSPI). To achieve this functionality, the TXB's I/Os are designed with weak DC drive strength to allow outputs to override existing inputs when the signal changes direction. As a result, the recommendation is that the system designers do not use the TXB to drive signals through long traces or high loads due to the weakened output drivers. Instead, the Fixed-Direction Voltage Translators are suggested.

For a list of recommended level translation devices for common interface types please visit TI's Voltage Translators and Level Shifters page.

2 TXB-Type Architecture Differences

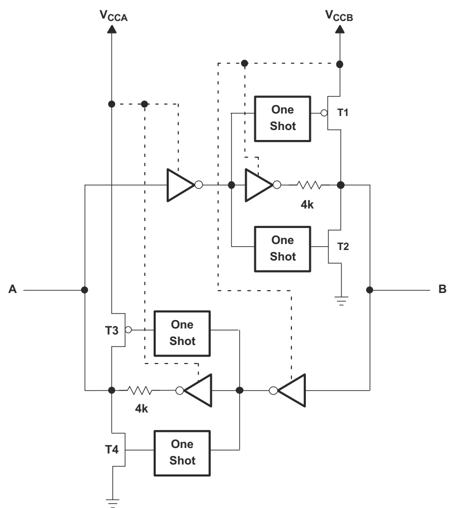

Figure 2-1. TXB010x Architecture

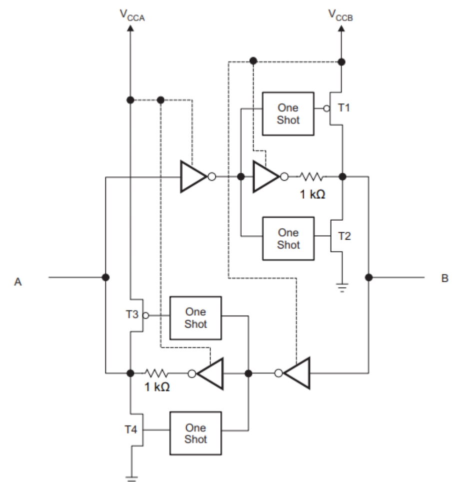

Figure 2-2. TXB030x Architecture

2.1 TXB0104 and TXB0304 Comparison

Both device architectures share similar buffer loop structures that are always re-driving the I/Os through the internal series resistors by maintaining the current DC logic state. In the event of an AC state (rising/ falling edge), the one-shot circuitry is turned on to reduce the output impedance. This effectively drives the output to VCC (during a logic high) or GND (during a logic low), with a faster slew rate to achieve higher data rates. Table 2-1 depicts the differences in TXB010x and TXB030x.

Table 2-1. Specs Overview of TXB-Type Translators

	Device	
Spec	**TXB0104**	**TXB0304**
V_{CCA}	1.2V- 3.6V	0.9V- 3.6V
V_{CCB}	1.65V- 5.5V	0.9V- 3.6V
Power Supply Restrictions	$V_{CCA} \leq V_{CCB}$	-
Internal Series Resistance	4kΩ	1kΩ
One-Shot Impedance (Typ.)	70Ω (V_{CCO}= 1.2V- 1.8V) 50Ω (V_{CCO}= 1.8V- 3.3V) 40Ω (V_{CCO}= 3.3V-5V)	30Ω (V_{CCO}= 0.9V- 1V) 10Ω (V_{CCO}= 1.1V- 1.7V) 5Ω (V_{CCO}= 1.8V-3.3V)
Max Data Rate	100Mbps	140Mbps
Input Driver Requirements	Drive Strength: ±2mA	Drive Strength: ±3mA

- For more information regarding TXB translators, see *A Guide to Voltage Translation With TXB-Type Translators*, application note.

2.2 Recommended Device Selection

While both TXB0104 and TXB0304 can be used for push-pull auto-bidirectional applications, the following are specific cases where one can be recommended over the other:

The TXB0304 is better designed for applications with the following:

- Symmetrical power supplies (V_{CCA} ≤ or ≥ V_{CCB})
- I/Os operating between 0.9V and 3.6V
- Data rates higher than 100Mbps at 15pF output load.
- Short trace lengths/ minimum capacitive loading with external impedance matching in the system

The TXB0104 is recommended for applications with the following:

- I/Os operating between 1.2V and 5.5V
- Data rates up to 100Mbps
- Short trace lengths/ minimum capacitive loading

3 Common Design Challenges

Recall that the TXB0104 and TXB0304 have internal one-shot circuitry, hence when paired with excessive loading at the outputs (long traces, connectors, and lumped capacitance), the output signal integrity will be impacted.

Their one-shot impedance are also different as shown in Table 2-1. If both devices are used under identical setups with similar output load conditions, the TXB0104 can be seen with improved signal integrity over the TXB0304 due to the better impedance match from the one-shot to the output load. As an example, the waveforms captured below in Figure 3-1 and Figure 3-2 show the 3.6V output signal with 15pF lumped capacitance at the TXB0104's output compared to the TXB0304's output. Observe the differences in rise and fall times (t_r/t_f) in relation to the overshoot % of both devices.

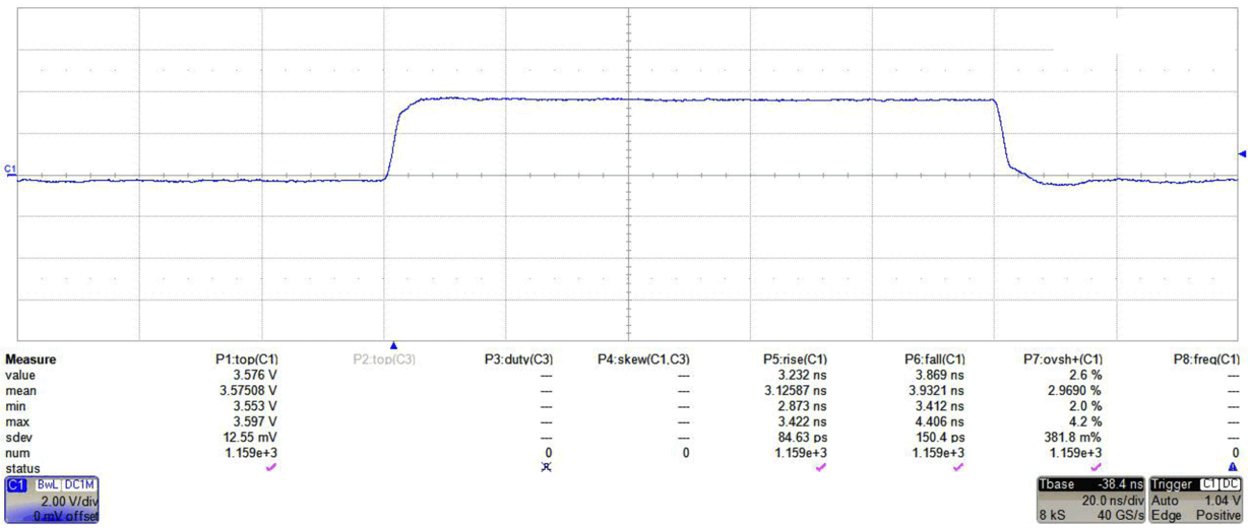

Figure 3-1. TXB0104, 3.6V Output Signal: t_r / t_f < 3.7ns With 2.6 % Overshoot

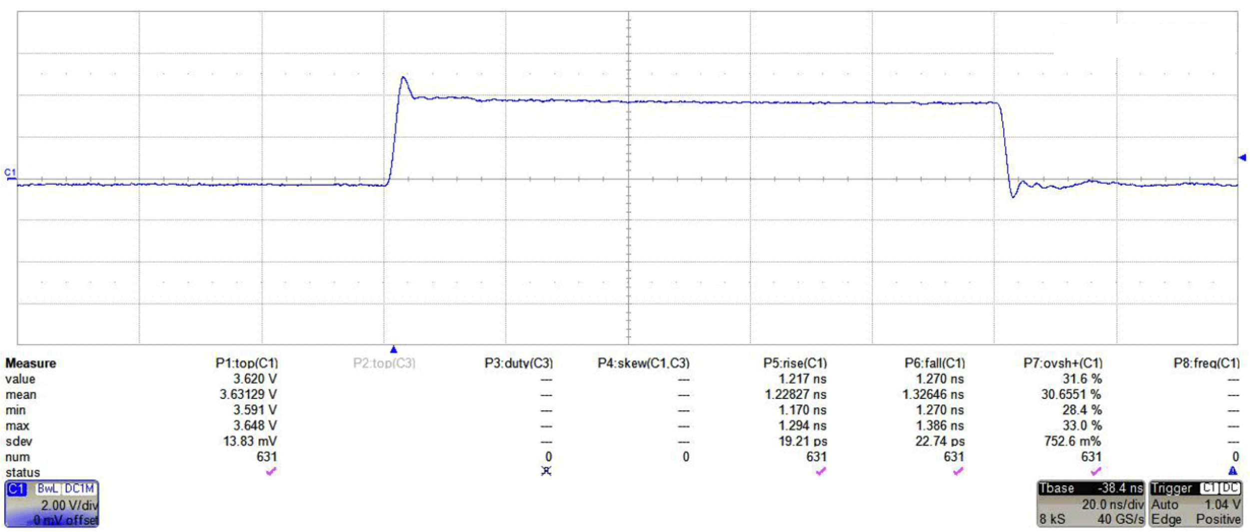

Figure 3-2. TXB0304, 3.6V Output Signal: t_r / t_f < 1.3ns With 31.6 % Overshoot

The stronger output impedance of the TXB0304 results in a higher overshoot when compared to the TXB0104. To resolve this, proper impedance matching techniques with the TXB0304 may be used as discussed in the below section Section 3.2.

3.1 Distributed Load (Transmission Line Effect)

Any logic device can experience transmission line effects such as ringing or oscillations when the driver is outputting a signal into a conductor medium due to the influence of the inductive and capacitive elements along the signaling path.

While higher data rate signals contain faster rise or fall times overall, the rise or fall time characteristics are more critical to transmission line effects. Simply because two signals are toggling at the same data rate with different rise or fall times, as shown in Figure 3-2, does not imply that the frequency content is the same. The faster rise or fall signal yields a shorter wavelength and thus contains higher frequency content- making the rise or fall time more susceptible to transmission line effects.

By the same principle, the TXB0304 having faster rise or fall edges than the TXB0104 results in the TXB0304 being especially prone to transmission line effects at shorter traces.

3.1.1 Cable Length Impact - Bench Findings

Shown are bench waveforms captured with TXB0304 connected to a 20+ in. and 4 in. cable length. Note the same input conditions were applied to both setups.

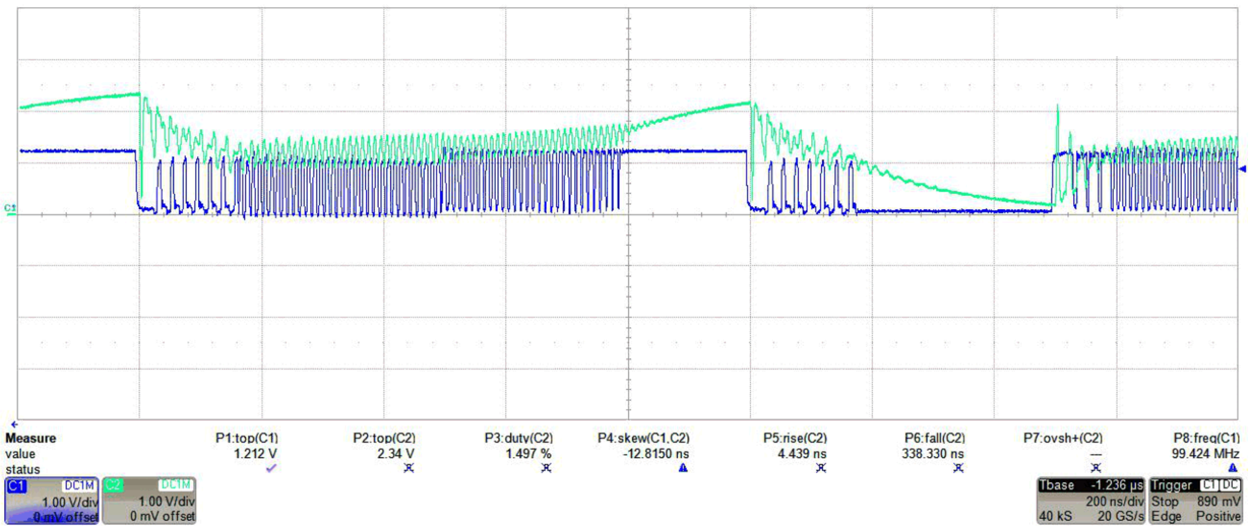

Figure 3-3. TXB0304, 1.2V Input (Dark Blue) to 2.5V Output (Teal) With 20+in. Cable

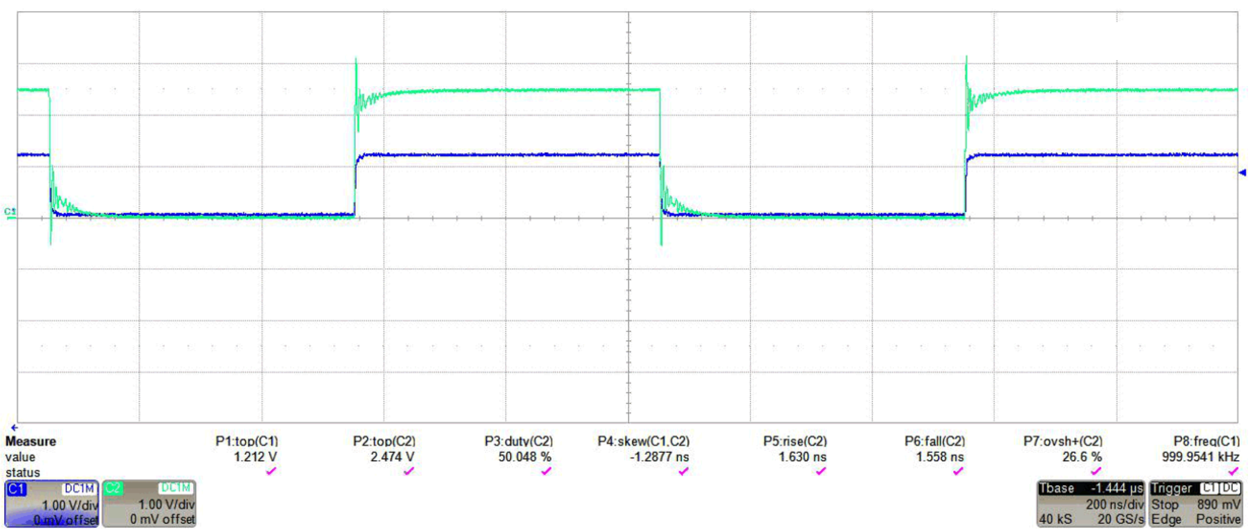

Figure 3-4. TXB0304, 1.2V (Dark Blue) to 2.5V Output (Teal) With 4 in. Cable

From the waveform captured in the 20+in. cable above, the input (Dark Blue) oscillates due to unintentional re-triggering of the one-shots at both the input and output sides. Recall that TXB architecture is similar to a buffer loop, with I/Os always being redriven to a known and similar state. When paired with long cabling however, the I/Os result in different logic states due to the timing delay caused by the 20+in. cable. The result is similar to the observed oscillations.

When the setup was swapped to a shorter cable (4in.) in Figure 3-4, the output signal was now more easily interpreted with no oscillations.

3.2 Impedance Matching

While reducing cable length helps reduce oscillations, there are also impedance matching techniques that can be used to dampen ringing or overshoots furthermore. System designers are recommended to implement series termination resistors at the output drivers of the TXB0304 to closely match the output to the transmission line.

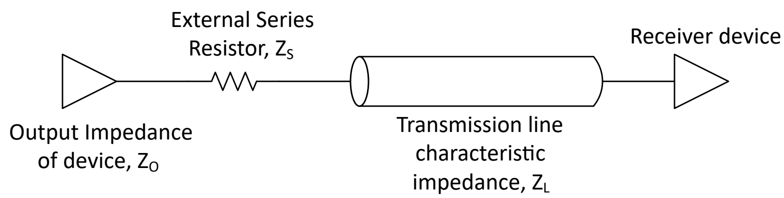

Figure 3-5. Impedance Matching with External Series Resistor

$$Z_O + Z_S = Z_L \tag{1}$$

3.2.1 Bench Setup and Results

To highlight the impact of the series dampening resistor, multiple resistor values were used for impedance matching with the TXB0304, then compared to the TXB0104 and competitor part. A second setup is also provided to replicate different transmission line characteristics.

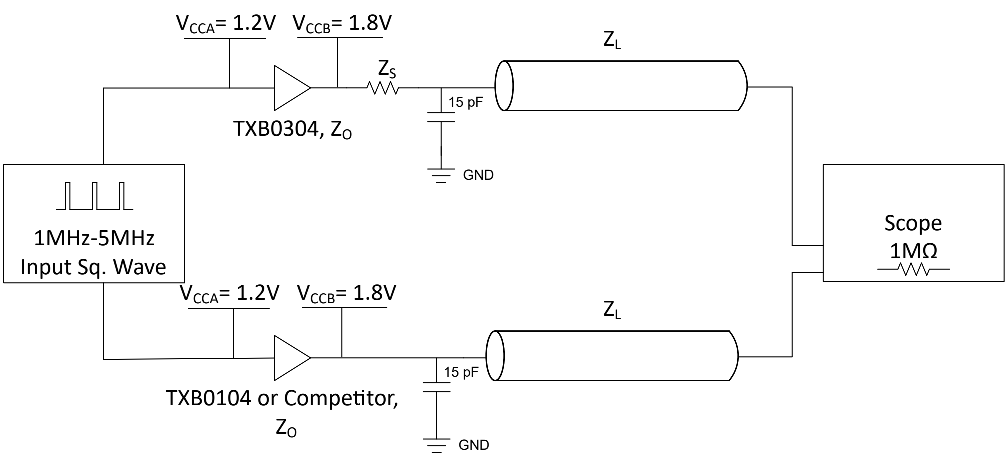

Figure 3-6. Impedance Matching Bench Setup

Note that not any series resistor can work and improve output conditions. System designers may need to test with different values that deem fit and compatible with the system requirements. The following example waveforms show the behavior of improper matching of TXB0304 to a transmission line. This is clear that both cases with 33Ω and 56Ω show reflections throughout the signal with no improvements.

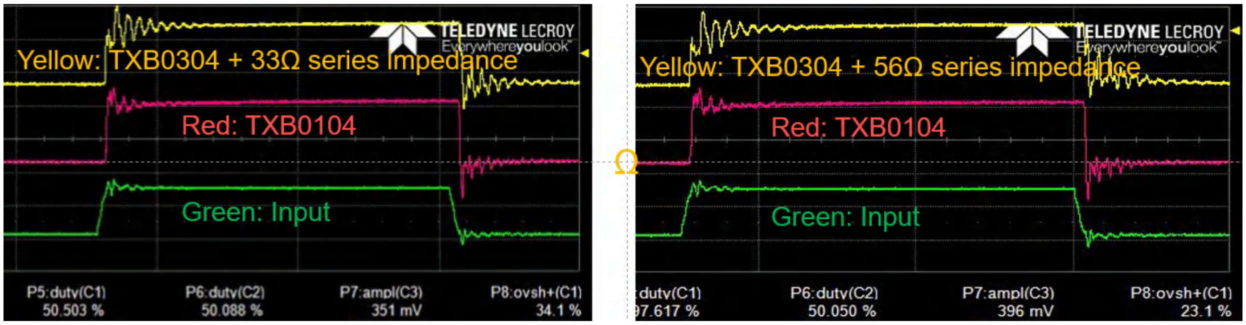

Figure 3-7. Output of the Unmatched TXB0304 (33Ω and 56Ω), TXB0104 (0Ω) , Competitor (0Ω)

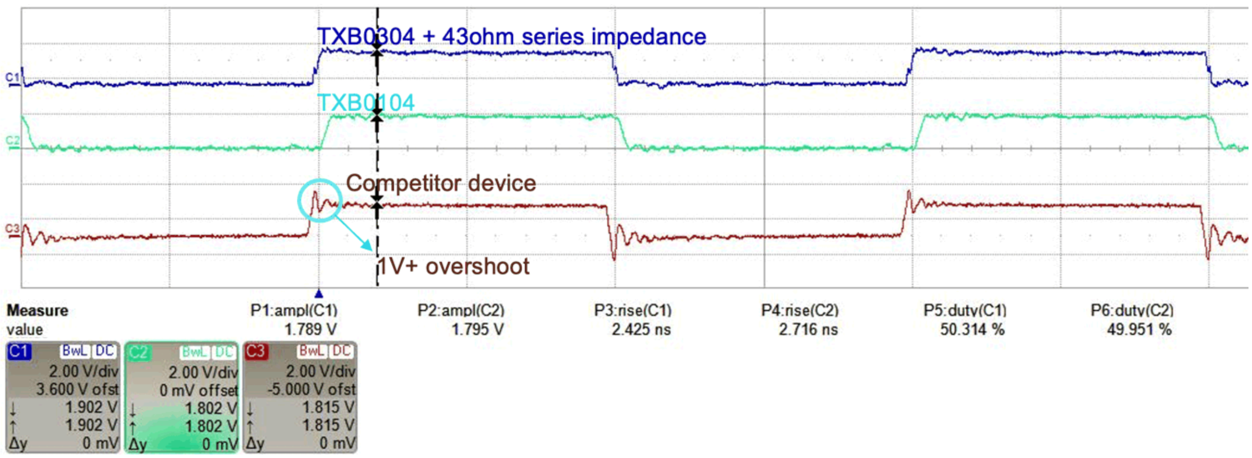

Figure 3-8. Output of the Matched TXB0304 (43Ω), TXB0104 (0Ω) , Competitor (0Ω)

- Once matched, TXB0304 observed designed for performance compared to other devices
  - Similar output characteristics to the TXB0104.
  - Less overshoot or undershoot than competitor device.
  - See device data sheets for acceptable lumped sum capacitance and data rates.

In the second setup, the cabling was swapped to imitate a different output load to the TXB. This time, a 56Ω series resistor was used as the resistor matched closer to the transmission medium.

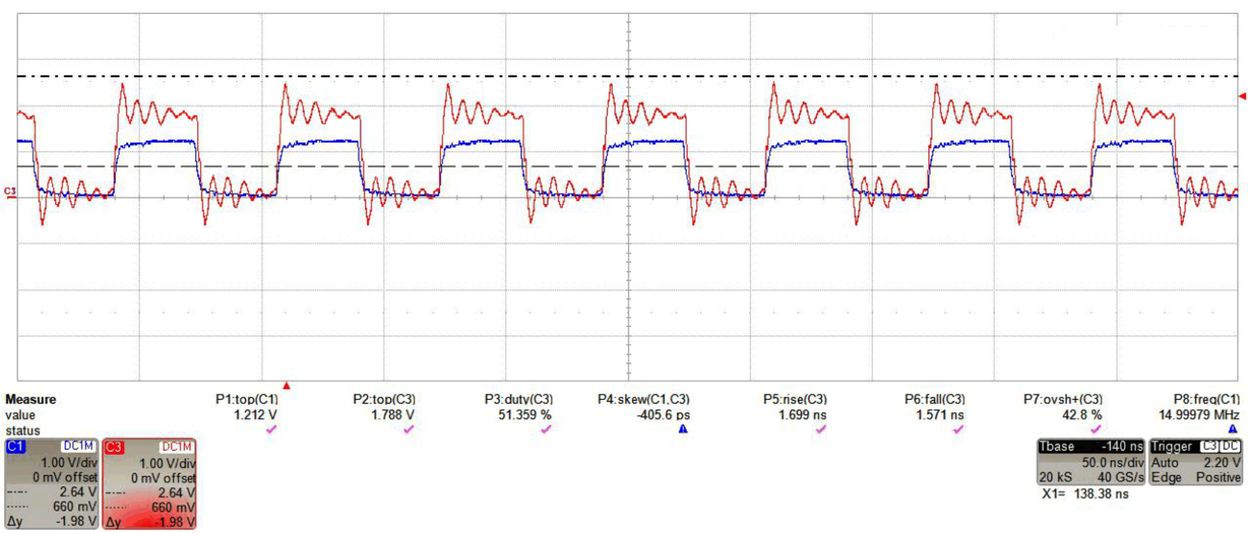

Figure 3-9. Output of the Unmatched TXB0304 (Red) With 0Ω Given Input Signal (Blue)

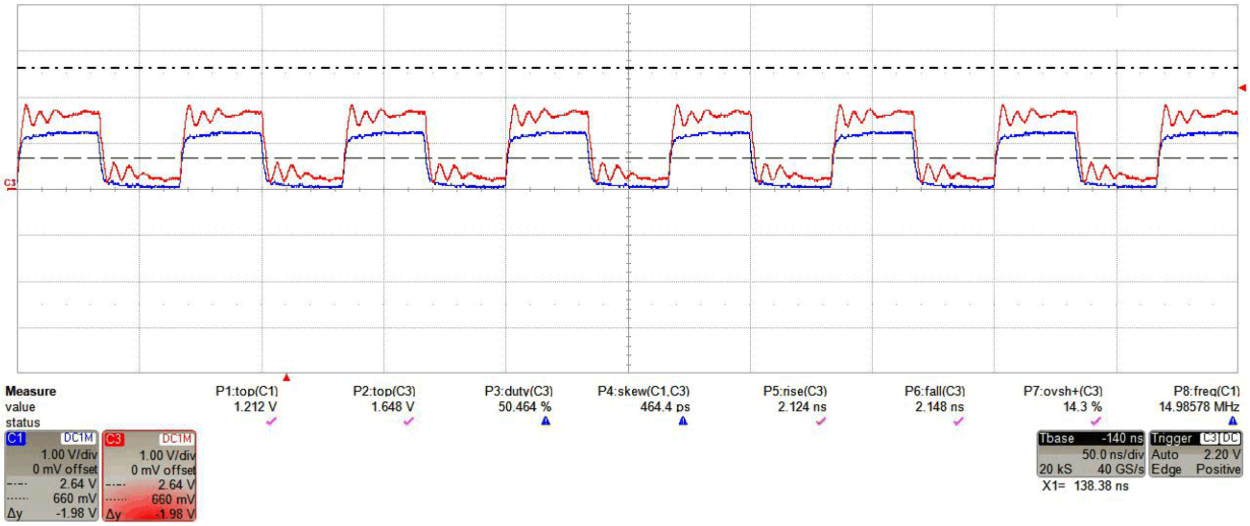

Figure 3-10. Output of the Matched TXB0304 (Red) With 56Ω Given Input Signal (Blue)

By using the 56Ω series resistor shown in Figure 3-10, oscillations become dampened and overshoot % decreased from 42.8% to 14.3%.

Note the two setups, Figure 3-8 and Figure 3-10 were benched with different cabling at the output of the TXB0304. In each case, the required series impedance value differed to effectively match the transmission line, which shows that trial and error might be needed to find the best match.

3.3 Lumped Load

Lumped capacitance at the output needs to be kept to a minimum to make sure proper operation of the internal one-shot architecture. The one-shot architecture is designed to stay on for a specific amount of time (approx. 10ns approximately 30ns) in the TXB0104 and TXB0304. When the device is used with heavy capacitive loads, the one-shot can time-out before the signal is driven fully to the positive rail, resulting in a large RC time constant for the remainder of the output high signal.

See *Leveraging Edge Rate Accelerators with Auto-Sensing Level Shifters* for further clarification on how the one-shot architecture operates.

4 Case Study

Take an example of an use case requiring 1.2V to 1.8V translation operating at 32Mbps. If we probe the output of device with a 20+ cable, the behavior can be seen similar to the Figure 4-1.

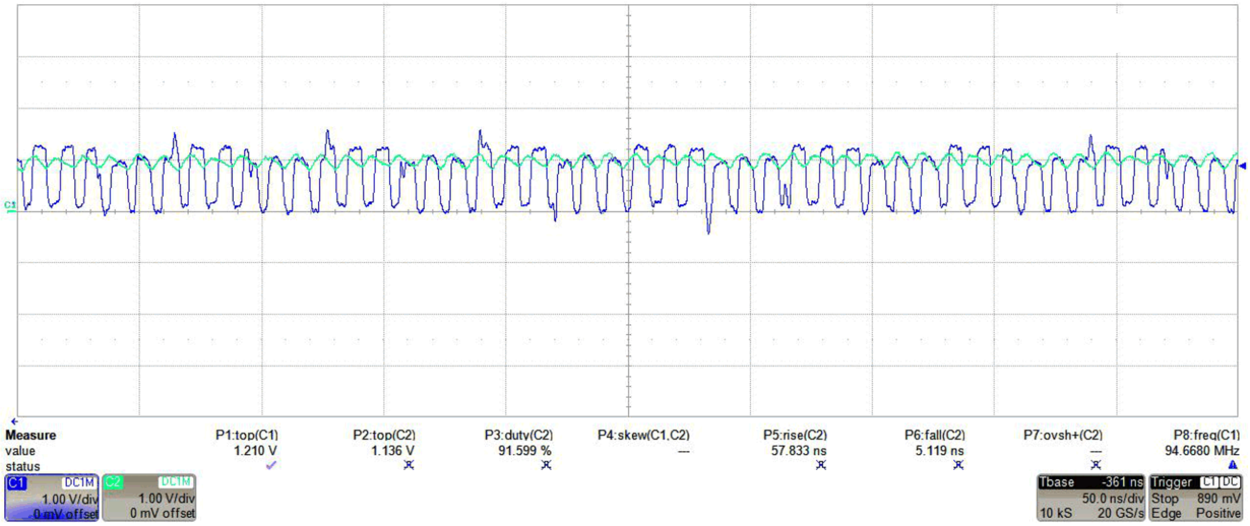

Figure 4-1. TXB0304, 1.2V to 1.8V Translation With Output Cabling of 20+ inch

As observed in Figure 4-1, the output (Teal) is unable to switch states due to the input (Dark Blue) toggling too fast. The result is the unwanted re-triggering of the one-shots at the input side when the output re-drives the incorrect/ delayed state back into the device due to the extrinsic delay from the 20+ in. cable. If a shorter cable is implemented, such as 4 in., the output signal is significantly improved as shown in Figure 4-2.

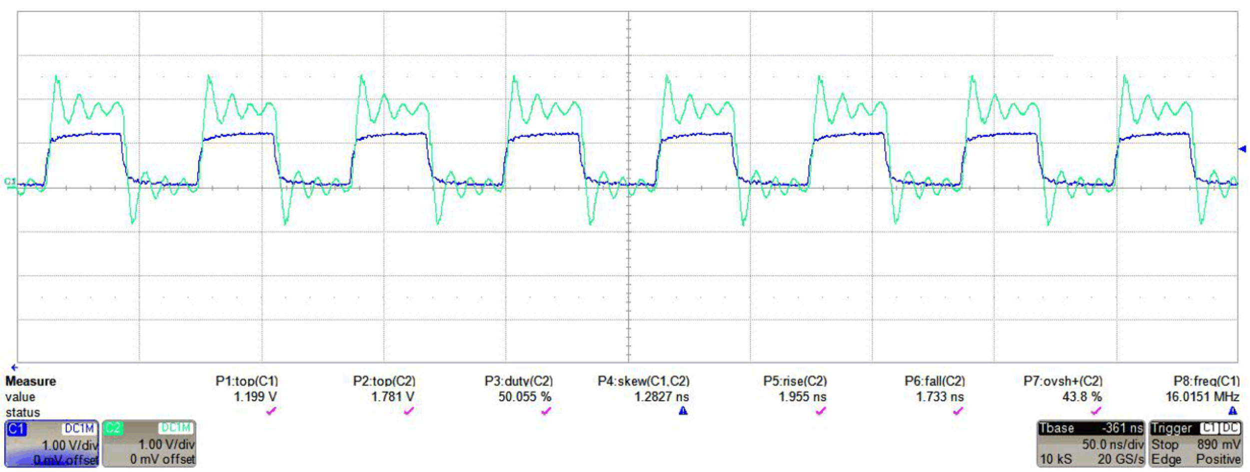

Figure 4-2. TXB0304, 1.2V to 1.8V Translation With Output Cabling of 9 in.

The output is now visible, though the overshoot % is high (44%), which can potentially damage downstream devices if unable to accept that voltage. Note the severe oscillations along the signal path, which is a result of impedance mismatch by the output driver of the TXB0304 facing external load. Again, the setup can be improved once more by reducing cable length and implementing series resistors at the outputs of the device. The final result after all adjustments can be shown in Figure 4-3.

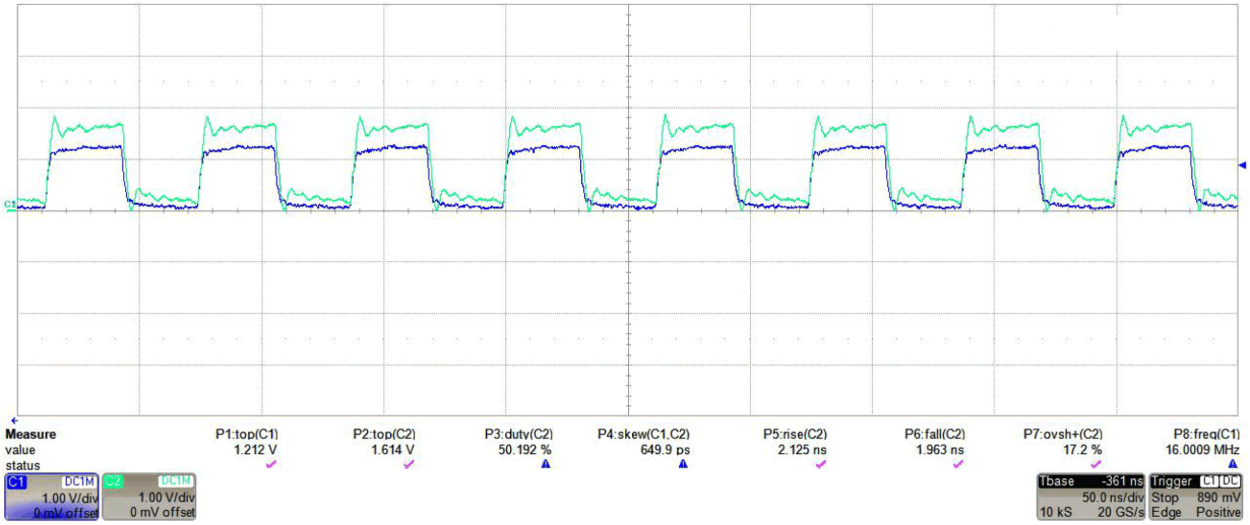

Figure 4-3. TXB0304, 1.2V to 1.8V Translation With Output Cabling of 4 inch with Impedance Matched to Transmission Line Length

5 Summary

- Devices with one-shots (such as TXB) are sensitive to reflections
  - To reduce reflections, use shorter connectors/ design with shorter PCB traces.
  - Properly design for appropriate impedance matching, dependent on the system's transmission line.
- TXB0304 can be mistaken as a weaker device (than TXB0104 or competitor devices).
  - This is due to TXB0304's stronger output impedance with a faster rise/fall time.
  - Such faster transition times are more sensitive to transmission line effects.
- As an example, Section 3 shows TXB0304 with stronger transient drive strength - rise time < 1.3ns (with overshoot) and TXB0104 rise time up to 3.7ns with little to no overshoot.

Design Considerations:

- Design with minimum PCB traces/connectors to reduce likelihood of transmission line effects
- Section 3 shows the TXB0104 and TXB0304 both used with a 50 Ω transmission line
- 0Ω series resistors can be populated at the outputs of TXB-Type Devices and swapped out later for dampening purposes
- Appropriate impedance matching is recommended
- TXB0104 (with a 1.8 V output impedance- 70 Ω) matched closer to the 50 Ω transmission line then the TXB0304 with 5 Ω
- The device with more impedance mismatch yielded more reflections
- Using a typical series dampening resister to match closer to the transmission line resolves the reflections. For more information, see [FAQ] Can I estimate appropriate dampening resistor value for level-shifter outputs?

6 References

- Texas Instruments, *A Guide to Voltage Translation With TXB-Type Translators*, application note.
- Texas Instruments, *Schematic Checklist - A Guide to Designing with Auto- Bidirectional Translators*, application note.
- Texas Instruments, *Do's and Don'ts for TXB and TXS Voltage Level-Shifters with Edge Rate Accelerators,* application note.