APPLICATION NOTE

ANP093 | WE-CCMF: Ceramic Common-Mode Filters for EMI Suppression and Signal Integrity in High-Speed Differential Interfaces

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1. INTRODUCTION

Ceramic Common Mode Filters (CCMF) are advanced multilayer common-mode chokes that are designed to suppress unwanted common-mode electromagnetic noise on high-speed differential lines while ensuring the integrity of the differential signal. In high-speed interfaces (e.g., USB, HDMI, DisplayPort, PCIe, MIPI), data is transmitted using differential signaling, where complementary signals travel on a pair of lines with a specific characteristic impedance (e.g., 90 or 100 Ω) to match the transmission line, reducing common-mode noise and improving signal integrity. Despite this, common-mode noise, resulting from signal imbalances or fast digital switching, can still arise, coupling equally onto both lines. This noise tends to radiate and interfere with sensitive wireless channels, a phenomenon referred to as antenna de-sense.

By exposing a high impedance to common-mode currents, CCMFs serve as targeted filtering solutions that attenuate high-frequency noise while permitting the appropriate differential currents to flow through with minimum attenuation. Consequently, CCMFs preserve the integrity of high-speed data streams while significantly lowering electromagnetic interference (EMI) emissions and enhancing wireless systems' receiver sensitivity.

Unlike traditional wire-wound ferrite common-mode chokes, CCMFs are constructed using multilayer Low-Temperature Co-fired Ceramic (LTCC) technology. This monolithic ceramic construction minimizes parasitic capacitance, which is critical for maintaining high common-mode rejection at very high frequencies where traditional wire-wound chokes typically fail due to self-resonance. Consequently, CCMFs achieve high common-mode attenuation at Gigahertz frequencies (such as the 2.4 GHz and 5 GHz Wi-Fi bands) within a miniature surface-mount package. Additionally, the ceramic body ensures excellent temperature stability and reliability, making these filters well-suited for modern consumer and industrial electronics.

2. UNDERSTANDING DIFFERENTIAL AND COMMON-MODE SIGNALS

2.1 Differential Mode Signals and EMC

Differential signaling is a method where two conductive lines transmit signals of equal magnitude but opposite polarity. This approach not only reduces susceptibility to external noise but also significantly minimizes electromagnetic interference (EMI) because the electromagnetic fields produced by the signals largely cancel each other through mutual inductance and capacitance coupling between the two coupled wires. Additionally, differential signaling can operate at lower voltage levels compared to single-ended signaling, thus decreasing power consumption and further reducing potential EMI issues. Due to these advantages, differential signaling supports substantially higher data rates and improved signal integrity, making it the preferred technique in high-speed interfaces such as USB, HDMI, DisplayPort, PCI Express and MIPI.

2.2 Common Mode Signals and EMC

Common-mode signals refer to unwanted noise that appears simultaneously and equally on both conductors of a differential signal pair. These unwanted signals can radiate from cables or PCB traces, significantly increasing electromagnetic interference (EMI) and potentially impacting nearby sensitive electronics. In practice, high-speed digital interfaces such as USB 3.x or HDMI 2.0 generate common-mode noise at frequencies that overlap with critical wireless bands (e.g., 2.4 GHz Wi-Fi and Bluetooth). This can lead to antenna de-sense, reduced wireless receiver sensitivity, degraded throughput and even communication failures. Therefore, effective suppression of common-mode signals is essential to maintaining robust wireless performance and meeting stringent EMI standards.

2.3 Common Mode Noise at 2.4 GHz and Real-World Impact

The 2.4 GHz ISM (Industrial, Scientific and Medical) band is widely utilized for wireless communication technologies, including Wi-Fi, Bluetooth and Zigbee. Harmonics and broad-spectrum noise are generated by high-speed digital interfaces, such as USB 3.x and HDMI 2.0, due to rapid switching transitions and high-speed data scrambling techniques. The high-speed data transmission of USB 3.x combined with spread-spectrum clocking and common-mode radiation effects, results in broadband noise extending into the 2.4 GHz frequency range, which can interfere with wireless communication systems. As Wi-Fi and Bluetooth receivers are highly sensitive to noise at 2.4 GHz, mitigating such interference is essential to ensure reliable connectivity.

The diagram on the left-hand side in Figure 1 illustrates the amplitude envelope of the USB 3.x data signal, approximated by a sinc-like spectral envelope of its harmonics. The spectrum extends far beyond 7 GHz. The right-hand side of Figure 1 shows the power density measured with a bandwidth of 100 kHz. It shows that broadband noise generated by USB 3.x devices, particularly USB 3.1 Gen 1, significantly impacts Wi-Fi and Bluetooth performance, especially in the 2.4 GHz range. USB 3.x activity generates radiated noise in the 2.4 GHz band, causing interference that reduces wireless receiver sensitivity, leading to dropped connections, higher latency and lower throughput. Observations in real-world applications include:

- Wi-Fi connectivity degradation in laptops when an external USB 3.x storage device is connected, due to radiation of spectral harmonics from USB-cable and the interfaces.
- Connectivity issues in wireless peripherals when USB 3.x hubs or external SSD enclosures operate near a Bluetooth mouse or keyboard, causing erratic behavior due to increased noise levels.
- Transmission failures in embedded IoT devices due to high-speed data buses unintentionally degrading the performance of integrated Wi-Fi modules.

2.4 Antenna De-Sense Phenomenon

Antenna de-sense is defined as the reduction in a wireless receiver's sensitivity caused by high levels of noise interference at its operating frequency. In case of 2.4 GHz noise, common-mode interference from high-speed digital circuits increases the overall noise level, which leads to a lower effective signal-to-noise ratio (SNR) for the wireless receiver (Figure 2).

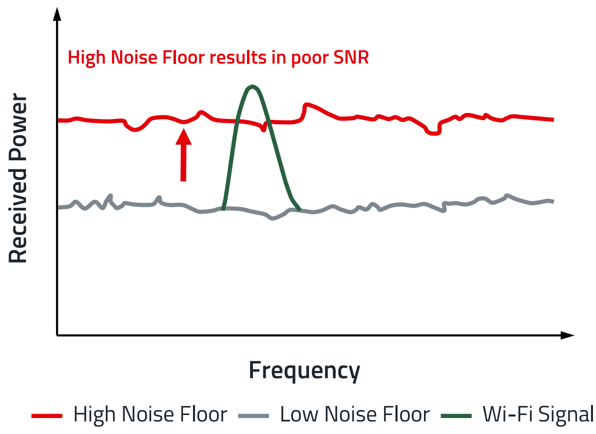


Figure 2: Illustration of the desensitization of the reception sensitivity due to interference signal.

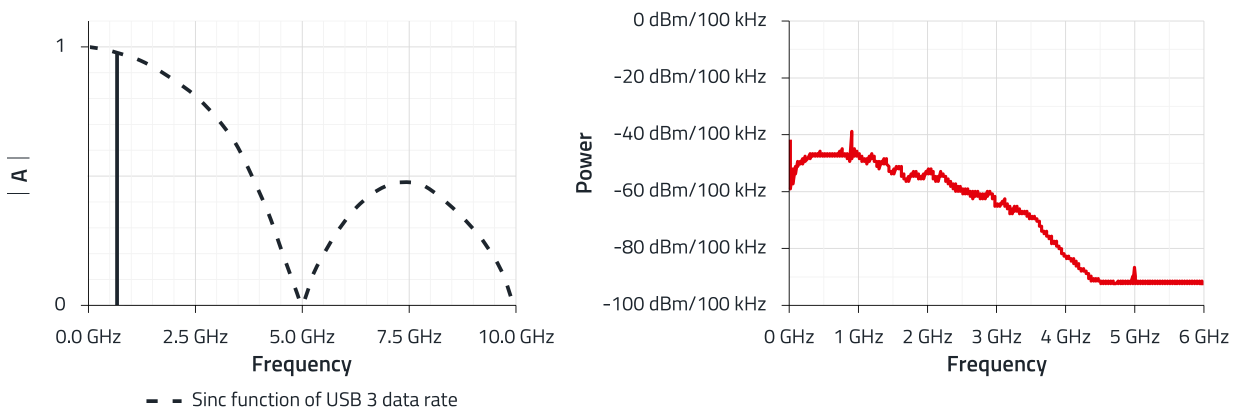


Figure 1: Spectral content and radiated emissions of USB 3.x signals and their impact on the 2.4 GHz ISM band.

Poor reception, lower data rates and in severe cases, complete communication failure can occur as a result. The introduction of common-mode noise suppression techniques, such as WE-CCMF, allows for a significant improvement in wireless performance by attenuating noise at 2.4 GHz before it radiates from PCB traces and cables. Integrating WE-CCMF into high-speed interfaces mitigates antenna de-sense, improving wireless coexistence.

3. WE-CCMF DESIGN PRINCIPLES

WE-CCMF was developed to address challenges related to maintaining signal integrity at multi-gigabit speeds while providing strong attenuation of common-mode RF noise.

3.1 Multilayer LTCC Construction

WE-CCMF is implemented in a 0504-inch package (approximately 1.25 × 1.0 mm footprint) and utilizes LTCC multilayer technology. Internally, it functions as a transmission-line, ensuring high reliability, compact size and superior high-frequency performance.

Unlike traditional ferrite-based common-mode chokes that use coiled copper wire conductors, LTCC filters utilize precisely structured embedded conductive layers within a ceramic substrate. This design enables high-performance filtering while maintaining a compact footprint. A schematic representation of the electromagnetic coupling in the filter is shown in Figure 3.

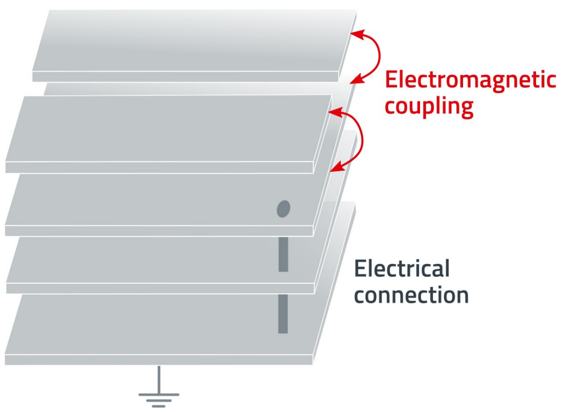


Figure 3: Schematic representation of the electromagnetic coupling in the LTCC filter.

High reliability is provided by LTCC structures, which offer excellent mechanical durability and resistance to thermal stress, ensuring robust performance in various operating conditions.

Low signal loss is achieved due to the absence of ferrite-based parasitic, which results in superior high-frequency performance and minimal attenuation of differential signals up to 60 GHz.

A compact design makes WE-CCMF ideal for integration into space-constrained devices, including smartphones, laptops, IoT devices and embedded systems.

Precision filtering performance is ensured by the internal LTCC geometry, which maximizes common-mode noise rejection while preserving high-speed differential signal integrity, allowing effective noise suppression without degrading data transmission.

3.2 Key Performance Parameters

WE-CCMF operates based on the principle of magnetic field interactions, distinguishing between differential and common-mode currents, which is the key to its filtering capability. Electromagnetic coupling occurs through the interaction of electric and magnetic fields between the combination of inductive and capacitive structures, allowing differential signals to pass while attenuating common-mode components based on their impedance characteristics. The common-mode filter design is influenced by high-frequency parasitic effects within the multilayer structure. At high frequencies, the arrangement of inductive and capacitive structure increases the impedance for common-mode currents, thereby suppressing unwanted noise.

Filters like the WE-CCMF utilize distributed inductance and capacitance across multiple internal layers. The 3D structure allows for tight coupling and controlled impedance paths, enabling specific filter characteristics that would be difficult to achieve with discrete components. Furthermore, LTCC devices are inherently protected due to their ceramic body and internal conductor layout, reducing radiation and crosstalk. This makes LTCC-based filters ideal for compact, high-speed digital applications where space, performance, and EMI compliance are critical.

Unlike traditional lumped-element filters, LTCC components implement embedded transmission line structures such as microstrip or stripline geometries within the ceramic stack. These act as distributed low-pass or band-stop filters rather than simple lumped-element equivalents. The filtering behavior arises from controlled impedance mismatches and propagation delays, allowing precise rejection of specific frequency bands, especially useful for GHz-range common-mode suppression. By designing these internal structures to behave like resonant stubs, coupled lines, or quarter-wavelength traps, LTCC filters can achieve high attenuation with minimal impact on differential signal integrity.

LTCC filters are extremely compact because the ceramic material has a high relative permittivity (εr ≈ 80), which shortens the wavelength of signals and allows smaller resonant structures. Their multilayer 3D construction enables stacking of inductive and capacitive elements, achieving complex filter behavior in minimal space. Additionally, the shortened transmission lines inside the ceramic material support embedded resonators and stubs that function efficiently at GHz frequencies within less than a millimeter.

The complex inner resonant structure of WE-CCMF is engineered to create common-mode band-stop notches at approximately 2.4 GHz and 5.0 GHz, frequencies common in wireless communications. When common-mode noise at these frequencies propagates along the differential pair, the filter presents high impedance, reflecting the unwanted noise.

Conversely, the structure for differential signals has a low net impedance and therefore only insignificant attenuation. The differential pair is routed through a precisely designed internal geometry, which maintains a consistent differential impedance of approximately 100 Ω and ensures minimal discontinuity. This construction allows signals to pass through with minimal distortion, even at very high frequencies. The differential-mode insertion loss remains close to 0 dB across most of the operating spectrum, only beginning to roll off above 8 - 12 GHz.

The differential cutoff frequency is specified as exceeding 8 GHz, at which point the insertion loss reaches 3 dB. This ensures compatibility with standard high-speed digital interfaces. The wide bandwidth is achieved due to the low parasitic inductance (~ 0.245 nH) and low parasitic capacitance of the LTCC construction. The impedance spectrum (Z vs f) for common mode exhibits a sharp increase into the kilo-ohm range at resonant frequencies, indicating strong attenuation. Outside the resonance frequencies the impedance drops back to a low value to prevent interference with intended signals. The device is rated as 5 V DC and 300 mA, providing sufficient capacity for signal lines. As these filters are not designed for DC power filtering at high currents, their primary function is the attenuation of common-mode noise on low-current signal lines. Additionally, a high isolation resistance (> 100 M Ω) ensures that DC or low-frequency currents do not leak between the differential pair.

The WE-CCMF series has been designed to meet the requirements of high-speed digital and wireless communication systems, the following is an overview of the most important parameters.

- Common-Mode Suppression: More than 30 dB attenuation at 2.45 GHz and 5 GHz minimizes interference with Wi-Fi, Bluetooth and other RF communication systems. In practical terms, the common-mode noise voltage is reduced to approximately 1/30 of its original amplitude, significantly decreasing radiated EMI. Additionally, attenuation of more than 20 dB is maintained across much of the 2 - 5 GHz frequency range.
- Differential Mode Insertion Loss: The differential signal experiences minimal attenuation (< 3 dB), preserving signal integrity even at multi-gigabit data rates. The differential-mode loss remains below 0.5 dB up to 5 GHz, based on measured data from parts such as 748032455. This corresponds to less than 11% signal power loss, which is acceptable for high-speed differential signals and support data rates up to 10 Gbps (Figure 4).

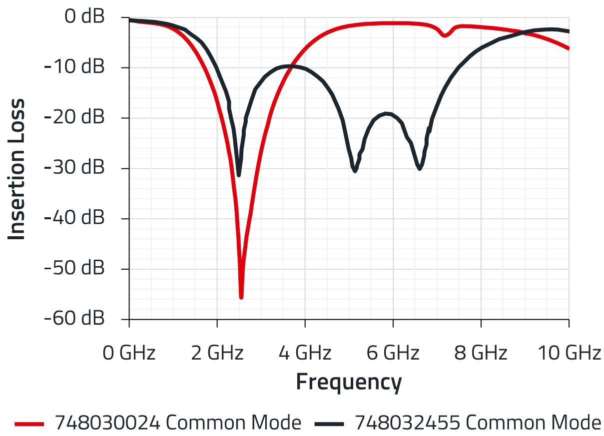


Figure 4: Gain of two band filters in the frequency range between 0 and 10 GHz.

Differential Mode Cutoff Frequency: A differential-mode cutoff frequency exceeding 12 GHz is supported by WE-CCMF, enabling the seamless transmission of data rates up to 10 Gbps and beyond.

- Rated Current and Voltage Handling: A current rating of 300 mA and an operating voltage of 5 V are provided by the filter, ensuring sufficient headroom for high-speed data line applications.

3.3 Magnetic Field Behavior & Filtering Principle

The filtering in an LTCC filter is primarily done through electromagnetic “field interaction”, rather than magnetic field cancellation like in a classic common-mode inductor. While classic common-mode inductors themselves work by creating magnetic fields that oppose changes in current, the LTCC filter's inductive components do not cancel the magnetic field directly but rather interact with common-mode signals to create high impedance at certain frequencies. The combination of inductance and capacitance in the LTCC structure leads to a resonance that effectively impedes common-mode currents. The inductive elements provide high impedance to common-mode currents at resonant frequencies, while capacitive elements help shunt these currents to ground. Common-mode signals, which appear in-phase on both conductors, induce a magnetic field that reinforces in the inductive components, increasing impedance and blocking the noise. Conversely, differential-mode signals, which have opposite current directions, cancel the magnetic fields in the inductive components, resulting in low impedance for these signals. This design selectively filters high-frequency common-mode noise, allowing differential signals to pass with minimal attenuation. The filter is tuned to specific resonant frequencies where impedance peaks, ensuring effective noise attenuation. Capacitors in the LTCC filter provide an additional path for common-mode signals to dissipate, particularly at higher frequencies. The compact and precise nature of LTCC technology allows for efficient integration of these components, improving filtering performance. The filter's performance is further enhanced by the ceramic material's ability to support high-frequency signal integrity.

3.4 Equivalent Circuit of Common Mode Noise Suppression

WE-CCMF incorporates a multistage LC resonance structure. The equivalent circuit, shown in Figure 5 consists of 11 reactive elements, forming a higher-order filter topology optimized for broadband common mode suppression.

The filter’s 5th-order design ensures a steep roll-off and notch filtering, providing a sharp transition between the passband (differential mode) and stop-band (common mode), which ensures efficient noise suppression and maintains signal integrity.

The LC resonance circuit plays a pivotal role in superior EMI suppression, crucial for maintaining high-speed data transmission without interference.

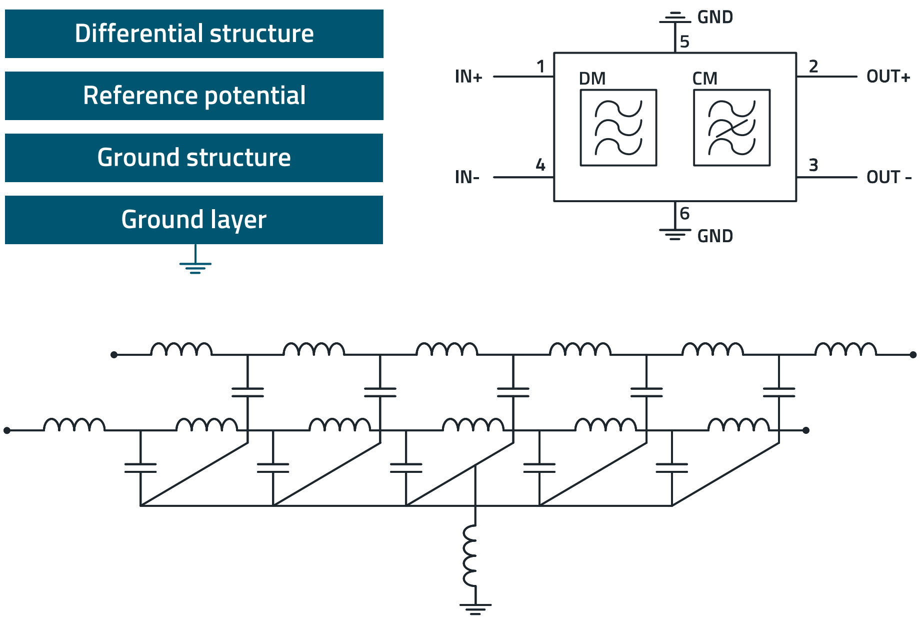


Figure 5: Block and Equivalent Circuit Diagram of the filter.

This design makes the WE-CCMF highly effective for modern electronic systems, providing strong electromagnetic compatibility (EMC) while operating at high frequencies. The advanced filtering capabilities of this filter ensure that common-mode noise is suppressed without compromising overall signal quality.

4. IMPLEMENTATION AND TESTING CONSIDERATIONS

4.1 PCB Layout and Placement Guidelines

To ensure optimal performance, the WE-CCMF should be placed as close as possible to the noise source or PCB exit point (e.g., USB, HDMI or PCIe connectors). This placement helps suppress common-mode noise before it can propagate along PCB traces or external cables, thereby reducing EMI emissions.

When designing the PCB layout, the following guidelines should be observed:

- Matched Impedance: Maintain a differential impedance of 85 - 100 Ω to align with WE-CCMF specifications.
- Symmetric Routing: Ensure equal trace lengths for both differential lines to avoid skewing and maintain signal balance.
- Via Placement: Avoid placing vias near the filter pads to minimize impedance mismatches. If necessary, use symmetrical via placement to avoid introducing mode conversion.
- Smooth Routing: Use the WE-CCMF as an extension of the differential transmission line. Minimize any discontinuities or sharp bends to preserve signal integrity.

Different PCB layout styles influence the effectiveness of common-mode noise suppression. For WE-CCMF, configurations with solid ground planes such as All GND or GND Connect are typically preferred due to their superior return path continuity and EMI behavior. Compact options like Via in Pad can be used in space-constrained designs but require careful symmetry to avoid imbalance. Layouts such as Top Plane or No Via are sometimes necessary due to board constraints, though they may come with performance trade-offs.

The grounding and layout configuration around WE-CCMF has a significant impact on both common-mode suppression and differential signal integrity. Figure 6 shows six common layout types, derived from both simulations and real-world measurements. These configurations can be selected based on required performance level and PCB space limitations.

Generic: A balanced and symmetrical routing style with well-distributed ground vias surrounding the signal traces. Ground connections are provided through a via fence and top-layer pours, offering good return path continuity. This layout serves as a baseline for performance and manufacturability in most applications.

GND Connect: GND pads of the WE-CCMF are directly tied to a solid top GND plane beneath the component. This layout provides the lowest impedance return path and delivers the highest common-mode suppression. It is the recommended layout for best EMC performance.

GND Etched: An internal GND plane directly underneath the CCMF is partially etched away. While maintaining the top layer GND, this layout reduces parasitic capacitance to inner layers, improving performance in multilayer designs.

All GND: All internal and external layers remain solid GND under the component. While this enhances shielding, it may lead to parasitic capacitance buildup, which can degrade high-frequency suppression.

Top Plane: Only the top copper layer is used for GND connection, with no internal GND planes below the CCMF. This layout minimizes coupling to inner layers but can slightly compromise reduce common mode suppression at lower frequencies (typically below 1 GHz), due to limited vertical coupling area and return path impedance when internal ground planes are omitted.

Via in Pad: To save space, vias are placed directly on the GND pads. While compact, this layout can disrupt the return path symmetry. Simulations show up to 5 dB degradation in common mode insertion loss (S_{CC21}), compared to optimal layouts with symmetric return paths. Use only when space constraints dictate.

No Via: No via fence is implemented around the trace edges or PCB perimeter. This layout has similar routing to the generic version but lacks shielding vias, leading to potential EMI issues. It is not recommended for sensitive or high-speed designs.

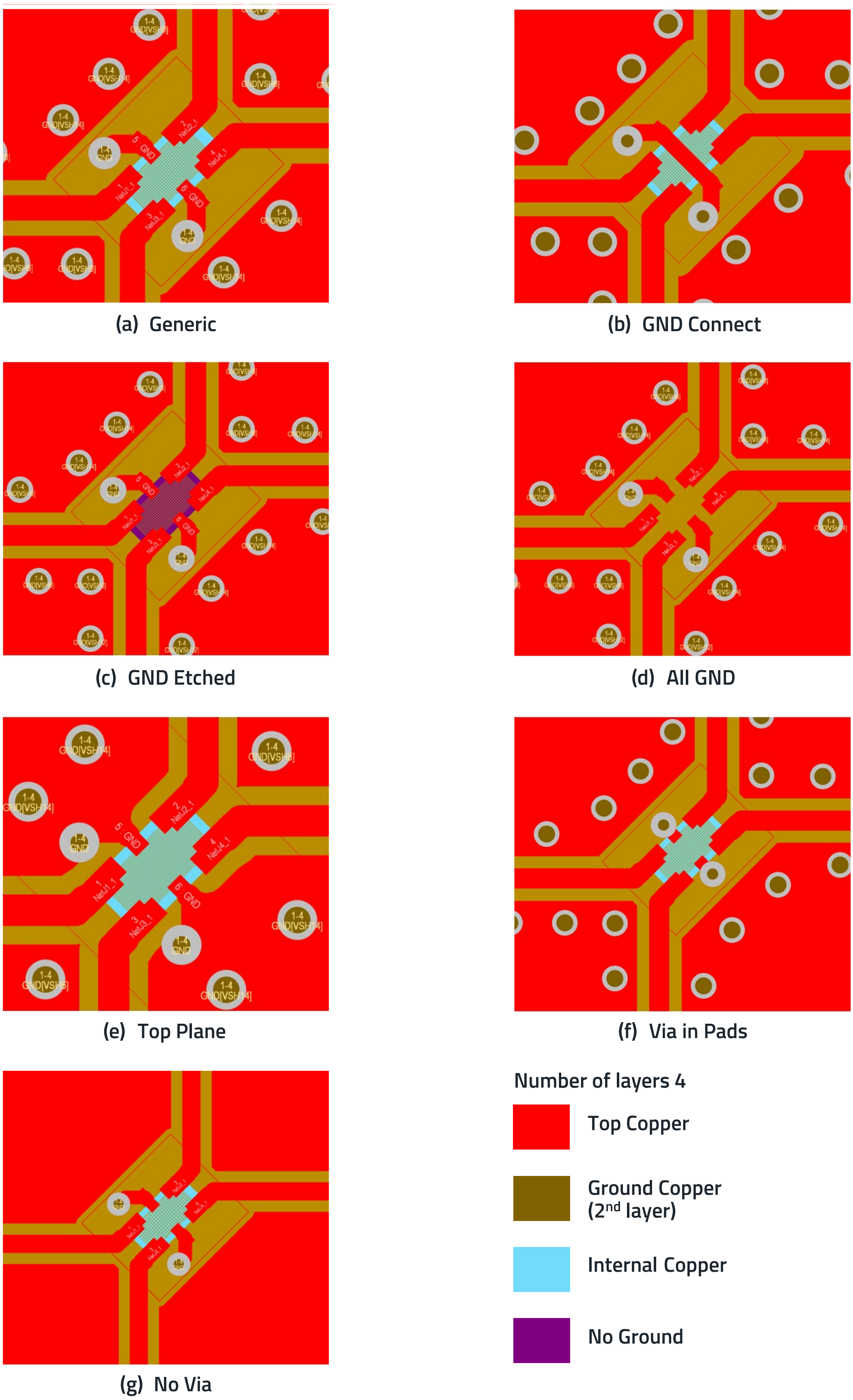


Figure 6: Layout variants for WE-CCMF.

4.2 Testing and Verification

WE-CCMF performance is verified using signal integrity and EMI measurements, with a VNA analyzing key S-parameters (S_{DD21}, S_{CC21}, S_{CD21}). A properly implemented WE-CCMF should exhibit:

- Minimal insertion loss (S_{DD21} close to ~ 0 dB) across the operating band, ensuring signal integrity. This is the desired signal path.
- High common-mode attenuation ($S_{CC21} \geq 30$ dB at 2.4 GHz and 5 GHz) particularly in optimal layouts (e.g., GND Connect or All GND) reducing interference with Wi-Fi and Bluetooth. This is the noise propagation through the filter.
- Low mode conversion (S_{CD21}) to maintain signal quality and minimize unwanted differential-to-common-mode energy transfer.

To validate these performance metrics in practical conditions, the following sections present measurement results for three WE-CCMF part numbers tested: 748030024, 748020024 and 748032455. Each was evaluated across six layout configurations to analyze differential-mode performance, common-mode suppression and mode conversion behavior.

4.3 Measurement Topology for WE-CCMF Testing (optional)

The measurement setup for WE-CCMF is based on a four-port differential device under test (DUT) configuration, as illustrated in Figure 7.

Figure 7: Four-port differential measurement setup for CCMF characterization.

This topology enables mixed-mode characterization of the DUT, including differential-mode and common-mode insertion loss, return loss, and mode conversion. Port 1 and Port 3, located on Side A, are designated as the input differential pair, while Port 2 and Port 4, positioned on Side B, are assigned as the output differential pair. The device under test (DUT), which is WE-CCMF, is positioned between these ports to allow for the evaluation of its performance in filtering common-mode noise while preserving the integrity of the differential signal.

Figure 8 shows an example of the 4-port test fixture which is connected to a PNA-X Network Analyzer using coaxial cables rated up to 26 GHz. Calibration was performed using ECal and Auto Port Extension to accurate results across the target frequency range.

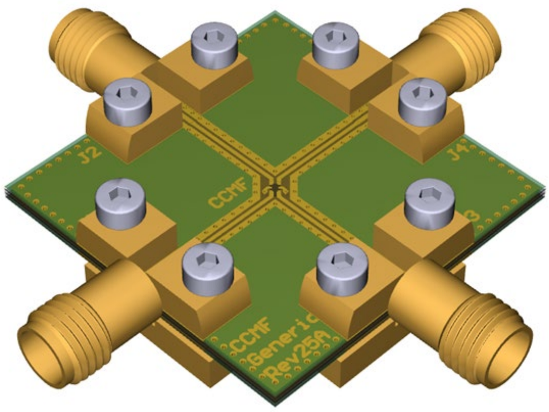


Figure 8: Test board with coaxial connectors used for S-parameter measurement.

For differential mode, insertion loss (S_{DD21}) is measured to determine how effectively the signal is transmitted through WE-CCMF. The cutoff frequency is defined at the -3 dB point to ensure minimal signal degradation.

For common-mode suppression, insertion loss (S_{CC21}) is measured to quantify the attenuation of common-mode noise, particularly at critical frequencies such as 2.4 GHz and 5 GHz.

For mode conversion, differential-to-common mode conversion (S_{CD21}) is evaluated to determine the extent to which differential signal energy is converted into common-mode noise.

Following measurements show what has already been described above under the layout requirements.

748030024

Table 1 shows the measurement results of S_{CC21}, S_{DD21} and S_{CD21} for part number 748030024 across six layout configurations. GND Connect and All GND layouts achieve strong common-mode attenuation, with suppression exceeding 30 dB at 2.4 and 5 GHz, while Via in Pad and No Via layouts exhibit significantly degraded performance.

In the optimal layouts, differential insertion loss (S_{DD21}) remains low (< 1 dB) and mode conversion (S_{CD21}/S_{DC21}) stays well below -30 dB, confirming excellent signal integrity. These results highlight the importance of grounding strategies and demonstrate that compact routing techniques like Via-on-Pad should be avoided when EMI performance is critical.

748020024

Table 2 shows the measured S_{CC21}, S_{DD21} and S_{CD21} for WE-CCMF part number 748020024 across different layout configurations.

Common-mode suppression (S_{CC21}): The Top Plane layout demonstrates the strongest attenuation, exceeding 30 dB at 2.4 GHz and 5 GHz. Other layouts, particularly GND connect, show irregular suppression curves or shallow nulls, indicating potential grounding issues or measurement artifacts.

Differential insertion loss (S_{DD21}): GND connect exhibits poor differential performance, with insertion loss starting near -6 dB. In contrast, Top Plane maintains stable transmission with insertion loss remaining under 1 dB, confirming its suitability for signal integrity.

Mode conversion (S_{CD21}): GND connect and Generic layouts exhibit higher common mode to differential mode conversion levels, reaching approximately –6 dB. This behavior indicates increased sensitivity to layout asymmetries and return path discontinuities. The Top Plane layout, by comparison, shows lower and more uniform mode conversion performance.

Overall, the differing measurement quality is most likely caused by layout-dependent fixture effects rather than by the CCMF itself. Layouts with better grounding, symmetry, and return-path continuity produced stable mixed-mode results, while Generic and Via-on-Pad style variants introduced parasitic effects, mode conversion, and possible measurement artifacts.

Layout	Common-Mode Suppression (S_{CC21})	Differential Loss (S_{DD21})	Mode Conversion (S_{CD21})	Comments
GND Connect (b)	> 30 dB at 2.4 & 5 GHz	< 1 dB	< -30 dB	Best overall; excellent grounding.
All GND (d)	> 30 dB at 2.4 & 5 GHz	< 1 dB	< -30 dB	Same as above; robust suppression.
Via in Pad (f)	Strongly degraded	Higher loss	Higher conversion	Compact but electrically harmful; avoid.
No Via (g)	Poor suppression	Less than optimal	Elevated conversion	Not recommended.
Others (6 layouts total)	Mixed	Mostly ok	Mostly ok	Grounding is the key differentiator.

Table 1: Electrical Performance Summary for 748030024.

Layout	Common-Mode Suppression (S_{CC21})	Differential Loss (S_{DD21})	Mode Conversion (S_{CD21})	Comments
Top Plane (e)	> 30 dB at 2.4 & 5 GHz; clean shape	< 1 dB	Low, consistent	Best layout; clear winner.
GND Connect (b)	Irregular suppression, shallow nulls	Starts near -6 dB (!)	Starts around 6 dB	Likely grounding or measurement issues.
Generic (a)	Moderate/unstable	Acceptable	High/inconsistent	Possible measurement artifacts.
Others	Mixed	Mostly ok	Mixed	Top Plane superior across all metrics.

Table 2: Electrical Performance Summary for 748020024.

Layout	Common-Mode Suppression (S_{CC21})	Differential Loss (S_{DD21})	Mode Conversion (S_{CD21})	Comments
Top Plane (e)	Single peak at ~ 5.8 GHz; matches datasheet	Good	-50 to -30 dB	Most accurate and stable.
All GND (d)	Dual peaks 5.2 & 6.1 GHz	Good	-50 to -30 dB	Wider suppression spectrum.
GND Etched (c)	Dual peaks 5.2 & 6.1 GHz	Good	-50 to -30 dB	Similar benefits to All GND.
Generic (a) / Via in Pad (f)	Not included			Data inconsistent; likely poor layout.

Table 3: Electrical Performance Summary for 748032455.

748032455

Table 3 shows the measured S_{CC21}, S_{DD21} and S_{CD21} for part number 748032455 across the tested layout configurations.

Common-mode suppression (S_{CC21}): Measurement results across different layouts reveal two distinct response patterns: one group displays a single attenuation peak near 5.8 GHz, while another shows dual peaks around 5.2 GHz and 6.1 GHz. Among all configurations, the Top Plane layout aligns most closely with the datasheet, with a clean single peak and broader suppression.

The All GND and GND Etched layouts exhibit two distinct nulls, offering wider spectral suppression but with a narrower bandwidth at 5.8 GHz compared to Top Plane. These alternative grounding strategies may be beneficial depending on application-specific EMI filtering needs (Figure 9).

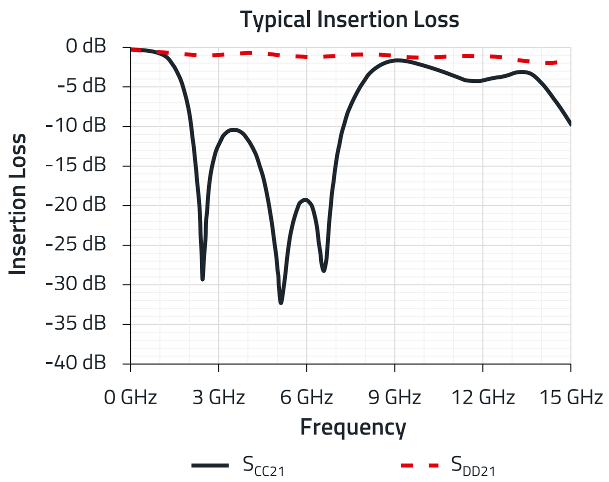


Figure 9: Datasheet chart.

Mode conversion (S_{CD21}): mode conversion remains well-controlled for most layout configurations, with S_{CD21} values consistently between -50 dB and -30 dB across the measured frequency range. These low levels of mode conversion indicate effective isolation between differential and common-mode signals, confirming good layout symmetry. Designs such as Top Plane, GND Connect and GND etch show particularly stable and clean traces. Layouts like Generic and Via in Pad are not included due to inconsistent data or measurement quality issues. Overall, the results confirm that proper grounding and trace design can effectively suppress undesired mode conversion.

Layout Recommendations:

The measurement is performed using an unbalanced (single-ended) test setup for the spectrum or network analyzer, while the actual application requires a balanced (differential) layout. Therefore, the observed issues and performance may differ, as real-world differential routing provides better symmetry and return path control, which significantly influences mode conversion and EMI behavior.

For spectrum-based measurements, the use of baluns or differential conversion networks is recommended to ensure proper excitation of the differential DUT. A purely single-end setup may introduce imbalance and measurement artifacts, leading to deviations from actual application behavior.

- Do not use Via in Pad or No Via configurations, as they result in degraded EMI performance.
- If possible, implement the All GND layout, which consistently shows the best performance across all tested part numbers.
- Avoid GND under the signal pads to maintain optimal coupling and filtering efficiency.
- For most designs, the Generic layout offers a reliable balance of performance and ease of implementation, except for part number 748020024, where Top Plane performs best.
- A detailed WE-CCMF footprint design guideline is available and recommends a symmetric footprint layout with dedicated ground vias, 10 mil ground traces, a 14 to 15 mil via-to-pad spacing, no surface connection between the two ground pads, no sharing of ground vias with nearby footprints, and placement as close as possible to the connector to ensure the intended EMC filtering performance.

5. EYE DIAGRAM MEASUREMENTS

The eye diagram test setup and measurement procedure used in this evaluation were implemented exactly as described in Application Note ANP007. The same signal source, receiver configuration, calibration methodology, and measurement sequence were applied without modification. A generic layout with a USB Type-C interface was used for these measurements.

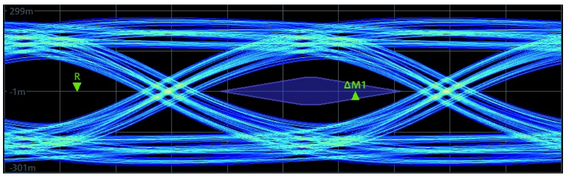
The measurements were performed to assess the high speed behavior of the differential channel when using the WE CCMF 748030024, 748020024, and 748032455. Tests were conducted at 5 Gbit/s, 10 Gbit/s, and 20 Gbit/s under various equalization and mask conditions to determine the usable data rate range and the required compensation.

Equalization compensates for frequency-dependent channel losses by boosting high-frequency components, thereby reducing inter-symbol interference and restoring eye opening. The differential stimulus was generated by the measurement instrument and applied to the channel containing the WE CCMF device, while signal acquisition and analysis were performed at the receiver using the same analyzer configuration defined in ANP007. Instrument based equalization (e.g., CTLE/DFE) was enabled as specified in the application note to reflect realistic high speed link operation.

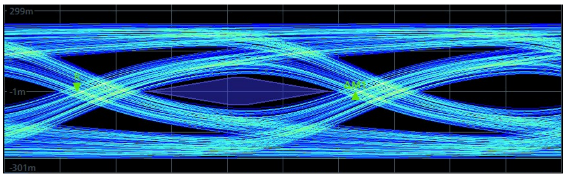
748030024

With equalization and mask, the eye is wide and well formed, showing comfortable margin and zero violations, resulting in a clear PASS. With mask but no equalization, the eye becomes smaller and shows more distortion yet still maintains enough margin to avoid any mask hits, so this condition also PASSes. Using equalization without a mask, the eye remains clean and symmetric, demonstrating strong compensation of channel loss and performance that would comfortably satisfy the mask limits. In the fully uncompensated case (no mask, no EQ), the eye stays open but with reduced amplitude and less uniform transitions, offering the least margin but still likely meeting typical 10 Gbit/s mask requirements (Figure 10).

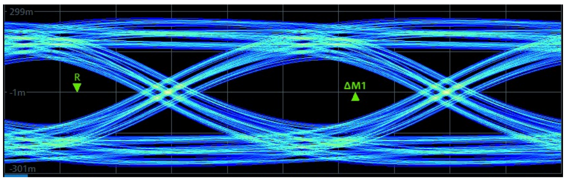
With equalization, the 20 Gbit/s eye opens noticeably and remains measurable, showing improved timing and reduced loss effects. Without equalization, the eye collapses, with minimal amplitude and strong ISI. Although EQ clearly improves the waveform, both conditions fail at 20 Gbit/s, with the equalized case performing better but still lacking sufficient margin for a pass (Figure 11).



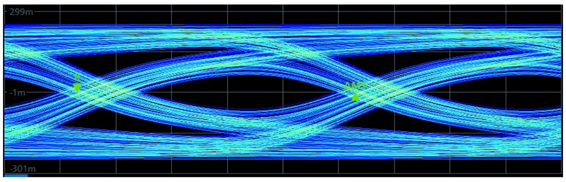
10 G with mask and with equalization



10 G with mask and without equalization

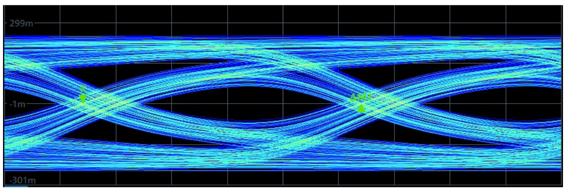


10 G without mask and with equalization

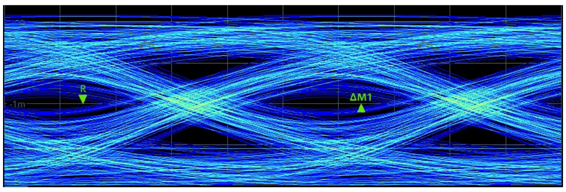


10 G without mask and without equalization

Figure 10: Comparison of 10 G eye diagrams under mask and equalization conditions.



20 G no mask and with equalization



20 G no mask and no equalization

Figure 11: Comparison of 20 G eye diagrams under mask and equalization conditions.

In summary, 748030024 supports 10 Gbit/s operation when equalization is applied, while the non-equalized channel provides only limited margin. At 20 Gbit/s the signal remains detectable, but reliable operation requires equalization and no pass result is achieved without it.

748020024

At 5 Gbit/s (no mask, no EQ), the eye remains fully open with a clearly defined horizontal and vertical aperture. The measured unit interval of ΔM_1 = 200 ps matches the expected UI, and the crossing points show no distortion. The result confirms that 748020024 supports 5 Gbit/s operation without equalization (Figure 12).

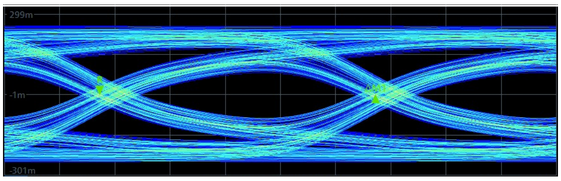
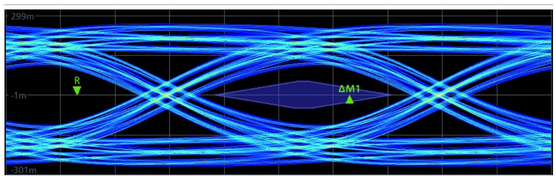


Figure 12: 5 Gbit, no mask and no equalization.

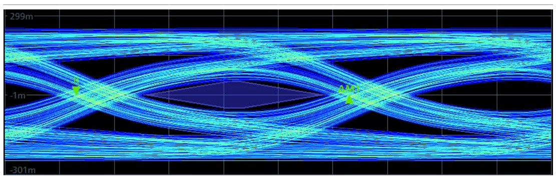
At 10 Gbit/s without equalization, the eye diagram is degraded and offers limited margin. However, when evaluated against the compliance mask, no violations occur and the signal formally passes, albeit with minimal headroom. Enabling equalization significantly improves the eye opening, both with and without the compliance mask.

In both EQ supported cases the measurements pass, and the version without mask shows the largest and most stable eye. These results demonstrate that 748020024 can reliably operate at 10 Gbit/s when moderate equalization is applied (Figure 13).

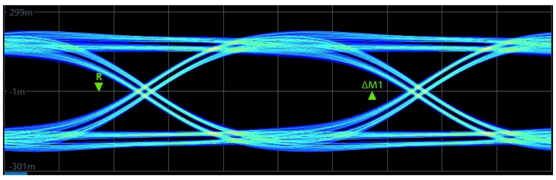
At 20 Gbit/s, the uncompensated eye (no mask, no EQ) is strongly reduced in height and width and does not meet a pass condition. Applying equalization improves the eye shape, but the available margin remains insufficient, and the measurement does not achieve a pass result even with optimized EQ settings. The choke and layout therefore do not support 20 Gbit/s operation within acceptable signal integrity limits (Figure 14).



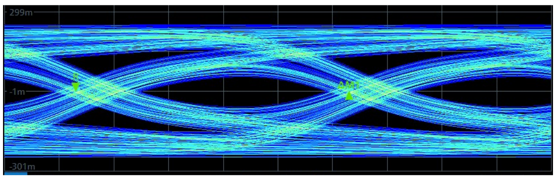
10 G with mask and with equalization



10 G with mask and without equalization

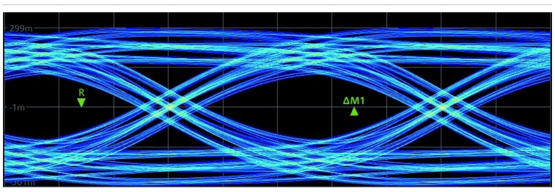


10 G without mask and with equalization

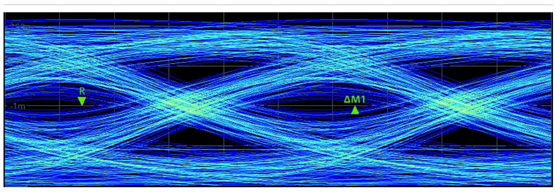


10 G without mask and without equalization

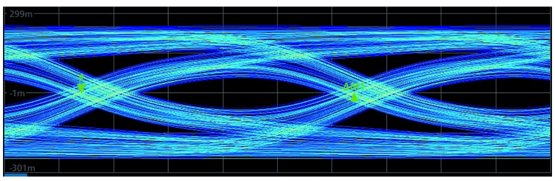
Figure 13: Comparison of 10 G eye diagrams under mask and equalization conditions.:



20 G with equalization (modified)



20 G without mask and with equalization



20 G without mask and equalization

Figure 14: Comparison of 20 G eye diagrams under mask and equalization conditions.

In summary, 748020024 supports 5 Gbit/s without EQ and 10 Gbit/s with EQ, while 20 Gbit/s does not achieve a pass result under any tested condition.

748032455

At 10 Gbit/s with equalization, the eye is clean and well defined, and the measurement passes the compliance mask with comfortable margin. When the mask is applied without equalization, the eye narrows and produces mask violations, resulting in a clear FAIL. Without the mask, the equalized eye remains stable and symmetric, showing strong improvement in both vertical and horizontal opening, while the non-equalized eye shows reduced amplitude and increased closure typical of an uncompensated channel.

Overall, 748032455 only achieves a passing 10 Gbit/s result when equalization is applied (Figure 15).

At 20 Gbit/s without equalization, the eye diagram shows a strongly closed opening with reduced amplitude and limited horizontal width. The dense trace overlap indicates significant high frequency loss and intersymbol interference, leaving only a small detectable eye. Without equalization, the channel cannot maintain sufficient margin at this data rate, and the resulting signal quality is well below typical mask requirements.

Even though no compliance mask is applied in this view, the limited eye height and pronounced closure clearly indicate that this condition results in a FAIL (Figure 16).

In summary, 748032455 only supports 10 Gbit/s operation when equalization is applied. The non-equalized channel fails the 10 Gbit/s mask test due to insufficient eye height and mask violations. At 20 Gbit/s the signal remains detectable, but even with equalization the eye is too limited for compliance, and no passing condition is achieved.

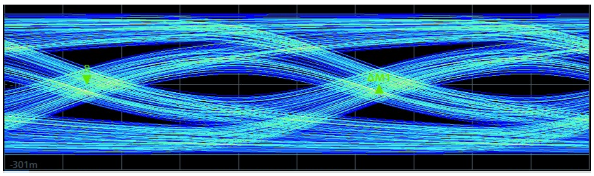


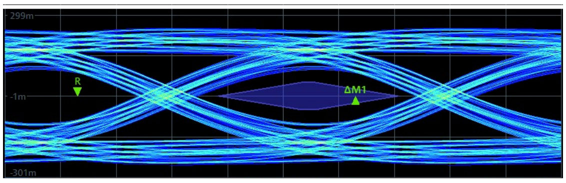
Figure 16: 20 G without mask and equalization.

6. CONCLUSION

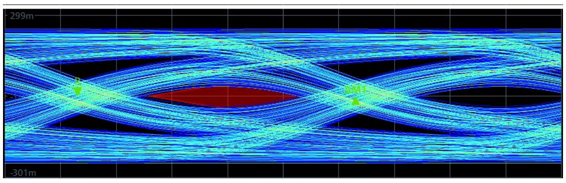
WE-CCMF series offers compact, high-performance filtering for common-mode noise in high-speed differential interfaces such as USB, HDMI, and MIPI. Measurement results confirm excellent differential signal integrity and strong common-mode suppression across 2.4 GHz and 5 GHz, crucial for improving EMC and wireless coexistence.

Among layout options, Via in Pad and No Via configurations consistently showed degraded performance and are not recommended. The All GND layout delivered the most suppression across all tested part numbers, especially when no copper keep-out is placed under the signal pads. The Generic layout provides reliable performance for most designs, except for part number 748020024, where Top Plane yielded better results.

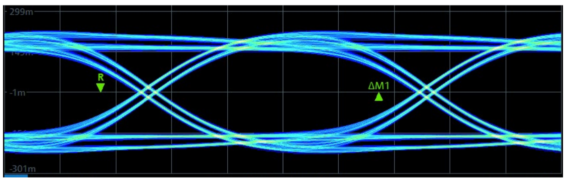
Overall, optimal layout practices, solid return paths, symmetrical routing, and strategic via placement are key to leveraging the full benefits of WE-CCMF filters in real-world applications.



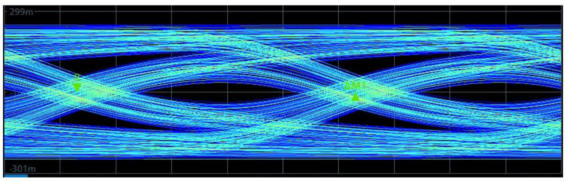
10 G with mask and equalization



10 G with mask and without equalization



10 G without mask and with equalization



10 G without mask and without equalization

Figure 15: Comparison of 10 G eye diagrams under mask and equalization conditions.

A APPPENDIX

A.1 References

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[5] WE-CCMF Footprint Design Guideline https://www.we-online.com/components/media/o172716v446%20WE-CCMF%20Footprint%20Design%20Guideline%20%28rev1%29.pdf

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