EMI Filter Connectors

Then and Now

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Environment

- Current requirements dictate EMI protection for commercial and military systems.
- EMI requirements in Europe are more severe than US.
- Being in a world economy some times it does not make since to make one for export and one for home.

Environment

- The requirements require EMI, ESD, EMP, and Lightning protection.
- Original solutions were to cut and try
- Time was never an major issue. Weeks were Ok.
- Some solutions were an over kill
- Things have changed for the better.

Goals

- Review of the types of devices.
- Provide tools to specify an EMI/EMP Conn.
- Product verification.

Devices

- There is a large selection to chose from:
  - Pi Filter
  - L Filter
  - T Filter
  - C Filter

  Common Mode or Differential Mode filter

  The question is always what should I use.

Design

- Once one has decided that a Filter Conn. Is needed, the question now is:
  - What signals must pass and those that shall not pass
  - Working voltages, AC or DC
  - Surge conditions, normal and abnormal

Design

- The working voltage needs to be considered with all normal transients.
- With an AC voltage, the rms value needs to be converted to the peak value.
- Most importantly the AC line frequency, 60 or 400 Hz needs to be identified.

Design

- The capacitor values need to be selected.
  – The operating data frequency needs to be considered.
  – The cut off frequency will need to be determined.
  – If at all possible, an RFI signature of the system is very helpful in determining the frequency that has to be filtered and the level needed.

Design

- Lightning, EMP, or ESD is a consideration.
  - Decision has to be made as to whether the capacitor should absorb the surge or provide a TVS device to reduce the surge.
  - First by analyzing the pulse which can be double exponential or sinusoidal, the DWV rating of the capacitor can be determined.

Design

- Pulse analysis can be accomplished with

$$V_O = V_p \left(1 - e^{-(tr / (Rs \times C))} \right)$$

- Here we are dealing with the source impedance, capacitance, and time to rise of the pulse.
- Fundamentally the equation relates one time constant of the pulse to the pulse time to rise.
- If the time constant is shorter than the time to rise, the pulse will be clipped.

Design

- The pulse analysis can assist in determining the magnitude of voltage that will appear across the capacitor.
- This becomes the DWV rating of the capacitor.
- This means that the voltage across the capacitor will appear across elements in the circuit of the system.

Design

- Transient devices to reduce the pulse level.
  - TVS diodes
  - MOV planar
- The peak pulse power that the device has to absorb has to be determined.
- Suppliers use standard pulse wave forms and the environment is never standard.

Design

- Diode suppliers have provided very good analytical tools that can convert the ratings from standard pulses to the specification requirements.
- Once the power rating has been determined, the device, TVS diode or MOV can be selected.
- Caution the MOV planar is limited to 38 volt standoff.

Design

- Device vs Surge Analysis Example for a 30KW device.
- Ratings:
  - Standoff - 260 volts (Maximum working voltage)
  - Vbr 289 volts min 320 volts max 5 ma
  - Ir 5µA at 260 volts
  - Vc 420 volts max
  - Ipp 71 amps with a 10 x 1000 µsec pulse

Design

- Pulse requirements
  - Wave form double exponential
  - V peak 750 Volts
  - I peak 150 Amps
  - Tr 6.4 µsec
  - T 50% decay 70 µsec.

Design

- Analysis
  - True current through the TVS is driving voltage minus clamp voltage divided by source impedance

  Ip = (750 – 410)/5 Ω = 68 Amps for a 6.4/70μ pulse
  - Peak pulse (Ppp) for a decreasing pulse width increases exponentially.

Design

- From the a time vs power curve a 70 µ sec pulse vs a 1000 µSec pulse we have 2.0 Ppp vs .6 Ppp.
  - Thus we have the ratio 2/.6 = 3.33.
  - The Ip for a 70 µsec pulse will increase by the same factor, hence 71 A x 3.33 = 237 A.
  - This is a 28.7% of TVS surge capability.

Design

- There will be a new clamping voltage:
  - The clamping voltage is linear from Vbr up to the max Vc, i. e. If the current is 50% of the rated value, the Vc will be at the mid point.
  - Hence we are dealing with a 28.7% of maximum, then the Vc with a 70 µsec pulse will be Vcnew = ((Vc-Vbr) x .286) + Vbr.
  - Vcnew = ((420-320) X .287) + 320.
  - Vcnew = 349 volts.

Design

- Additional Options:
  - Ground pins – resistance to shell.
  - Feed through pin – capacitance.
  - Additional capacitance in the same array.

    There can be up to two but the ratio should not exceed 2 to 1.
  - Cross talk between circuits – magnitude.
  - Differential noise filtering – selected pairs.

Specification-Capacitance

- Capacitance
  - The device tolerance is +/-20% and in some cases could be GMV.
  - This test is performed at 1 kHz with a bridge potential of .1 to 1 volt depending on cap magnitude.
  - This test is always performed before the voltage tests to avoid dielectric polarization.

Specification-Dielectric

- Dielectric Integrity
  - Dealing with reputable suppliers the construction of the capacitor element, called an array, with proper specification on the drawing, will meet the application requirements.
  - The device still needs a test. There are two used to verify the dielectric, they are the DWV and IR test.

Specification-Dielectric

- The tests depending on the voltage rating should be performed in one of two ways.
- For a rating of 200 volts DC working, the DWV would be 500 volts DC. (2.5 x working voltage)
  - The DWV potential would be applied and held for 3 to 6 seconds between each pin and all others commoned with the connector shell.
  - At the end of the time line, the IR would be measured. The IR test should be a max of 15 sec.

Specification-Dielectric

- For those capacitors that are rated greater than 800 VDC for DWV, the test should be adjusted.
  - The tester should group all contacts together, each line isolated from each other by a min of 100 ohms.
  - The test DWV potential should be applied to all contacts in the group to ground and held for 3 to 6 seconds.
  - At the end of this test, the IR test between each contact and all others should be done at 500 VDC.

Specification-Dielectric

- For suppliers that use automatic test equipment economy of scale can be achieved by using matrix testing where several contacts are tested at the same time. The contacts are selected so that each contact tested is surrounded by contacts that are connected to shell common. A 100 contact connector at 6 sec dwell per contact would take 13 minutes but a matrix test of 10 contacts in a group would only take 1 minute for the same test.

Specification-Insertion Loss

- Insertion Loss:
  - Amphenol has developed a tool based on actual device performance that is used to evaluate the expected performance of a new filter.
  - The expected minimum limits that it generates is conservative but reliable for all Pi filters and quite good for ‘C’ filters.
  - For all others we use Spice models to generate expected performance.

Specification-Insertion Loss

- However each is only as good as the data input and some times the actual part and a measurement will provide the actual minimums.
- However product verification during manufacture is another issue.
  - Frequency is a limitation for the Production Inspection. This is 100MHz with standard commercial equipment.
  - The other is a maximum insertion loss limit of 80 dB.

Specification-Insertion Loss

- Insertion Loss is determined by the type of filter selected. Once selected there are three elements that will affect how well the connector will perform. These are:
  - Capacitor with in limits,
  - Ferrite bead if an ‘L’, ‘T’, or ‘Pi’ filter, and
  - Grounding to the connector shell.

Specification-Insertion Loss

- Filter characteristics:
  - These style filters will have a performance of 20 dB/element per decade from the cutoff.
  - If the capacitor is not connected to the pin with a low impedance joint, as the frequency increases the performance will roll off and not achieve the limit specified. A Pi will act like an ‘L’ at some frequency between 10 and 100 MHz.

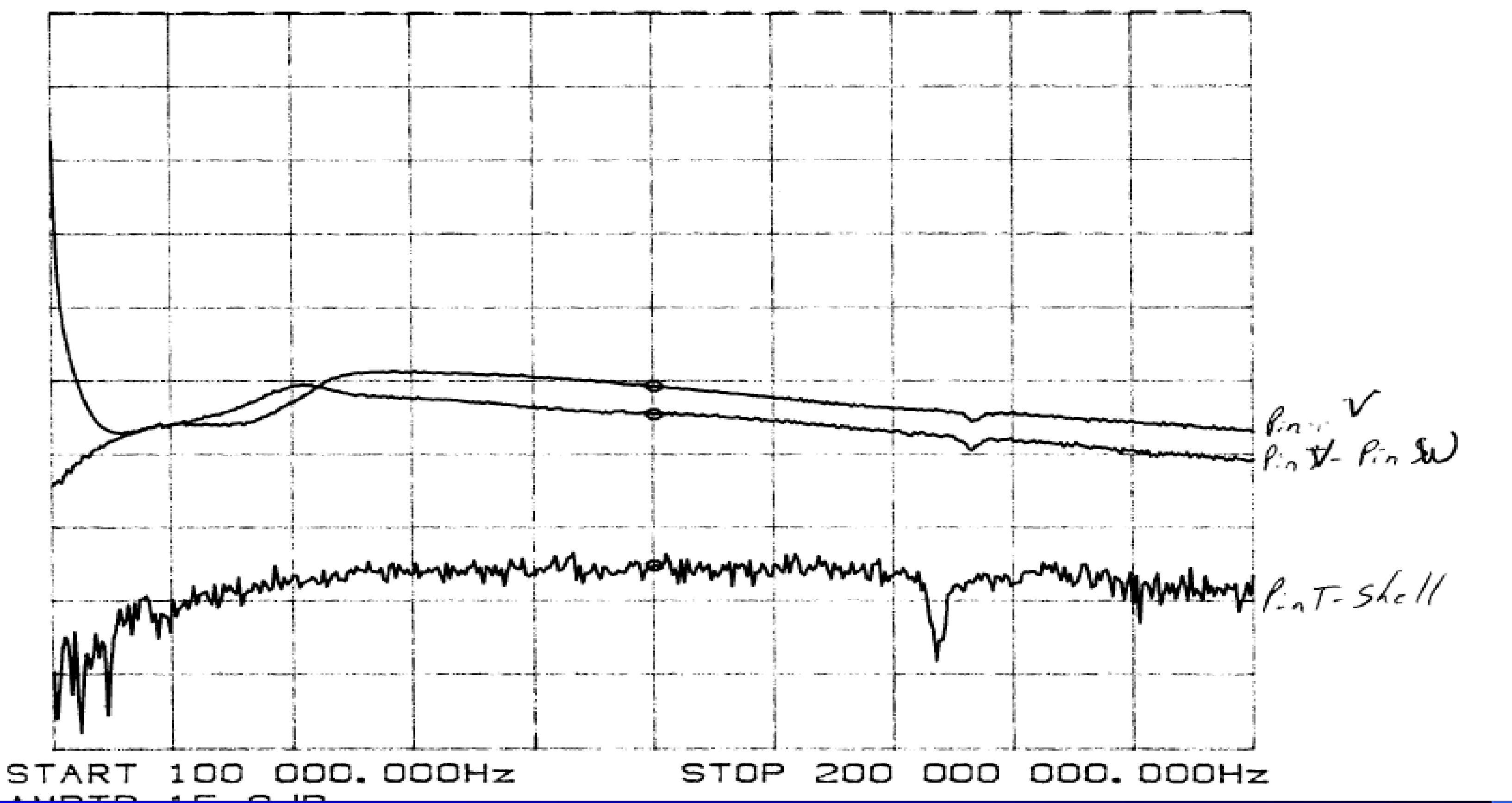
Specification-Insertion Loss

- If the ferrite is missing, the performance will be limited to a two element filter.
- A cracked ferrite will behave the same but at a slightly higher frequency.
- Ferrites have an impedance property that if not met as supplied, the performance will also be substandard.

Specification-Insertion Loss

- Grounding of the filter to ground is very important to include the design of the spring and the interference between the capacitor ground ring and the shell.
  - A filter not grounded properly will have a ground impedance between it and the shell that will roll off the filter performance again between 10 and 100 MHz.

Specification-Insertion Loss



Specification-Insertion Loss

- Characterization of filter performance:
  - During product qualification a frequency sweep through the design range will provide assurances that minimum are met by design.
  - During production this is an other issue.
    - 100 % inspection of each contact in each connector is expensive – There are SCDs that require 100% inspection.
    - AQL sampling of connectors or contacts in each is an other approach.
    - No testing is also an approach. Here capacitance, DWV, and IR are relied on to provide the certification.

Specification-Insertion Loss

- What limits are appropriate for the application has to be determined and then specified.
- The worst situation is that requirements will specify a 8 to 12 nFd Pi filter and list an insertion loss minimum of 55 dB at 100 MHz.
- This device can easily meet this, however at this limit, all of the defects listed above will meet this limit leaving the user with a substandard filter that can cause additional issues, ie cross talk.

Specification-TVS

- TVS devices, MOV or diodes require special consideration as to the verification tests needed.
- Test with an EMI filter will be different that those without an EMI filter.
- In all cases, diode verification of Ir and Vbr are necessary.
- If it is a low capacitance device, the capacitance needs verification. This has to be verified at 1 MHz which is different than the filter.

Specification-TVS

- If the connector is a combination of EMP and EMI, the filter properties will have to be verified before the TVS in inserted.
- The total capacitance of the diode plus the EMI filter have to be considered when the competed connector is tested.
- The insertion loss of this combination can provide surprises with a resonance at the lower frequencies that can decrease the intended insertion loss performance.

Specification-TVS

- A First Article inspection is necessary to verify the device Vc at maximum clamping current. This is a very difficult test and should not be done as part of the acceptance.
- Under no circumstances should the EMP/EMI connector be subjected to an IR/DWV test as with the EMI connector. The TVS devices will be affected and possibly damaged.

Specification-Special

- There are times when special needs are requiring special extra testing.
- These usually are thermal cycling between –55 °C to + 125 °C, 5 cycles with a 30 minute dwell at each temperature.
- Then there is the need to have a burn-in test which can be any combination of temperature, +85°C or 125°C, for 48 to 96 hours with working voltage or DWV voltage applied.

Specification-Special

- Amphenol has added the facility to monitor continuously the insulation resistance at temperature for the duration of the test.
- This is with all contacts grouped together with an isolation resistance of 1000 ohms on each line.
- This data will pick out defectives that will never be seen with the standard burn-in test where the connector is not looked at except before and after.

Specification-Special

- For space applications, there may be the need to do a degas operation prior to shipping the connectors.
- This is 48 hours at 125°C and 10-4 torr.
- For diodes, we have set up a facility to perform an HTRB and check Ir at temperature while at test and after at 25°C without removing the voltage from the device.

Specification-Special

- There are several considerations that are very important:
  - How is the connector to be soldered and post cleaned.
  - Is there a need to have positional location of a PC tail connector. The Mil Spec does not cover this and many users have situations where after mounting the connector to the board the connector does not line up with the chassis.

Options

- As a rule most filter connectors are used in applications were the need is to remove common mode noise.
- When there is a issue with differential noise, there is a solution that can be used in the filter connector with or with out common mode noise.

Options-X2Y®

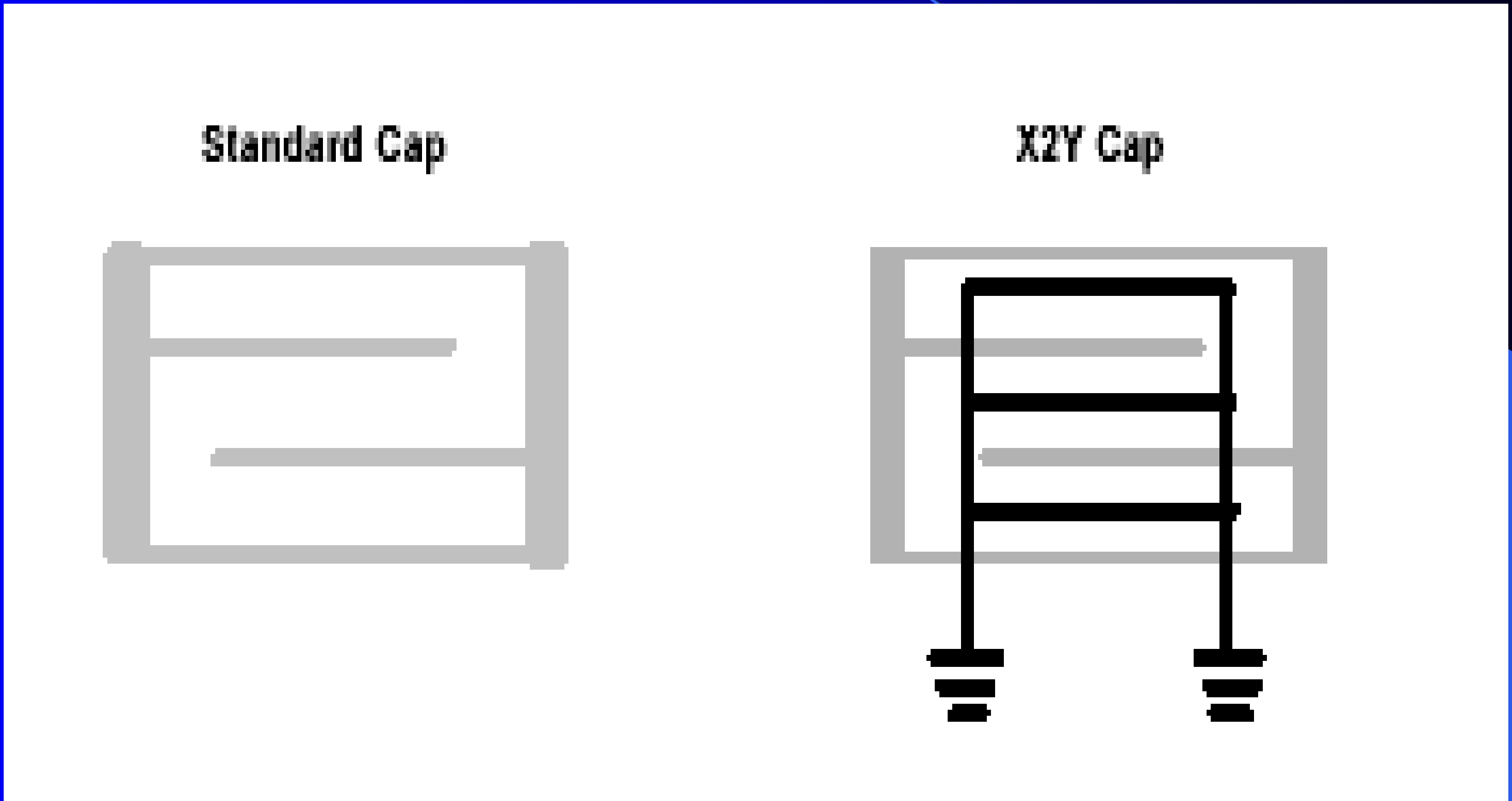
- The most common problem causing the differential noise is that signals are being passed through the connector that have a ground reference that is at another potential than the connector shell.
- This is quite common with digital differential signals and power supply lines.
- In using the connector shell for the filter reference with these lines passing through the filter, there have been serious issues where additional capacitance has been added to the internal board to adjust for the additional noise.

Options-X2Y®

- This solution to these issues is to use a capacitor, planar or chip, that has been made with the patented design from a company called X2Y®.
- These devices due to the internal construction of the electrode layers, achieve a significant boost in performance that has better performance with less capacitance
- Because both hot electrodes share the center ground electrode, simultaneous E and H field cancellation occurs within the part.

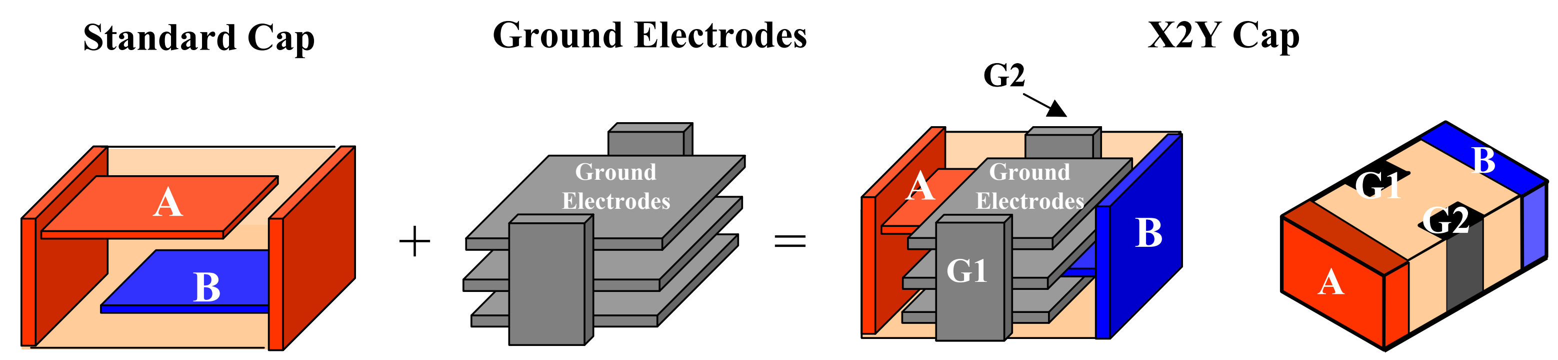
Options-X2Y®

Courtesy X2Y Attenuators,LLC



Options-X2Y®

Courtesy X2Y Attenuators,LLC

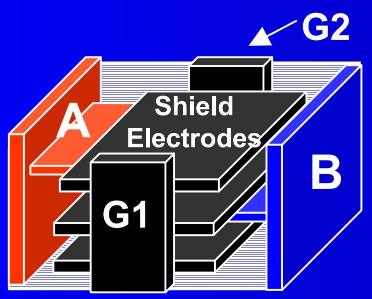


Options-X2Y®

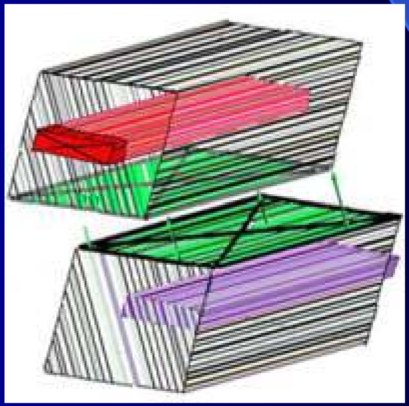
Courtesy X2Y Attenuators,LLC

The X2Y design is similar to a dual rectangular coaxial structure that was studied and modeled by the National Bureau of Standards*. The internal Faraday cage forms a shielded container for each conductor inside the capacitor. At high frequency, the circuit noise in each capacitor will choose the low impedance path of the shield and opposing noise currents will cancel.

X2Y® Capacitor



Two Rectangular Coaxial Transmission Lines (RCTL)



***Reference** to "Theoretical and Experimental Analysis of Coupling Characteristics of Dual TEM Cells" by P.F. Wilson, D.C. Chang, Department of Electrical Engineering, University of Colorado & M.T.Ma, M.L. Crawford, Electromagnetic Fields Division, National Bureau of Standards, Boulder, CO 80303 © 1983 IEEE

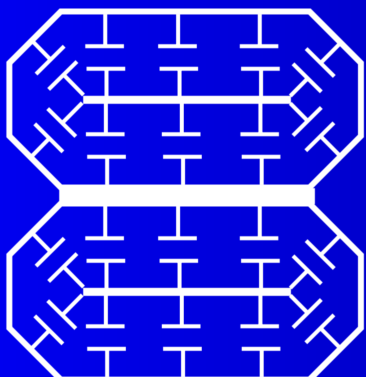
Options-X2Y®

Courtesy X2Y Attenuators,LLC

X2Y is a circuit inside a capacitor that can operate simultaneously in multi-modes.

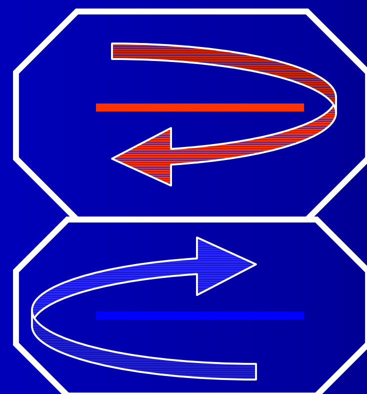
Side view of dual Transverse Electromagnetic (TEM) model

Common Mode Noise Coupling



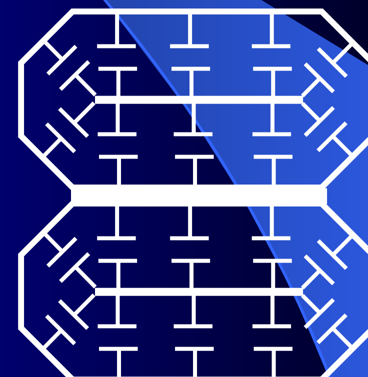
NOTE: Common mode noise cancels at center ground plane when capacitors go into self-resonant frequency.

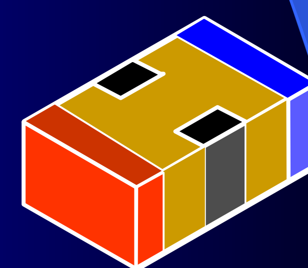
Differential Mode Noise Coupling



NOTE: Differential mode noise cancels at center ground plane when currents are 180° out of phase.

X2Y: Differential and Common Mode



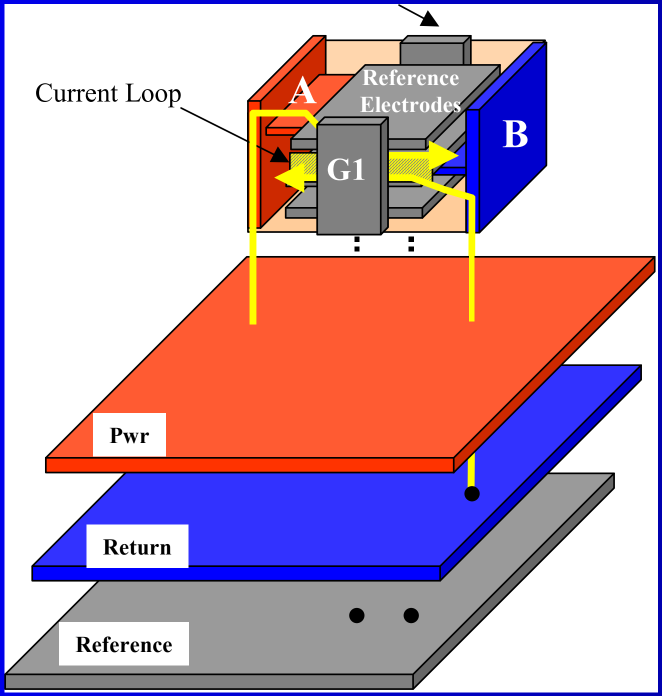


Options-X2Y®

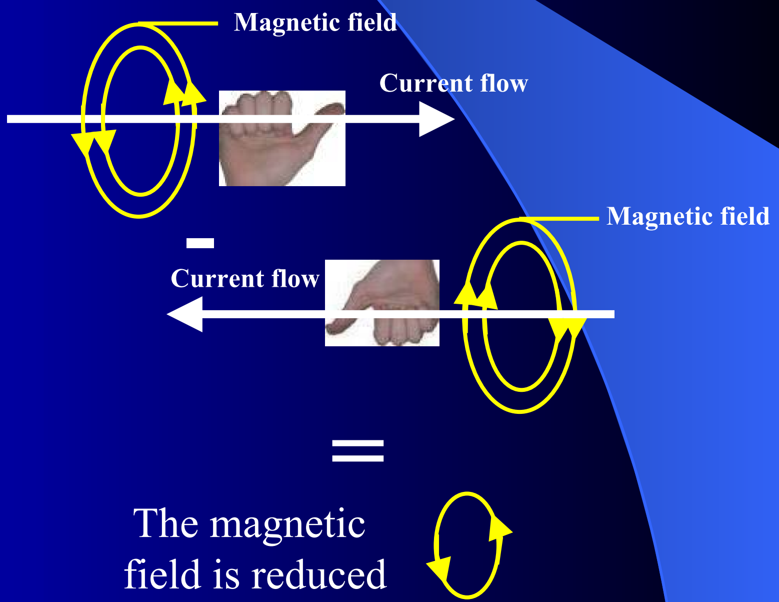
Courtesy X2Y Attenuators,LLC

In X2Y *every other layer* within the single component body is in opposition to cancel the magnetic fields.

X2Y Capacitor



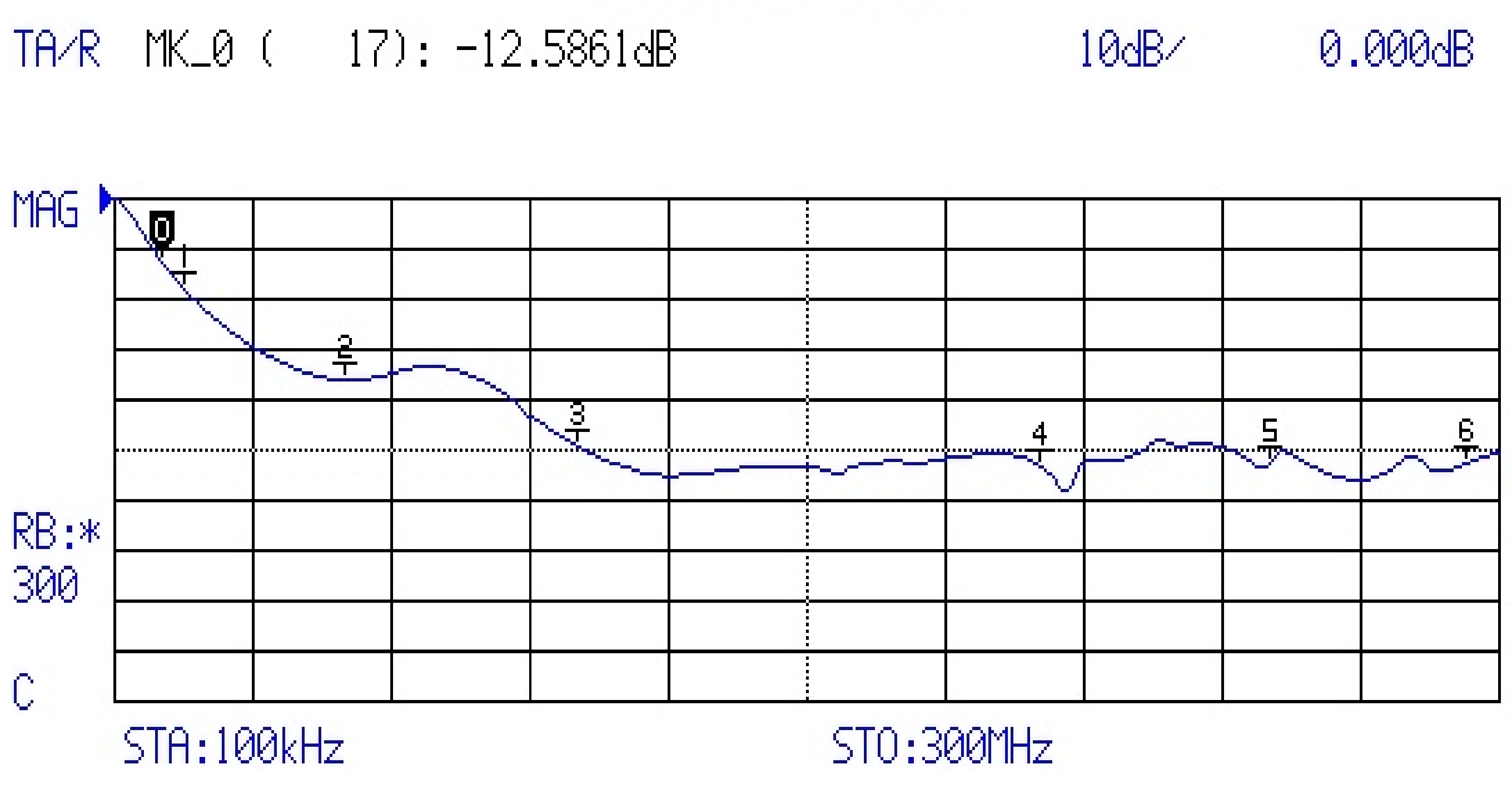
Right Hand Rule



Options-X2Y®

- The advantages include:
  - No series resistance due to the by pass application
  - Very low internal inductance
  - Balanced pair
  - Single chip vs two or three
  - Higher insertion loss with less capacitance.
  - Balanced pairs track over time, temperature, and frequency.

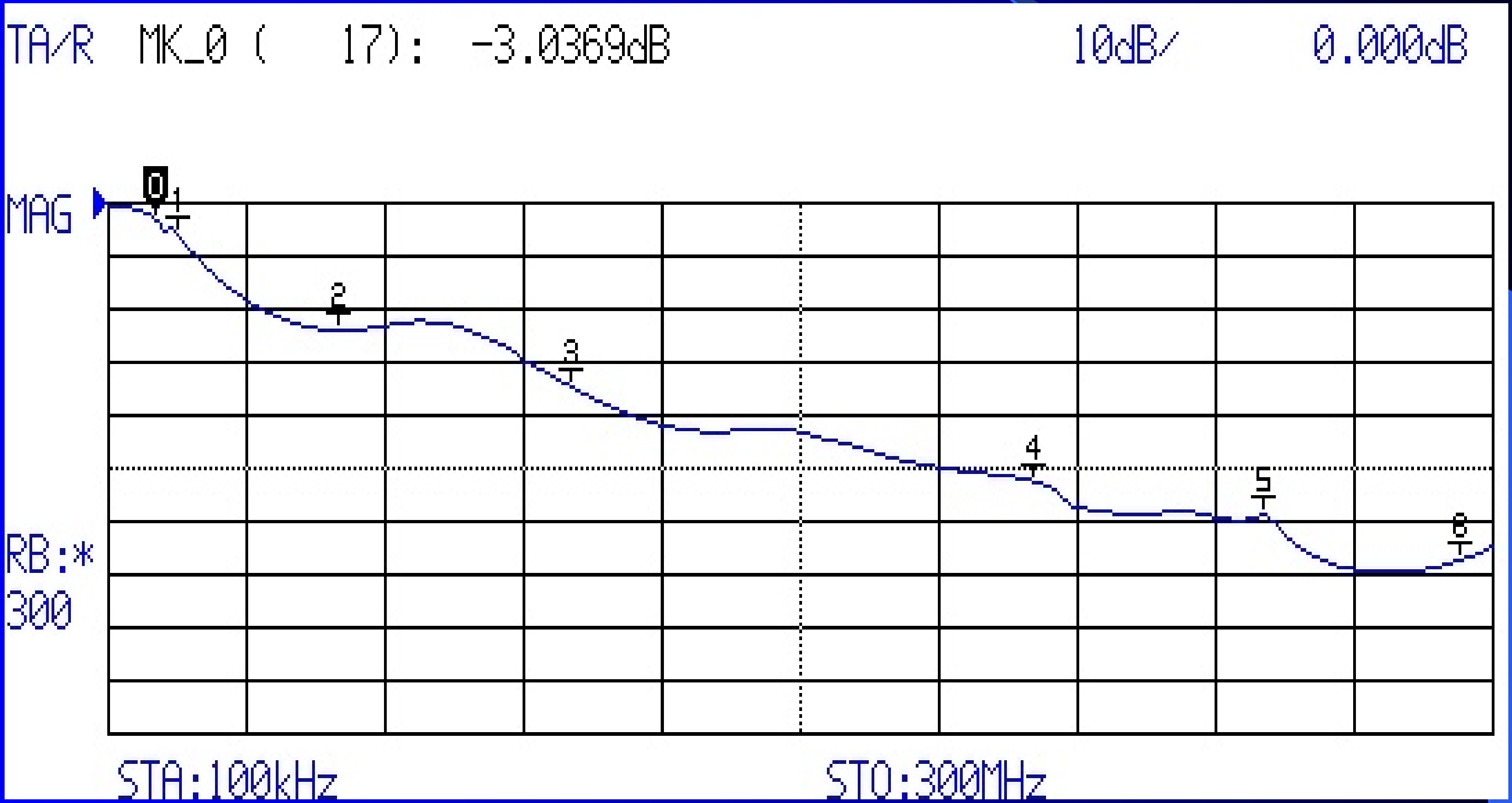
Options-X2Y® 4800 pF



Options-X2Y® 4800 pF

MKR	POINT	FREQUENCY	VALUE
*A0	17	10.296 6MHz	-12.5861dB
A1	25	15.095MHz	-17.9996dB
A2	83	49.883 4MHz	-36.1645dB
A3	167	100.266 6MHz	-49.1953dB
A4	334	200.433 2MHz	-53.0062dB
A5	417	250.216 6MHz	-52.5210dB
A6	488	292.802 4MHz	-52.6975dB

Options-X2Y® 1000 pF

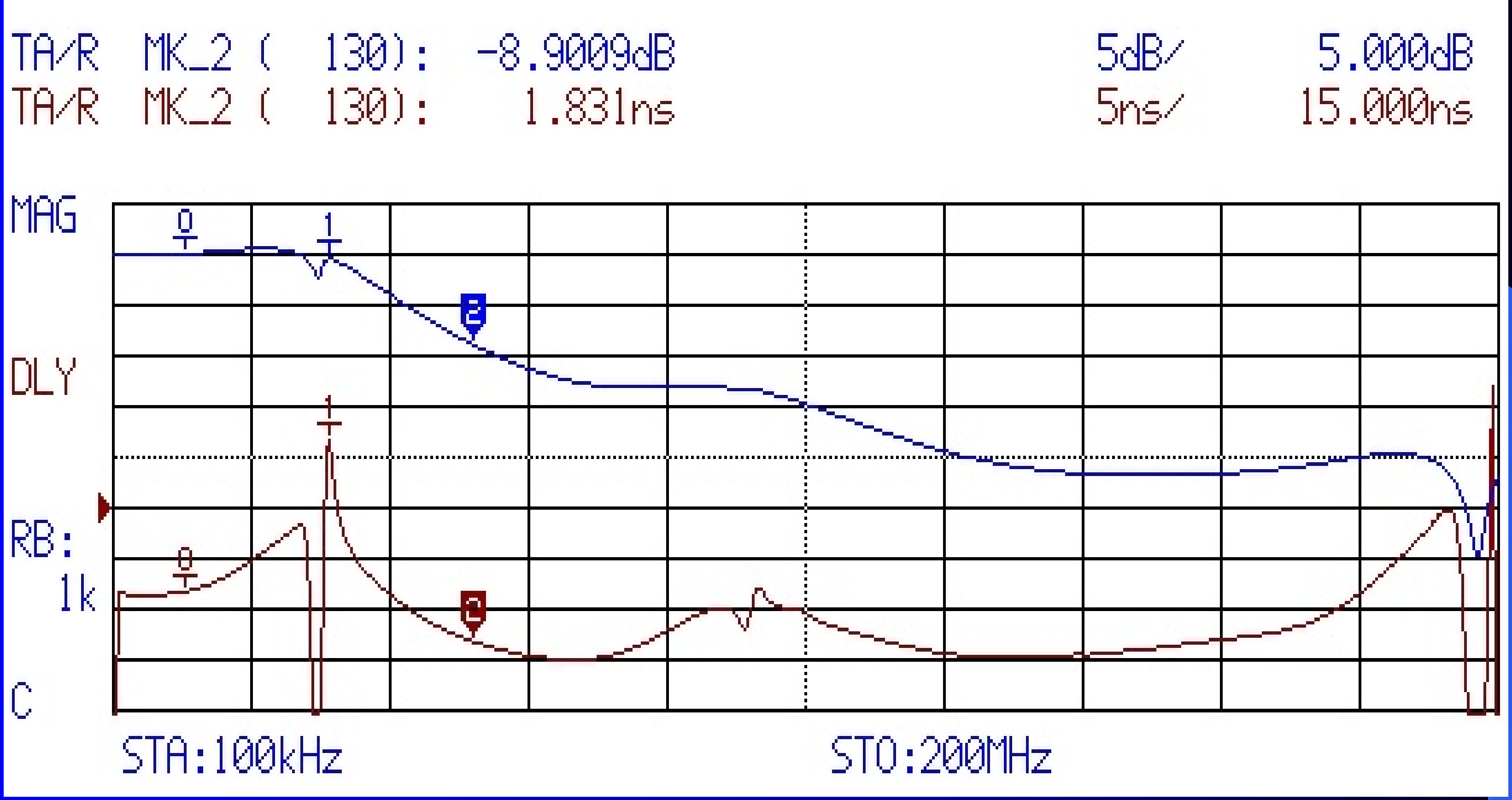


Options-X2Y® 1000 pF

MARKER LIST(TR-A)

MKR	POINT	FREQUENCY	VALUE
*A0	17	10.296 6MHz	-3.0369dB
A1	25	15.095MHz	-6.0389dB
A2	83	49.883 4MHz	-24.0010dB
A3	167	100.266 6MHz	-34.5906dB
A4	334	200.433 2MHz	-52.4392dB
A5	417	250.216 6MHz	-58.8527dB
A6	488	292.802 4MHz	-67.2606dB

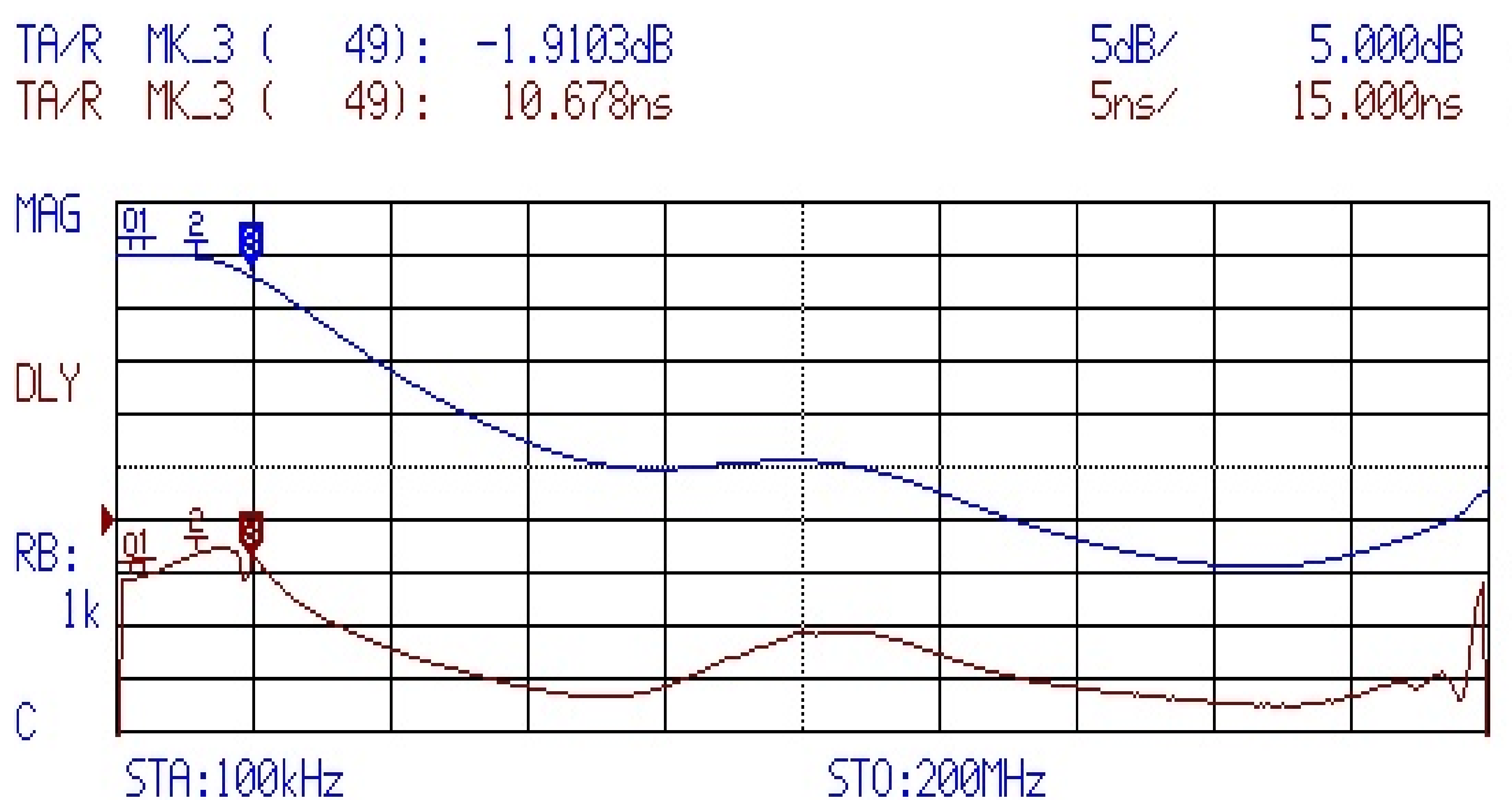
Options-X2Y® 232 pF



Options-X2Y® 232 pF

MKR	POINT	FREQUENCY	VALUE
A0	26	10.494 8MHz	0.0574dB
A1	78	31.284 4MHz	-0.4438dB
*A2	130	52.074MHz	-8.9009dB
B0	26	10.494 8MHz	6.756ns
B1	78	31.284 4MHz	21.560ns
*B2	130	52.074MHz	1.831ns

Options-X2Y® 482 pF



Options-X2Y® 482 pF

MARKER LIST(TR-A&B)

MKR	POINT	FREQUENCY	VALUE
A0	5	2.099MHz	-0.0302dB
A1	10	4.098MHz	-0.0122dB
A2	29	11.694 2MHz	-0.1709dB
*A3	49	19.690 2MHz	-1.9103dB
B0	5	2.099MHz	9.346ns
B1	10	4.098MHz	9.689ns
B2	29	11.694 2MHz	11.760ns
*B3	49	19.690 2MHz	10.678ns

Source Control Drawing

- The final considerations are:
  - Contact termination, PCB, solderwell, crimp, etc.
  - Connector style-Receptacle, Jam Nut, Box or Wall mount, Hermetic, Plug , adapter, or thru bulkhead.
  - Connector Mil Specification for inter mate configuration control.

Source Control Drawing

- Overall length – adding a filter will increase connector length.
- Flange location – to control penetration into the box.
- Plating – Shell, must be conductive
- Plating - contacts.
- Flange, box or wall mount, with threaded inserts, helicoils, or clinch nuts. Clinch nuts require a wider flange to control edge cracking and Helicoils need a thicker flange.

Source Control Drawing

- Will a flex be attached to the connector PC tails?
- Is a double flange needed to attach a PCB of header?
- Will the connector need a special leak rate to suit a special application, ie immersion in water to a depth of 3 feet?

Conclusion

- Filter connectors are a special breed and have evolved to provide many special features that are not available to the standard MS or non MS connector.
- Specials especially to flange or shell are not an issue and can be provided as needed without delivery delays and serious cost issues. In fact most can save on installed cost at the user.

Author Bio

Leonard Krantz

Leonard has born in Buffalo New York in 1938. He has received a Bachelor of Science degree in Physics from Canisius College.

From 1961 to 1963, he served in the Army stationed at Ft Bragg NC. In 1963, he joined the then Bendix Corporation, as a Test Engineer in the Magneto test lab, moving to the Connector test lab after 6 years, then to the Engineering Design group as a Senior Design Engineer for Filter Connector products, then to his current position of Engineering Manager for the EMI/EMP products. During this period, he developed the test methods and techniques for electrical testing of filter and EMP products that were later transformed into computer controlled test stations. Except for a brief period, from 1995 to 1998 with CARON then Winchester Electronics, he has been with Amphenol Aerospace for 40 years.

He is the holder of a minimum of 10 patents in the related field of filter connector design.