How Bad is Bad?
Cavity Signal Injection and Mitigation

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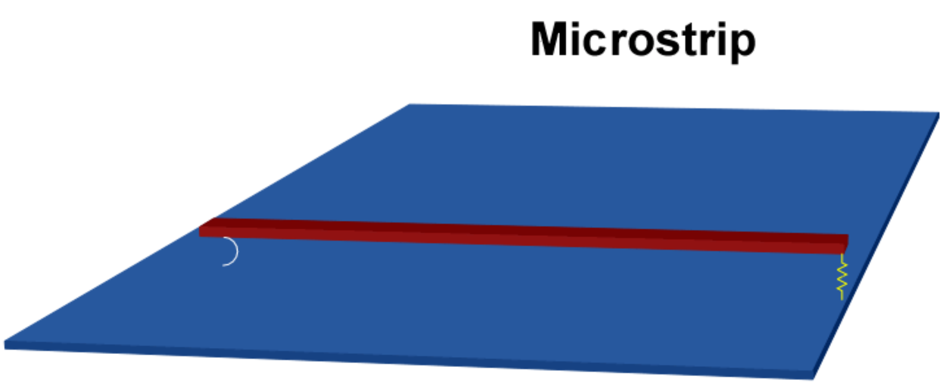
Signals and Cavities

- Almost all signal energy travels through dielectrics.
- Signal traces and return planes almost completely reflect E/M energy, binding it into a limited dielectric volume.
- A signal trace that follows one contiguous return plane sets up TEM propagation between the trace and the plane.

Simple Microstrip Signal Transmission

- Signal is bound by the signal trace and a solid return plane.



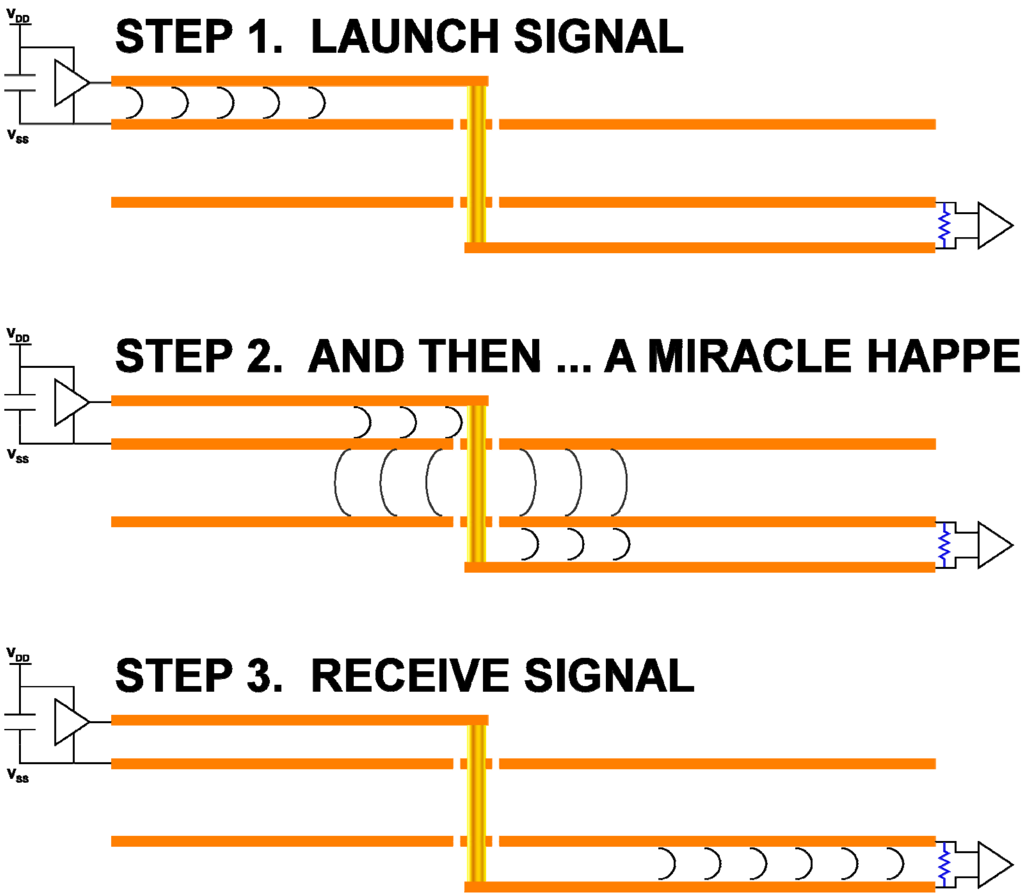
Simple Microstrip Signal Transmission

TRAVERSING A CAVITY

STEP 1. LAUNCH SIGNAL

STEP 2. AND THEN ... A MIRACLE HAPPENS

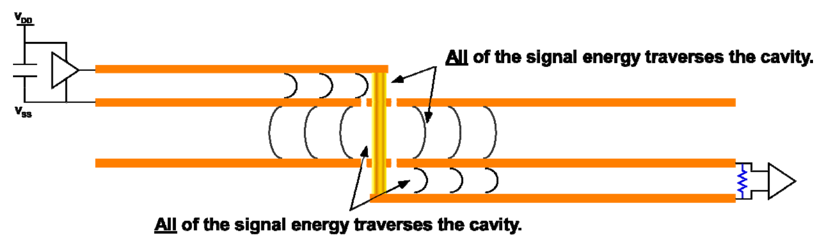
STEP 3. RECEIVE SIGNAL



About That Miracle…

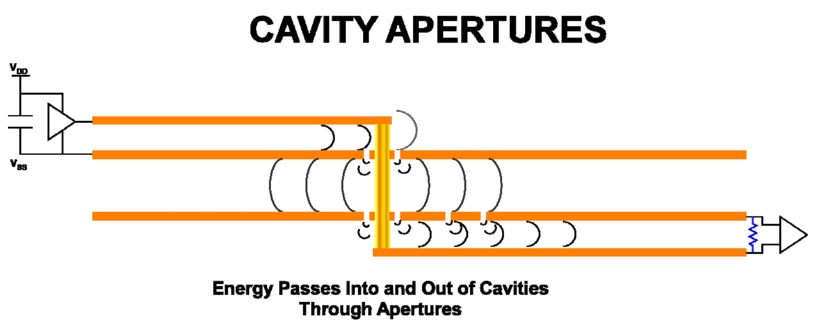
- Virtually all signal energy passes through dielectric.
  - Metal almost completely reflects the E/M energy.
- The energy disperses in the X-Y plane until:
  - Stitch vias, or bypass capacitor structures reflect it.

THE MIRACLE THAT MUST HAPPEN



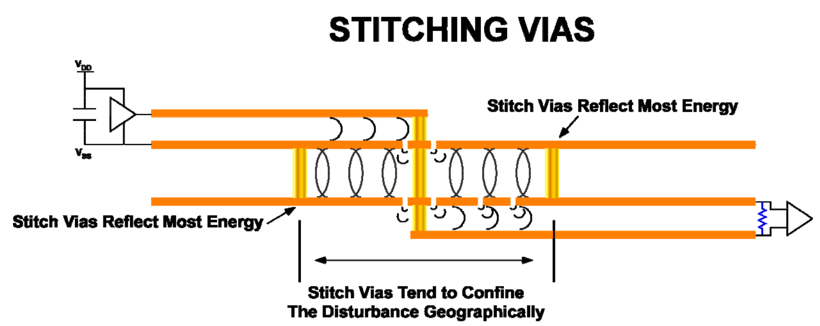
Cavity Apertures

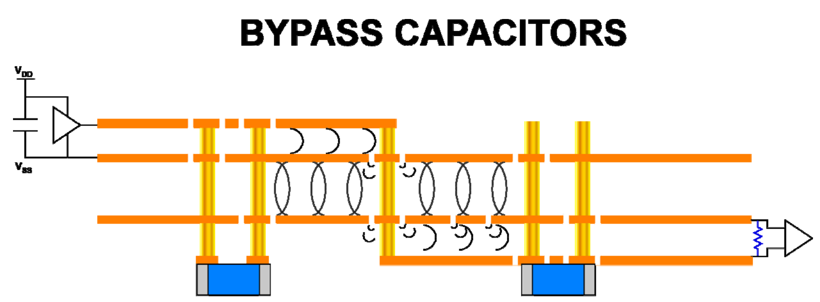
- Metal almost completely reflects E/M energy.
- Energy passes through the Z axis through apertures.
  - A completely unperforated plane would form one side of an ideal Faraday shield
- Metal in proximity reflects energy, guiding most of it.



Stitching Vias, Bypass Caps

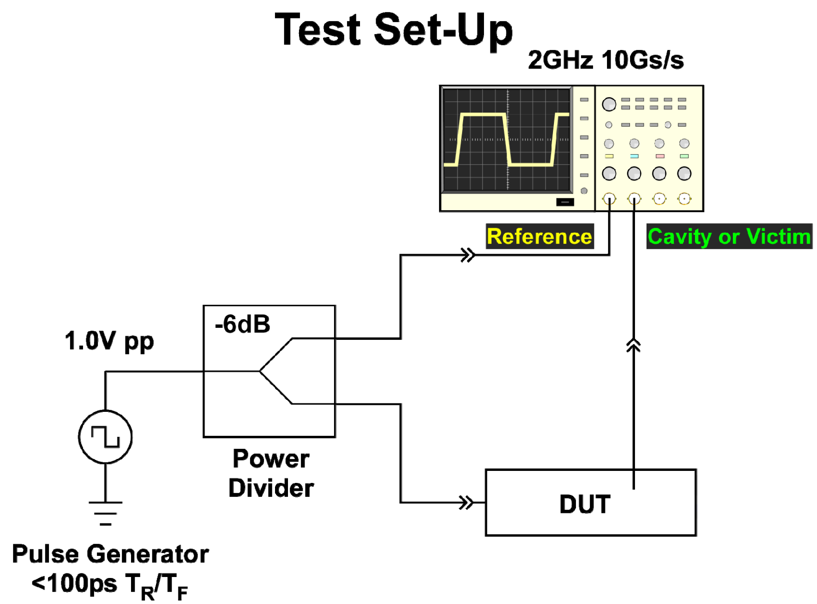
- Stitch vias and bypass capacitors form reflection boundaries.
- Effective inductance of stitching via is limited by cavity thickness.
- Effective inductance of bypass cap includes capacitor and via length from the cavity wall to the capacitor mount.





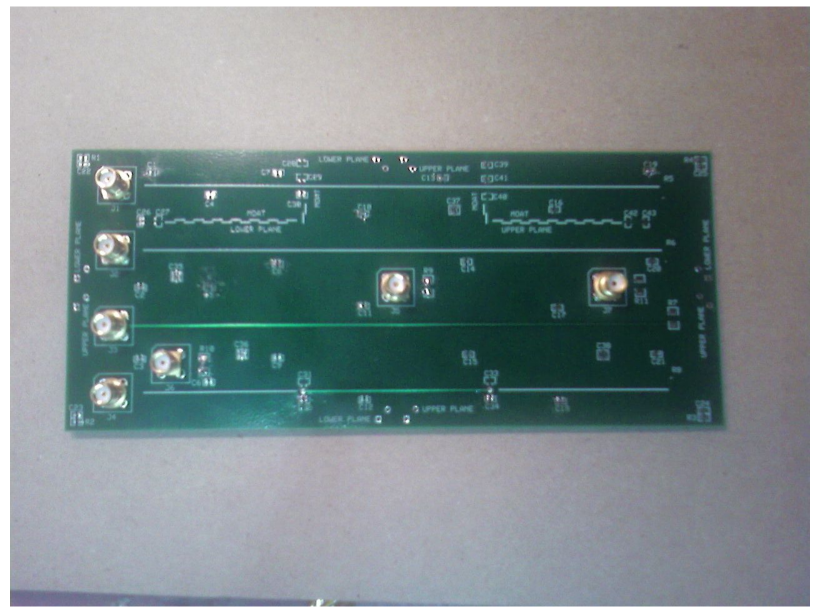
Cavity Injection Test Set-Up

- Pulse generator with moderately fast T_R/T_F, comparable to DDR2, DDR3
- 6dB wideband > 18GHz power divider
- DUT fixture
- 2GHz Scope
- Vary input power w/ attenuator between pulse generator and the power divider



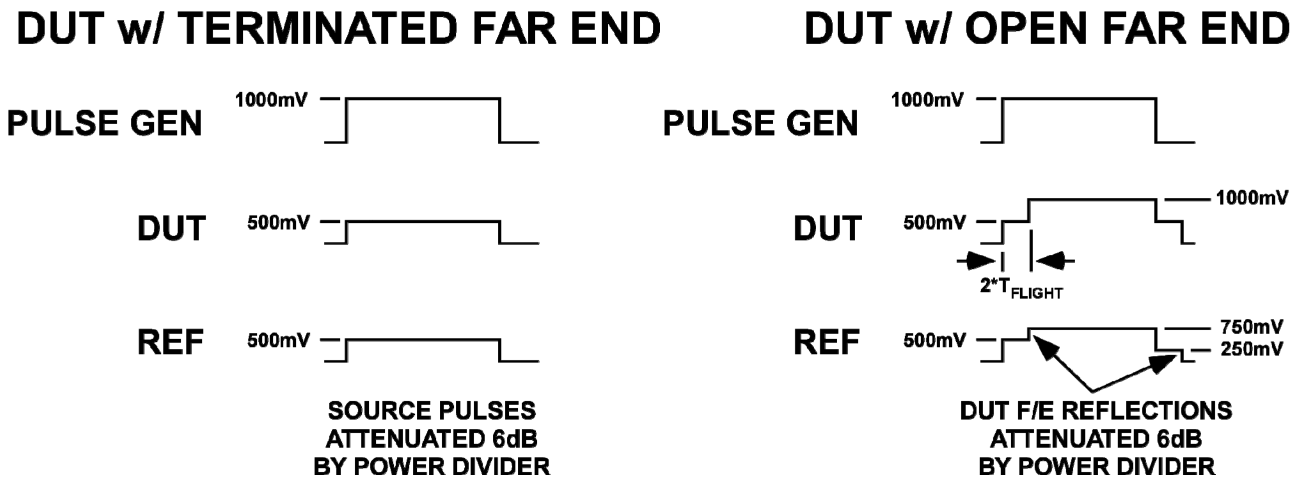
Cavity Injection Test Set-Up

- DUT Fixture:
- Trace 1
  - Layer 4, crosses split in Layer 3
- Trace 2
  - Contiguous over solid Layer 3
- Trace 3
  - Contiguous over solid Layer 2
- Trace 4
  - 2” Layer 1
  - 2” Layer 4
  - 2” Layer 1
- Three cavity probes
- Locations for bypass and stitching capacitors.



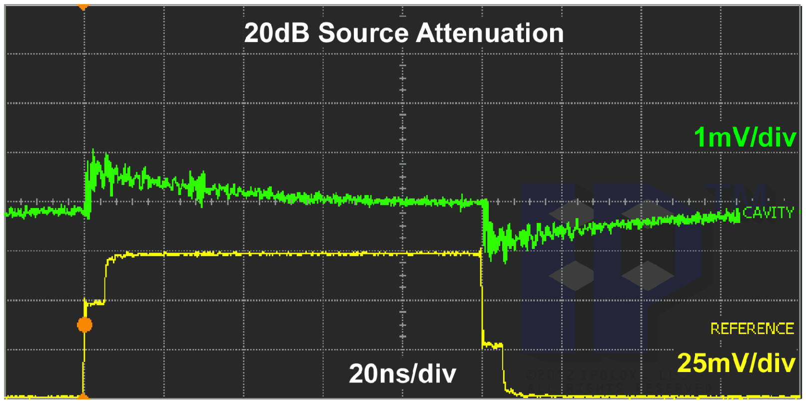
Signal Archetypes

- 1V signal from pulse generator
  - 0.5V leading edges into DUT and REF monitor ports
- Open DUT traces reflect 0.5V edge
- 6dB attenuator cuts DUT reflection voltage seen by REF in half.



Linear Additive Power

Cavity Disturbance No Bypass, Center Cavity Probe
2" Layer 1 -> 2" Layer 4 -> 2" Layer 1 Microstrip Aggressor



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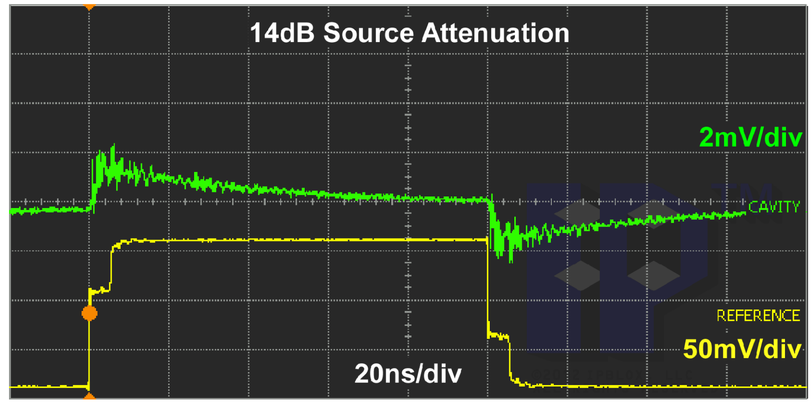

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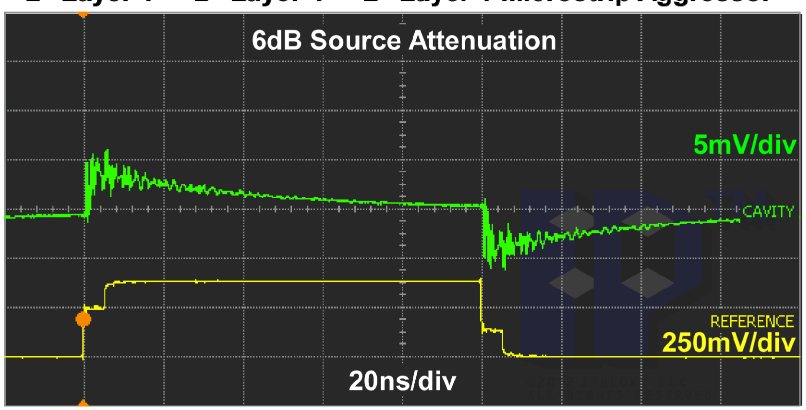

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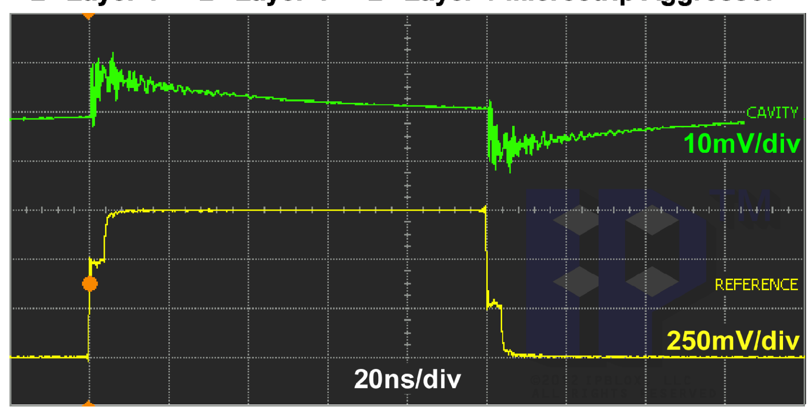

Linear Additive Power

- Cavity disturbance voltage linearly proportional to aggressor √power
  - 100X change in power = 10X linear change in voltage
- What about victim signals?

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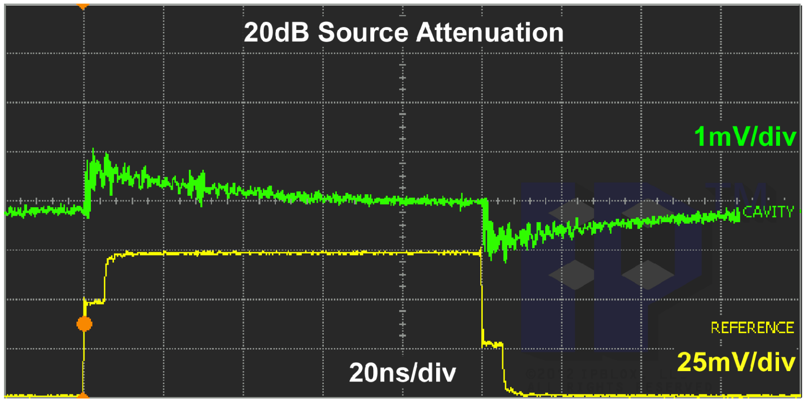

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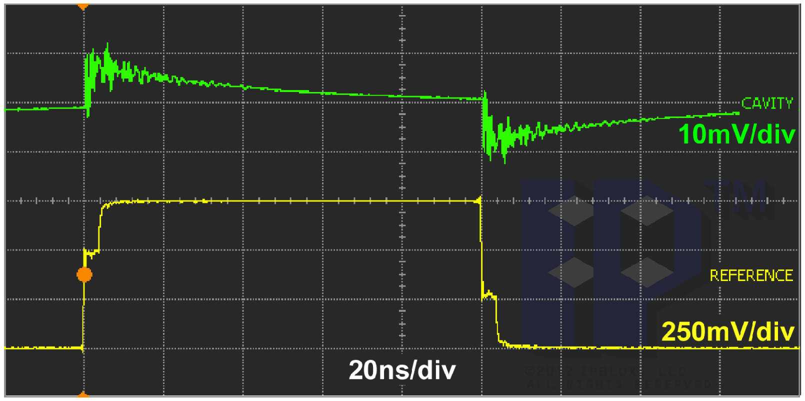
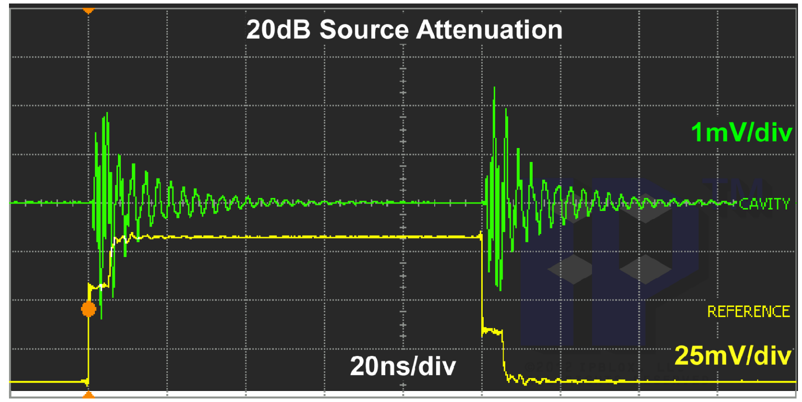


Victim Crosstalk Power

- Cavity disturbance voltage linearly proportional to aggressor √power
  - Mimics cavity noise scaling

Cavity Disturbance No Bypass, Plane Cross Victim
2" Layer 1 -> 2" Layer 4 -> 2" Layer 1 Microstrip Aggressor



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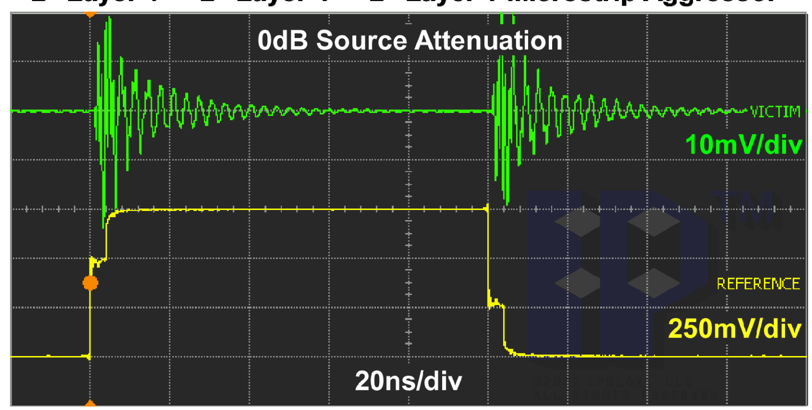


Key Points

- When a signal traverses any cavity, the entire signal energy is impressed across the local impedance of the cavity.
- Noise power adds linearly.
- Ohm's Law still applies: $V_{NOISE} = \sqrt{(P_{NOISE} * Z)}$
- Cross-talk coupled onto other signals that traverse / couple to the cavity also scales linearly in power.

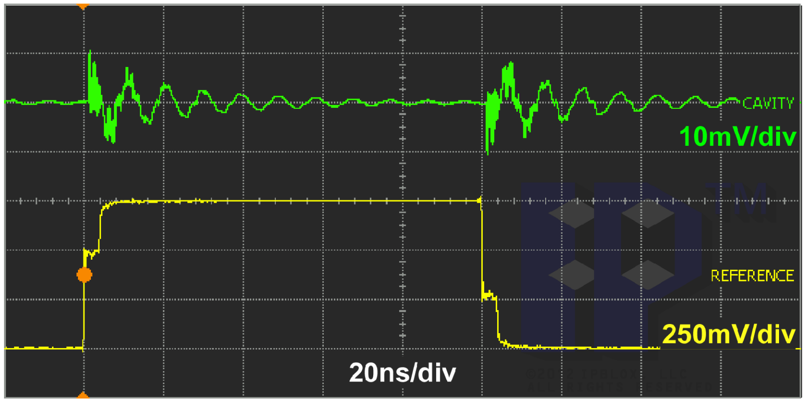
Mitigation Strategies

- Decrease injected power
  - Don’t traverse the cavity
  - How effective are stitching capacitors?
- Decrease cavity impedance
  - Thinner dielectric
  - Loaded dielectrics
  - Cavities with one voltage: via stitch density
  - Power cavities: bypass capacitor density
  - Tame resonances.

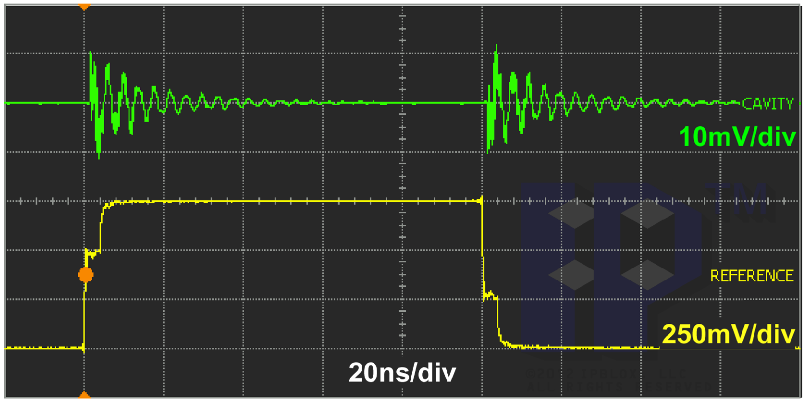
Stitch Via Effectiveness

- Cavity planes joined by only one via exhibit stiff resonances at low frequencies.
- Increasing the number of tie points divides the geometry, pushing resonant frequency up and overall noise down.

Cavity Disturbance Single 0 Ohm Resistor Plane to Plane
2" Layer 1 -> 2" Layer 4 -> 2" Layer 1 Microstrip



Cavity Disturbance Four 0 Ohm Resistor Plane to Plane
2" Layer 1 -> 2" Layer 4 -> 2" Layer 1 Microstrip



Signal Stitch Capacitor Effectiveness

- Effectively another bypass cap
  - Idea is to minimize impact of cavity spreading L
- Depends on signal spectra and attached inductance to the traversed cavity.
  - Typical 0402 500pH + 20pH / mil to cavity center
    - 1.0 – 1.2nH to cavity in center of 0.062” PCB
  - 100ps T_R = 3.5GHz F_{KNEE}
  - 1nH = 22 Ohms @ 3.5GHz

Stitch Capacitor Effectiveness

- Adding a stitch capacitor to each transition decreased victim pp noise by 38%.
  - Effectiveness limited due to capacitor mounted inductance and signal spectrum

Cavity Disturbance No Bypass, Plane Cross Victim
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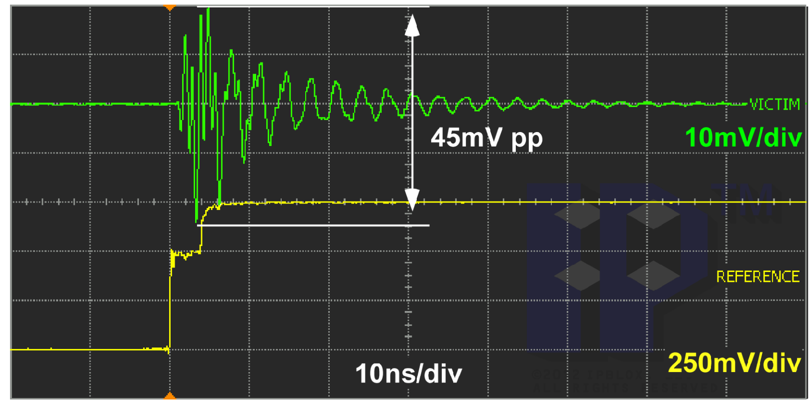

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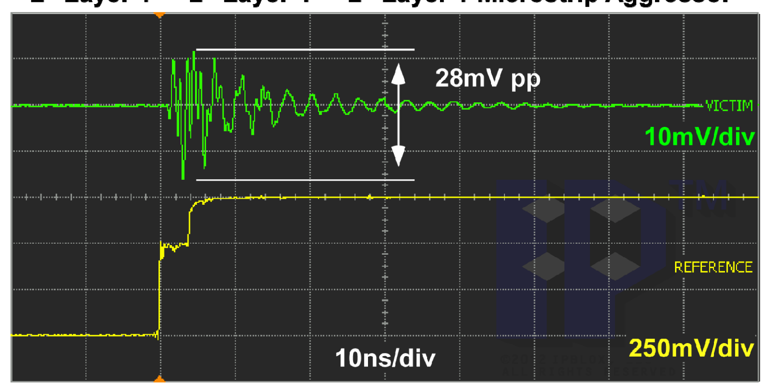


One Stitch Capacitor Each Cavity Transition

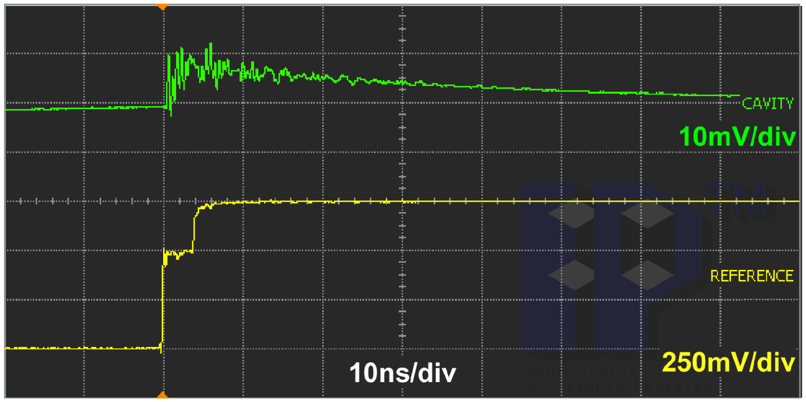
Bypass Network Effectiveness

- Bypass capacitors provide inductively limited shunt paths through a power cavity.
- Resonance forms at cross-over frequency between discrete network distributed L and cavity C.
- Frequency proportional to $1/\sqrt{L}$
  - For like package and attachment caps frequency is proportional to $\sqrt{n}$, where n is the number of capacitors
  - For fast T_R signals, unless the PCB is turned black with caps, the cavity Z sets the initial impulse amplitude.

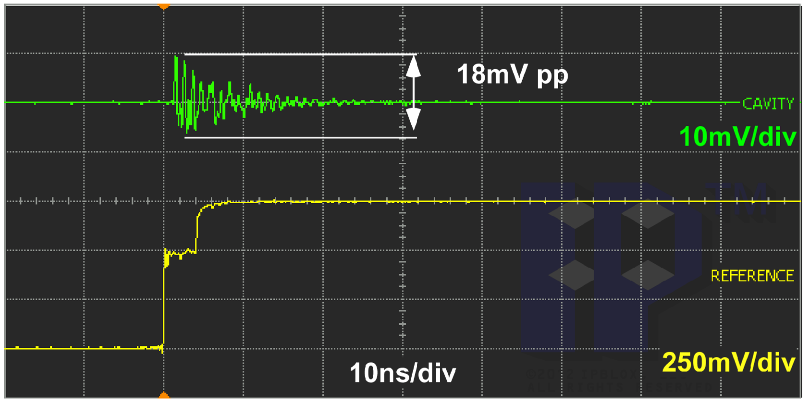
Bypass Network

- Bypass network provides low and medium frequency shunt.
- HF shunt current is drawn from the cavity itself.
- Bypass network resistive near F_{CO}

Cavity Disturbance No Bypass
2" Layer 1 -> 2" Layer 4 -> 2" Layer 1 Microstrip Aggressor



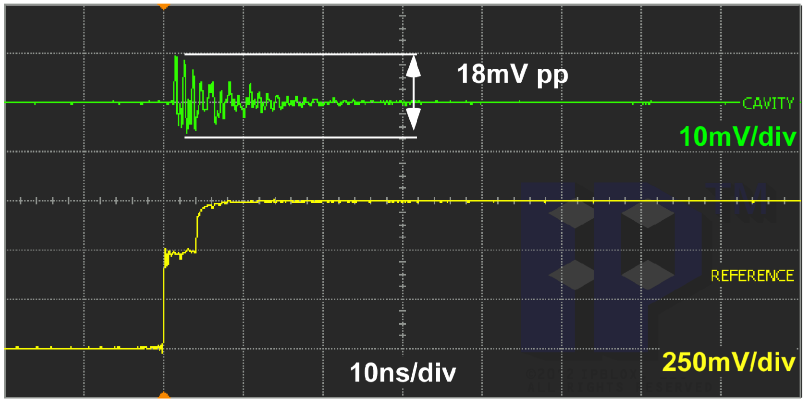
Cavity Disturbance 10X Bypass
2" Layer 1 -> 2" Layer 4 -> 2" Layer 1 Microstrip Aggressor



Reduce Excitation Power

- Where a choice of termination is available, such as which types of signals traverse a cavity, double terminations cut injected power by half versus series terminations alone.

Cavity Disturbance 10X Bypass
2" Layer 1 -> 2" Layer 4 -> 2" Layer 1 Microstrip Aggressor



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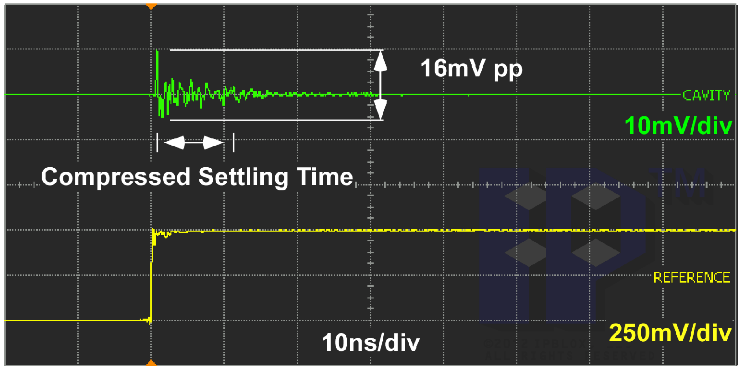
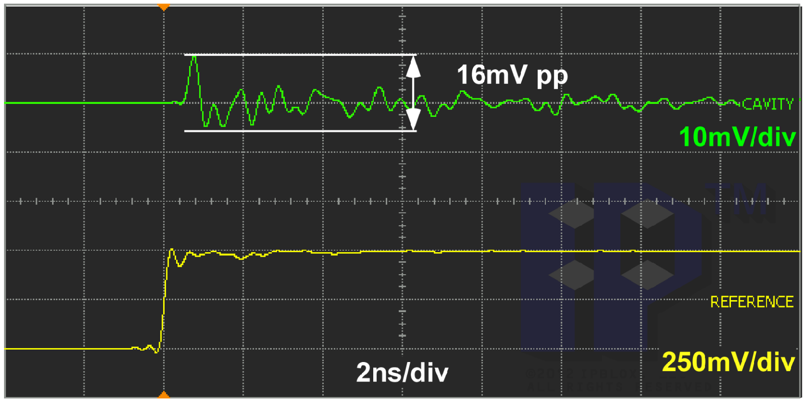


Aggressor End Terminated

Reduce Excitation Power

- Reduced excitation plus careful bypass settles quickly.
- Initial impulse still dominated by the cavity only response.

Cavity Disturbance 10X Bypass
2" Layer 1 -> 2" Layer 4 -> 2" Layer 1 Microstrip Aggressor



Aggressor End Terminated

Reduce Coupling Efficiency

- Rx / Tx reciprocity
  - Reduce victim coupling w/ stitch cap(s).

Cavity Disturbance 10X Bypass, Plane Cross Victim
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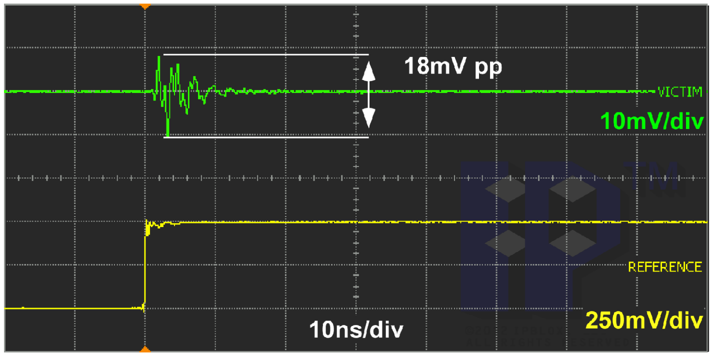

Aggressor Terminated
One Stitch Capacitor Each Cavity Transition

Cavity Disturbance No Bypass, Plane Cross Victim
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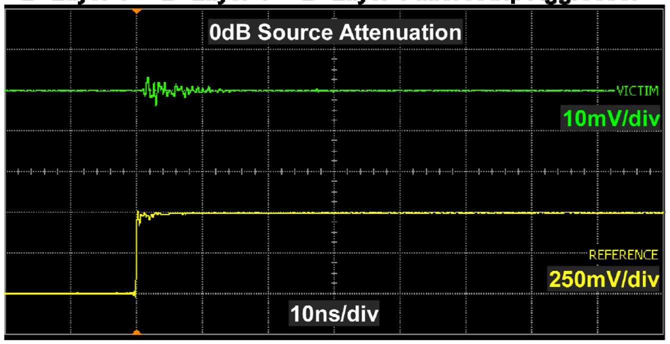

Terminated Aggressor
Plane Stitch @ Both Traverses
Slot Cross Cap @ Victim

Summary

- I/O signals that traverse cavities inject the entire signal energy into the cavity.
- Injected power adds linearly, while noise voltage increases as the square root of the number of signals.
  - A few signals can be OK where many can be disastrous.
- The easiest mitigation when available is to only traverse cavities with dense stitching vias.
- Traversing cavities tied with capacitors induces noise that depends on:
  - Cavity thickness, Er, bypass complement, signal spectrum, and mounted capacitor inductance, and how well the bypass network is designed to avoid a large cross-over resonance with the cavity.
  - Thin cavities exhibit low HF impedance

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