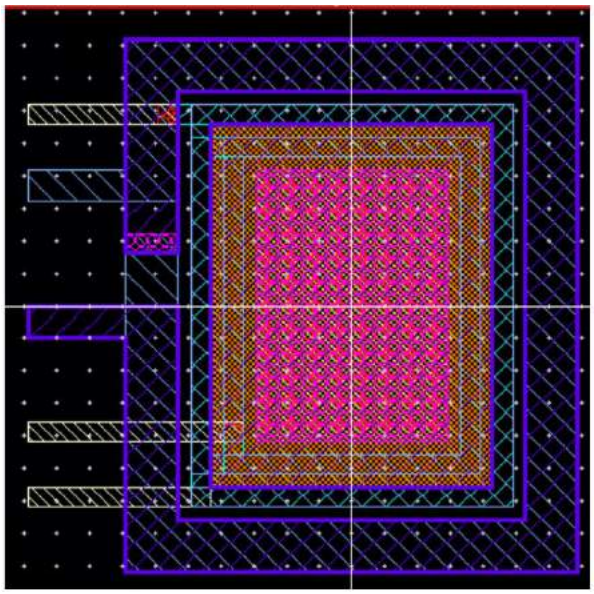
Current RF

CurrentRF PowerPad

Up to 40% Digital and Dynamic Power Reduction
Creates Lowest Impedance Point in IC Power Grids
Dynamic Control of Reservoir Capacitance
PowerGrid Series Inductance Reduction
On-Chip EMI Reduction



General Description

The CurrentRF PowerPad is an embedded Dynamic Power Reduction IP Suitable for Power and Ground Bondpad Overlays. The IP is intended to replace IC Power and Ground Bondpads, leading to an almost zero IC area increase with PowerPad integration. The IP features Capacitance Multiplication, Series Inductance Nullification, EMI Reduction, and Dynamic Power Energy Harvesting. The CurrentRF PowerPad IP creates the lowest Impedance point in IC power grids aiding in maximum on chip supply line filtering, showing an up to a 600X improvement in effective and reservoir capacitance. The IP features a circuit noise activated dynamic input current controlled reservoir capacitance, and can function as a “stand-alone” on-chip DCAP, or work in parallel with existing DCAP structures. Due to the negative feedback embedded in the IP, the CurrentRF PowerPad features a 25% reduction in effective series inductance (ESL). The IP operates by feeding back a portion (nominally 20%) of the bypass current flowing through on-chip bypass capacitors, feeding back current onto the chip power grid, lessening bypass capacitor deep discharge, and lessens deep recharge from system supplies, thus reducing overall chip dynamic power draw. These effects substantially reduce RF Emissions from chip power grids making systems less vulnerable to cyber hacking and more secure. The IP draws no current for operation, thus maximizing block efficiency.

Topology

Ultra-Low Impedance Input Design
Single High Impedance Output
Bi-Directional Bypass Operation
Proprietary/Patented Topology

Features

40% Digital/Dynamic Power Reduction
On-Chip EMI Reduction
600X Increase in Effective Capacitance
25% Reduction in Capacitor ESL

Functional Description

The CurrentRF PowerPad IP is a Supply and Ground Bondpad overlay with embedded feedback which is activated by dynamic noise current applied to it's Dvdd supply terminal. The embedded feedback creates conditions in which capacitive filtering is enhanced, normally thrown away current is recycled, and ESL is reduced, thus creating the lowest impedance point for noise in IC Power Grids.

Figure 1 shows the operation of the CurrentRF PowerPad. The IP block replaces the normal Power or Ground pad (see Figures 2 and 3) with a custom balun, it forming a magnetic connection from the digital supply line to PowerPad internals. The IP fits into any given bondpad, and can be configured into almost any aspect ratio, giving it maximum versatility and flexibility in customer designs.
The IP is designed to be placed into the Padring on ICs, achieving almost zero circuit area increase, achieving 40% Digital Power reduction.

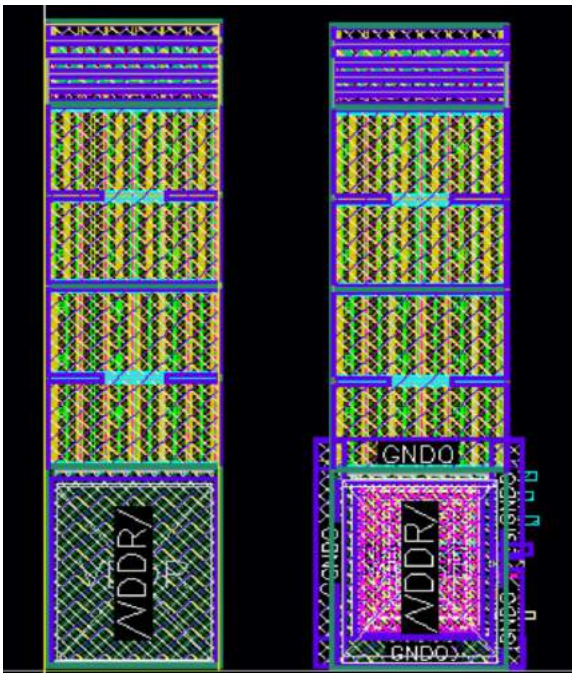


Figure 2: PowerPad Supply Pad Mod

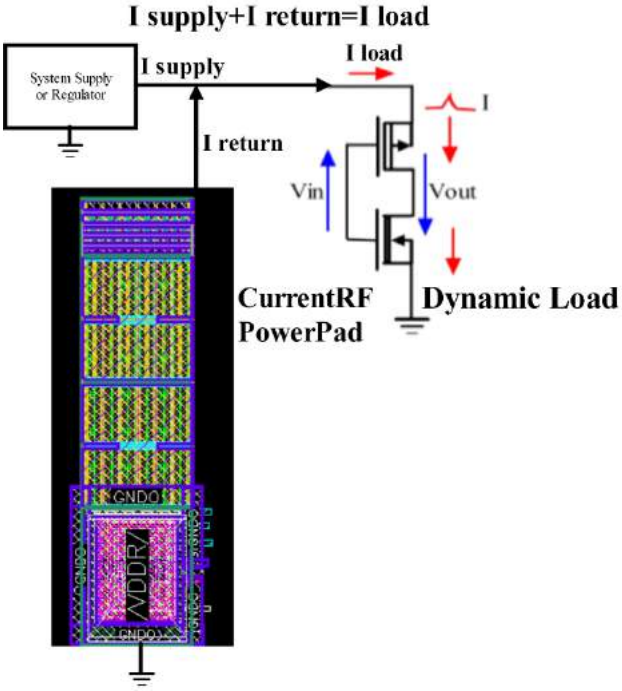


Figure 1: PowerPad Operation

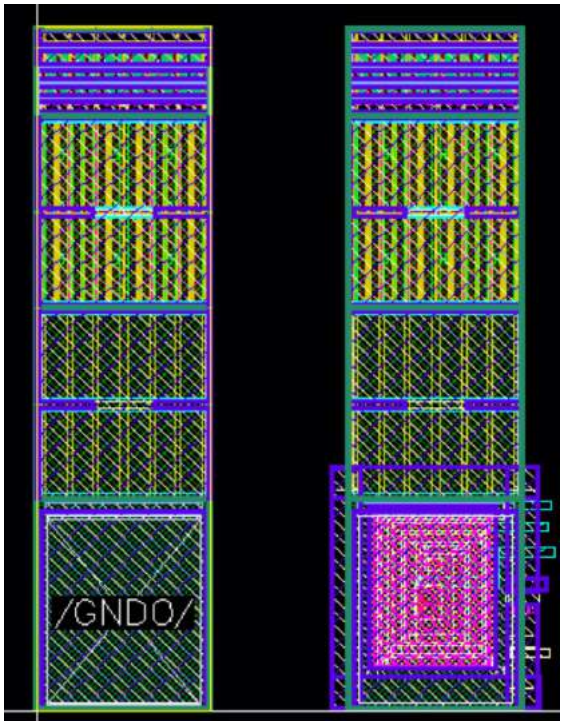
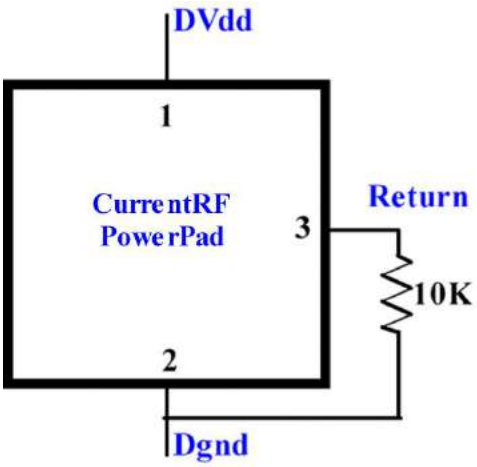


Figure 3: PowerPad Ground Pad Mod



Symbol	Pin	Type	Description
Dvdd	1	Power	Supply
Dgnd	2	Power	Ground
Return	3	Signal	Output Bias
			(Connect to 10K
			on-Chip Resistor)

Figure 4: CurrentRF PowerPad IP Block Diagram and Pinout

Figure 2 shows the CurrentRF PowerPad IP cell and pinout. Three connections are all that is needed for IP block operation. Dvdd and Dgnd are identical in function to conventional DCAPs. The return pin is connected to a 10K ohm on-chip bias resistor, the opposite end of the resistor connected to Dgnd.

Dynamic Power Savings Characteristics

(Digital and Mixed Signal ICs)

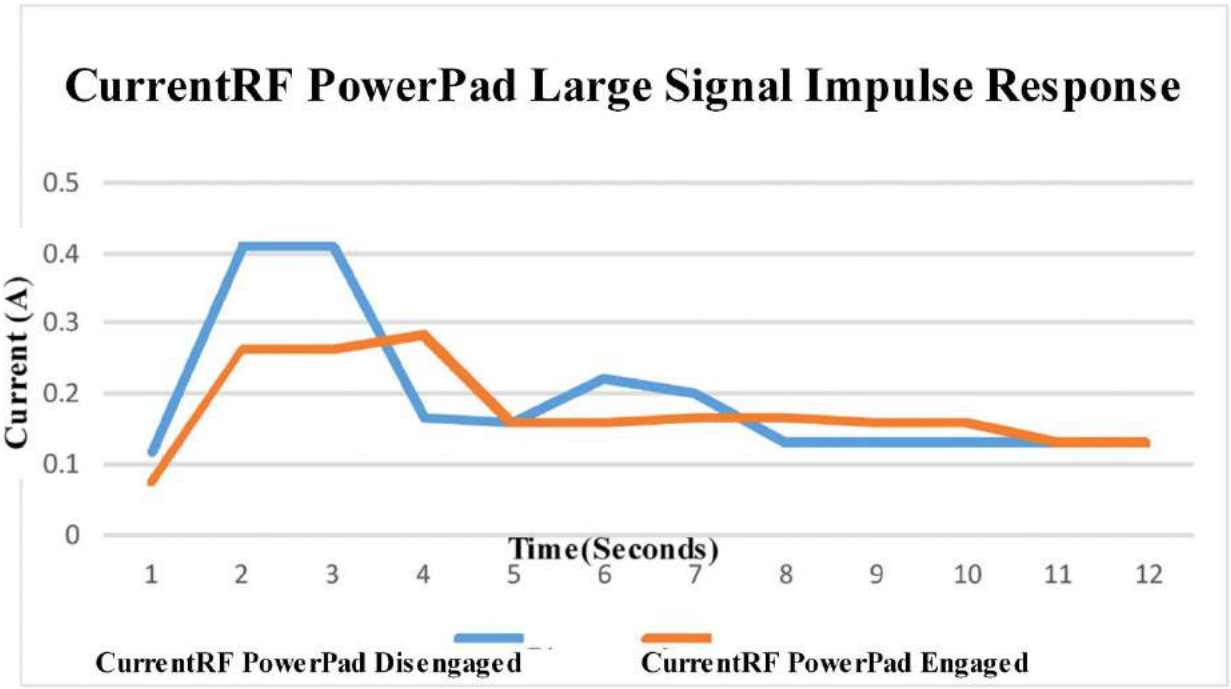


Figure 5: CurrentRF PowerPad IP Cell Transient Surge Suppression Response

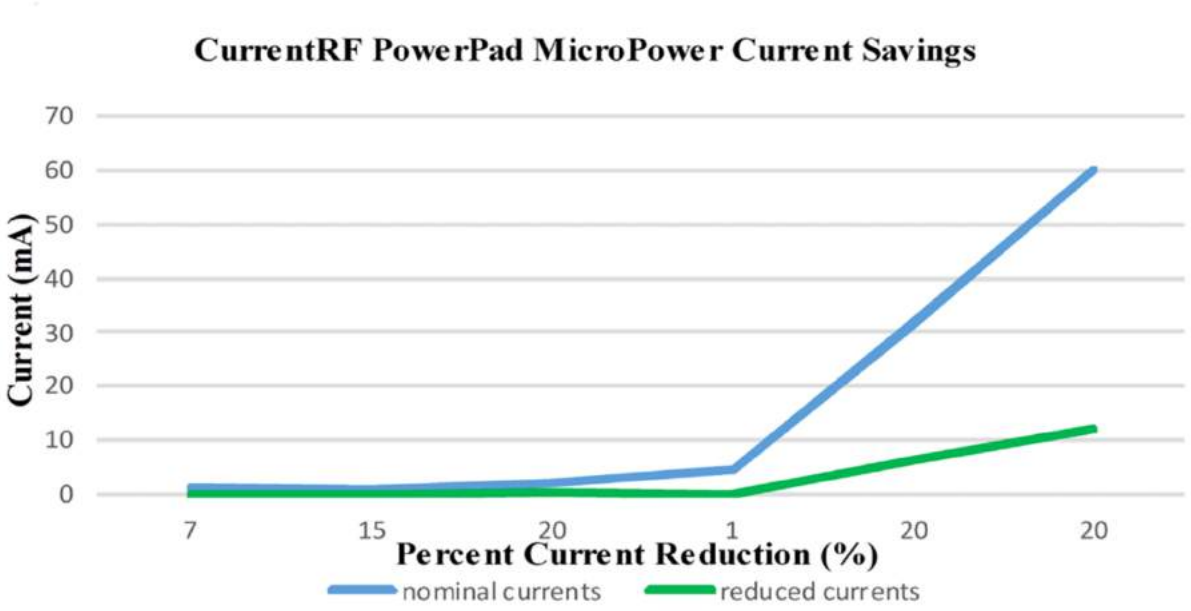


Figure 6: CurrentRF PowerPad IP Cell Nominal Dynamic Current Reduction

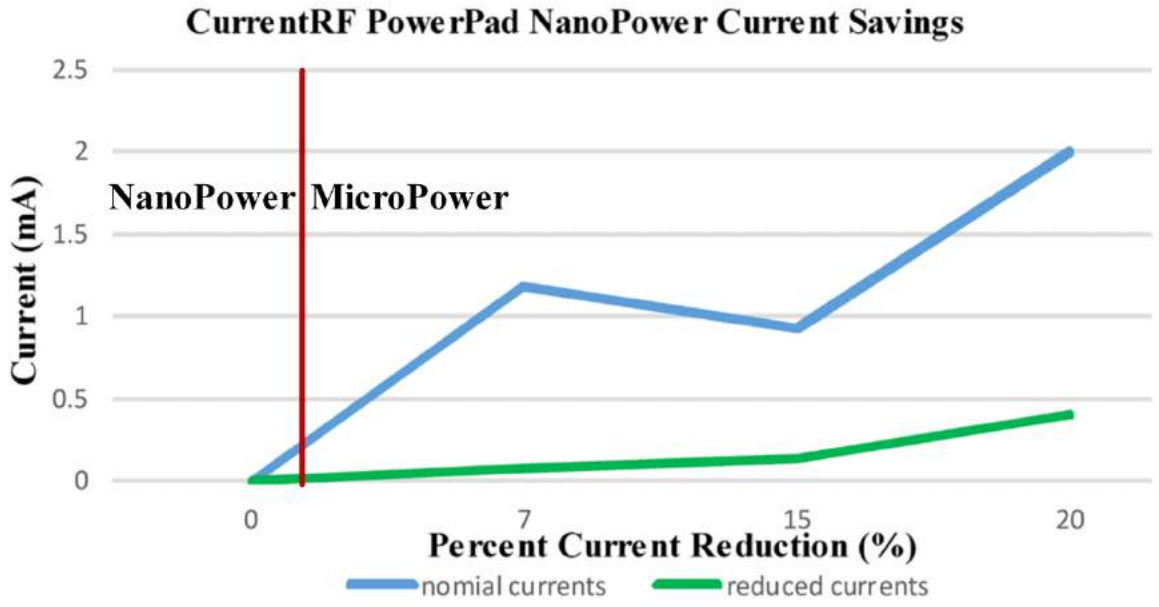


Figure 7: CurrentRF PowerPad IP Cell MicroPower/NanoPower Dynamic Current Reduction

Figures 5, 6, and 7 detail the surge current, micro-power and nano-power response and current savings of the CurrentRF PowerPad IP. The percentage savings range from 40% to 10% savings dependent of conditions and nominal power level. Even at nano-power levels (250uA and below) 1% savings are realized when digital processing is turned on.

Dynamic Power Savings Characteristics

(Electric Vehicles)

The CurrentRF PowerPad IP, when inserted on the ground side of any capacitor, prevents the deep discharge of said capacitors, thus lessening amount of re-charge current required from the battery or supplies in digital and mixed signal systems. The amount of savings is governed by Kirchoffs Current Law for AC circuits, in that the normal On-Chip DCAP overlap current flow (Big Current in RED) is magnetically processed, inverted, and a portion of that original current is fed back (Small Current in BLUE) to cancel a portion of the original current. This action is shown in Figure 8.

This action will happen in any bypass cap system, and the greatest effect and advantage is in DC-Link Capacitors in the drive train of Electric Vehicles. The typical amount of current saved, thus EV Driving Range increased, is shown in Figire 9. Given a nominal 60 Amp Current flow from the EV batteries to drive the switches in Traction Inverters, the nominal current savings is roughly 6 Amps, which roughly translates to a 10% increase in EV Driving Range, Surge current reducton peaks at 14 Amps. The Peak surge reduction is important, in that the battery current surges are what degrade battery longevity, requiring expensive EV battery replacements.

Figure 10 shows the CurrentRF PowerPad minimum current reductions shown in EV testing. These minimum current reductions are similar to that seen in the micro-power savings in Figure 6.

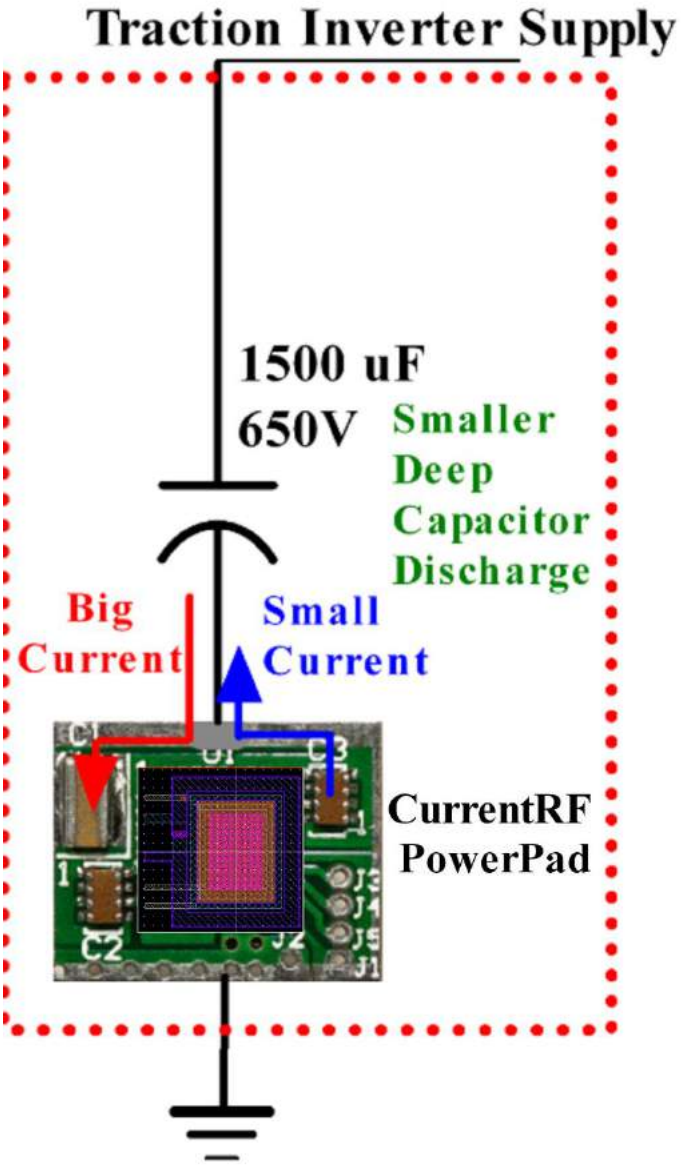


Figure 8: PowerPad inserted on the Ground Side of Capacitors

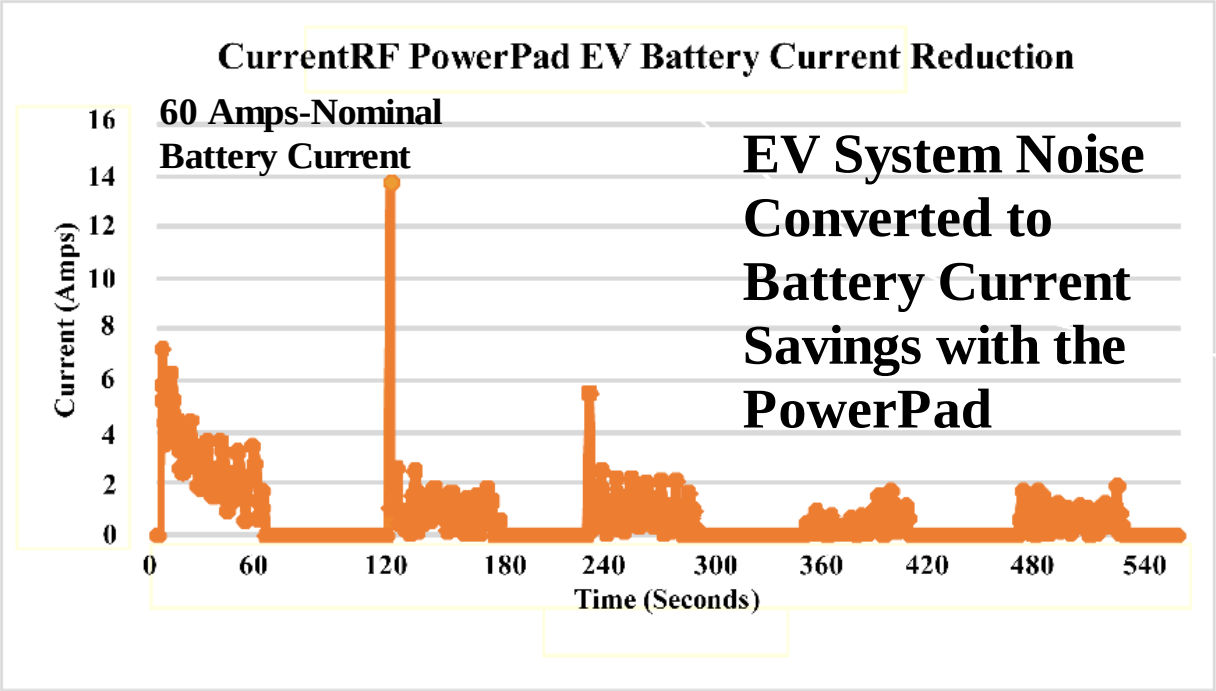


Figure 9: Powerpad Current Reduction in EVs, resulting in 10% additional Driving Range

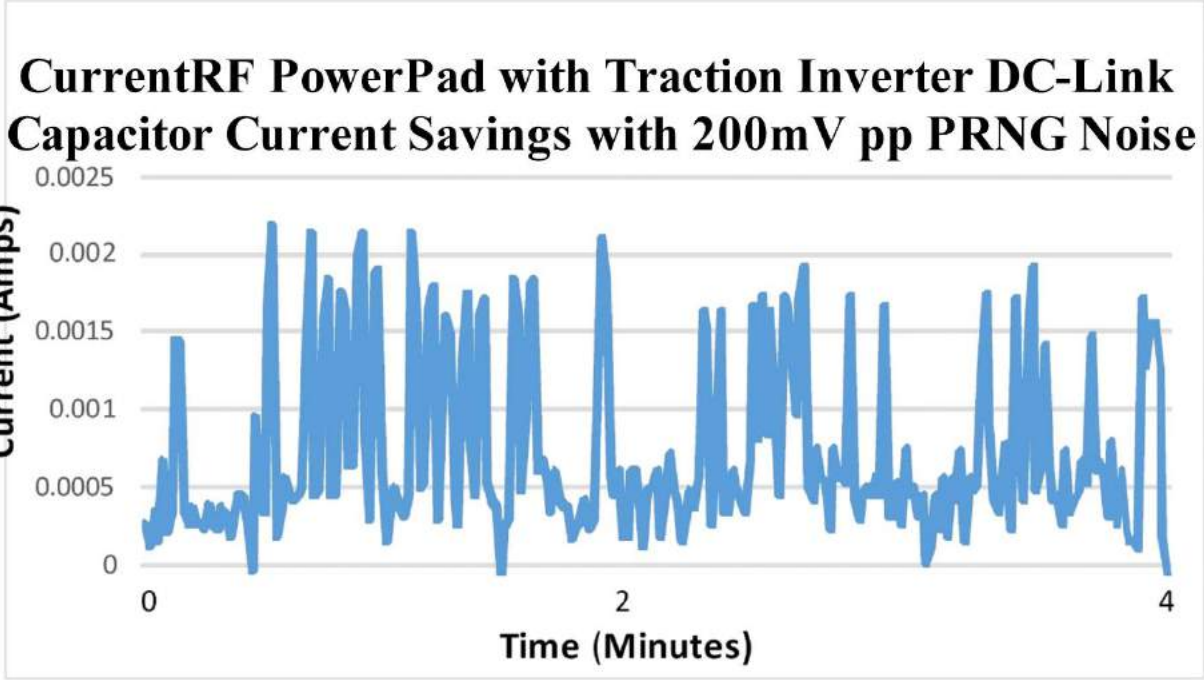


Figure 10: PowerPad Minimum Current Savings in EV Systems

PowerGrid Lowest Impedance Point and Inductance Nullification

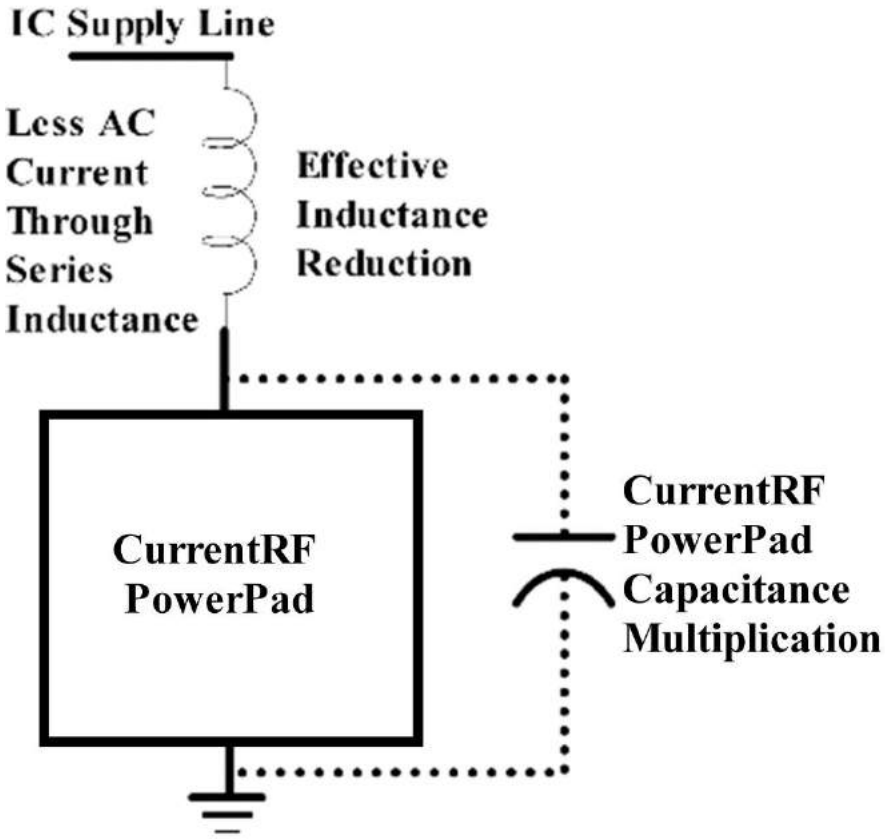


Figure 11: CurrentRF PowerPad IP Effective Inductance Reduction and Lowest Impedance Point Generation

Figure 11 shows the electrical mechanisms that create the lowest impedance node in PowerGrids when utilizing the CurrentRF Powerpad IP as bondpad replacements.The IP reduces the effect of power grid inductance by reducing the impulses created by switching overlap currents created by digital logic (Kirchoffs Current Law for AC Circuits-- shown in Figures 1 and 8—less total AC current draw, less inductive reactance), and the effective capacitance increase (see Figure 13) plus the Capacitive Multiplication described in Figure 14. This lessening of inductive reactance and the increase in Dynamic Capacitance leads to a lower LC resonant frequency, pushing the lowest impedance point lower in the spectrum, which aids in attracting switching noise currents in the system, aiding the Dynamic Power reduction the CurrentRF Powerpad IP affords.

Small Signal Broadband Impedance--Broadband Frequency Response

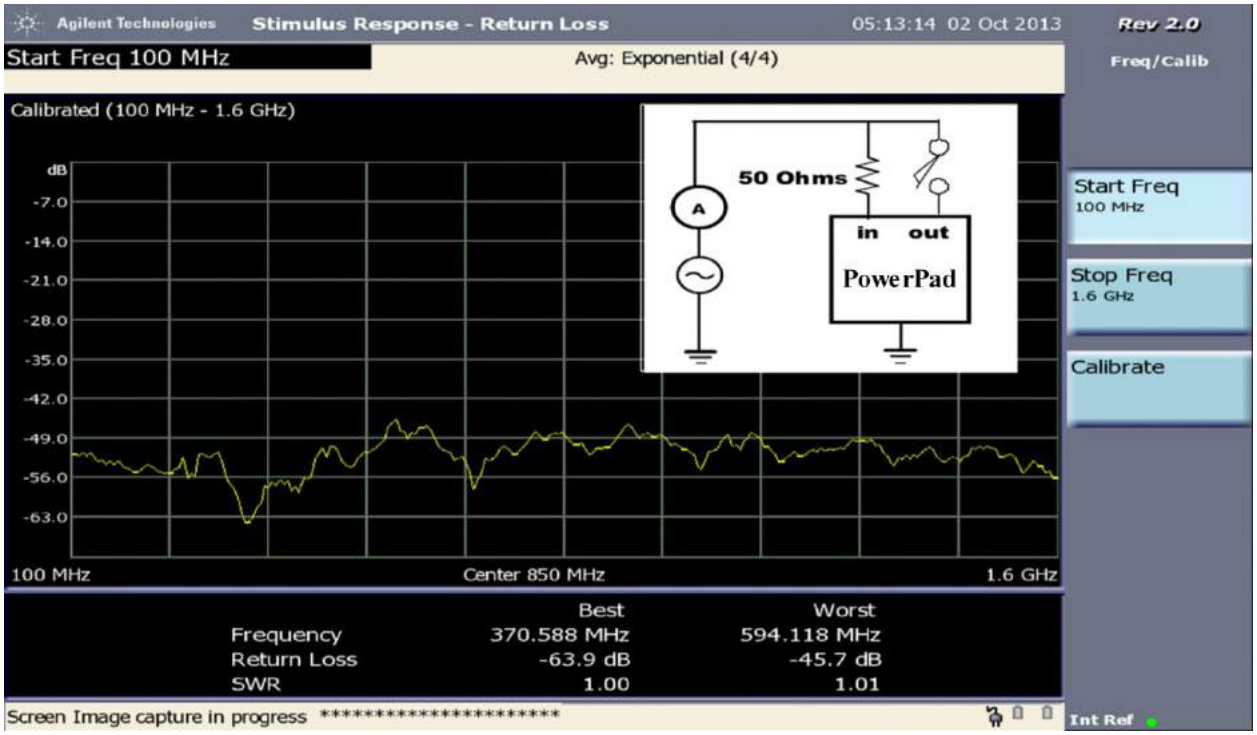


Figure 12: CurrentRF PowerPad IP Small Signal S11 Input Plot (Disengaged)

The S_{11} return loss plot in Figure 12 graphically displays the bandwidth, input impedance, EMI suppression, and spectral response of the CurrentRF PowerPad IP. The plot in Figure 12 shows a CurrentRF PowerPad IP bandwidth ranging from 100Mhz to 1.6Ghz and the wideband S_{11} return loss of the device. With a series 50 Ω resistor placed at the input of the PowerPad IP, as seen in Figure 12, the overall VSWR of the device input is quite good, varying from nearly perfect, VSWR of 1.0 at 370Mhz, to a worst case VSWR of 1.01. The Figure 12 plot shows that the low input impedance of the device is negligible to the total input resistance, and does not show much variation over the input bandwidth of the IP.

In Figure 12, with the CurrentRF PowerPad IP disengaged, looking exclusively into the on-chip input front capacitance (original chip DCAPs in this example), the best return loss/SWR and the lowest impedance point occurs at 370Mhz (-64dB) and corresponds to a capacitive low impedance magnitude of 39 Micro Ohms. A short math proof is as follows:

Equation 1:

$$50 * invlog\left(-\frac{dB}{10}\right) \cong 1/(2 * \pi * f * C)$$

Using the CurrentRF PowerPad IP data, the lowest impedance point frequency in the Figure 12 plot, as well as the “Best” return loss and SWR numbers from the Network Analyzer, gives:

$$50 * invlog(-\frac{63.9dB}{10}) \cong 1/(2 * \pi * 370Mhz * on\ chip\ DCAPs)$$

Solving yields:

$$20\mu\Omega \cong 39\mu\Omega$$

Which, within measurement and error tolerances, the results are essentially equal.

Narrowband spectral peaks and dips remain, however, in Figure 7, indicative of imperfections in the matching of the power grid on the IP evaluation board, test system cabling, and connectors.

The plot in Figure 13 shows the S_{11} spectral results of the CurrentRF PowerPad IP's negative feedback and power grid compensation. The Figure 12 plot demonstrates an increase in overall "returned" current (a 7 dB decrease in return loss, a slightly higher worst case VSWR of 1.03 vs. 1.01), but much reduced spectral peaks and dips, with respect to the plot in Figure 12. This return loss and VSWR decrease is not due to typical load mismatch effects, but is the result of CurrentRF PowerPad IP action, returning current to the system for reuse. Thus, in the plot in Figure 13, the network analyzer power detectors show the device current return and negative feedback compensating for the imperfections present in the power grid on the CurrentRF PowerPad IP evaluation board, test system cabling, connectors, etc.

Using the same input DCAPs as was used in the Figure 12 plot, and engaging the CurrentRF PowerPad IP, the best return loss/SWR the transfer function lowest impedance point is translated down to 170Mhz(-56.3dB), as seen in Figure 13. Accounting for a +7 dBm scaling with respect to the Figure 12 plot, this due to return currents flowing from the CurrentRF PowerPad IP output into the Network Analyzer detectors, the low impedance point corresponds to a capacitive low impedance of 42 Micro Ohms. This low impedance dip in Figure 13 fits the impedance and frequency characteristic that would be seen utilizing 2X the value of the on-chip input DCAPs. This measurement confirms the effective capacitance increase generated by the action of the CurrentRF PowerPad DCAPs. The math for this condition as follows:

Equation 2:

$$50 * invlog((-dB - 7dB)/10) \cong 1/(2 * \pi * f * C)$$

Using the CurrentRF PowerPad IP data, the lowest impedance point frequency in the Figure 13 plot, as well as the "Best" return loss and SWR numbers from the Network Analyzer gives

$$\left(50 * invlog\left(\frac{(-56.3dB-7dB)}{10}\right)\right) \cong 1/(2 * \pi * 170Mhz * 2x\ on\ chip\ DCAPs)$$

Solving yields

$$23.4\mu\Omega \cong 42\mu\Omega$$

Which, within measurement and error tolerances, the results are essentially equal.

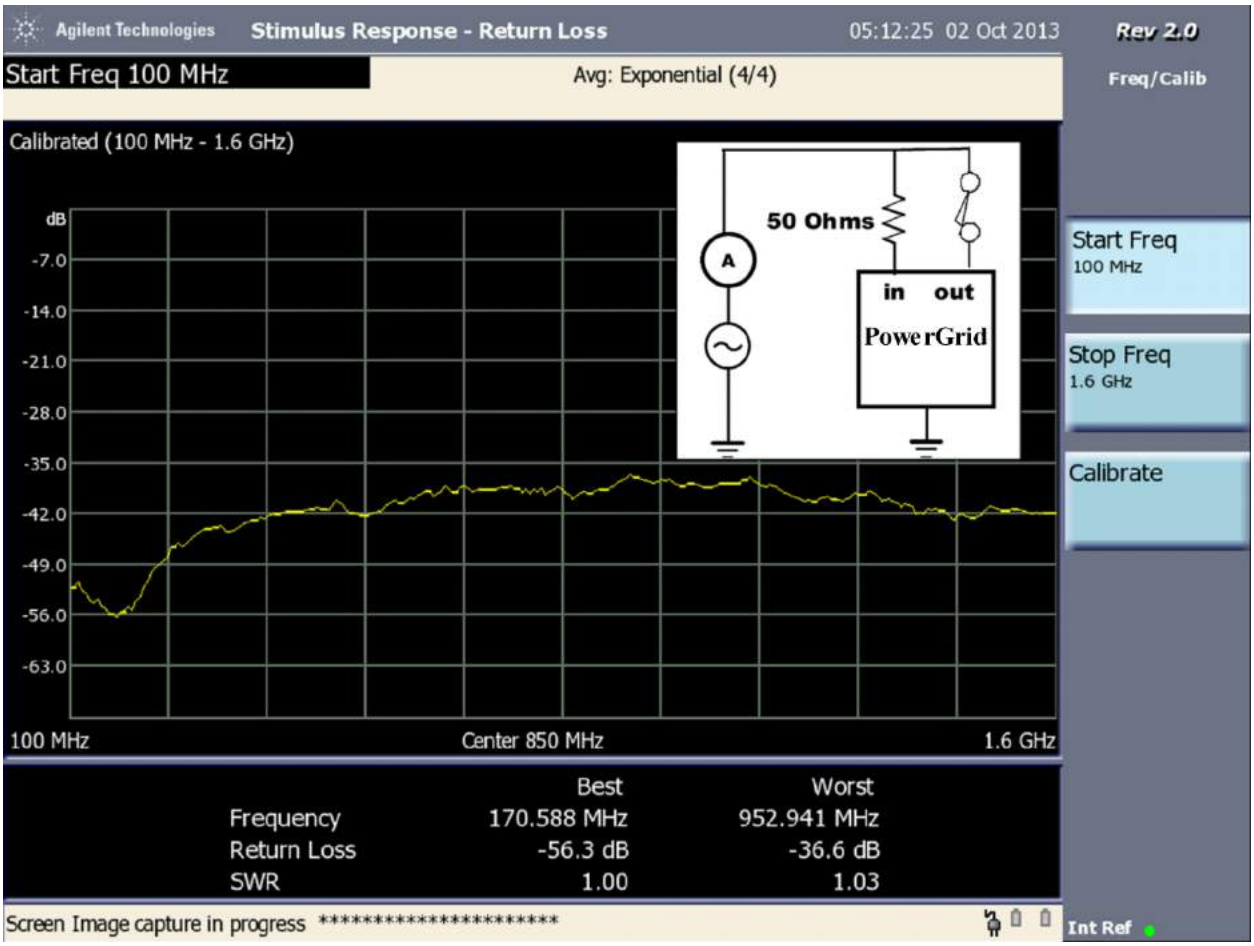


Figure 13: CurrentRF PowerPad IP Small Signal S11 Plot (Engaged)

Large Signal Reservoir Capacitance Behavior

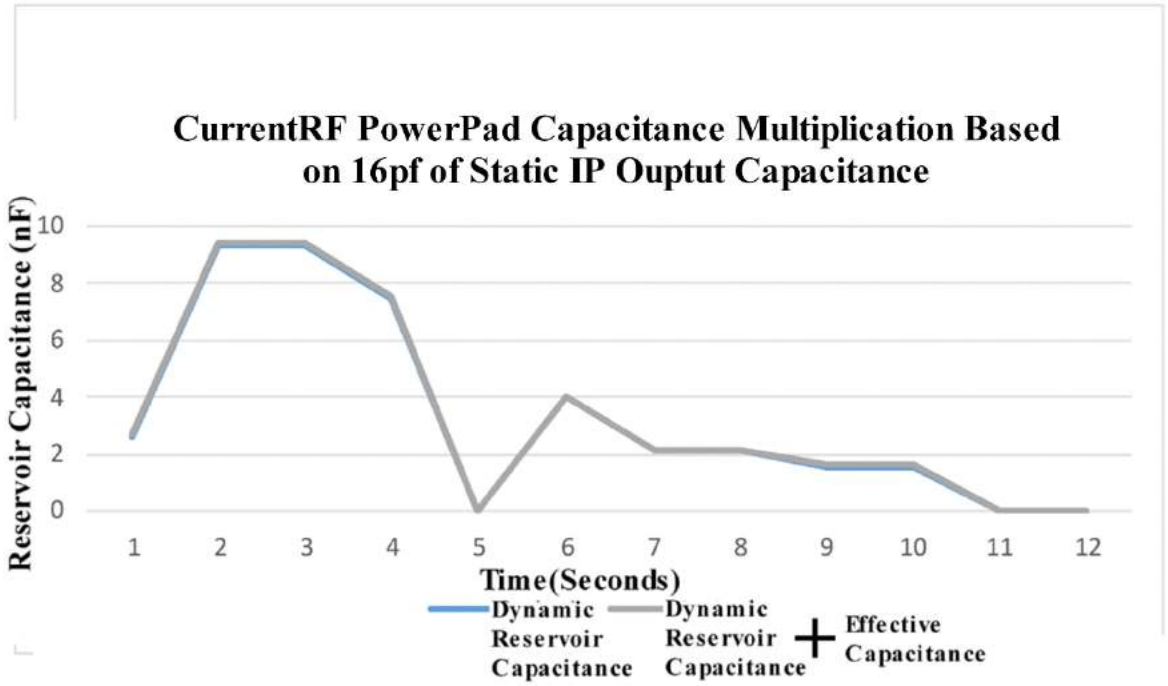


Figure 14: CurrentRF PowerPad IP Dynamic Reservoir plus Effective Capacitance on chip IP Performance (16pf Static Output Capacitance)

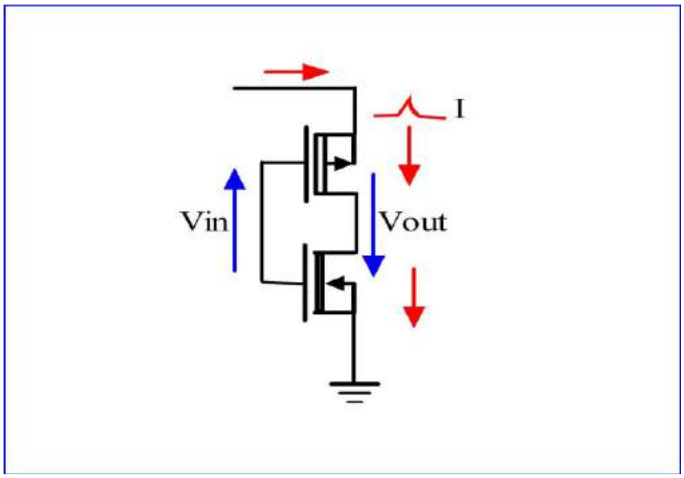
Figure 14 shows the total CurrentRF PowerPad IP dynamic reservoir and effective capacitance increases that are the result of the load current impulses imposed on the system supply grid and the CurrentRF PowerPad IP. The **grey** curve is the combination of the dynamic reservoir and effective capacitance, or total capacitance that the CurrentRF PowerPad IP generates in response to high current impulses, the **blue** curve is the dynamic reservoir capacitance alone. As one can see, the dynamic reservoir capacitance magnitude far outweighs the effective capacitance, and the dynamic reservoir capacitance driven by the magnitude of input dynamic current and supply voltage perturbations.

With a 16pF static output or return capacitance used on the CurrentRF PowerPad IP, the magnitudes of the reservoir capacitance approach 10nF. This is almost an order of magnitude increase (600X) with respect to the capacitance provided by standard on chip MOS DCAPs. This is a good example of how the CurrentRF PowerPad IP can dynamically enhance supply bypassing at the IC level of integration.

So**,** the 2X increase in small signal effective capacitance, the dynamically controlled increases in large signal, reservoir capacitance, the 25% reduction in ESL, and the resulting 20% to 36% drop in overall Dynamic Current and Power Draw, leads to better high frequency (lower ESL) and low frequency (higher Effective and Reservoir Capacitance-- leading to better filtering capability) filtering (broader dynamic range), and an up to 20% reduction in dynamic power draw. These characteristics lead to lower RF emissions from power grids, cleaner internal chip supplies, smaller DCAP footprints(if filtering area is a concern) lower chip dynamic power dissipation(lower thermal footprint), and greater circuit capacity.

RF EMISSIONS & WASTED ENERGY in Integrated Circuits-The Root Cause

Much energy is wasted in IC chip design, a portion of this waste radiating into free space. In the attempt to keep digital supply lines clean from the noise effects created by high frequency surges of overlap current in CMOS based logic, IC decoupling/reservoir capacitors are used to shunt this current to ground, thus keeping on-chip supplies clean. This current is generally ignored by chip designers, and is treated as “throw away” or ignored current and energy. Unless on-chip supplies are corrupted beyond a 50mV limit, this current is discarded and ignored.



Overlap current will not be ignored, however. Not only is it the source on dynamic power dissipation in chip designs, it shows up spectrally, radiating into space from power grids in ICs, giving away important system information, allowing hackers to gain access and compromise data.

CMOS logic based overlap current flow is the primary source of dynamic power dissipation in digital and mixed signal ICs. If even a small portion of this current can be recovered and reused, chip power dissipation is reduced and data is made more secure.

Figures 15 through 19 are various examples of CurrentRF PowerPad RF Emission and dynamic power reduction on various processes and circuit architectures.

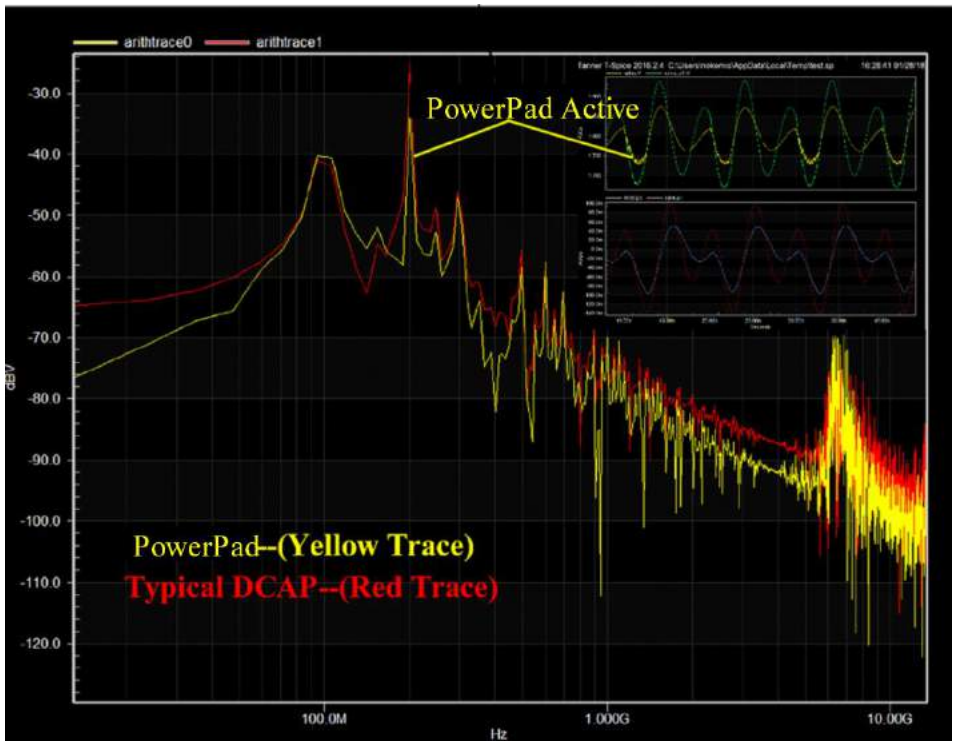


Figure 15: CurrentRF PowerPad IP Noise Magnitude Reduction (Manufacturing Process: Jazz Semiconductor CA18)

The plot in Figure 15 features not only a drop in overall emissions (the **yellow** curve in Figure 15), but also a 6dB drop in radiated emissions at 200Mhz, which translates to a 75% attenuation of power grid radiated energies(a quarter power point).

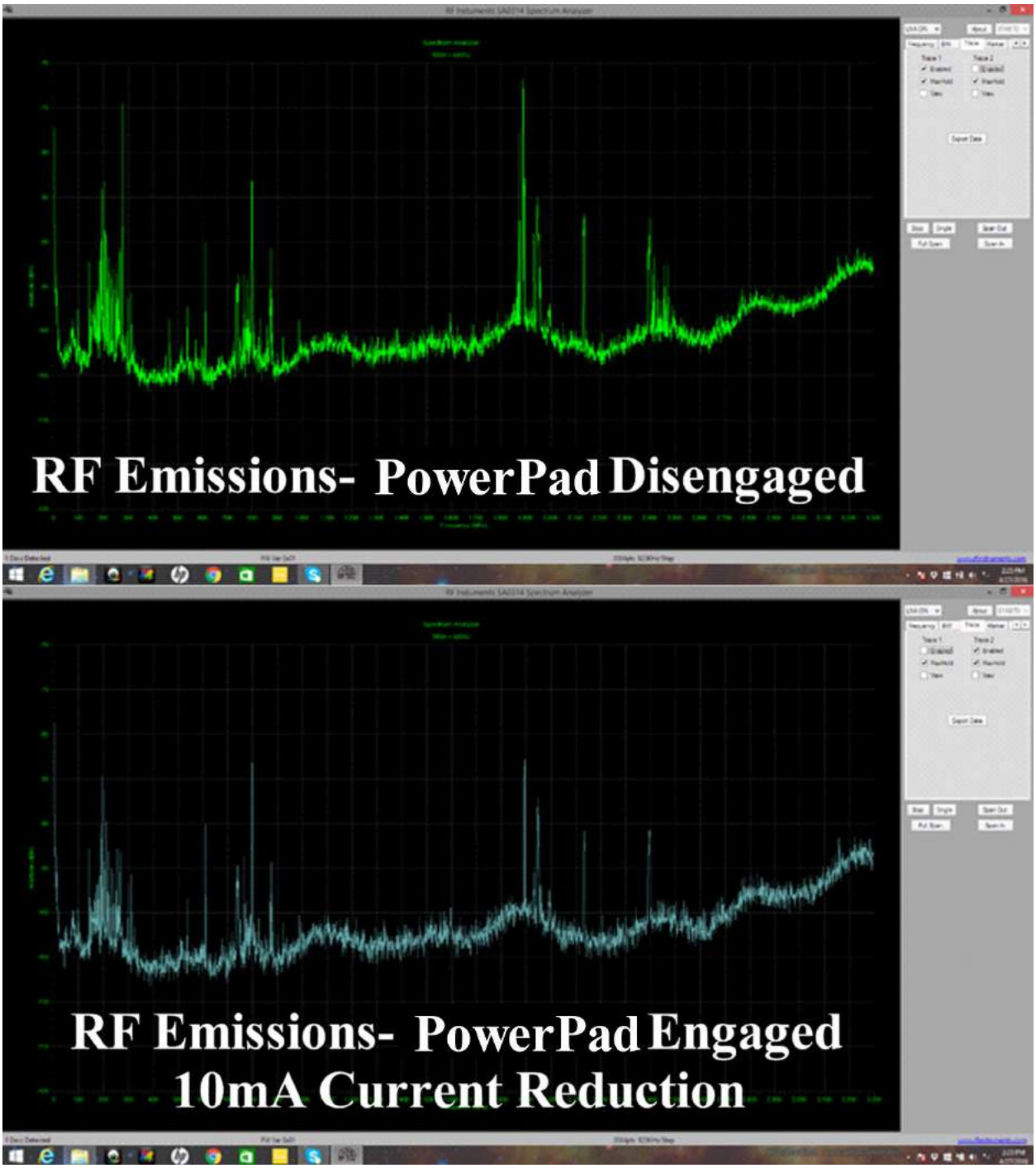


Figure 16: CurrentRF PowerPad IP Embedded in a Server Ethernet Controller (prototype)

The Figure 16 plot also shows an overall drop in radiated emissions due to CurrentRF PowerPad IP feedback, featuring a 12 dB drop (a 16X reduction) in radiated emissions at ~1.9Ghz. The overall current saved from this reduction in dynamic current is ~10mA.

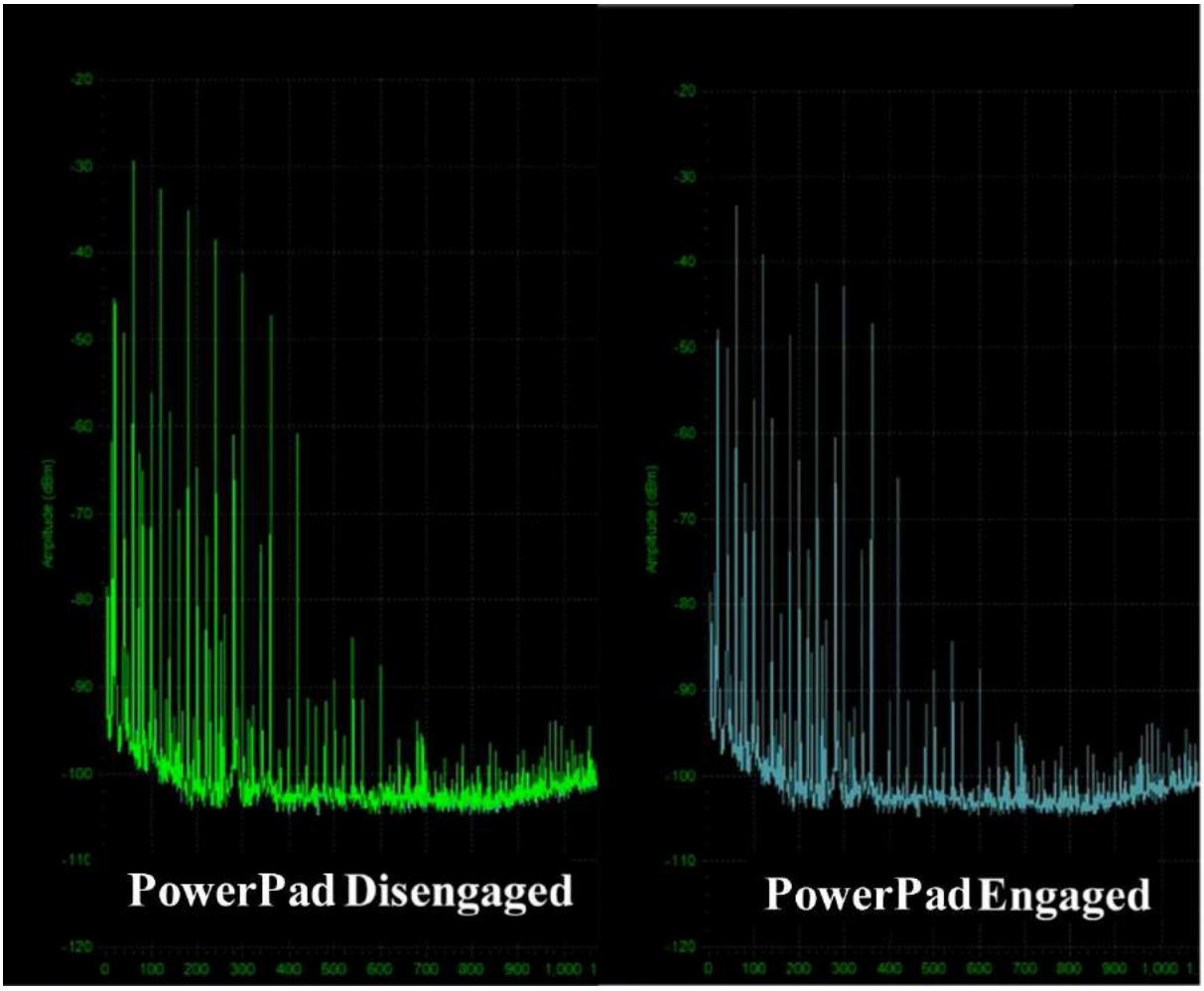


Figure 17: CurrentRF PowerPad IP Test Chip Results-20% Current Reduction (Manufacturing Process: GF_018RF)

Figure 17 shows a 6 dB (half power point) broadband RF Emission reduction in a square wave spectrum measured on the CurrentRF PowerPad IP test chip power grid. A 20% dynamic current reduction was seen as the result of the emission reduction.

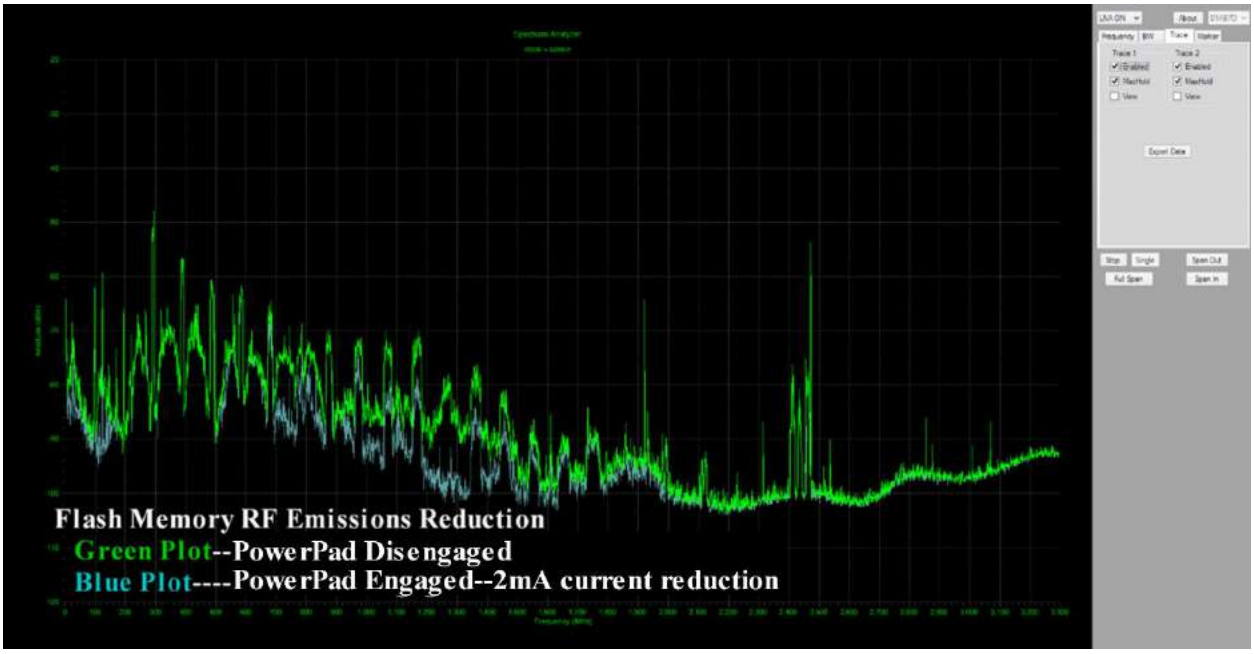
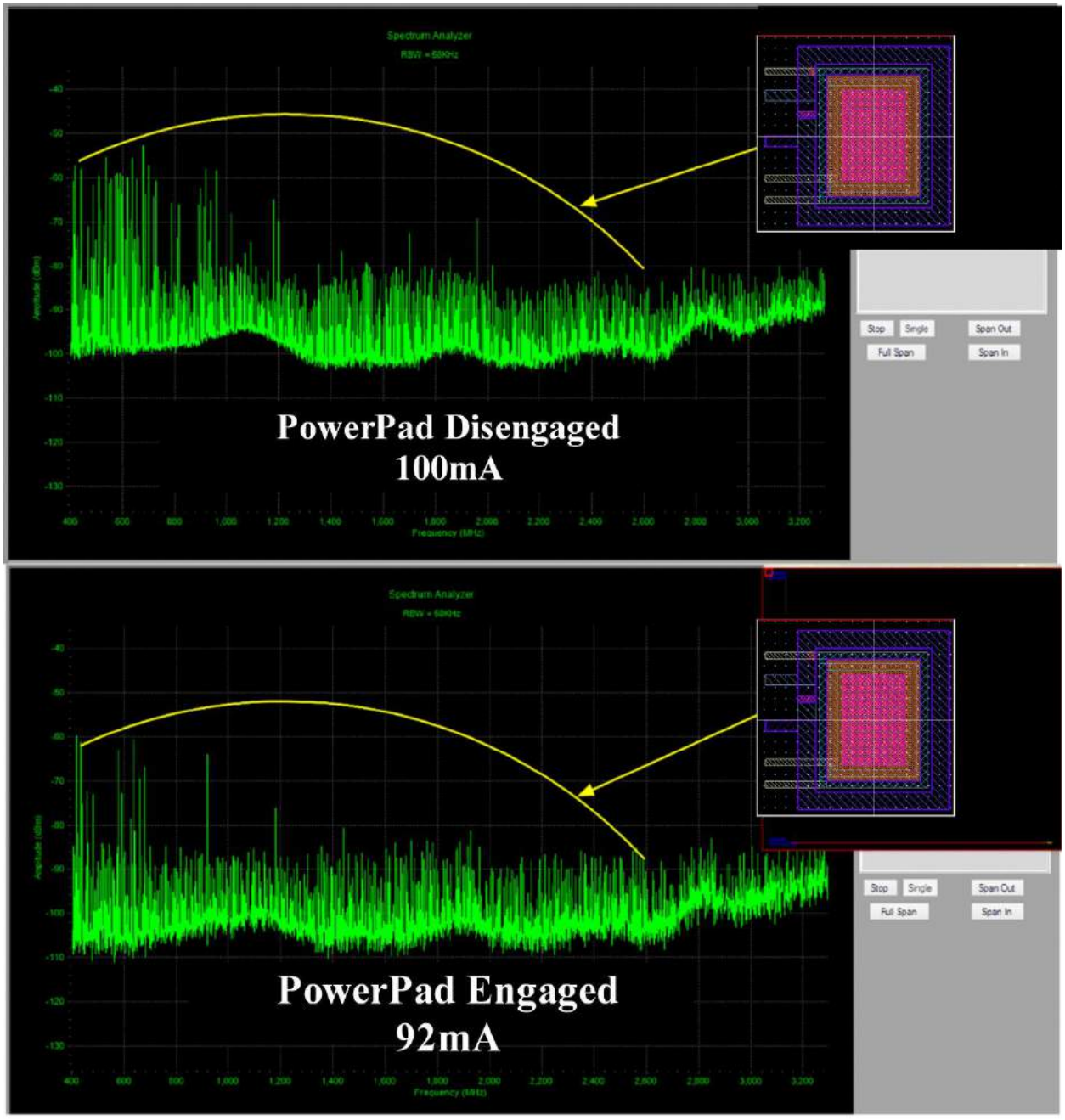


Figure 18: CurrentRF PowerPad IP embedded in Flash Memory

Figure 18 shows the disengaged/engaged RF emission spectrums that are the result of the CurrentRF PowerPad IP embedded in a flash memory power grid. A 2mA dynamic current reduction is seen as the result of PowerPad IP activity.



Missing/Suppressed Frequencies Above
Equals Cancelled Emissions and Current Saved

Figure 19: CurrentRF PowerPad IP embedded in a Pseudo Random Generator Test IC (Manufacturing Process: GF_018RF)

Figure 19 demonstrates an 8 mA dynamic current reduction that is the result of CurrentRF PowerPad IP RF Emission reduction as a consequence of PowerPad IP activity on the power grid of a pseudo random test generator produced by CurrentRF. The pseudo random test generator chip was designed to not only test the CurrentRF PowerPad IP, but demonstrate the ability of the IP to be integrated into larger digital circuits.

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