

Low Distortion Design – 4

TIPL 1324

TI Precision Labs – Op Amps

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Prepared by John Caldwell

Prerequisites: Noise 1 – 3

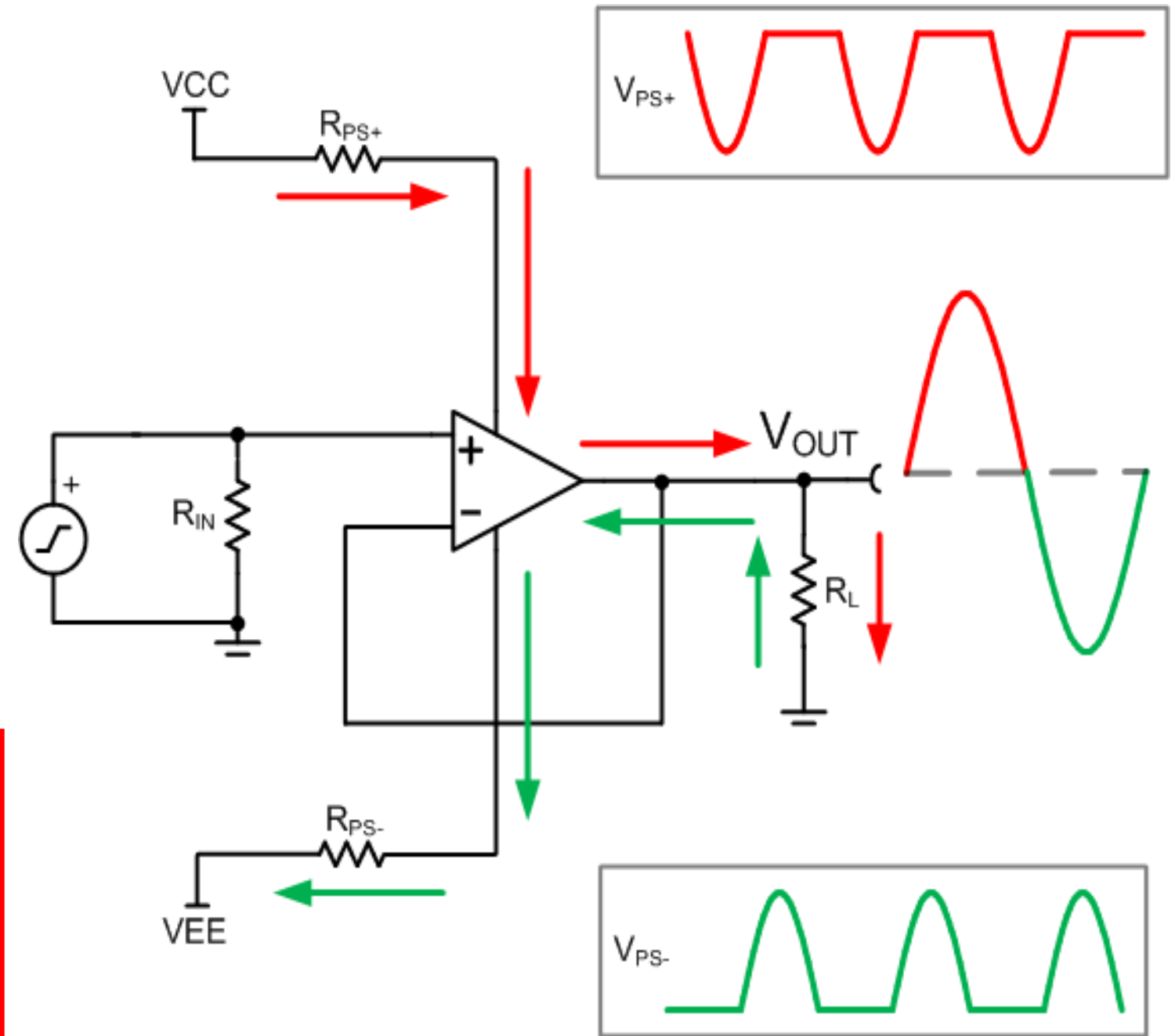
(TIPL1311 – TIPL1313)

Distortion from Power Supplies

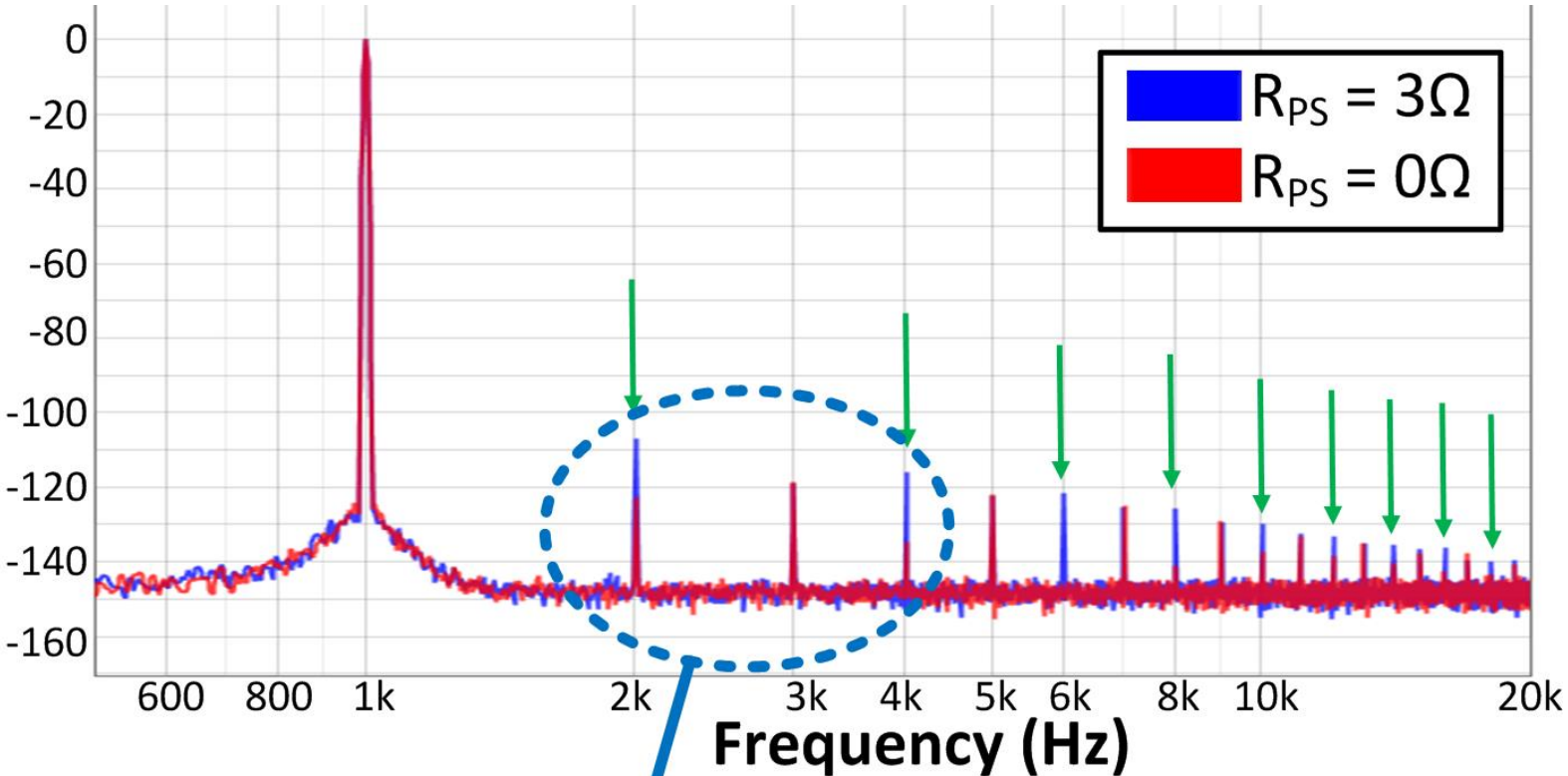
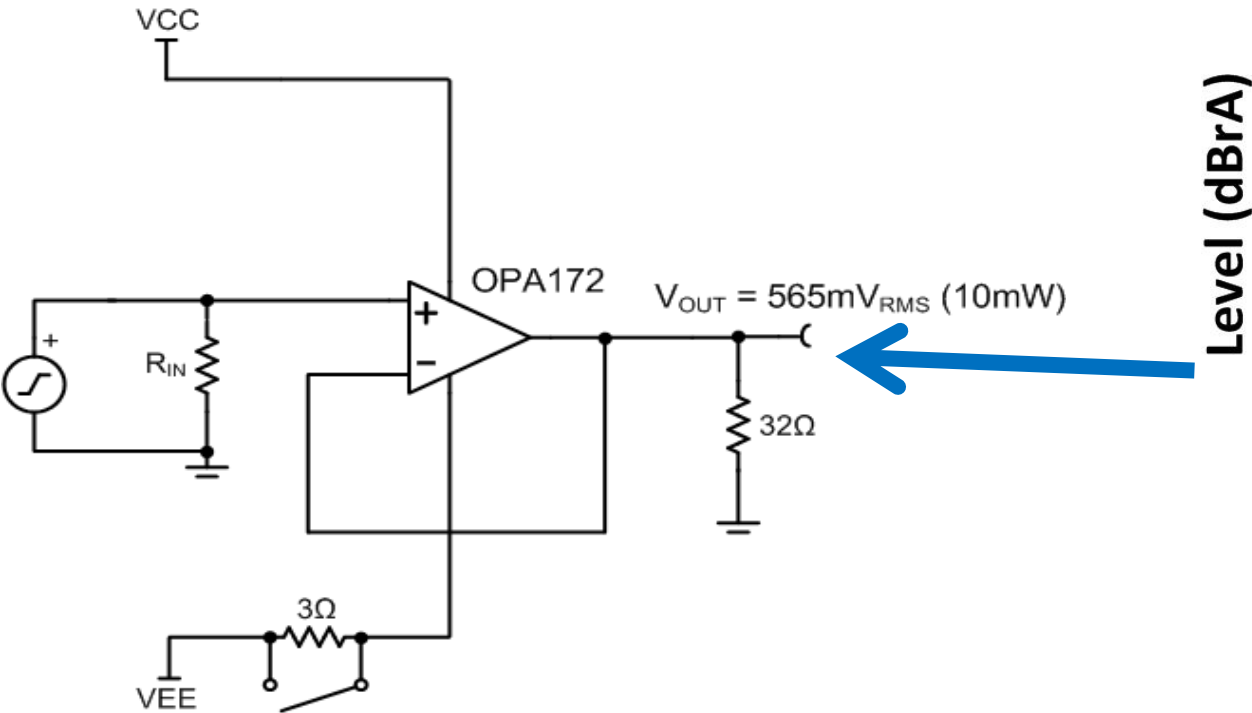
- Power supplies can contribute distortion as well as noise
- Power supplies have non-zero Z_{out}
 - Output impedance of an LDO or switching converter
- Op amp supply drops for a half-cycle of the output waveform
 - Half-wave rectified sine waves have even harmonics:

Half wave rectified sine wave: $\omega_0 = \frac{2\pi}{T}$

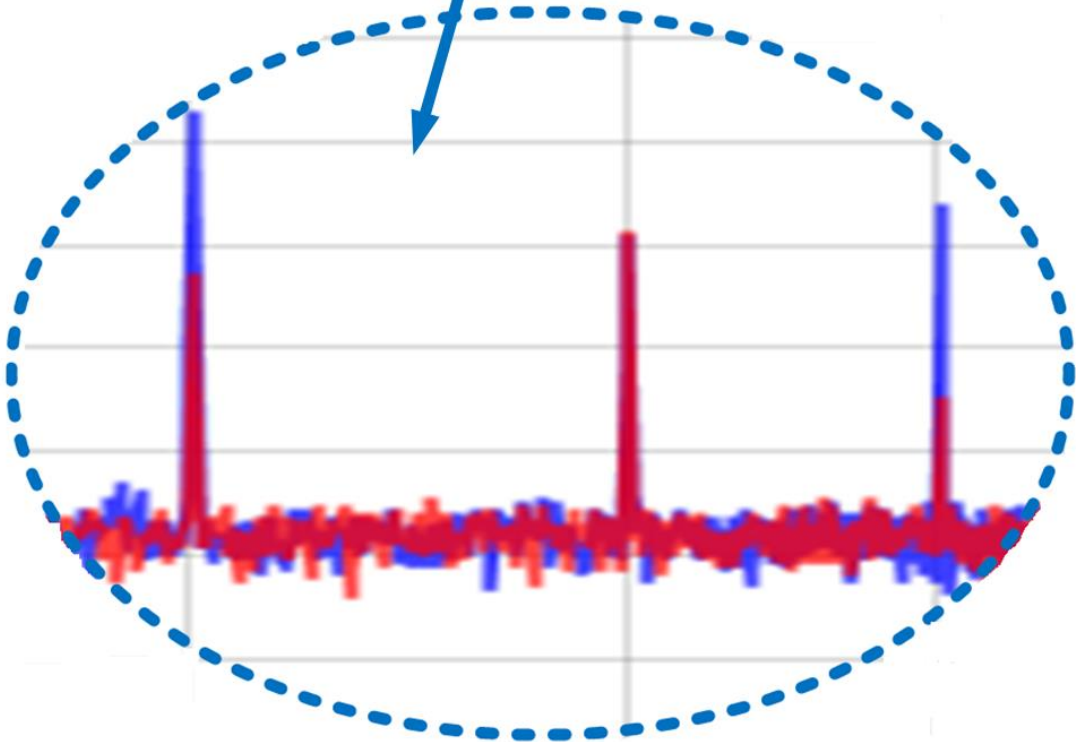
$$f(t) = \frac{A}{\pi} + \frac{A}{2} \sin \omega_0 t - \frac{2A}{\pi} \sum_{n=1}^{\infty} \frac{\cos(2n\omega_0 t)}{4n^2 - 1}$$



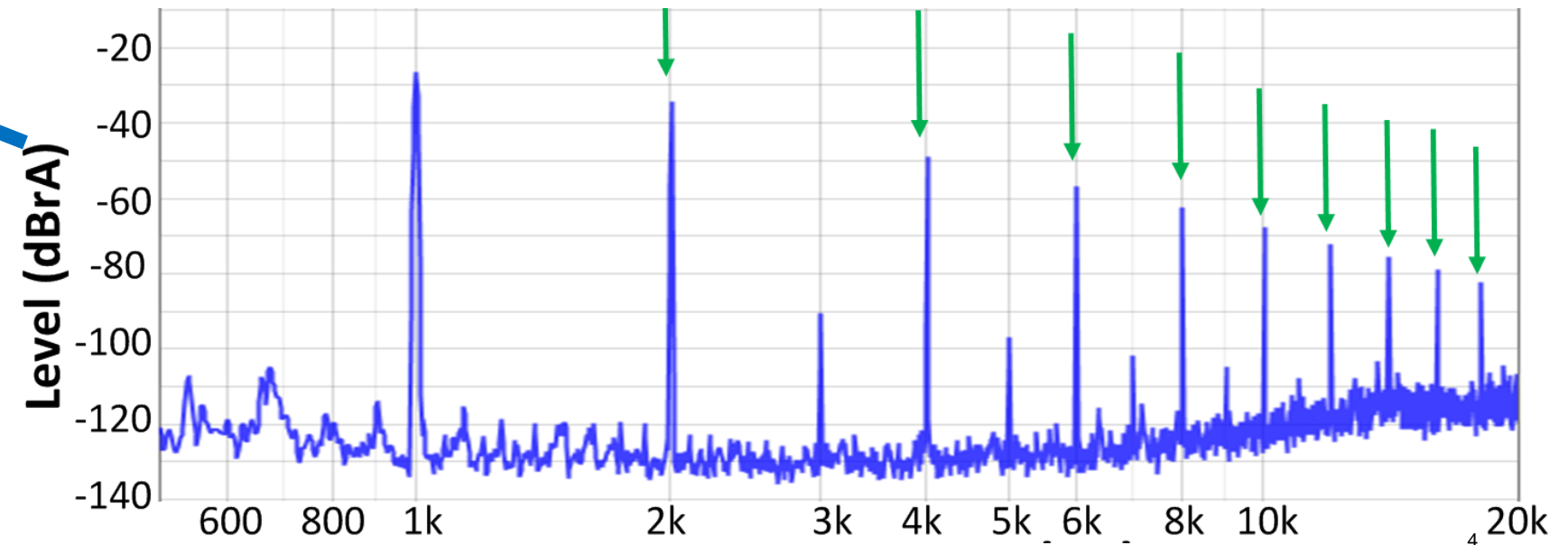
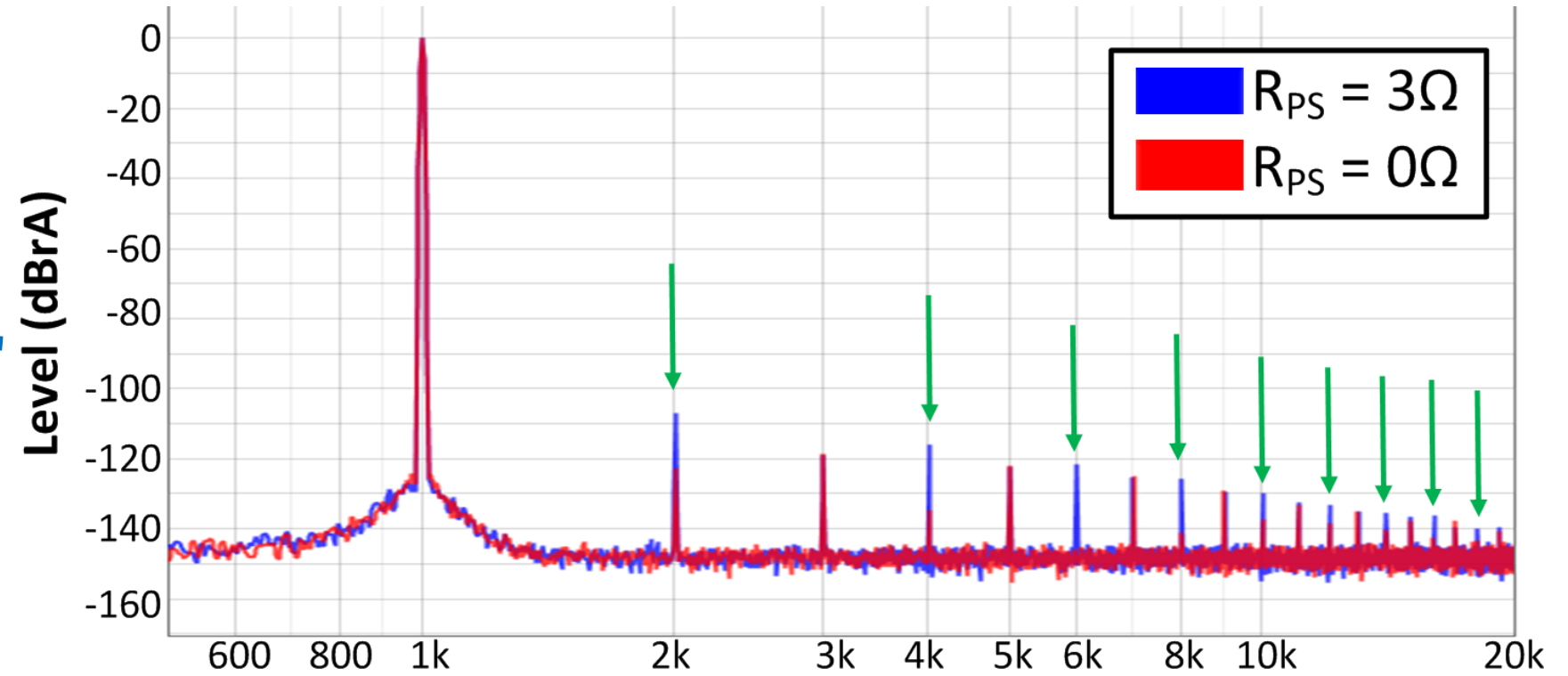
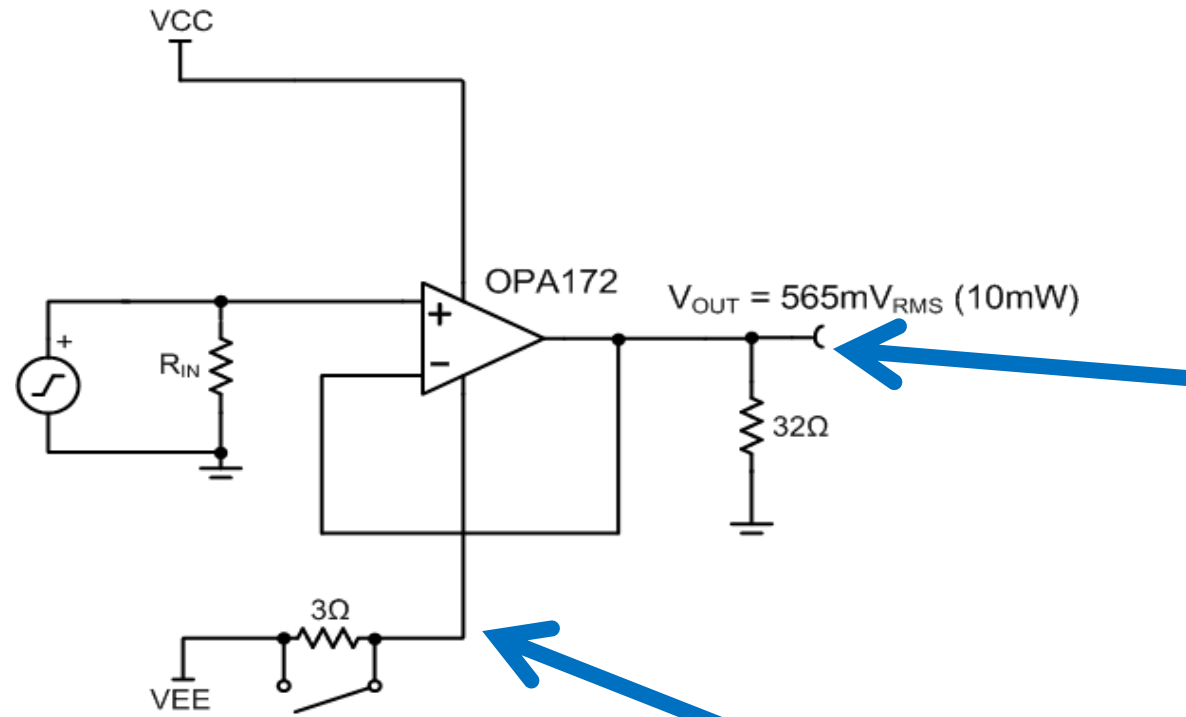
Demonstration – FFT of Output



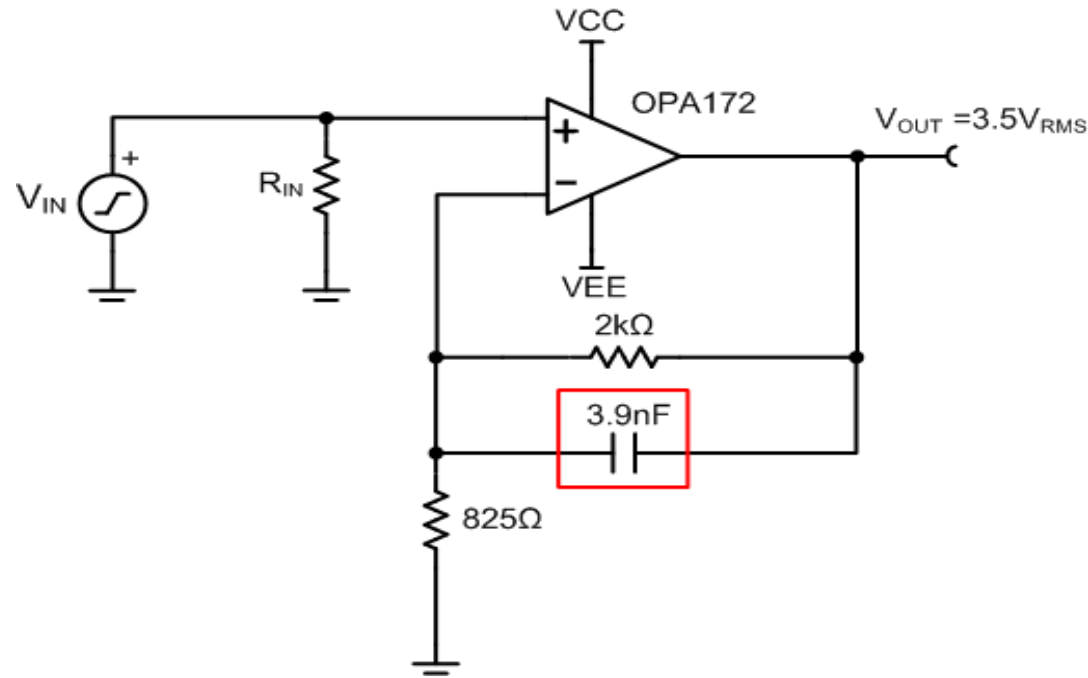
Harmonic	0 Ohms	3 Ohms
2 nd	-122dB	-107dB
4 th	-134dB	-116dB
6 th	-147dB	-121dB
8 th	-140dB	-125dB



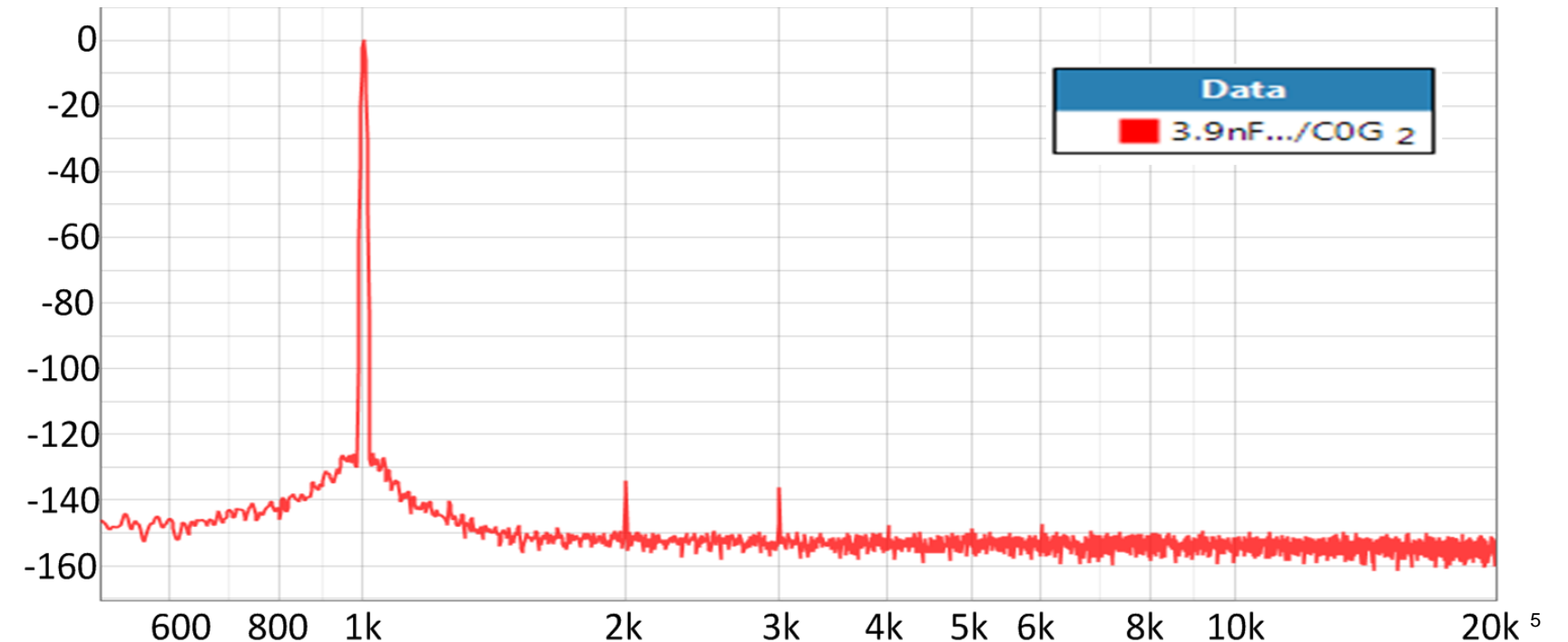
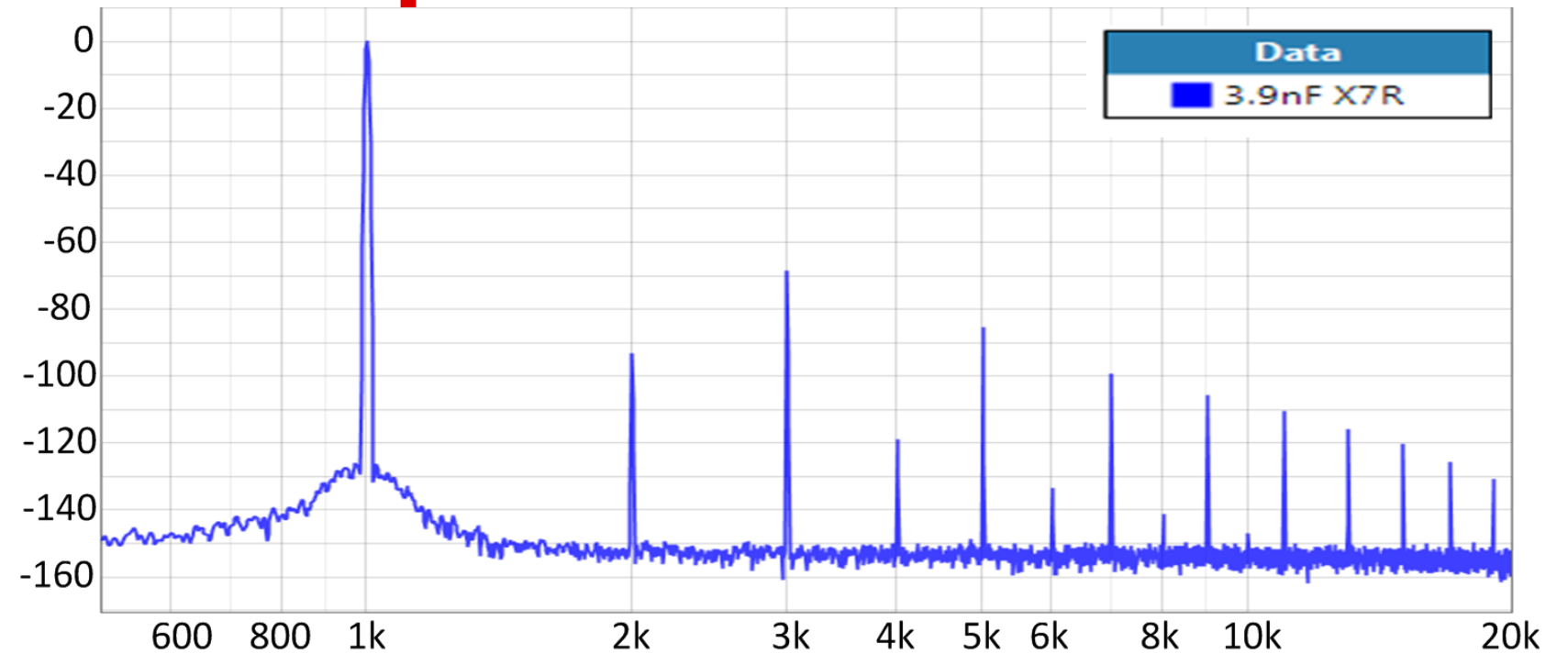
Demonstration – FFT of Power Supply



Distortion from Ceramic Capacitors



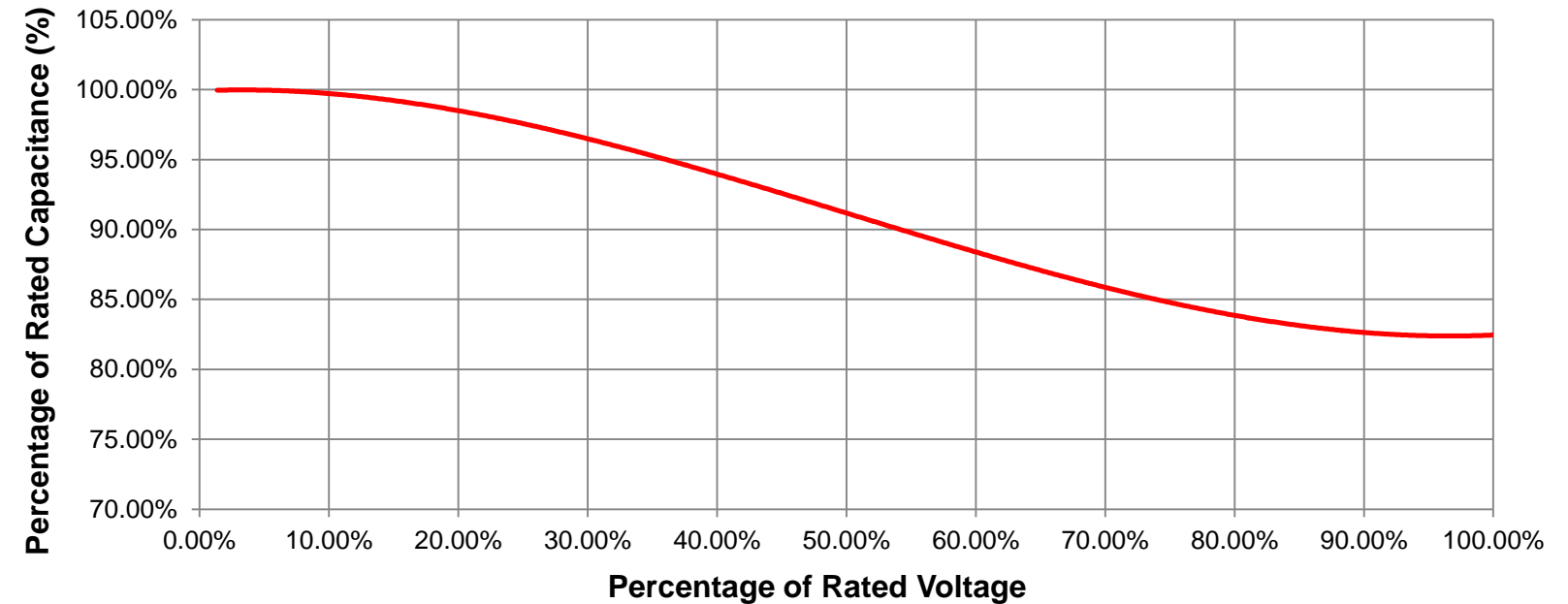
- Non-inverting amplifier circuit
 - Gain: 3.42
 - Output voltage 3.5Vrms
- 3.9nF Feedback Capacitor
 - 50V Rated
 - Voltage Drop: 2.48Vrms
- THD:
 - X7R \rightarrow -68dB (Blue)
 - NP0/C0G: -135dB (Red)



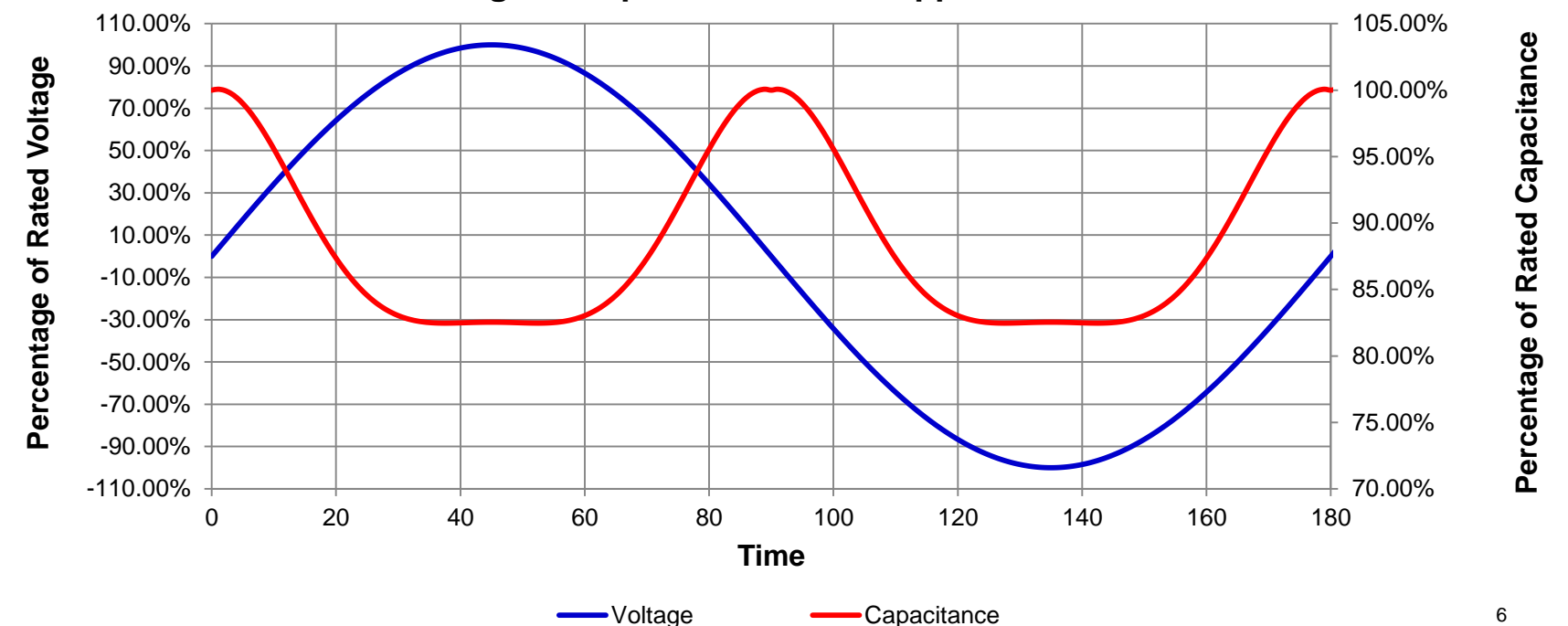
Distortion From Ceramic Capacitors

- Capacitance of Class II & III ceramics will vary greatly with the applied voltage
 - This is known as the “voltage coefficient of capacitance” or VCC
- Causes:
 - Dielectric constant changes with the intensity of an applied electric field
 - Capacitor dimensions change with an applied electric field
 - Reverse piezoelectric effect (ceramic capacitors)
 - Electrostatic force (Polyester film capacitors)
- The top graph shows a typical voltage coefficient curve from a manufacturer’s datasheet
- The bottom graph shows how the value of the capacitor will change in real time for an applied sine wave

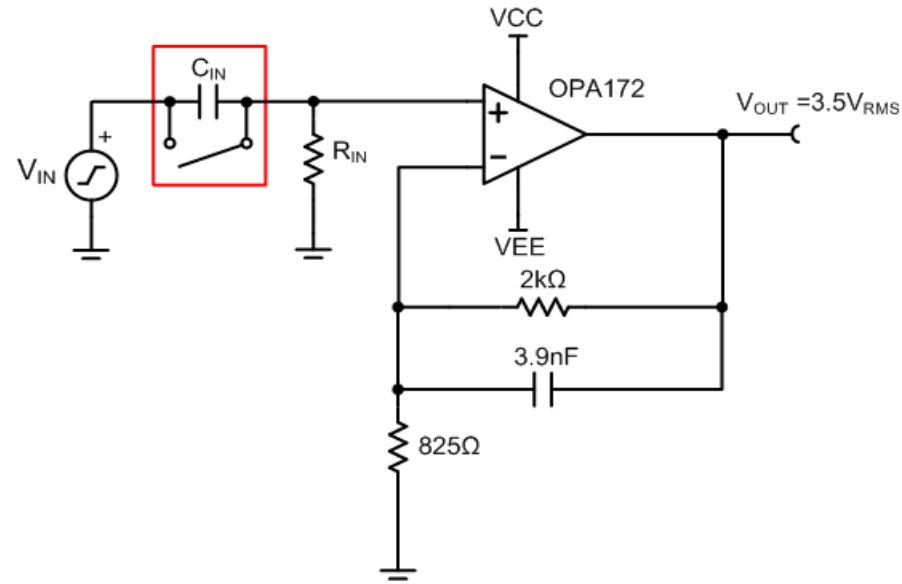
Example Voltage Coefficient of an X7R Capacitor



Change in Capacitance for an Applied Sine Wave

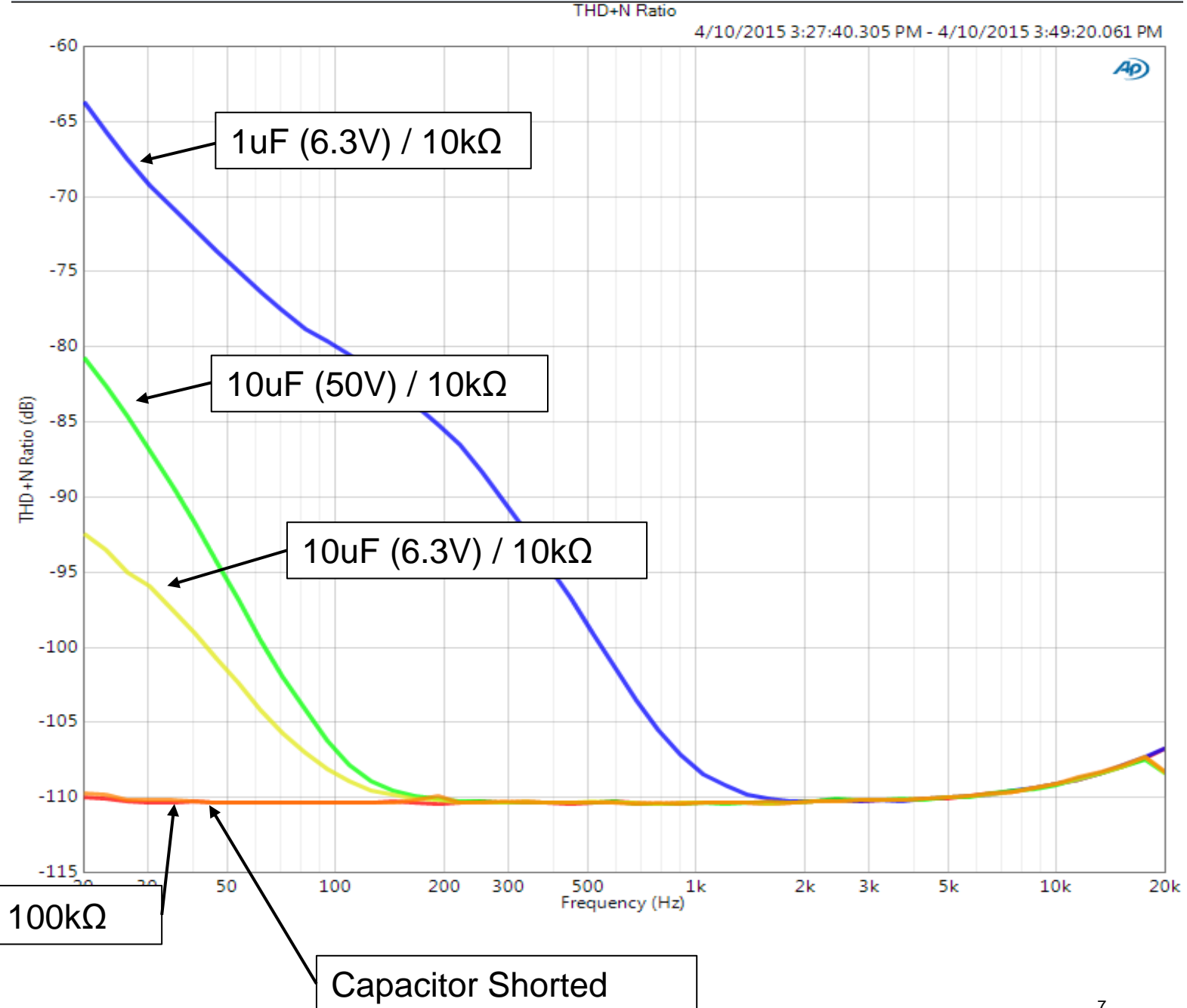


What About AC Coupling Capacitors?



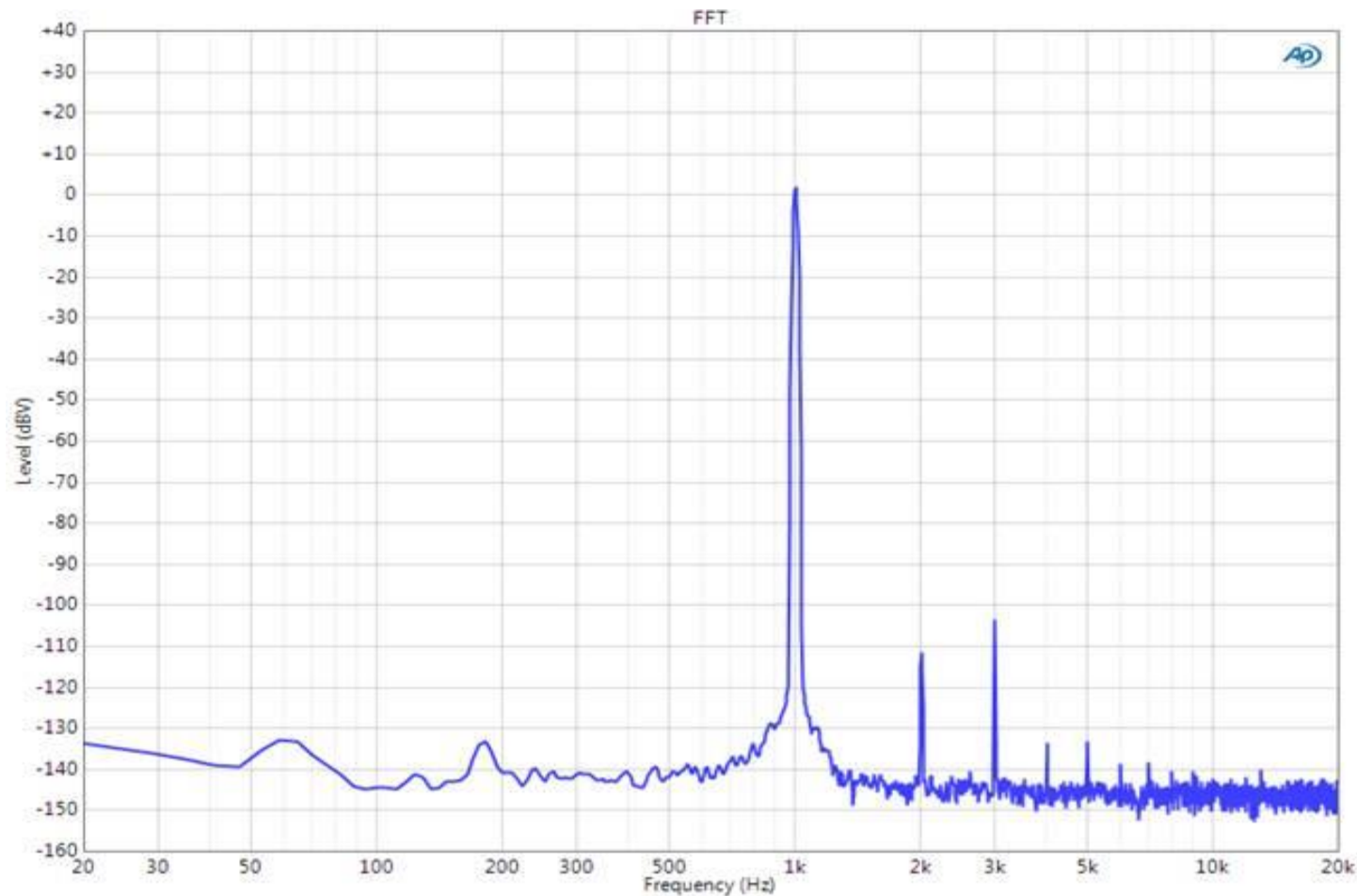
- AC coupling capacitors may also produce distortion
- Voltage across the coupling capacitor increases as the low frequency cutoff is approached.
- Place the low frequency corner >2 decades below desired passband.

$$f_c = \frac{1}{2\pi R_{IN} C_{IN}}$$

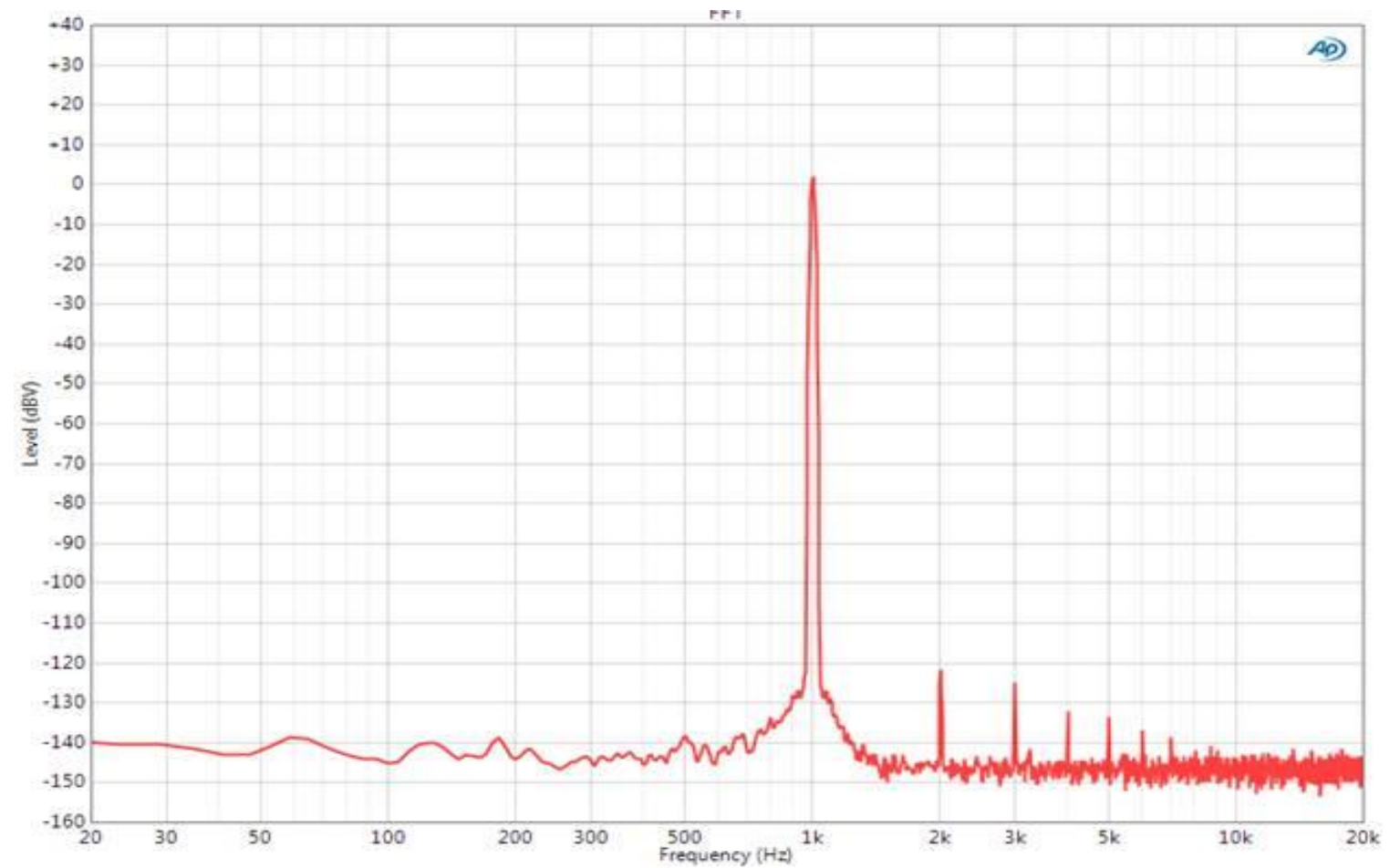


Distortion from Surface Mount Resistors

- Thick film resistors may produce distortion
 - Voltage coefficient of the resistive element
 - Usually only seen for large signal voltages ($>3V_{\text{RMS}}$)
 - Effect is worst for small package sizes and high resistance values

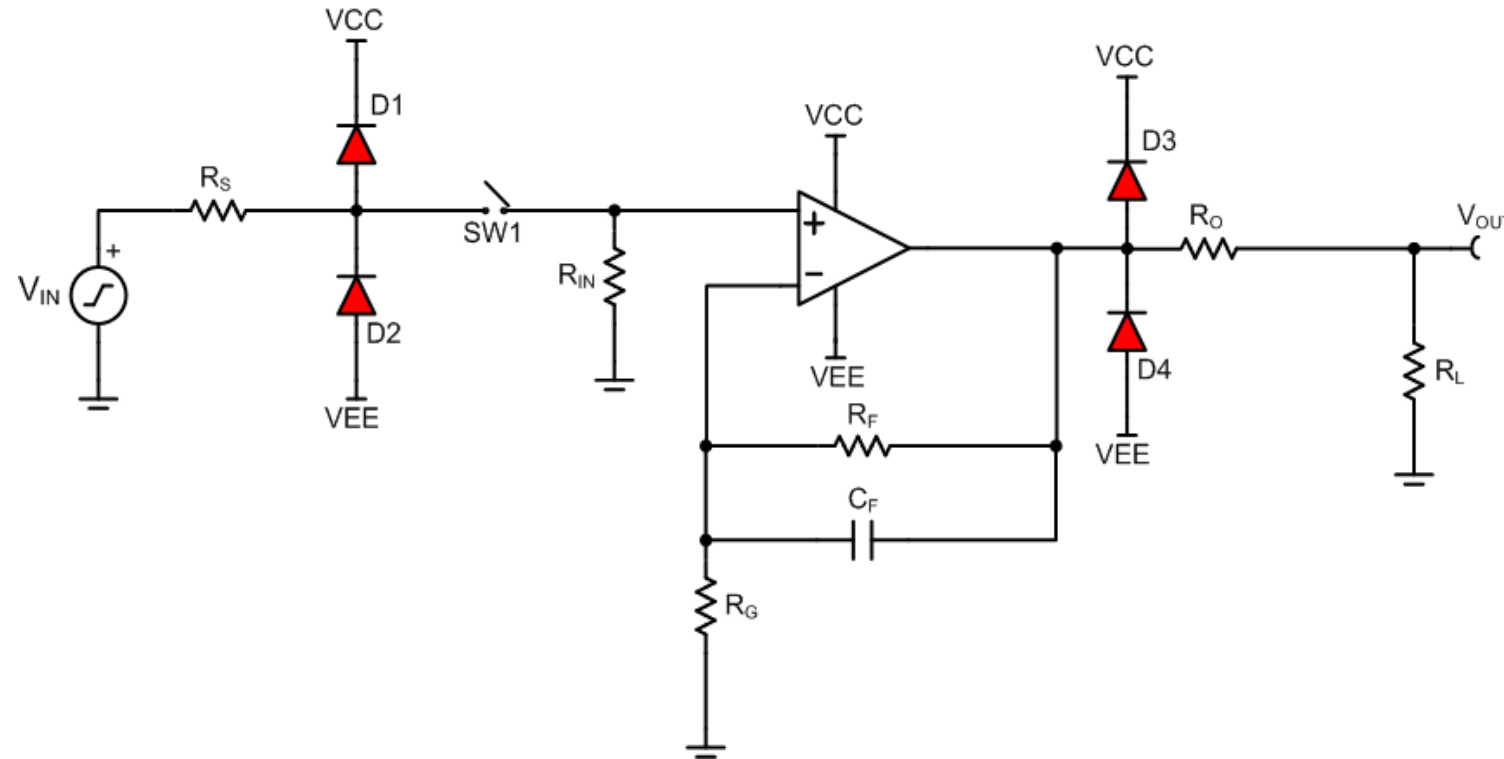


Thick Film, 0603



Thin Film, 0603

Distortion from External ESD Protection

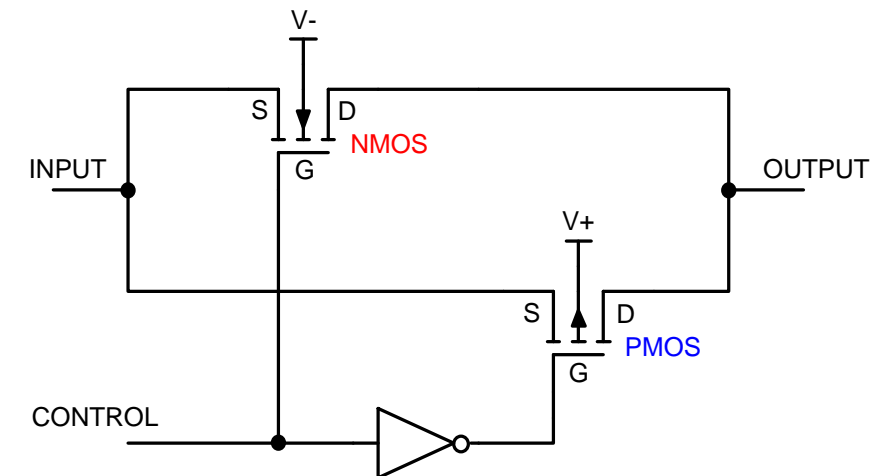
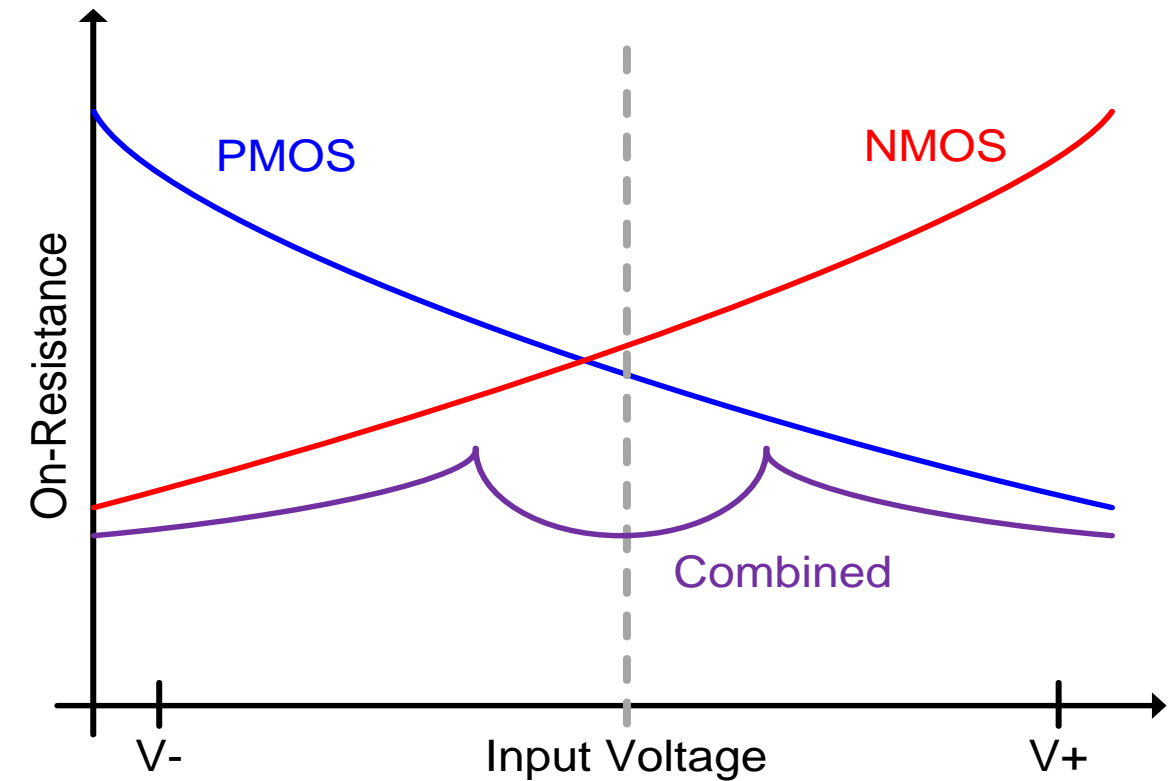
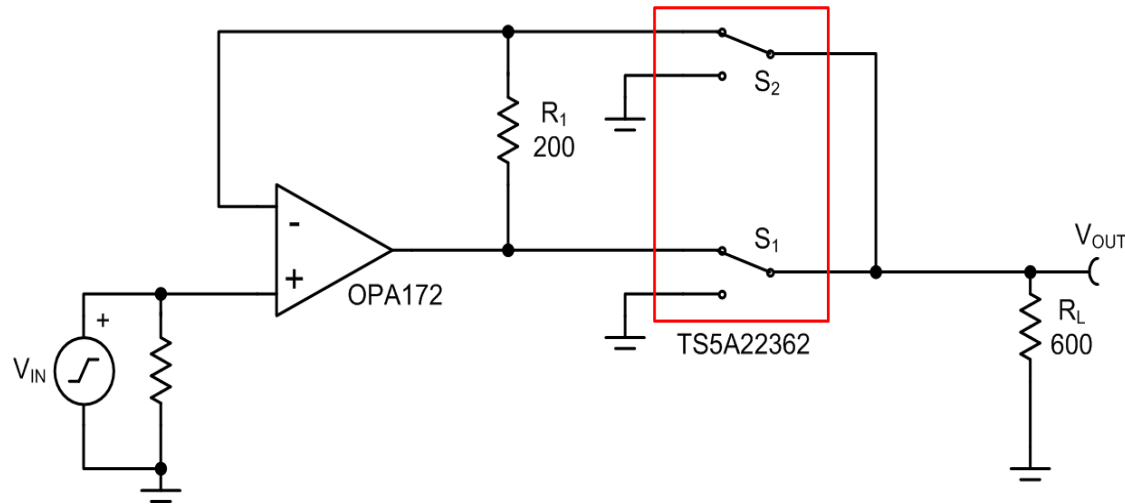


- The capacitance of ESD diodes varies according to the equation:
- The signal across the ESD diode causes its capacitance to change
 - Draws a non-linear current
 - Converted to a non-linear voltage by source impedance
- Chose diodes with the lowest junction capacitance possible!
- Place them at low impedance nodes
 - Non-linear current drawn does not produce a non-linear voltage

$$C_D \approx \frac{C_{DO}}{\sqrt{1 + \frac{V_R}{0.7}}}$$

CMOS Switch Impedance

- CMOS Switches are composed of NMOS and PMOS devices in parallel
 - Allows them to conduct current in both directions
- Control voltage (V_G) is typically constant
- Signal voltage (V_S) is variable
- Changing V_{GS} modulates the on-resistance of the FETs
- Varying impedance creates distortion
 - Worst for high load currents / low load impedances
- Increase load impedance
- Close feedback loop around the switch



“Reducing Distortion from CMOS Analog Switches” Caldwell, 1Q2015 AAJ

Reducing Distortion From External Sources

- Minimizing distortion from power supplies
 - Chose op amps with high PSRR in the desired passband
 - Design power supplies to limit their output impedance
 - Bulk decoupling capacitors, linear regulators, short PCB traces
- Capacitors
 - Use NP0/C0G ceramic or Polypropylene film capacitors in the signal path
 - For AC coupling capacitors set $f_c > 2$ decades below the passband
- Resistors
 - Use thin film surface mount resistors (Larger packages are better)
 - Through-hole metal film resistors are also very good
- ESD Protection
- CMOS Switches

Thanks for your time!
Please try the quiz.