EDICON 2017 Electronic Design Innovation Conference & Exhibition
Where high frequency meets high speed.

Designing Power For Sensitive Circuits

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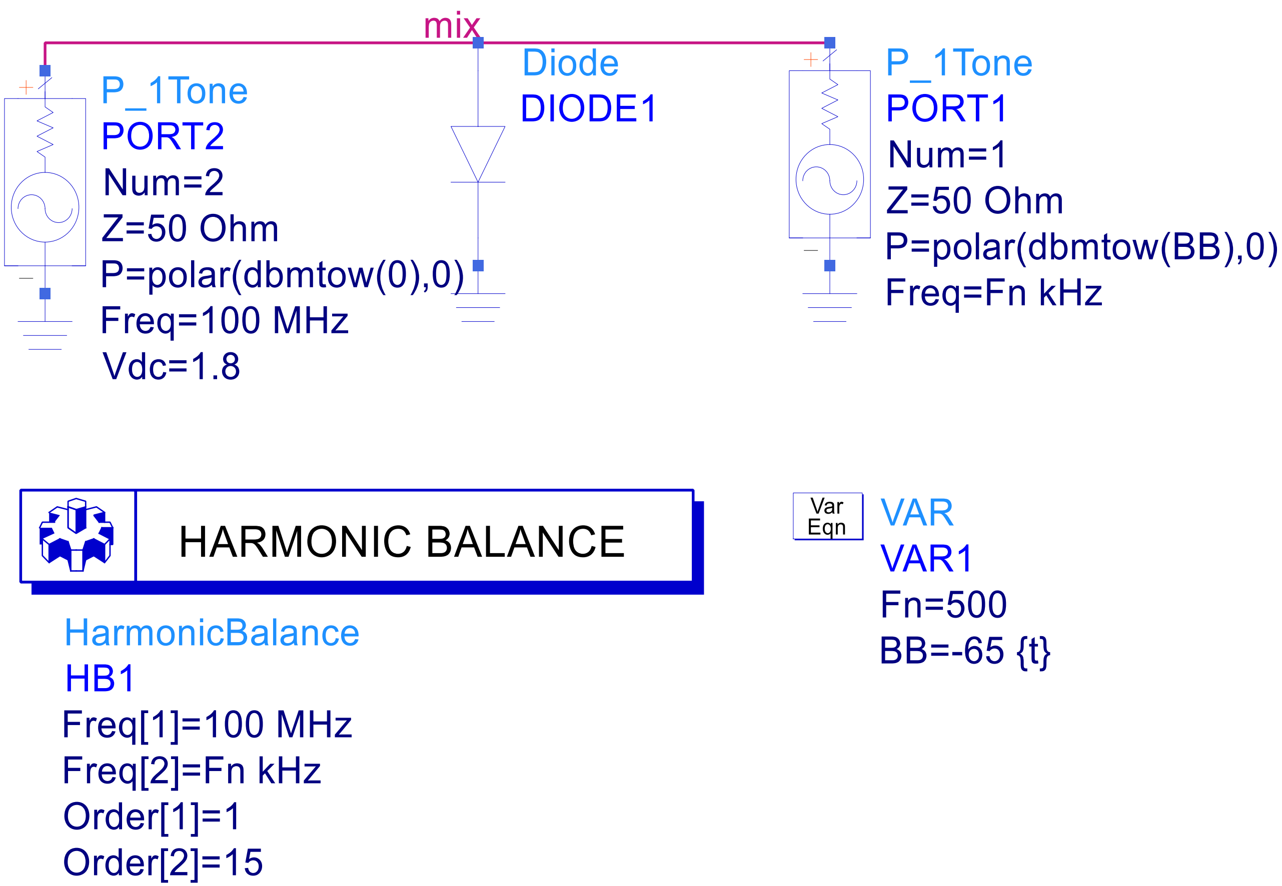
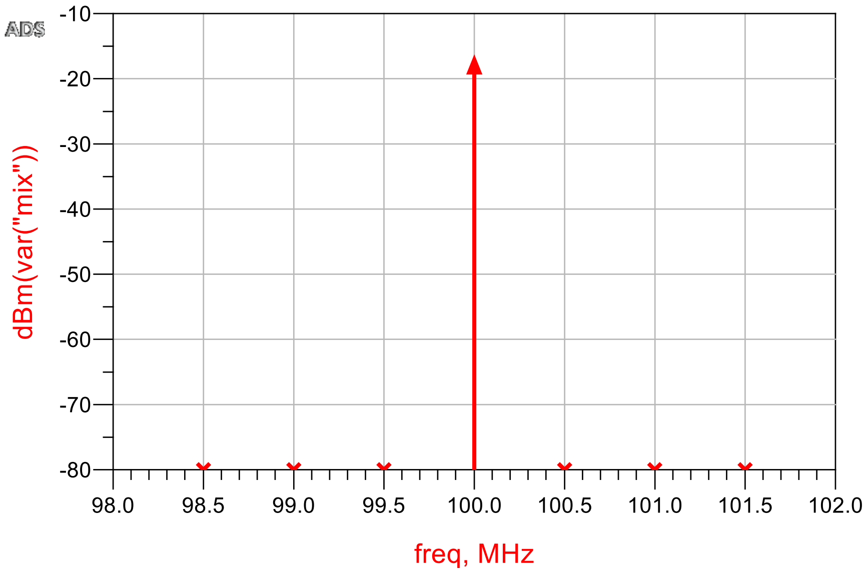
What are sensitive circuits?

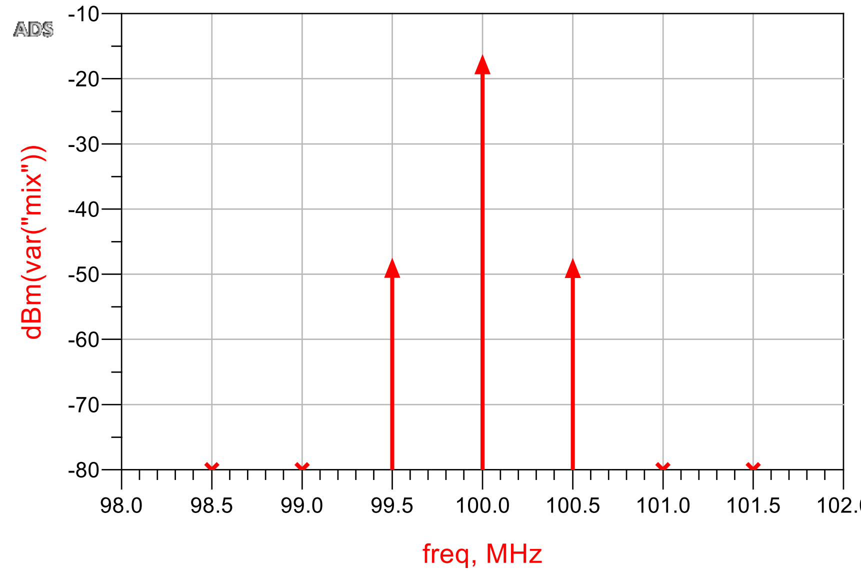
Many low power circuits are hyper-sensitive to power supply noise.

Examples of hyper-sensitive circuits include clock oscillators (XOs), low noise amplifiers (LNAs), phase locked loops (PLLs), mixers and precision voltage references to name just a few.

Sensitivity to power supply noise




ADS
-10
-20
-30
-40
-50
-60
-70
-80
dBm(var("mix"))
98.0
98.5
99.0
99.5
100.0
100.5
101.0
101.5
102.0
freq, MHz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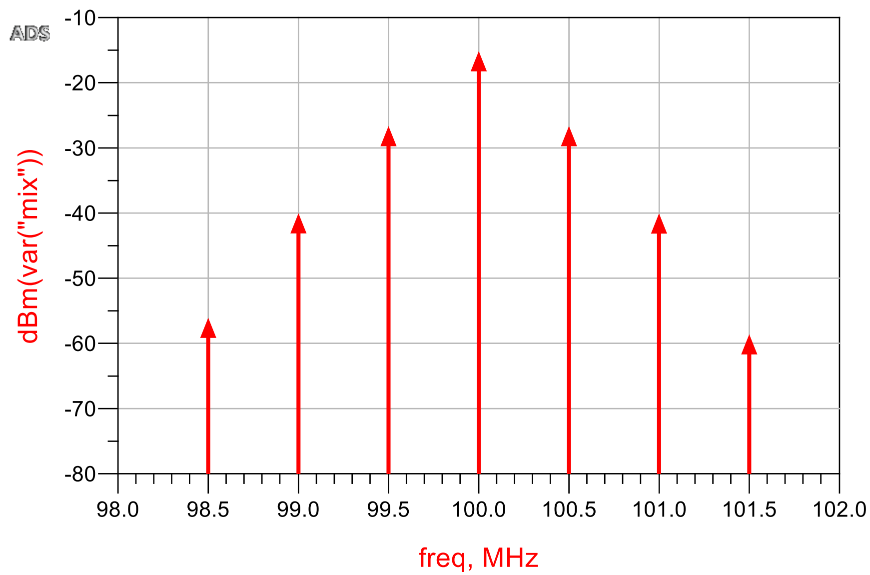
freq, MHz


ADS
-10
-20
-30
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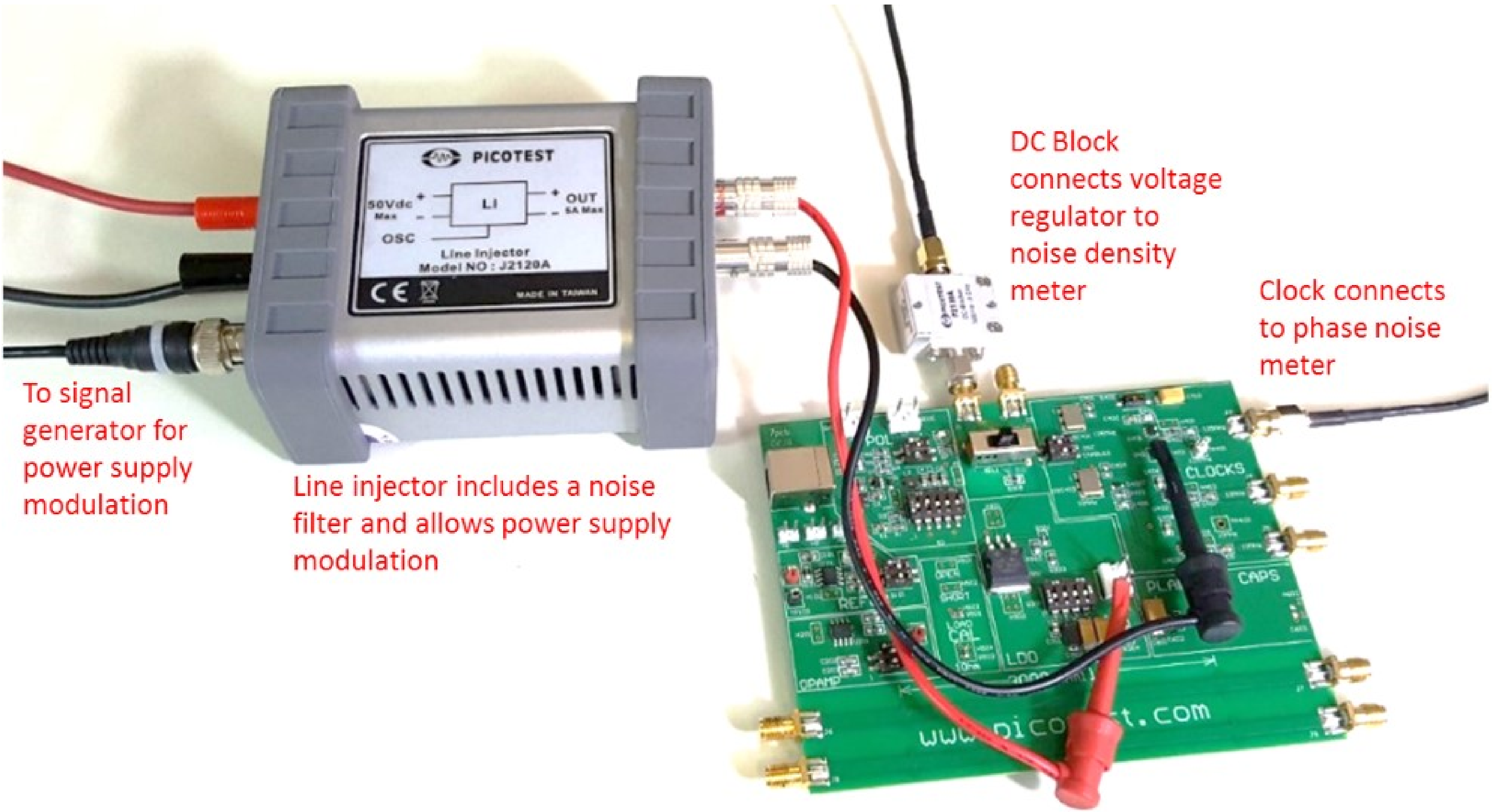
-50
-60
-70
-80
dBm(var("mix"))
98.0
98.5
99.0
99.5
100.0
100.5
101.0
101.5
102.0
freq, MHz

Defining Sensitivity



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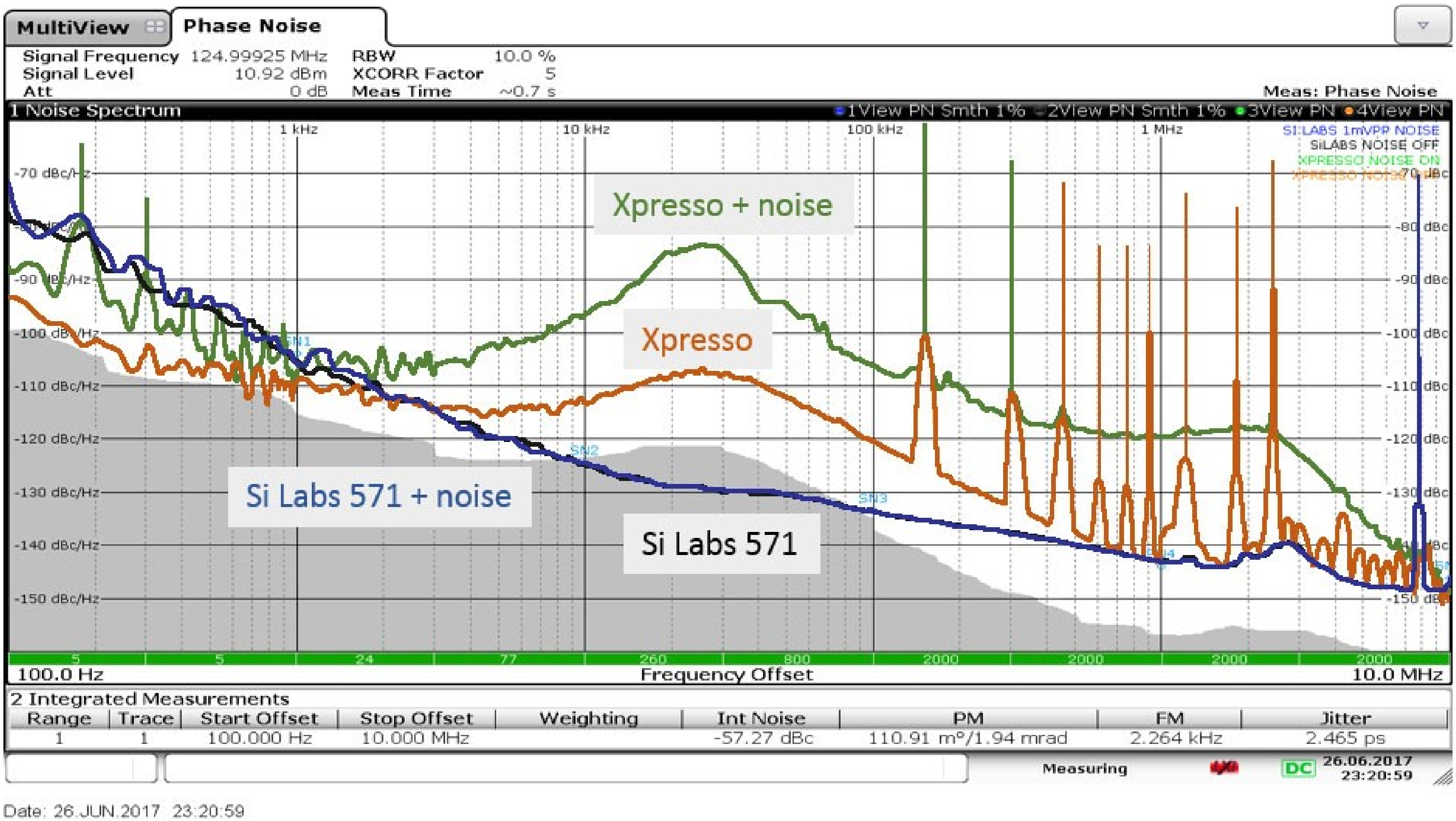
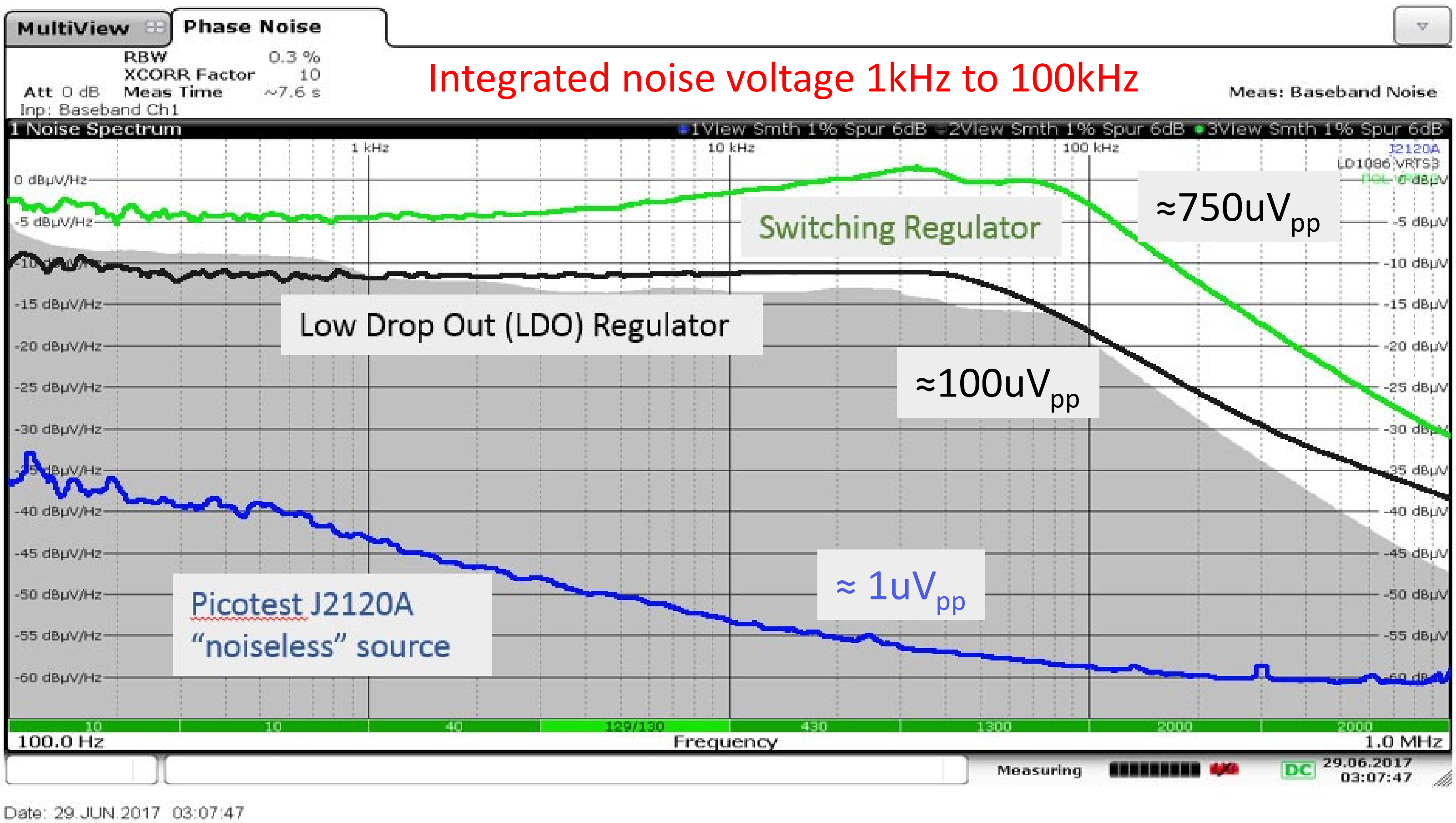
Not all sensitive circuits are sensitive

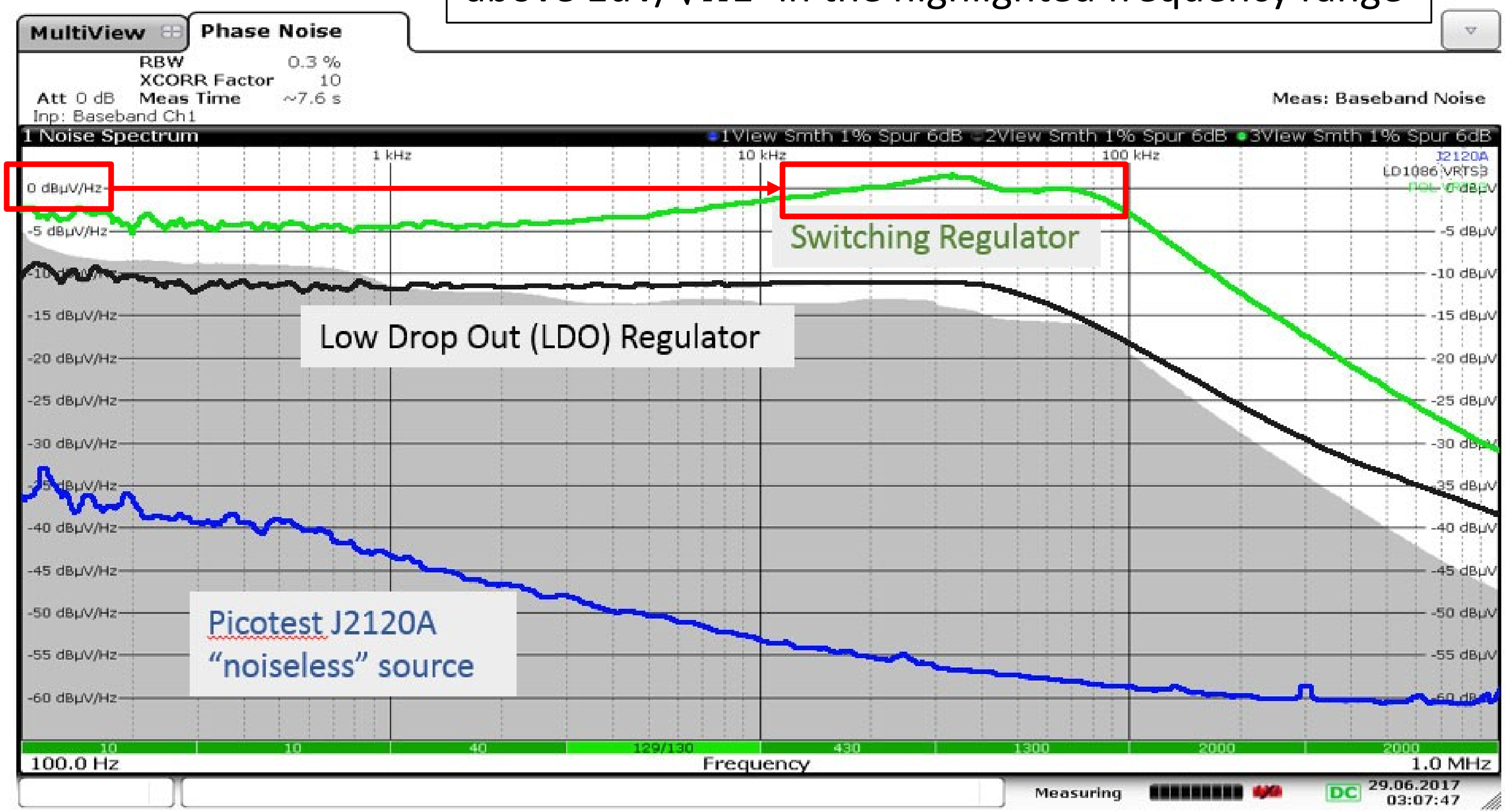


Noise Density 3 Voltage Regulators



Switching Regulator Noise Density

The switching regulator noise density is a little above 1uV/$\sqrt{Hz}$ in the highlighted frequency range



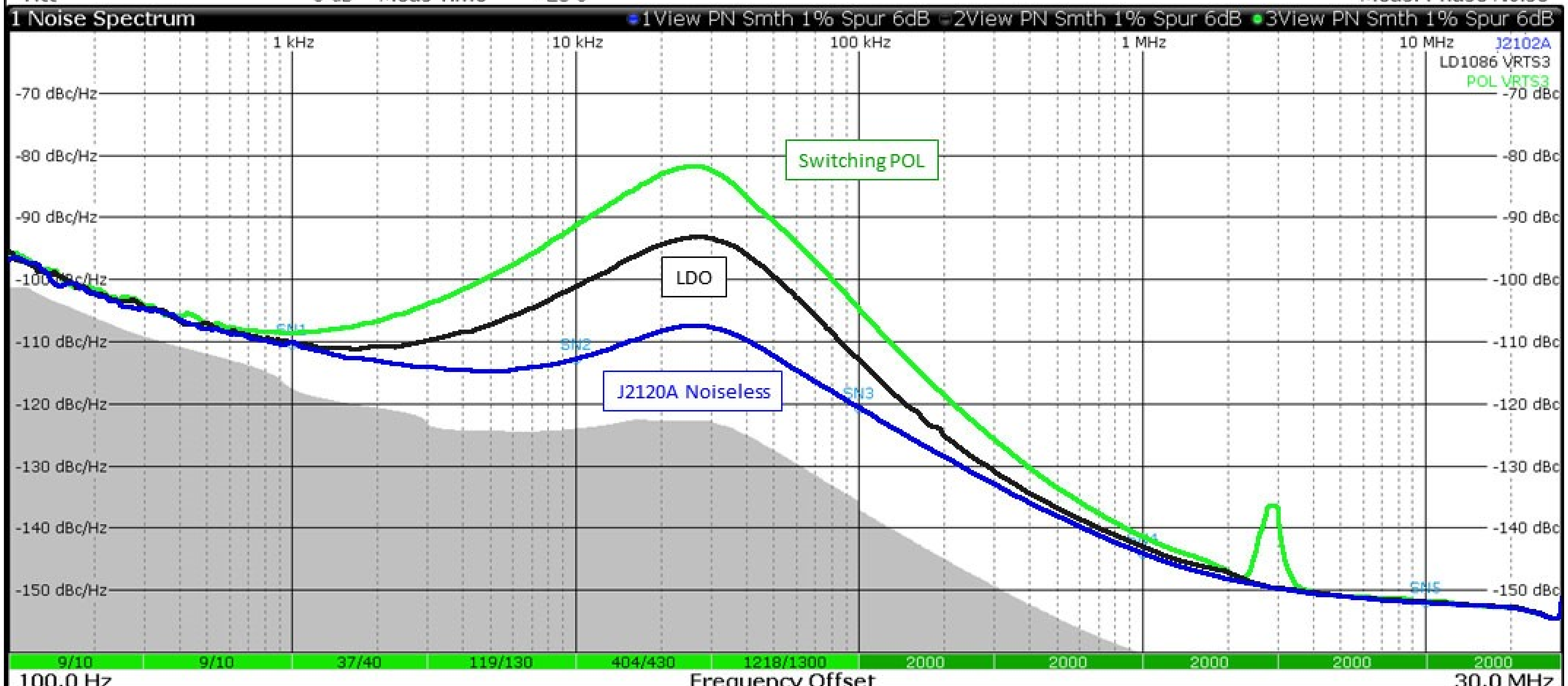
Date: 29.JUN.2017 03:07:47

Phase Noise 3 Voltage Regulators

MultiView | Phase Noise

Signal Frequency	124.99934 MHz	RBW	0.3 %
Signal Level	11.20 dBm	XCORR Factor	10
Att	0 dB	Meas Time	~23 s

Meas: Phase Noise



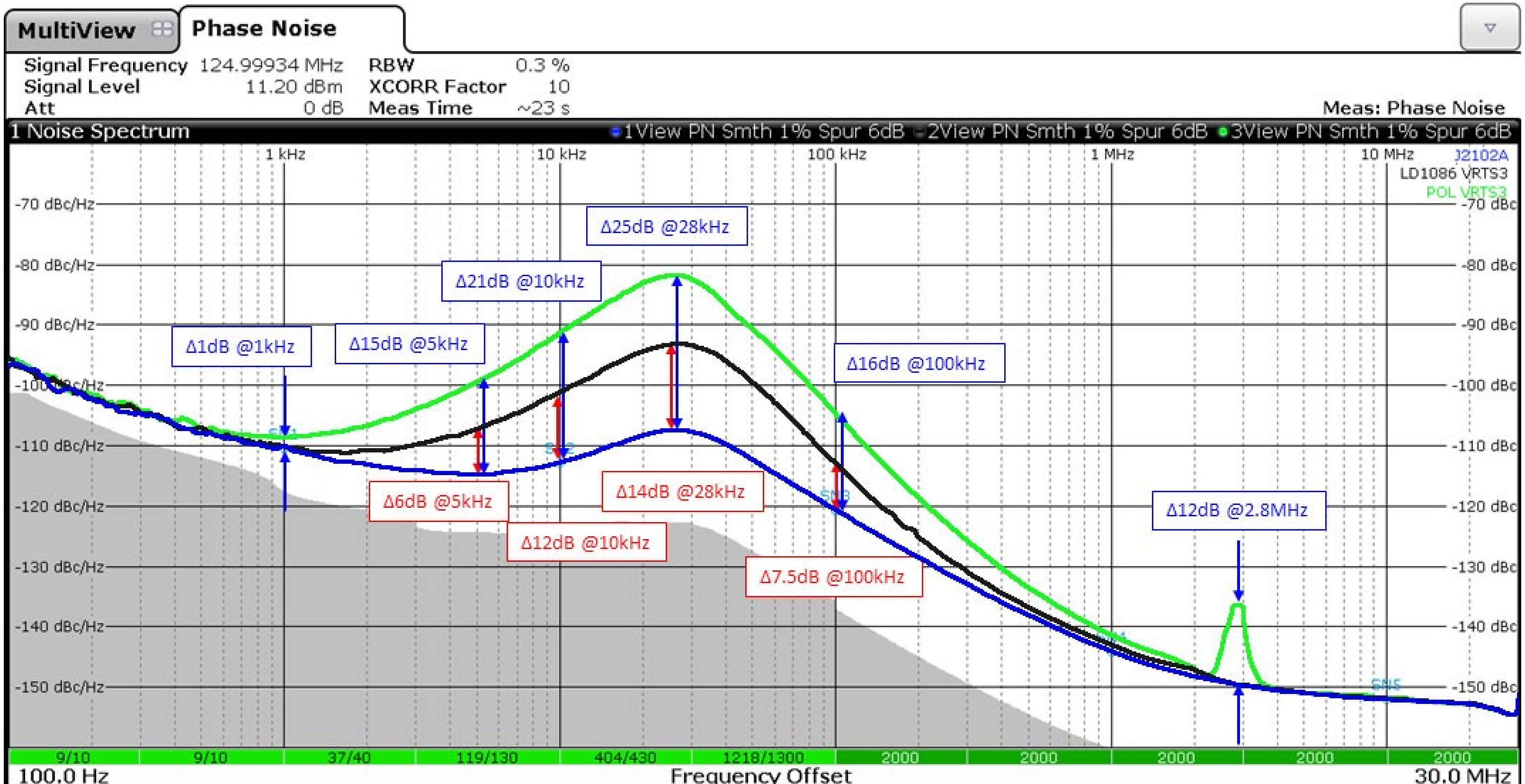
2 Integrated Measurements

Range	Trace	Start Offset	Stop Offset	Weighting	Int Noise	PM	FM	Jitter
1	1	100.000 Hz	30.000 MHz		-61.43 dBc	68.76 m°/1.20 mrad	2.832 kHz	1.528 ps
2	2	100.000 Hz	30.000 MHz		-48.71 dBc	297.12 m°/5.19 mrad	2.905 kHz	6.603 ps
3	3	100.000 Hz	30.000 MHz		-38.27 dBc	988.54 m°/17.25 mrad	2.964 kHz	21.968 ps

Measuring DC 29.06.2017 03:47:07

Date: 29.JUN.2017 03:47:07

Assessing the Damage



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1	1	100.000 Hz	30.000 MHz		-61.43 dBc	68.76 m°/1.20 mrad	2.832 kHz	1.528 ps
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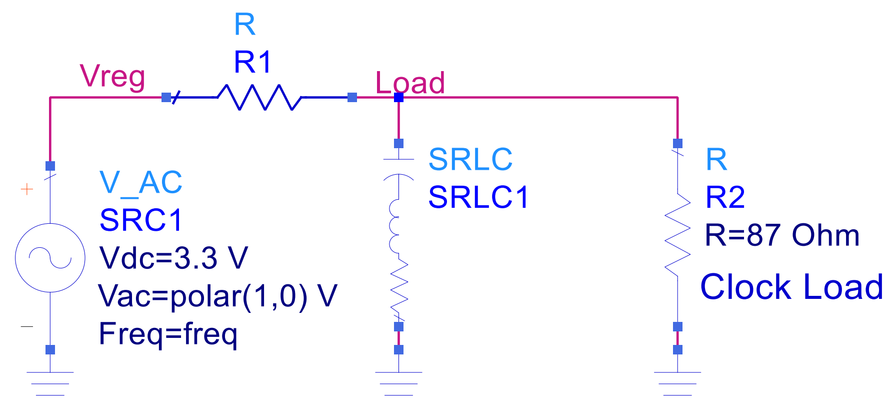
Measuring DC 29.06.2017 03:47:07

Date: 29.JUN.2017 03:47:07

Simplest Noise Filter

Regulation and noise are not the same thing and counterintuitively they oppose each other



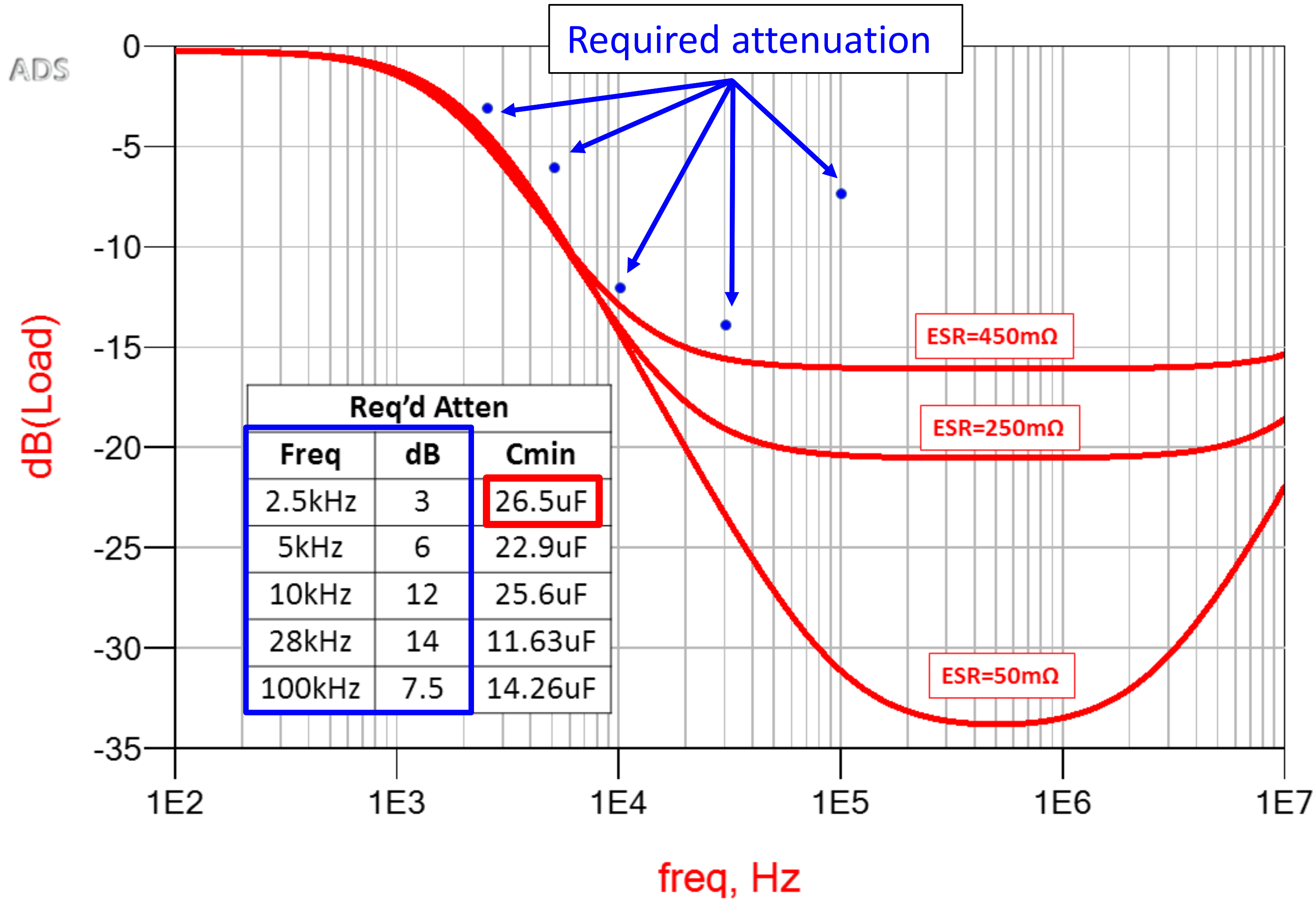
How much voltage can you give up?

$$R1 = \frac{100mV}{Idc} = \frac{100mV}{39mA} = 2.60\Omega$$

$$C1(dB, f) = \frac{0.159 \cdot \sqrt{e^{0.2303 \cdot dB}} \cdot e^{-0.115 \cdot dB} \cdot \sqrt{e^{0.2303 \cdot dB} - 1}}{R \cdot f}$$

$$ESRmax = \frac{0.707 \cdot R}{e^{0.115 \cdot dBmax} - 1}$$

Determining the Capacitor



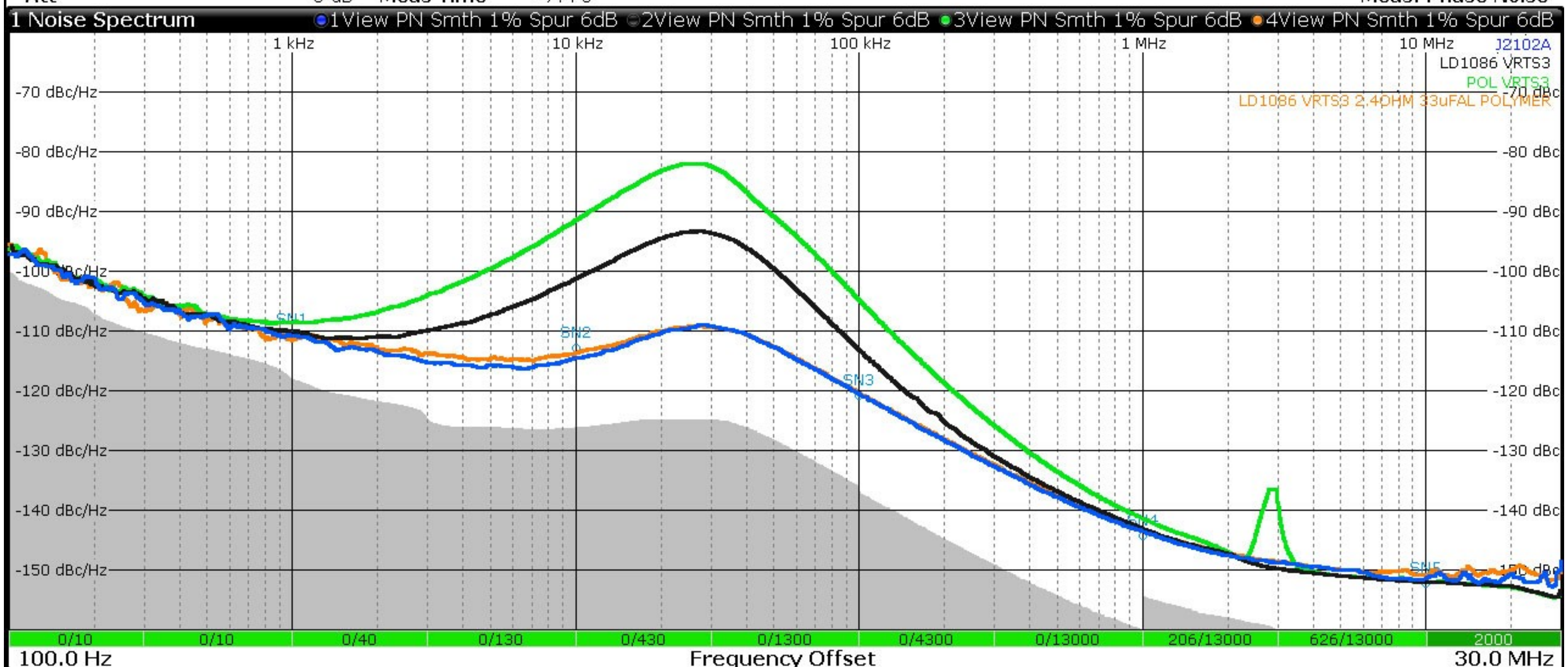
Req'd Atten		
Freq	dB	Cmin
2.5kHz	3	26.5uF
5kHz	6	22.9uF
10kHz	12	25.6uF
28kHz	14	11.63uF
100kHz	7.5	14.26uF

33uF/30mΩ ESR + 2.4Ω Filter

MultiView | Phase Noise

Signal Frequency	124.99970 MHz	RBW	1.0 %
Signal Level	11.11 dBm	XCORR Factor	10
Att	0 dB	Meas Time	~7.4 s

Meas: Phase Noise



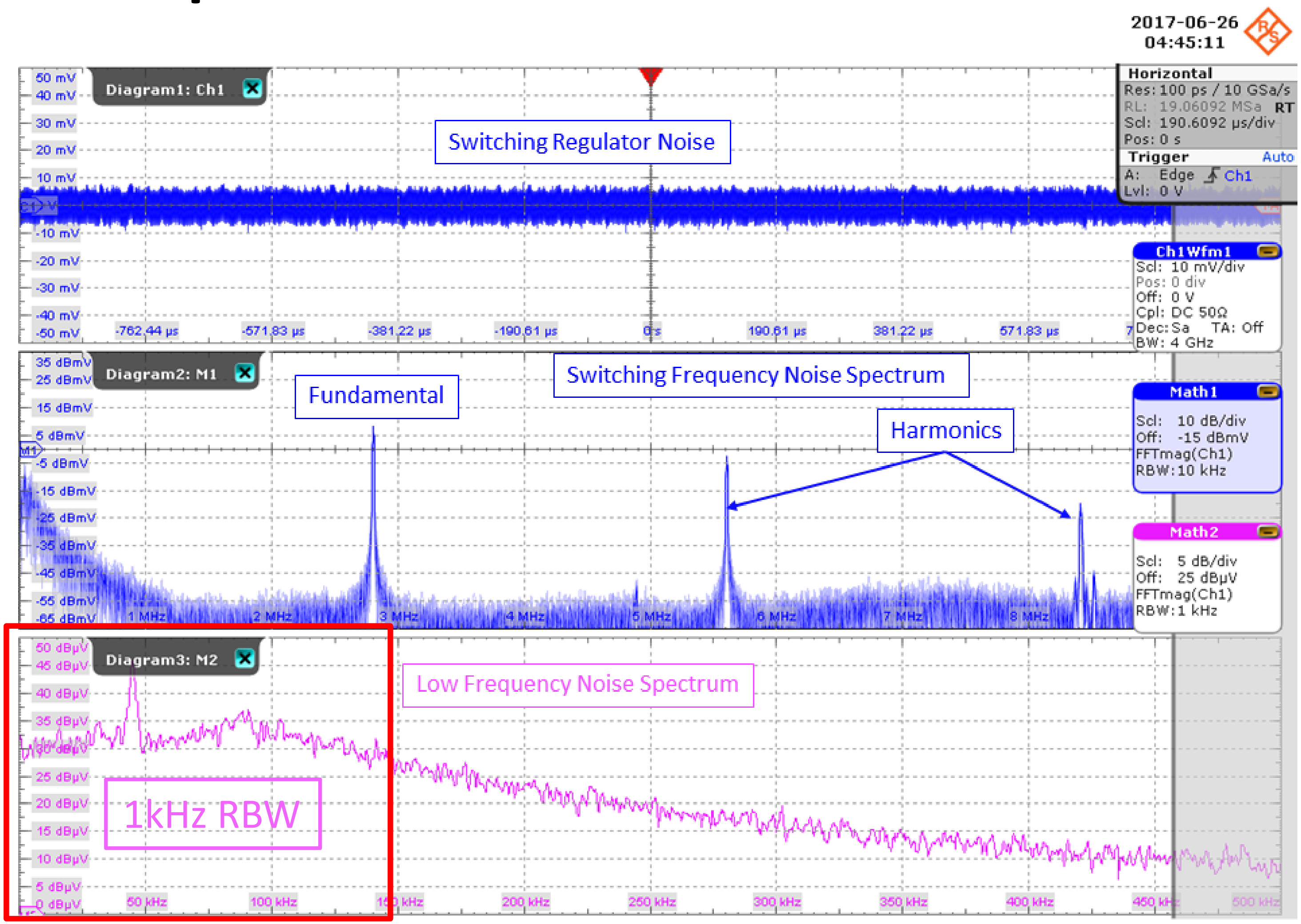
2 Integrated Measurements

Range	Trace	Start Offset	Stop Offset	Weighting	Int Noise	PM	FM	Jitter
1	1	100.000 Hz	30.000 MHz		-62.25 dBc	62.50 m°/1.09 mrad	3.593 kHz	1.389 ps
2	2	100.000 Hz	30.000 MHz		-48.71 dBc	297.12 m°/5.19 mrad	2.905 kHz	6.603 ps
3	3	100.000 Hz	30.000 MHz		-38.27 dBc	988.54 m°/17.25 mrad	2.964 kHz	21.968 ps
4	4	100.000 Hz	30.000 MHz		-62.05 dBc	64.00 m°/1.12 mrad	3.961 kHz	1.422 ps

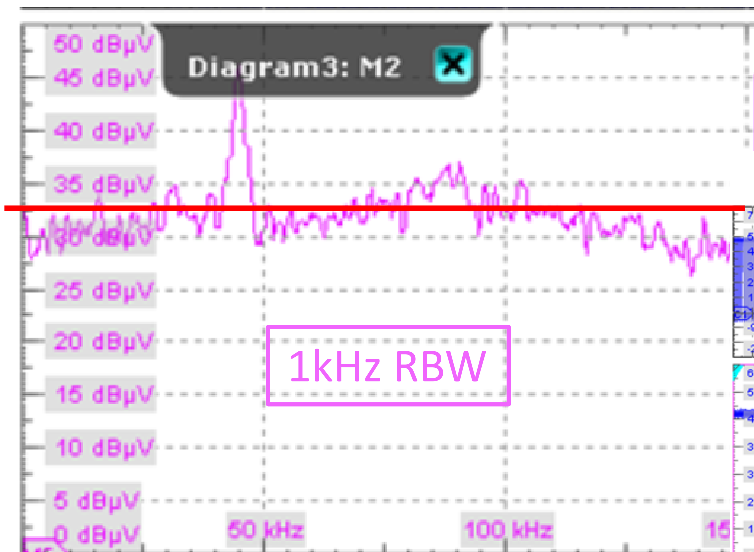
Measuring DC 30.06.2017 05:09:38

Date: 30.JUN.2017 05:09:38

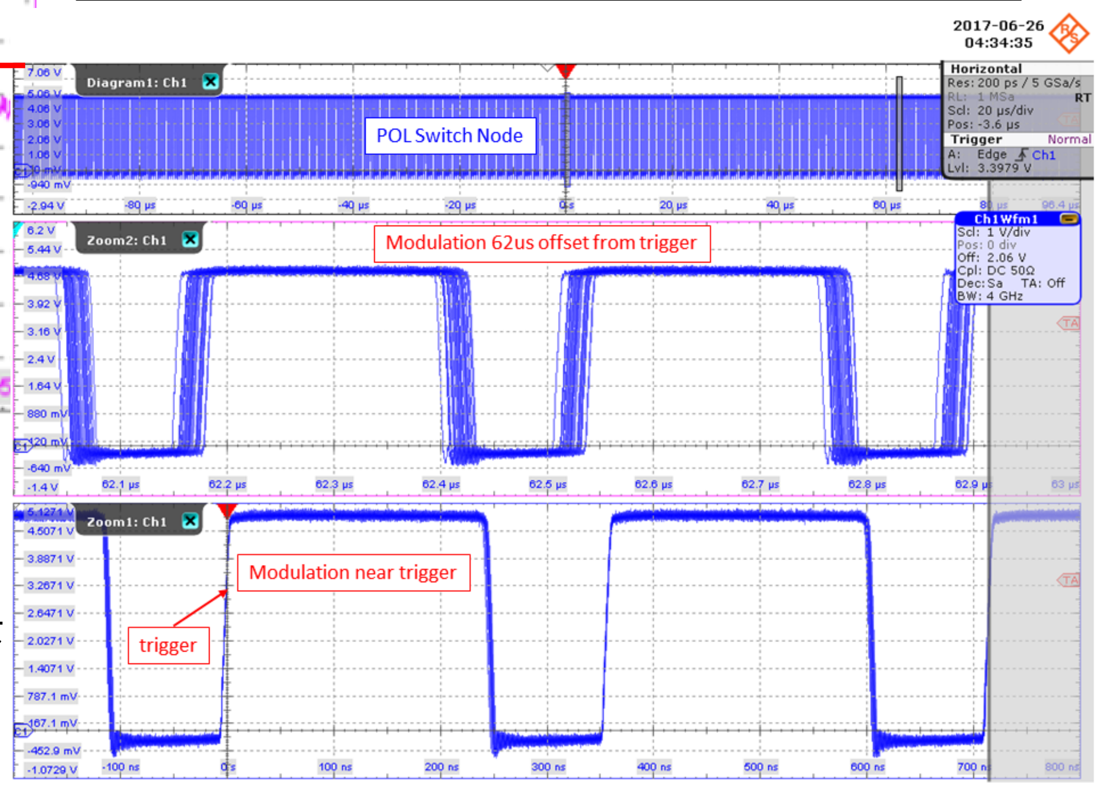
Unexpected Noise – 2.8MHz POL



Why The Low Frequency Noise?



This is in very good agreement with the signal source analyzer noise density measurement

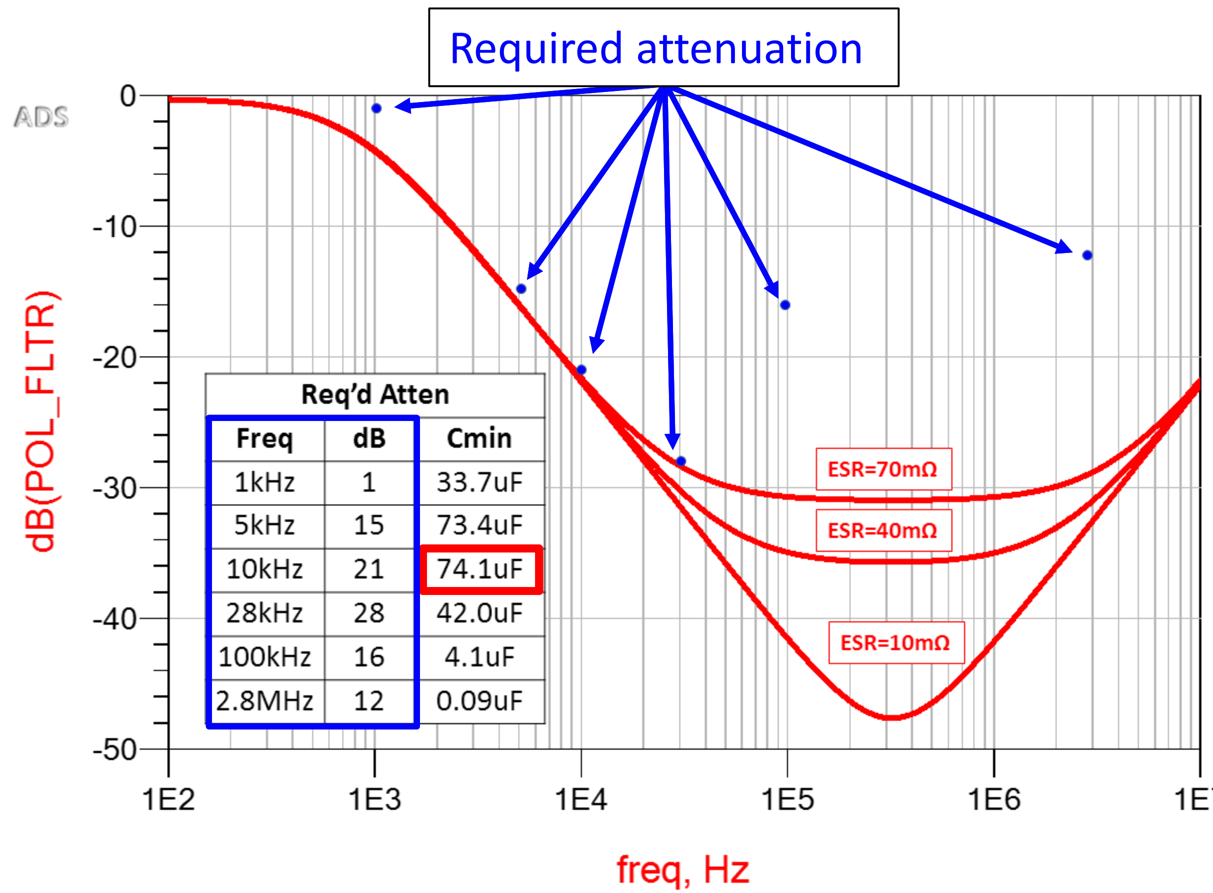


$32dBuV\ at\ 1kHz\ RBW\ (40uVpk)$

$$32dBuV \cdot \sqrt{\frac{1Hz}{1kHz(RBW)}} \cong 1.2uV/\sqrt{Hz}$$

The modulation noise is accounted for

Despite the 2.8MHz switching frequency it's the 10kHz range that defines the filter



Req'd Atten		
Freq	dB	Cmin
1kHz	1	33.7uF
5kHz	15	73.4uF
10kHz	21	74.1uF
28kHz	28	42.0uF
100kHz	16	4.1uF
2.8MHz	12	0.09uF

About Ferrite Beads

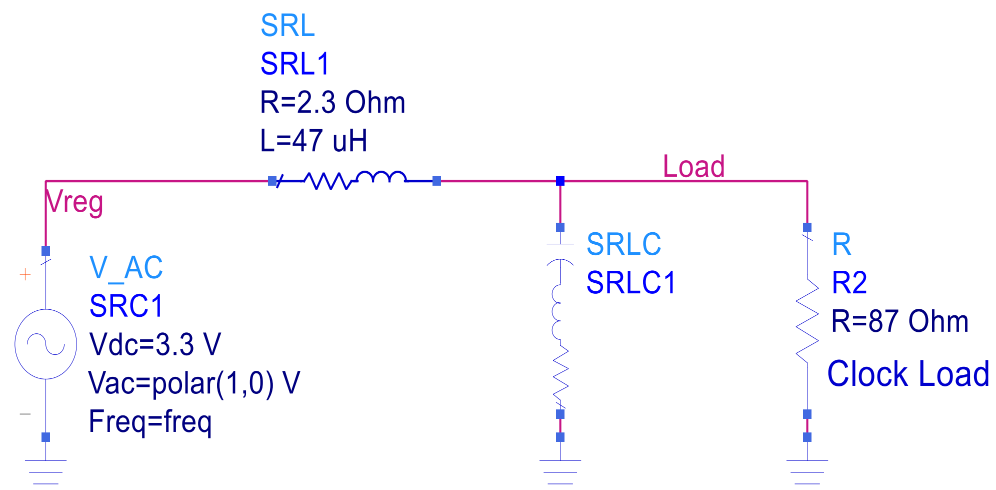
For Q=0.5

$$L_{max} = 0.5 \cdot C \cdot R^2$$

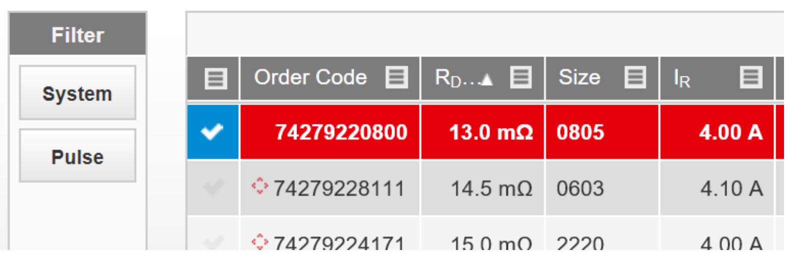
IF R approaches zero
then NO INDUCTANCE ALLOWED

$$ESRmax = \frac{0.707 \cdot R}{e^{0.115 \cdot dBmax} - 1}$$

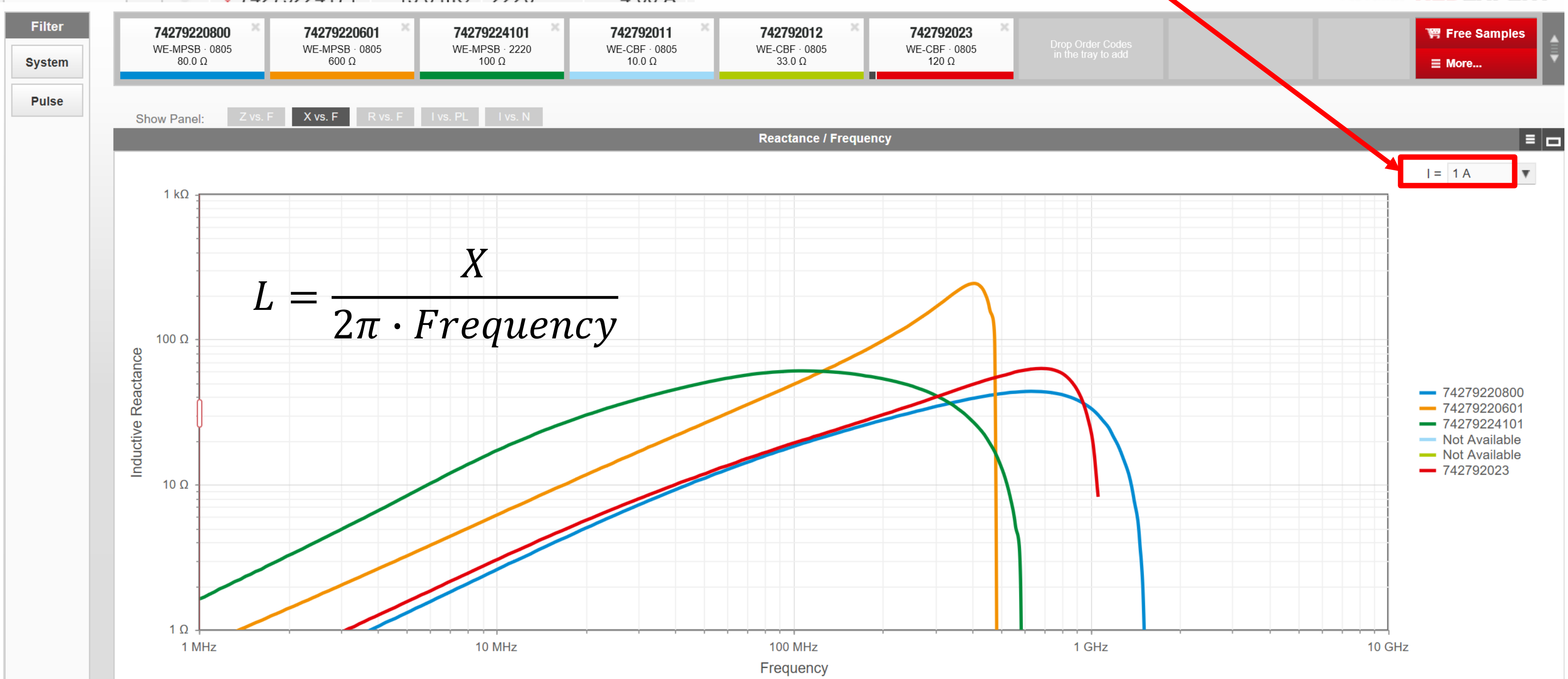
$$R = \frac{100mV}{Idc} = \frac{100mV}{39mA} = 2.60\Omega$$



Bead datasheets generally include DCR and high frequency resistance, but look for Inductive reactance and DC Bias data or measure it yourself



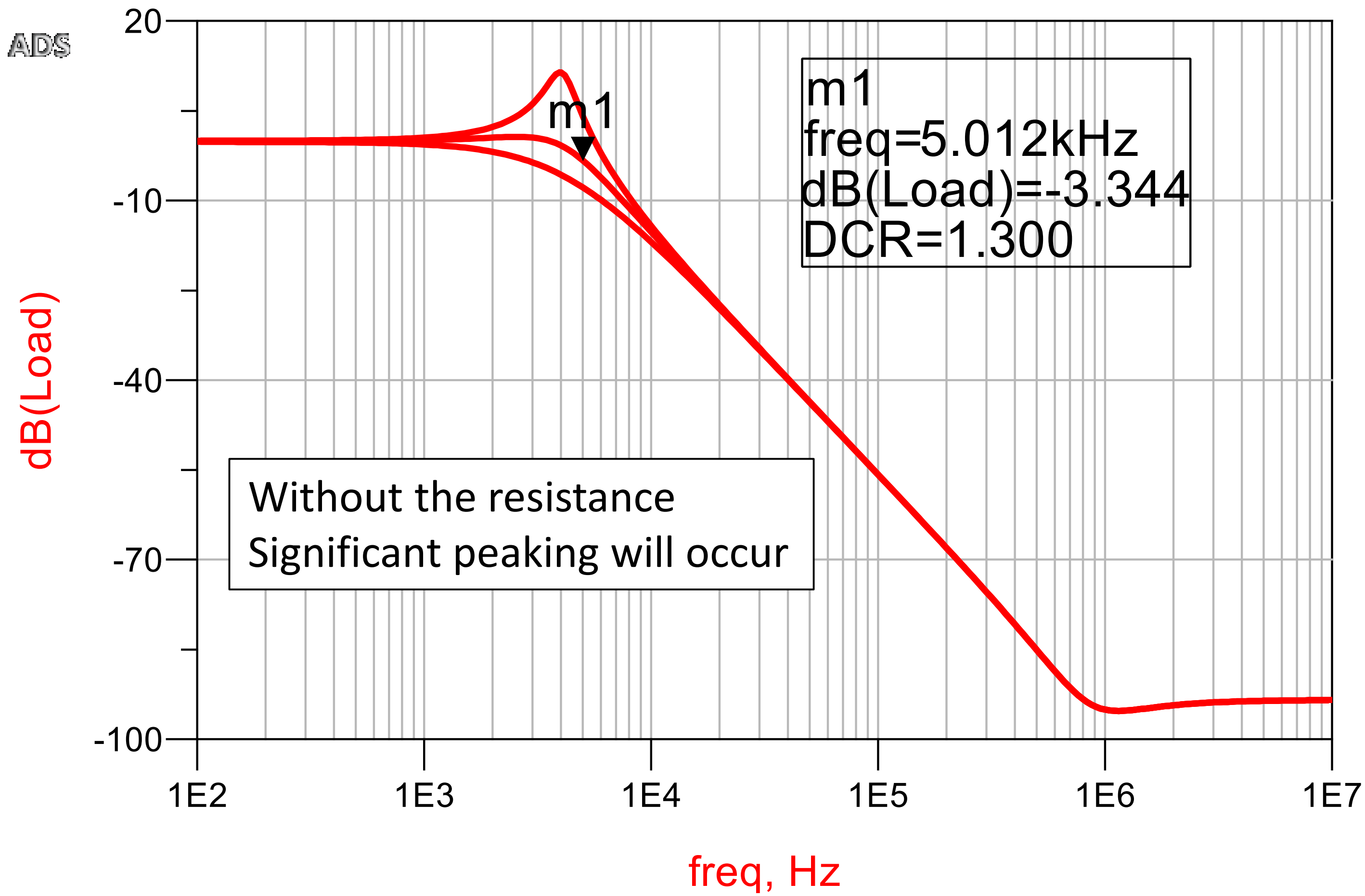
Assess over the entire operating current range



$$L = \frac{X}{2\pi \cdot Frequency}$$

Courtesy of Wurth Electronik

0.3, 1.3 and 2.3Ohm resistance



Without the resistance
Significant peaking will occur

"RF" Ultra-Low-Noise Options

The precision ultra-low-noise voltage regulator offers precision in the output voltage and low noise

BUT

Count the capacitors!

Is this better or just different?

Precision voltage vs ultra-low noise

TYPICAL APPLICATION CIRCUIT

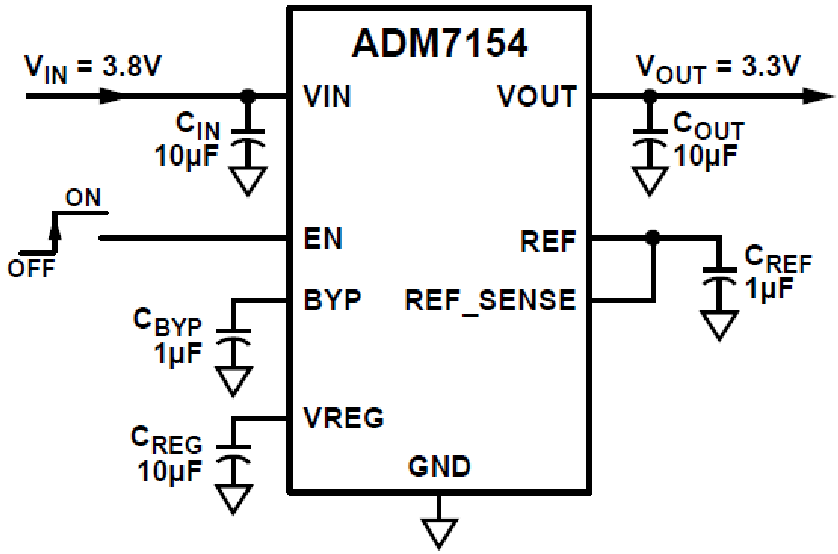
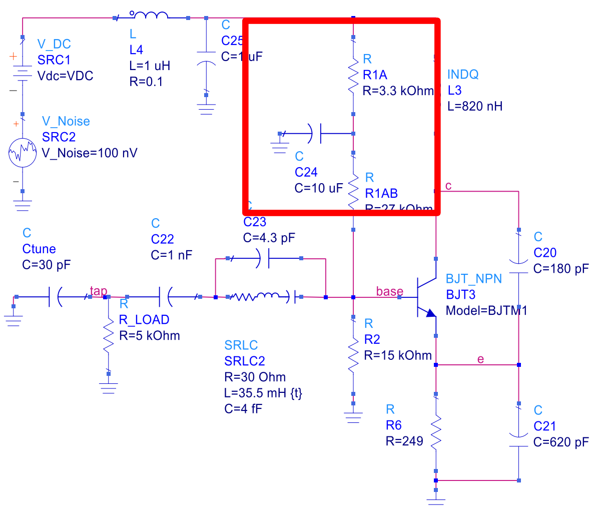


Figure 1. Regulated 3.3 V Output from 3.8 V Input

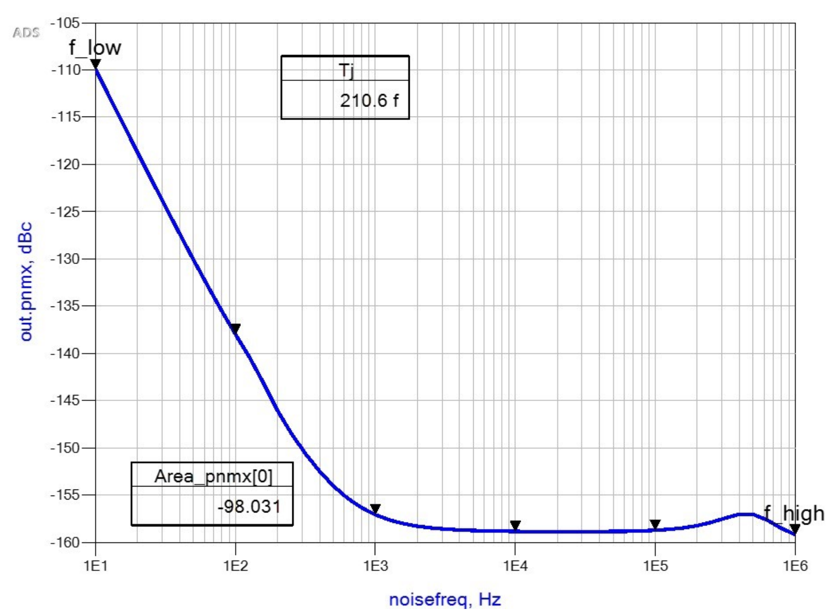


Top Tips

Low current bias also needs to be filtered.

Include phase noise and jitter in your simulations

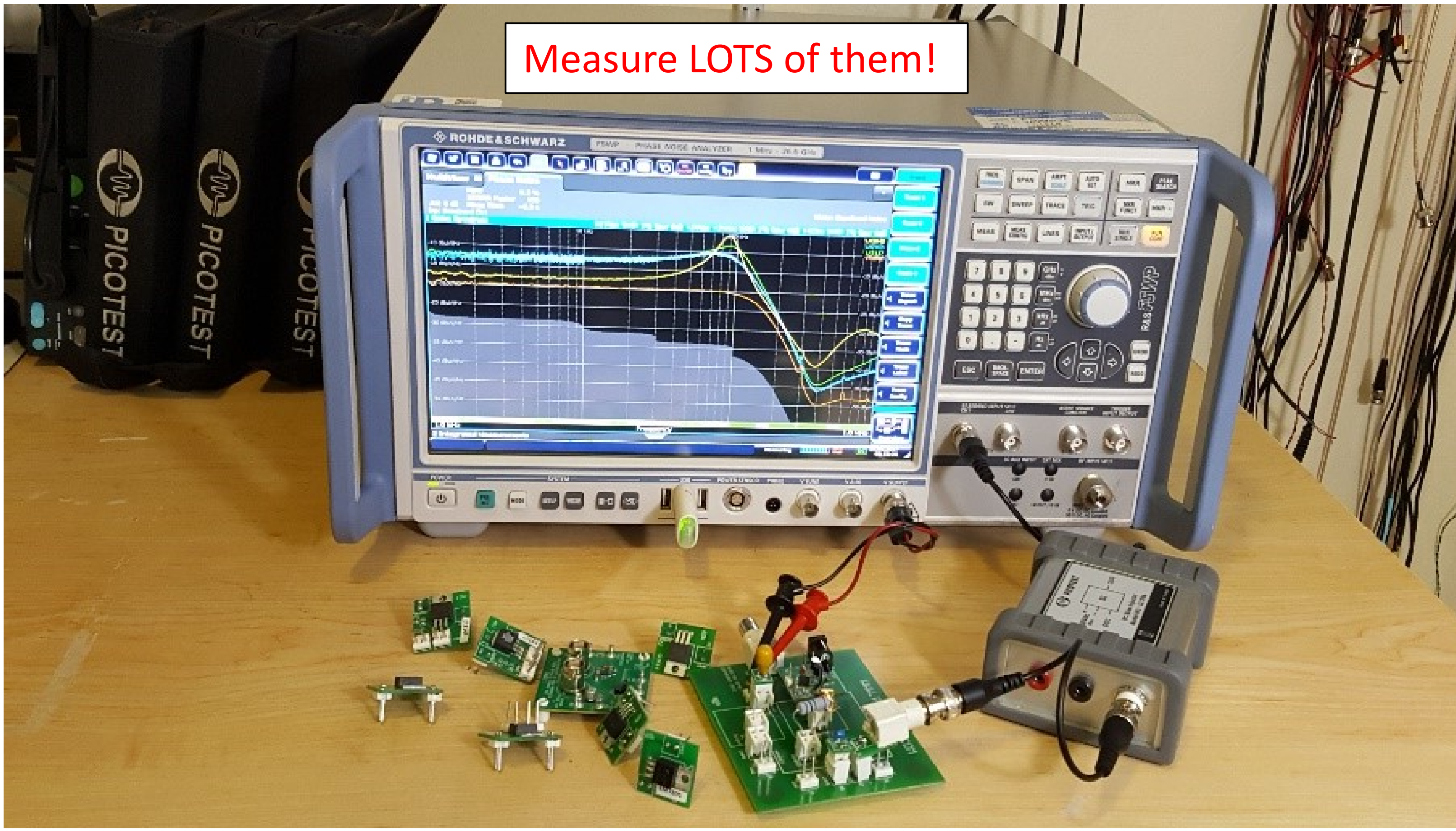
Higher value caps are generally better than lower value caps



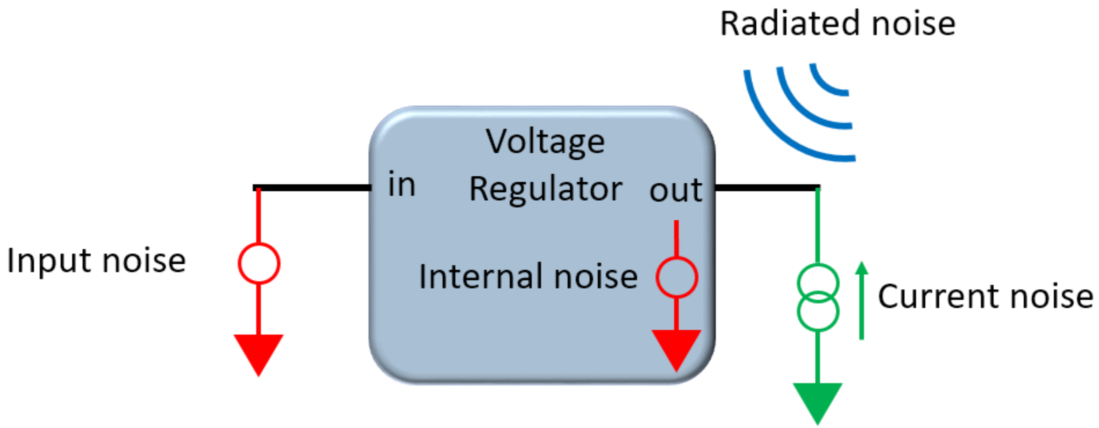
HB.freq[1]
13.40391 MHz

noisefreq	f_low
10.00 Hz	-109.939
noisefreq	f_10
10.00 Hz	-109.939
noisefreq	f_100
100.0 Hz	-137.978
noisefreq	f_1k
1.000 kHz	-157.073
noisefreq	f_10k
10.00 kHz	-158.824
noisefreq	f_100k
100.0 kHz	-158.711
noisefreq	f_high
1.000 MHz	-159.195

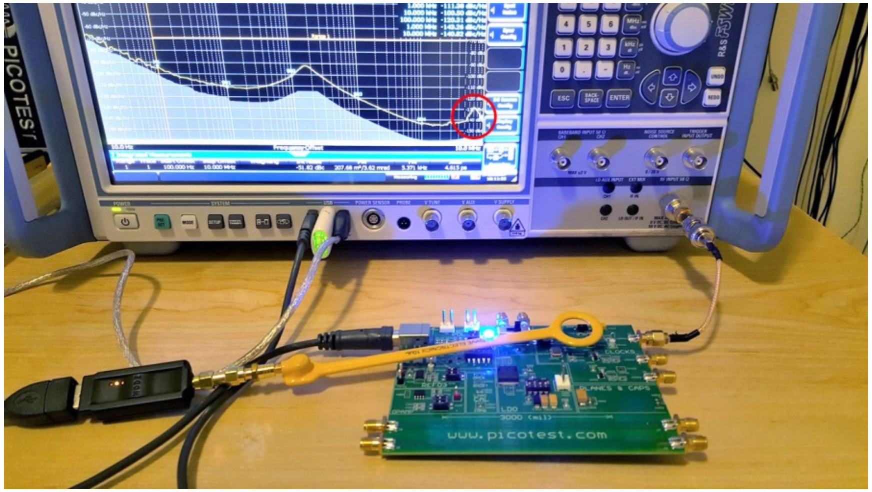
Not all regulators are created equal



Consider all the ways noise gets in



Watch the coaxial cables and power interconnects also



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Thanks for Attending this Session!

In this session I shared

- How to determine the circuit sensitivity to power supply noise
- How to choose the best voltage regulator
- How to design an optimum power supply noise filter
- A few of my top tips for designing power for sensitive circuits

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