Protecting ADC with TVS Diode

TI Precision Labs – ADCs

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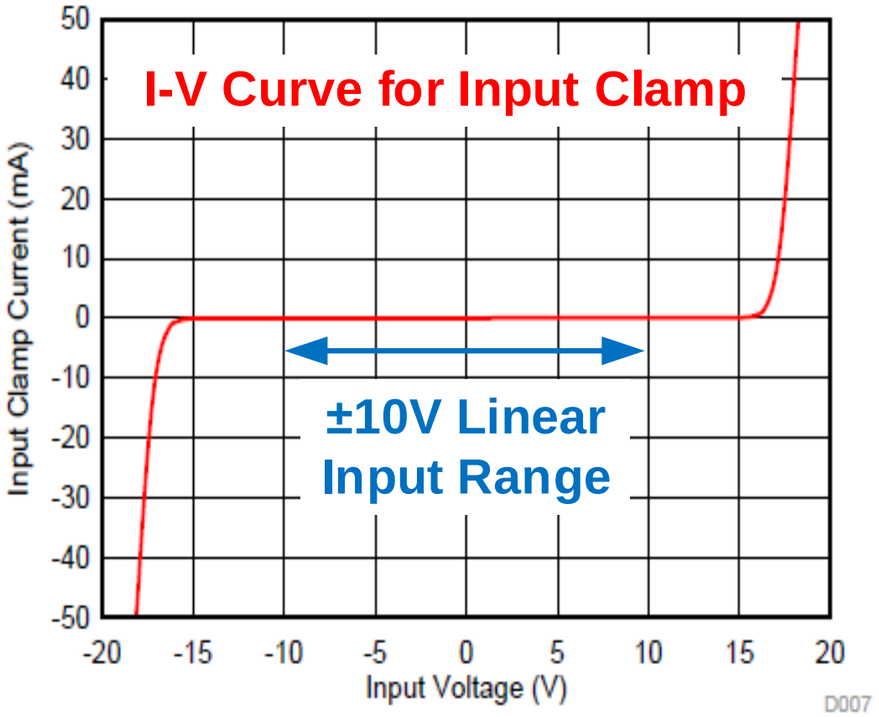
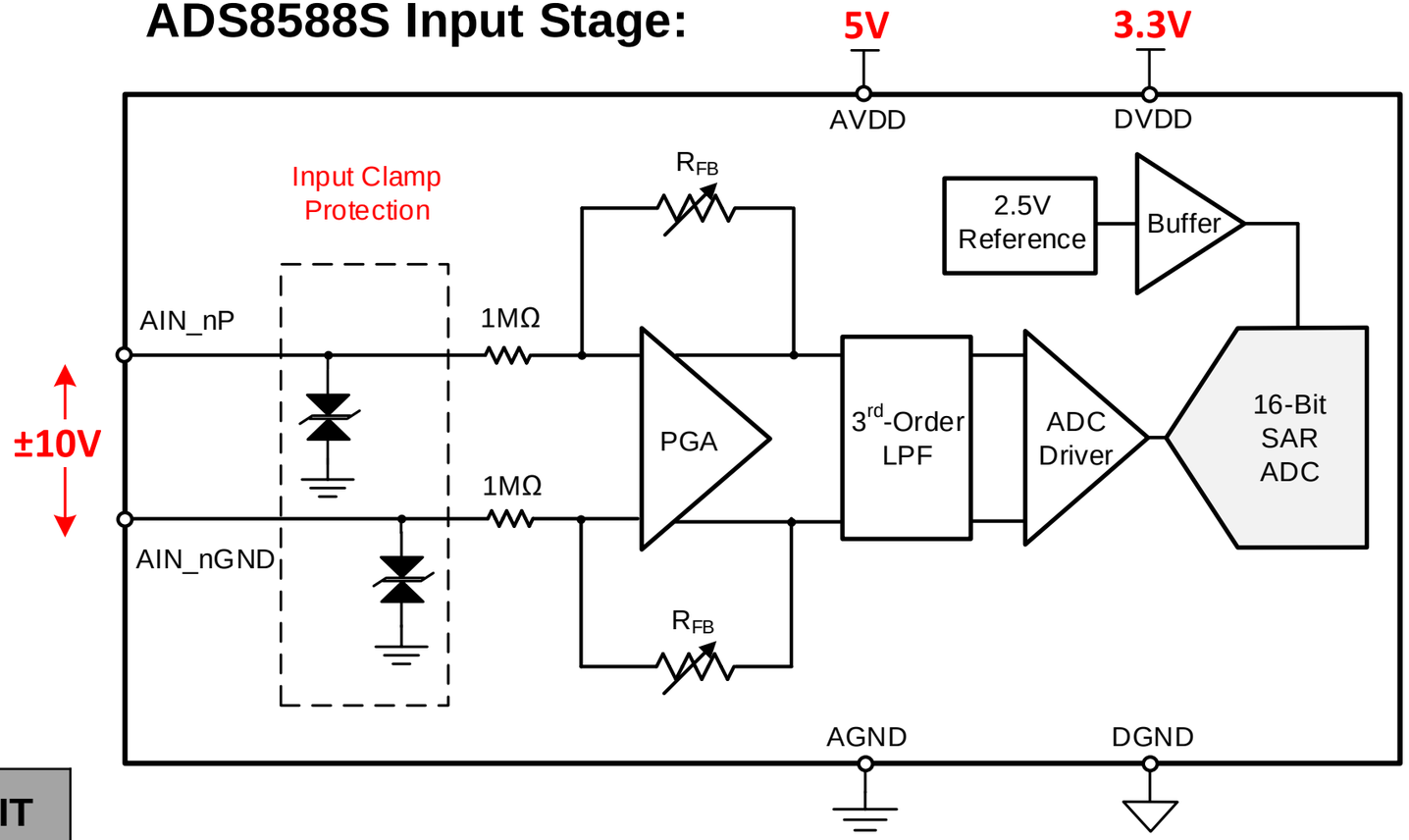
Back-to-Back Zener Diode on ADC Input

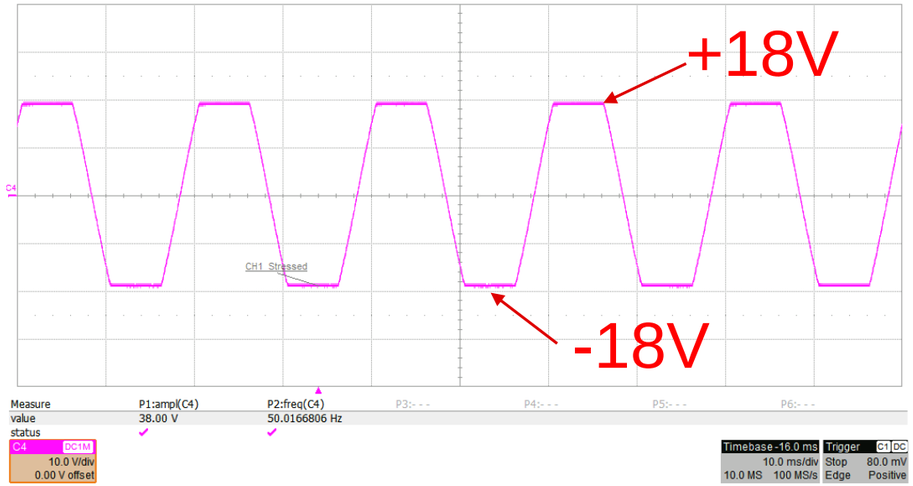


ADS8588S Input Stage:

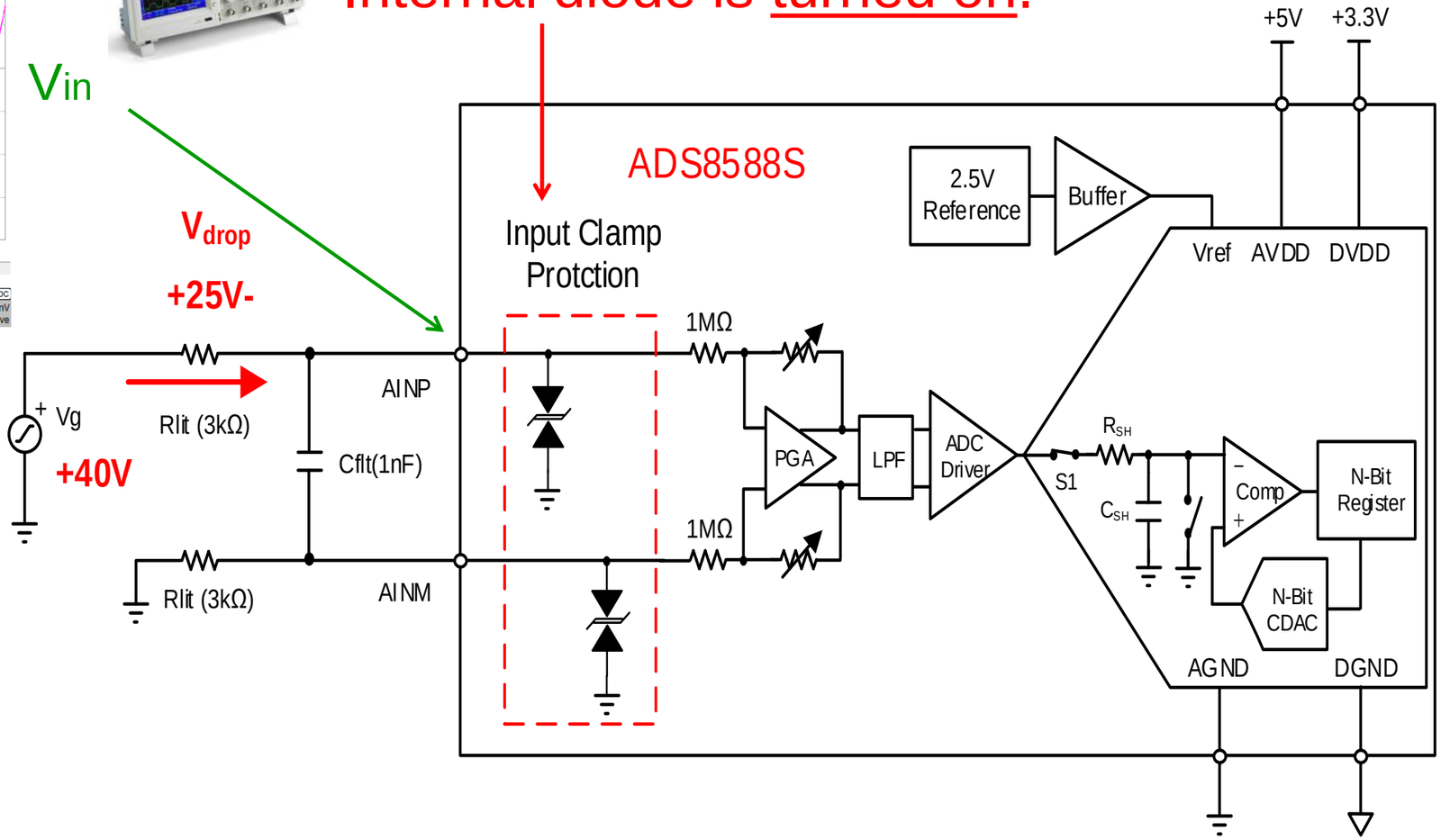


Absolute Maximum Ratings	MIN	MAX	UNIT
Analog input voltage to AGND	-15	+15	V
Input current	-10	+10	mA

Solution 1: Protection with Internal Back-to-Back Zener Diode



Internal diode is turned on.



ADS8588S Abs Maximum Ratings:

Parameter	Min		Max	Unit
V_{in_Abs}	**-15**		**+15**	V
I_{in_Abs}	**-10**		**+10**	mA

Select Rflt (±40V EOS):

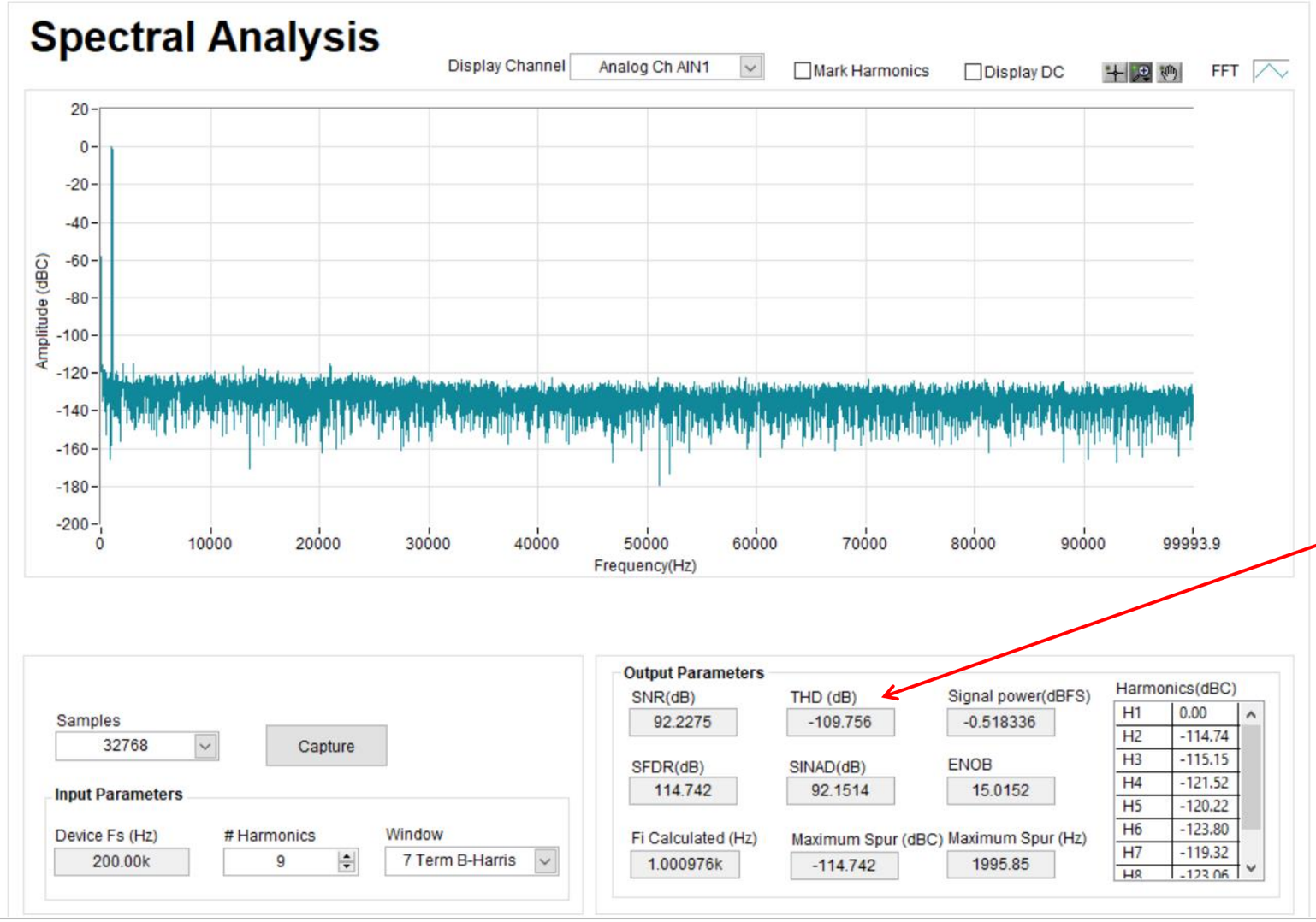
$$R_{flt} \geq \frac{40V - 15V}{10mA} \geq 2.5\ \text{k}\Omega$$

Select R_{flt} = 3kΩ in this example.

- A simple resister in series with input limits the current to ADC.

Back-to-Back Zener diode Protection on Device – Hardware Performance

(Rflt=3kΩ, Cflt=1nF, ADS8588S at 200ksps maximum sampling rate)



Performance without external diode
Measured on ADS8588SEVM (200ksps):

Parameter	Min	Typ	Max	Unit
SNR	**91**	**92**		dB
THD		**-110**	**-95**	dB

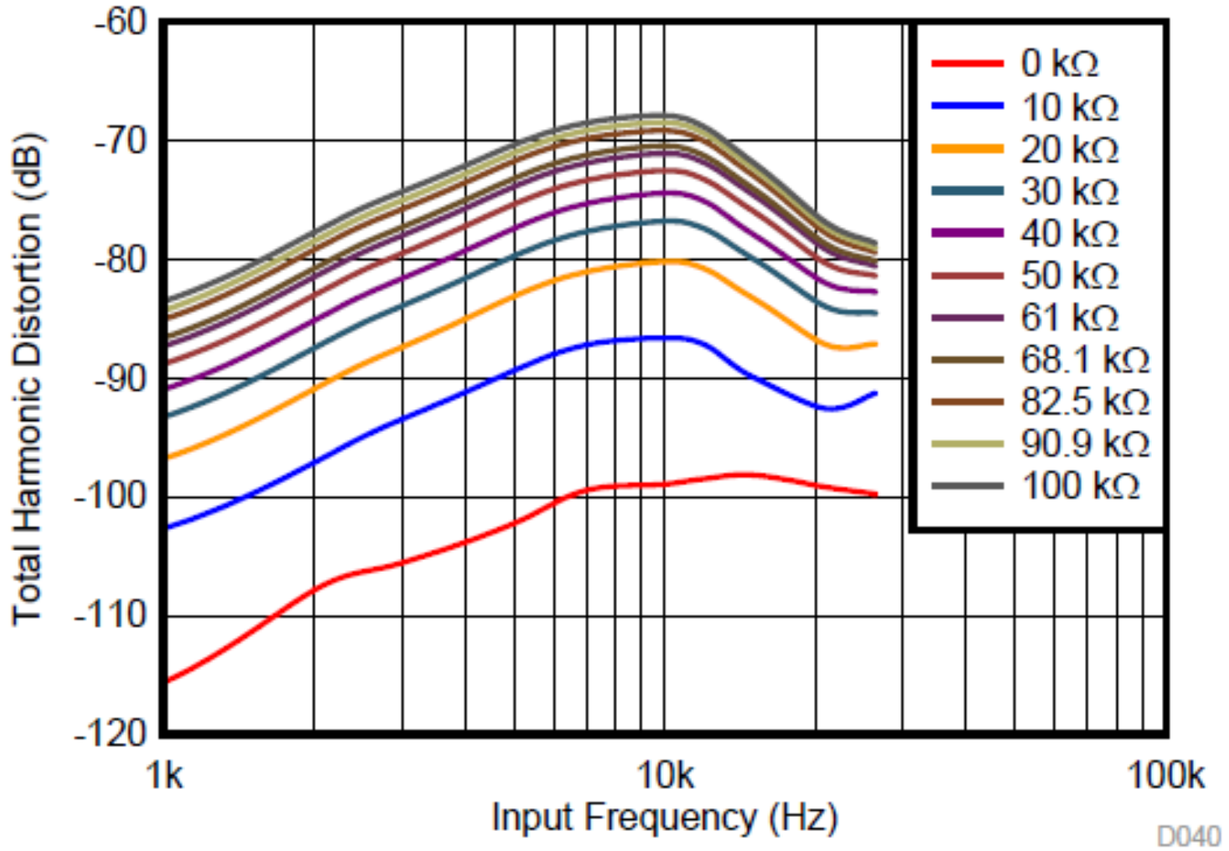
Measured with 3kΩ Rfilt:

SNR = 92.2dB

THD = - 109.7dB

(Tested on ADS8588SEVM)

THD vs Source Impedance (R_{flt}+R_g) with ADS8588S



Source: ADS8588S Datasheet.

- Nonlinear capacitance associated with input clamp on device causes the degradation with external resistors.
- The larger value resistor(R_{flt}):
  - Smaller current to ADC.
  - Small package size and less Power dissipation.
  - Less risk for continuous EOS.

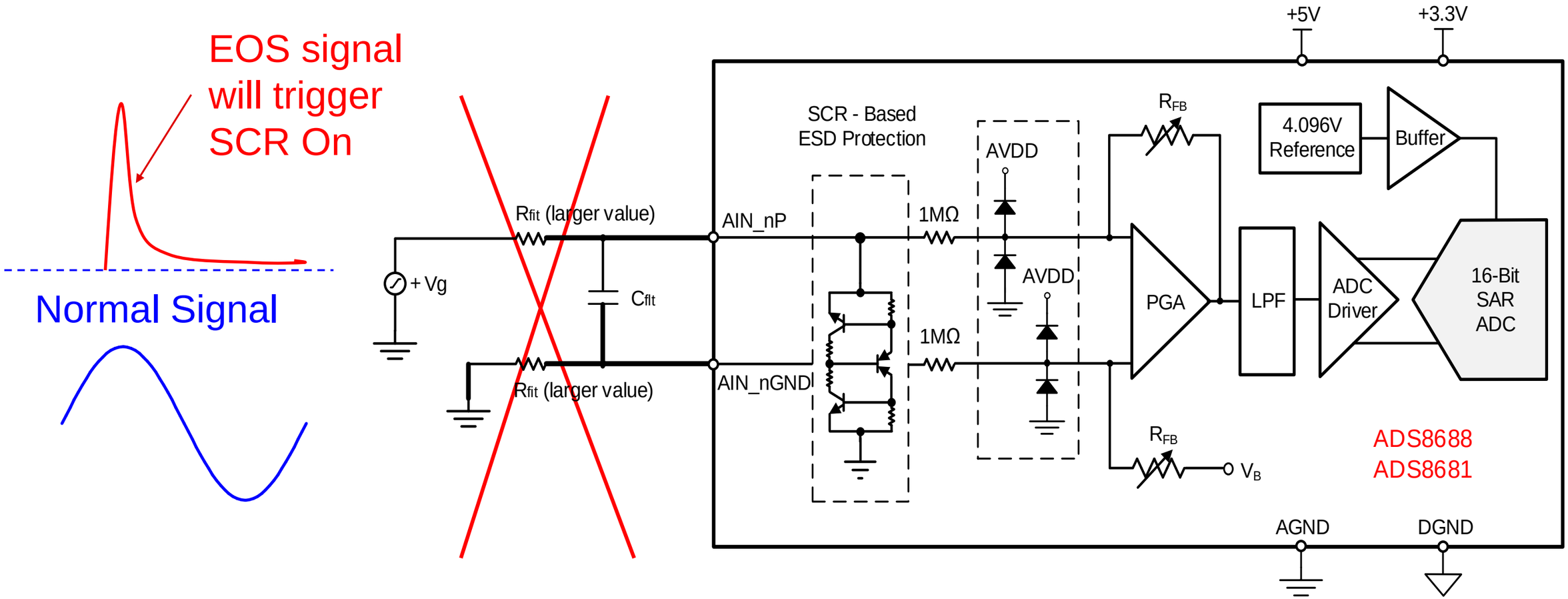
But can lead to worse THD:

- 3kΩ -> -109.7dB THD
- 15kΩ -> -98.9dB THD
- 24.9kΩ -> -95.1dB THD

(ADS8588S-200ksps EVM board with 1kHz sinewave input).

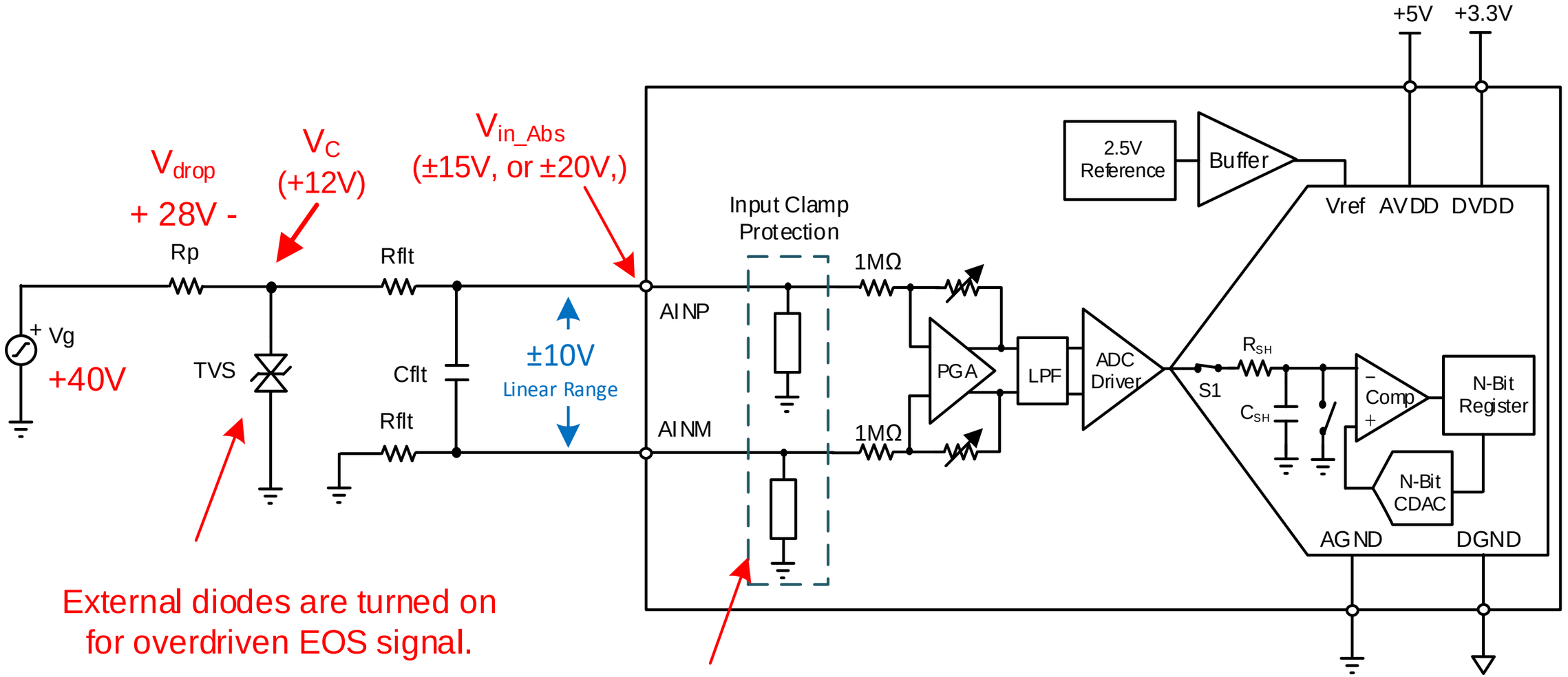
Note: Continuously turning on internal diode may affect device's lifetime.

Wrong Protection for ADC with SCR-Based Input



- Do not use this solution because an EOS signal may trigger a Latch-up.
- An external diode is needed to protect the ADC.

Solution 2: External TVS Diode Protection



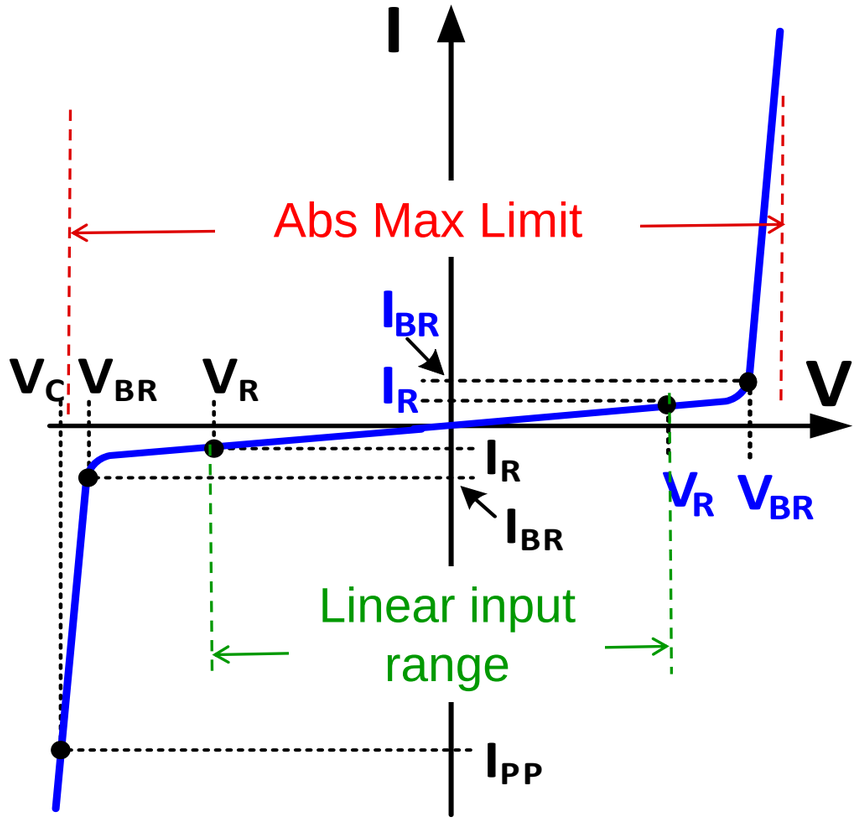
TVS Diode V-I Curve

Set $\mathbf{V_R \geq V_{in}}$ Maximum voltage of normal input signal

Note: leakage current I_R is specified at V_R

Bidirectional TVS

Symbol	Parameter
V_{BR}	Breakdown voltage
V_R	Stand-off voltage
V_C	Clamping voltage
V_F	Forward voltage drop
I_{BR}	Breakdown Current @ V_{BR}
I_R	Reverse Leakage @ V_R
I_F	Forward Current @ V_F
I_{PP}	Peak Pulse current @ V_C



Set V_R and V_{BR} to select TVS diode

Set $V_R \geq V_{in}$ Maximum voltage of normal input signal.
Set $V_{BR} < V_{in\_Abs}$ Absolute maximum input range of ADC.

ADS8588S Data Sheet

Absolute Maximum Ratings					
Parameter		**MIN**	**TYP**	**MAX**	**UNIT**
Analog Input to AGND (V_{in_Abs})		-15		+15	V
Normal Input Signal (Range Pin=1, TA = –40°C to +125°C)					
AIN_nP Signal (V_{in})		-10		+10	V

TVS Diode Specifications

Part Number	MFG	Reverse Standoff Voltage(V_R)	Breakdown Voltage (V_{BR})		Clamping Voltage Max (V_C)	Reverse Leakage (I_R@V_R)	Breakdown Current (I_{BR}@V_{BR})	Peak pulse Current (I_{PP})	Peak Power Dissipation (P_{PP})
			Min	Max					
SMCJ10CA	Bourns	**10V**	11.1	12.3	17V	5uA	1mA	88.3A	1500W

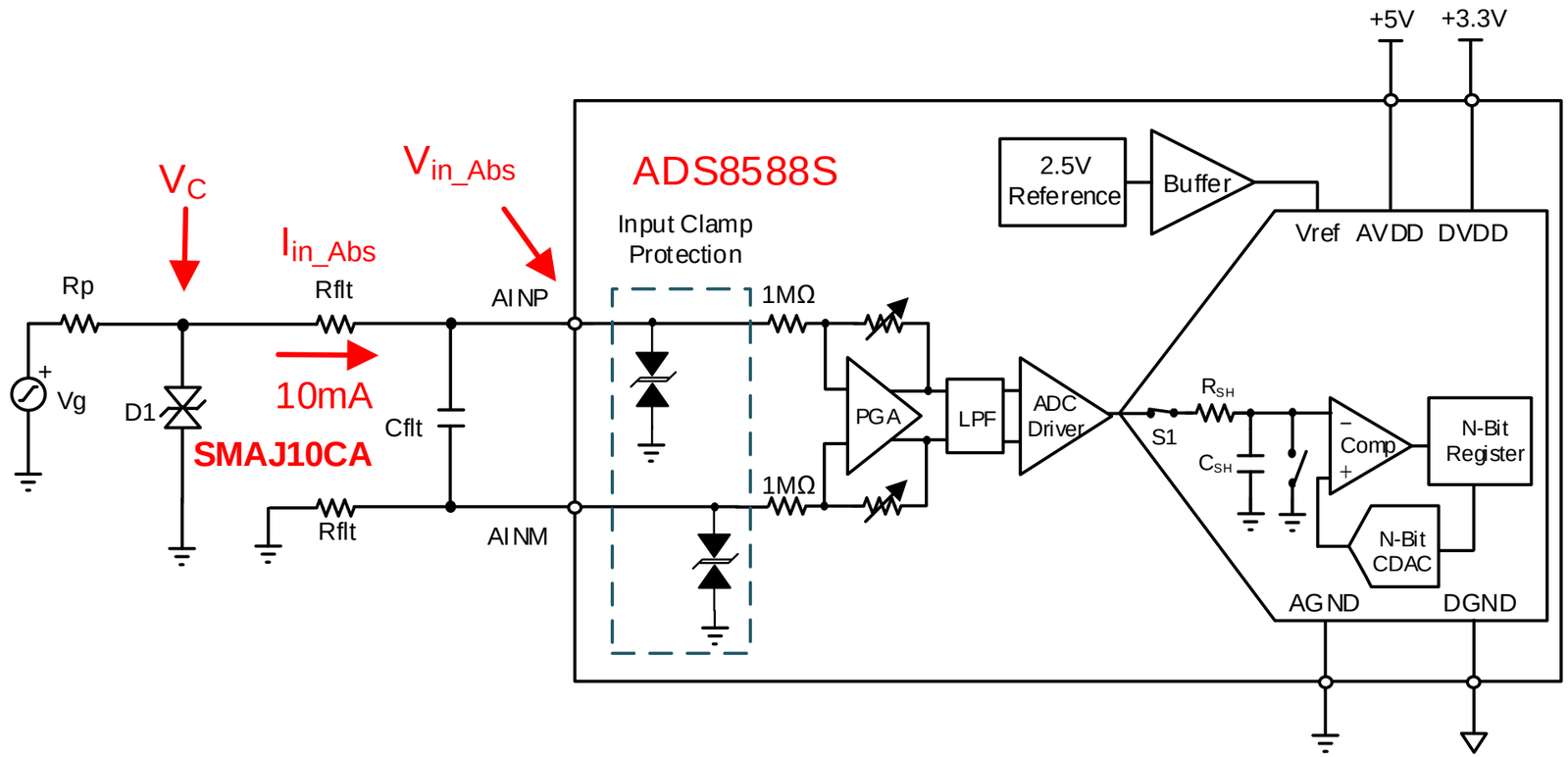
Choose Rp to limit power in Rp and TVS

Part Number	MFG	Reverse Standoff Voltage(V_R)	Breakdown Voltage (V_{BR})		Clamping Voltage Max (V_C@I_{PP})	Reverse Leakage Max (I_R@V_R)	Breakdown Current (I_{BR}@V_{BR})	Peak pulse Current (I_{PP})	Peak Power Dissipation (P_{PP})	Steady State Power Dissipation (P_{PP})
			Min	Max						
SMCJ10CA	Bourns	10V	11.1	12.3	17V	5uA	1mA	88.3A	1500W	5.0W

1	$R_P \geq \frac{(V_{in\_AbsMax} - V_{BRmin})^2}{P_{RPmax}} = \frac{(40V - 11.1V)^2}{1W} = 835\Omega$ $(\boldsymbol{choose\ 1k\Omega})$
2	$I_{max} = \frac{V_{in\_AbsMax} - V_{BRmin}}{R_P} = \frac{40V - 11.1V}{1k\Omega} = 28.9mA$
3	$P_{TVSmax} = I_{max} \cdot V_C = (28.9mA)(17V) = 491.3mW$

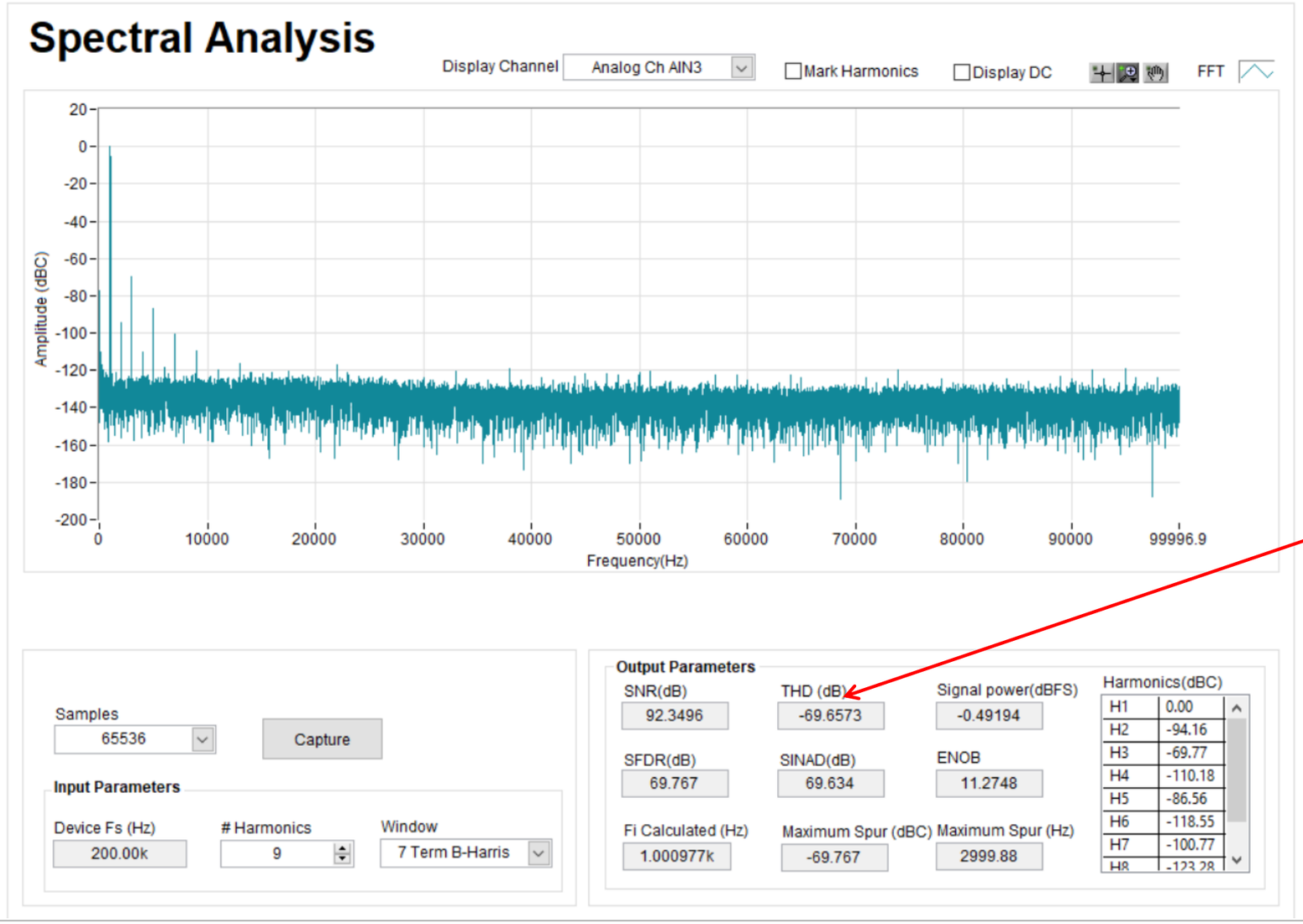
Selecting R_{flt} for Abs Ratings to Prevent damage

Parameters known:		
1	V_{in_Abs} (ADC)	$\pm 15V$
2	I_{in_Abs} (ADC)	$\pm 10mA$
3	V_{C_Max} (TVS)	$17V$
4	I_{PP} (TVS)	88.3A
Select R_{flt} :		
1	R_{flt}	$R_{flt} \geq \frac{(17-15)V}{10mA} \geq 200\Omega$
2	**Select R_{flt} =1kΩ**	



External TVS (SMCJ10CA) – Hardware Performance

(TVS - SMCJ10CA, R_p=1kΩ, R_{flt}=1kΩ, C_{flt}=1nF, ADS8588S at 200ksps sampling rate)



Performance without external diode
Measured on ADS8588SEVM (200ksps):

Parameter	Min	Typ	Max	Unit
SNR	**91**	**92**		dB
THD		**-110**	**-95**	dB

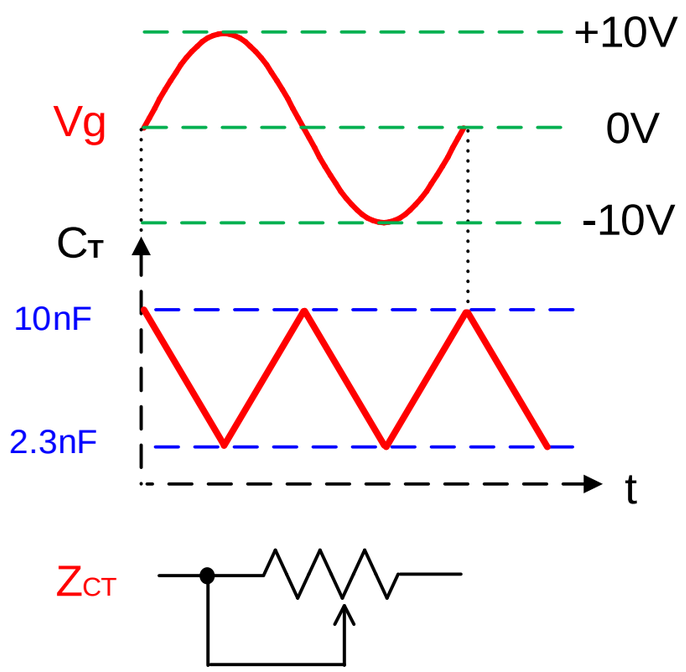
Measured with TVS:

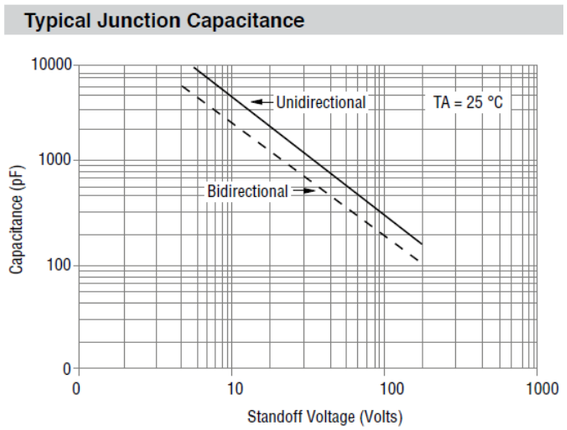
SNR = 92.3dB

THD = - 69.6dB

Capacitance Variation Causes Worse THD

- Capacitor(C_T) is viewed as a capacitor(frequency) controlled resistor with a 1/Zc variation in impedance as capacitor(frequency) value variation.





SMCJ10CA from Bourns

$$Z_{C\_min} = \frac{1}{2\pi \cdot f_{in} \cdot C_{T\_max}} = \frac{1}{2\pi \cdot 1kHz \cdot 10nF} = 15.9k\Omega$$

$$Z_{C\_max} = \frac{1}{2\pi \cdot f_{in} \cdot C_{T\_min}} = \frac{1}{2\pi \cdot 1kHz \cdot 2.3nF} = 69.2k\Omega$$

TVS Diodes

TVS Diodes: Electrical Characteristics and Performance Measurement Result

Part Numbers	MFG	Reverse Standoff Voltage (V_R)	Breakdown Voltage (V_{BR})		Clamping Voltage Max (V_C)	Capacitance Variation (C_T) **	Reverse Leakage Max (I_R@V_R)	Breakdown Current (I_{BR}@V_{BR})	Peak pulse Current (I_{PP})	Measured THD (dB)	Peak Power Dissipation (P_{PP})
			Min	Max							
SMCJ10CA	Bourns	10V	11.1	12.3	17V	2.3nF - >10nF*	5uA	1mA	88.3A	**- 69.6**	1500W
SMA6J10A	TSM	10V	11.1	12.3	15.7V	200~400pF	5uA	1mA	38.2A	**- 79.5**	600W
PGSMAJ10CA	TSM	10V	11.1	12.3	17V	80~160pF	5uA	1mA	23.5A	**- 81.8**	400W

* The datasheet does not directly show the capacitance at 0V, it is much larger than 10nF regarding the trend.

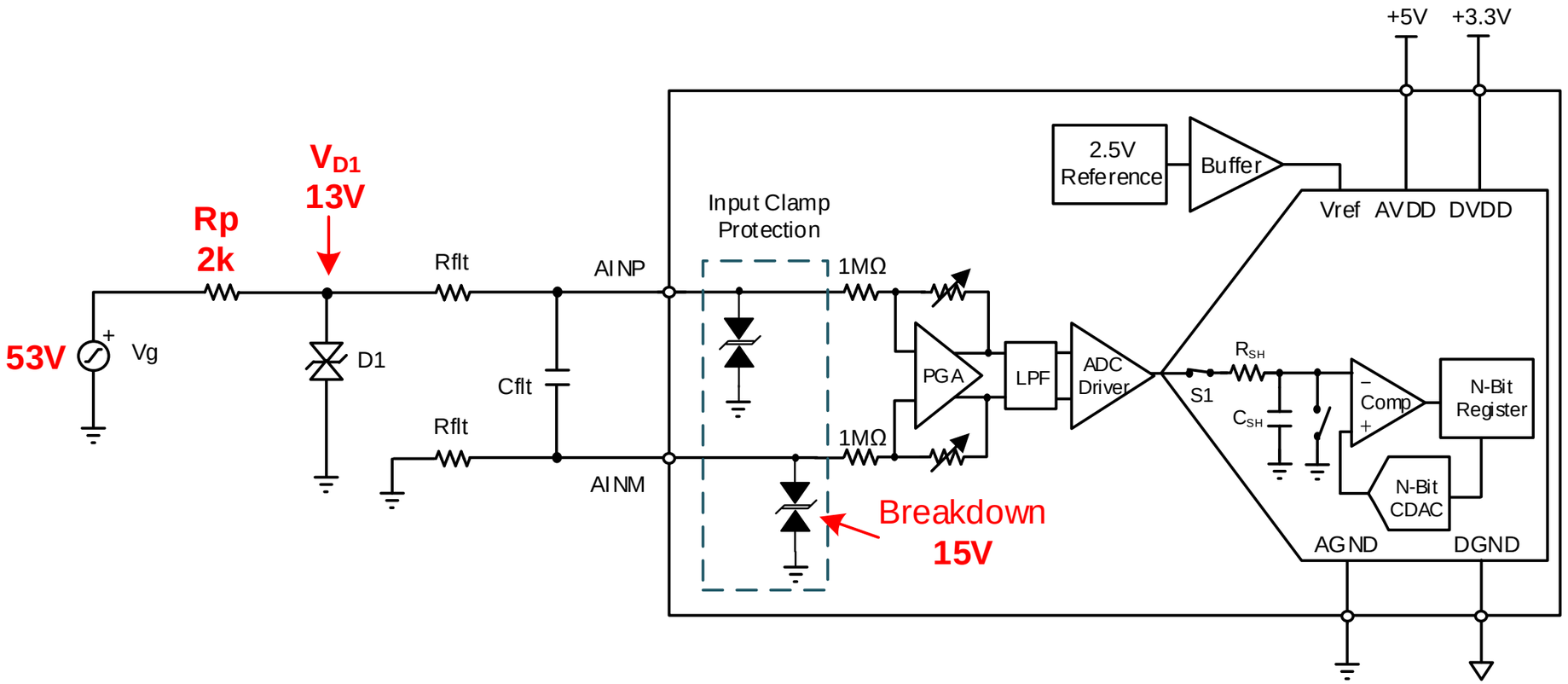
** These are estimated value from the capacitance curve in the datasheet.

Note: the ADS8588S specified typical THD = -110dB

Thanks for your time!
Please try the quiz.

Questions: Protecting ADC with TVS Diode

1. For the circuit below, what is the power dissipated in RP for a continuous 53V overstress input voltage?
   a. 0.4W
   b. 0.6W
   c. 0.8W
   d. 1.0W



Questions: Protecting ADC with TVS Diode

2. (T/F) A current limiting resistor can be used as input protection in devices with an internal Back-to-Back Zener ESD cell.
   a. True
   b. False

3. (T/F) A current limiting resistor can be used as input protection in devices with an internal SCR type ESD cell.
   a. True
   b. False

Questions: Protecting ADC with TVS Diode

4. What is the main performance limitation caused by using a series resistor with a TVS diode?
   a. The nonlinear diode capacitance and series resistance create distortion
   b. Noise caused by the series resistance reduces SNR.
   c. Temperature drift from the input resistance effects gain error
   d. The circuit is more susceptible to RF noise

5. (T/F) A low capacitance TVS diode can be used to reduce THD.
   a. True
   b. False

Questions: Protecting ADC with TVS Diode

6. A ±12V input range should be protected with what kind of TVS diode?
   a. Bidirectional, with Breakdown = 12V
   b. Unidirectional, with Breakdown = 12V
   c. Bidirectional, with Stand-off = 12V
   d. Unidirectional, with Stand-off = 12V

Thanks for your time!