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Design Note – DN05118/D

Filtering Common Mode Overshoot at the Inputs of ON Semiconductor NCS21xR and NCS199AxR Current Sense Amplifiers (CSA's)

Device	Application	R_{Shunt}	Input (V_{IN})	Output Voltage (V_{OUT})	Input Offset Voltage	Package
NCS213R	Consumer	25 mΩ	40 kHz Square Wave, 5VPP, 5ns edge	1.65 V to 2.15 V	±100 µV	SC70-6, UQFN10

Circuit Description

This design note describes how to suppress transient overshoot at the input of the NCS21xR and NCS199A1R current sense amplifiers. There are two specification criteria of interest: The ABS Max range of (GND – 0.3 V) to +30 V which if exceeded could damage the device; and the specification range of -0.3 V to 26 V over which the device is guaranteed to function properly. Note that the common-mode voltage range limits are separate and independent of the supply voltage (V_S) limits. This design note assumes that the power supply pin of the device is fed from a separate and conditioned source within the limits of the specifications for that pin.

At times, a current sensing application may have a large amplitude and fast switching common-mode signal on the line that the shunt is in. Frequently this signal may have overshoot on the rising or falling edge. If the overshoot exceeds the specification range of -0.3 V to 26 V the device may not function properly. Note that the negative limit of -0.3 also applies as an ABS Max rating which, if exceeded, could damage the device (with overshoot in the rising edge direction, overshoot should be below the ABS Max of 30 volts to avoid damage). In order to not damage the device and ensure proper operation, this overshoot condition must be filtered before reaching the inputs of the amplifier.

The circuit and conditions shown in Figure 1 produce a signal at the inputs to the amplifier that violates the ABS Max spec for the input common mode voltage of "GND – 0.3 V." The first question would be why doesn't this damage the device? The ABS Max section of the data sheet allows the voltage ratings of any pin to be exceeded so long as current is limited to less than 5 mA which has been established in this example. Nonetheless, safe, proper functioning is not guaranteed unless it is clamped to less than 0.3 V.

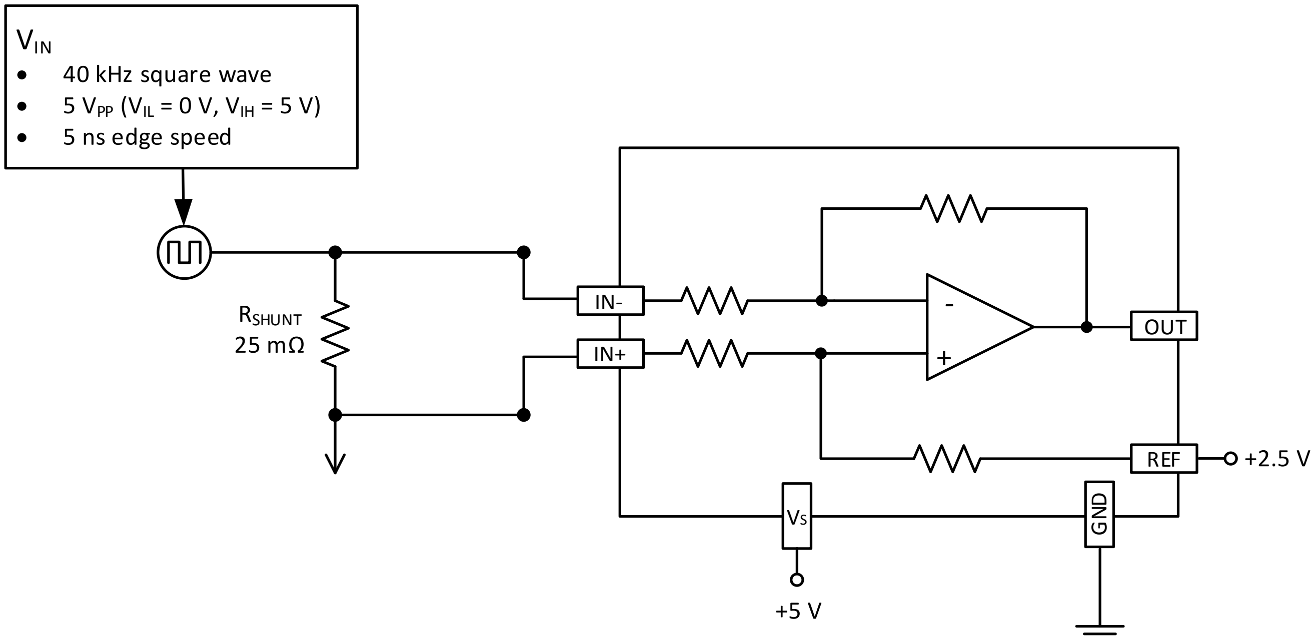

Figure 1: Circuit schematic and conditions causing overshoot that violates the ABS Max conditions of the datasheet.

Overshoot Exceeding Absolute Maximum (ABS Max) Datasheet Spec for VCM

The yellow waveform in Figure 2 shows the unfiltered signal seen at the inputs of the amplifier. The overshoot on the falling edge reaches a maximum of -1.5 V below GND. This is 1.2 V beyond the -0.3 V spec; albeit, the time that the input signal spends at this voltage is for a very short duration since the pulse width of this overshoot is about 19 ns (See Figure 3).

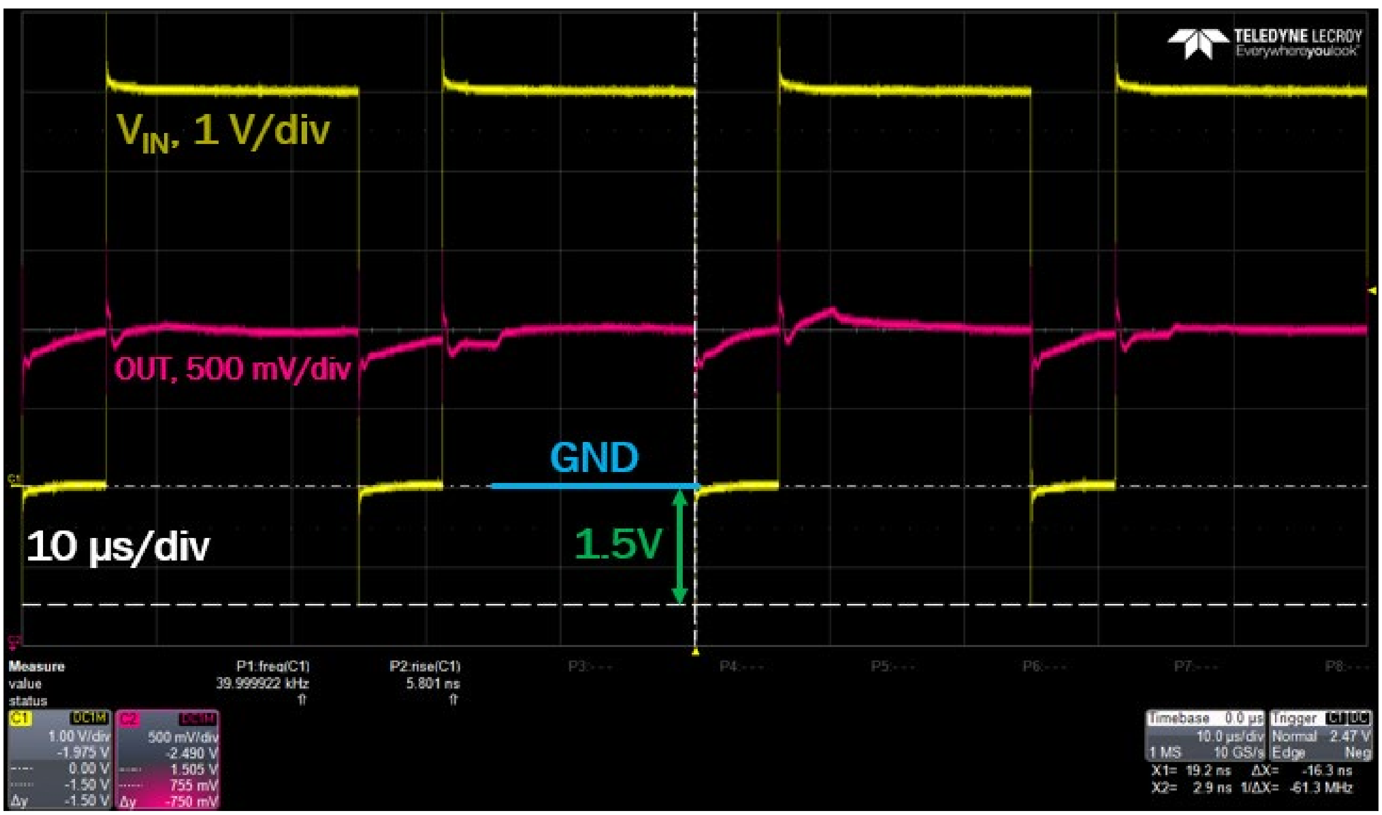

Figure 2: No common mode filter. Common mode overshoot on the falling edge of V_{IN} of -1.5 V; exceeding the spec of -0.3 V by -1.2 V (10 µs/div).

Figure 3 below shows a zoomed in view of the falling edge overshoot.

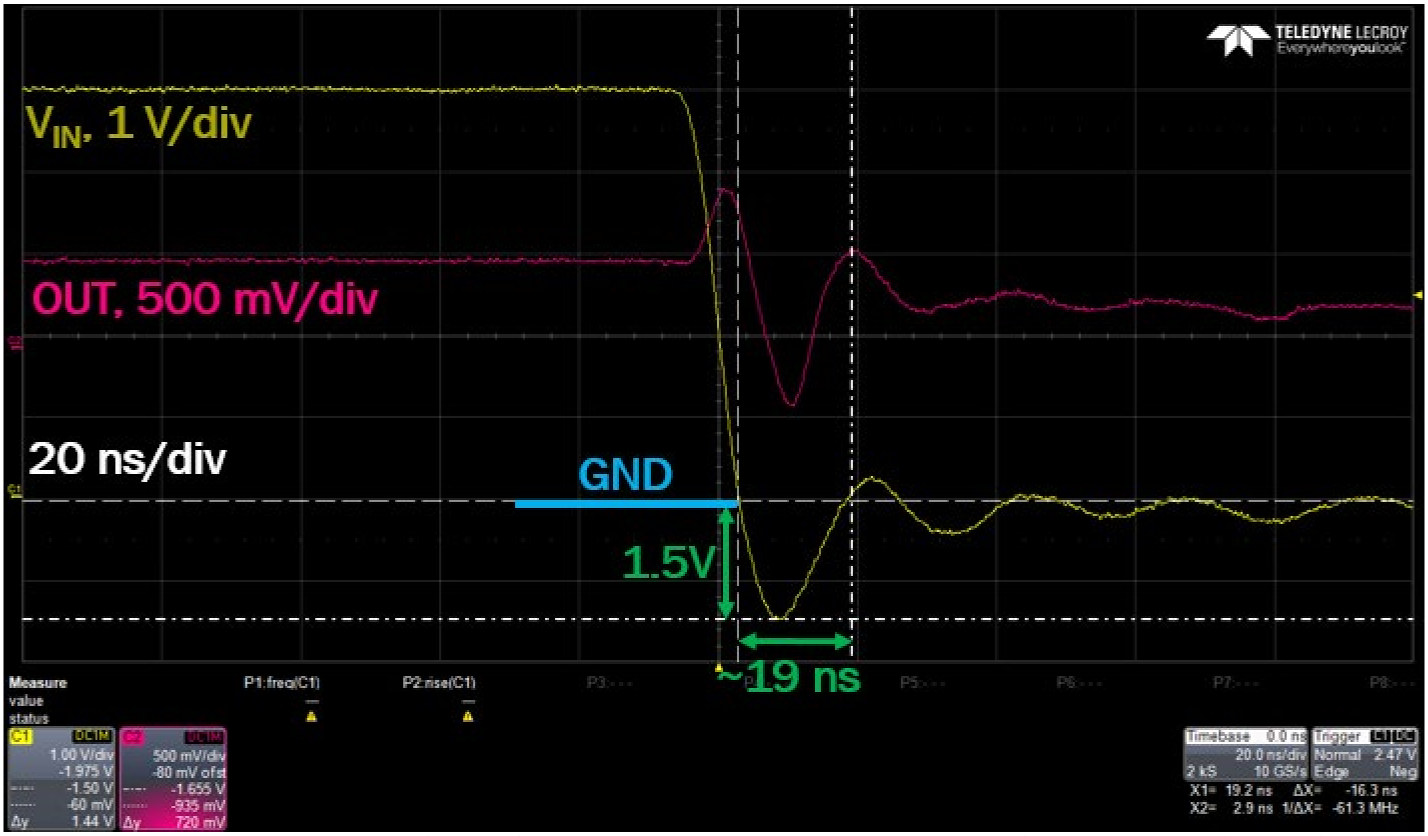

Figure 3: No common mode filter. Common mode overshoot on the falling edge of V_{IN} of -1.5 V; exceeding the spec of -0.3 V by -1.2 V (20 ns/div).

Common Mode Filtering

Common mode filtering is used less frequently than differential mode filtering (see the "Input and Output Filtering" subheading of the "Basic Connections" applications information section of the NCS21xR datasheet for detailed instructions on how to implement a differential input filter). Most often, common mode filtering is needed for high frequency and RF suppression (EMI). In RFI and EMI cases where the filter cutoff is at a high enough frequency, a pair of equal value capacitors connected from each input to ground will suffice (see "C_{CMFILT}" in Figure 4). If the cutoff frequency is well within the typical amplifier bandwidth, less than around 100 kHz, capacitor matching becomes more important in order for capacitor mismatch not to introduce common mode errors. One available solution is a commercially available capacitor pair referred to as an X2Y capacitor.

When implementing input filtering on the NCS21xR and NCS199AxR current sense amplifiers, it is always recommended to use resistors (see "R_{FILT}" in Figure 4) that are ≤10 Ω so that performance is not degraded. To calculate the value required for the the filter capacitors (C_{CMFILT}), first determine the -3 dB cutoff frequency (f_{-3dB}). The required capacitor value can then be calculated by:

- $C_{CMFILT} = \frac{1}{2\pi f_{-3dB} R_{FILT}}$
- $f_{-3dB} = \frac{0.35}{\text{Edge Speed}}$

The “Edge Speed” is the measured edge of the V_{IN} signal from 10% to 90%. The -3dB frequency (f_{-3dB}) of first order systems, such as the first order filter to be implemented, can be calculated from this equation. The goal is to filter out the high frequency content that makes up the overshoot and to use the smallest capacitor value possible and at the same time allow margin for process and temperature variation and component tolerance. Even after calculating the capacitor value, it is likely going to be necessary to experiment with different capacitor values in order to dial in the needed performance from the circuit.

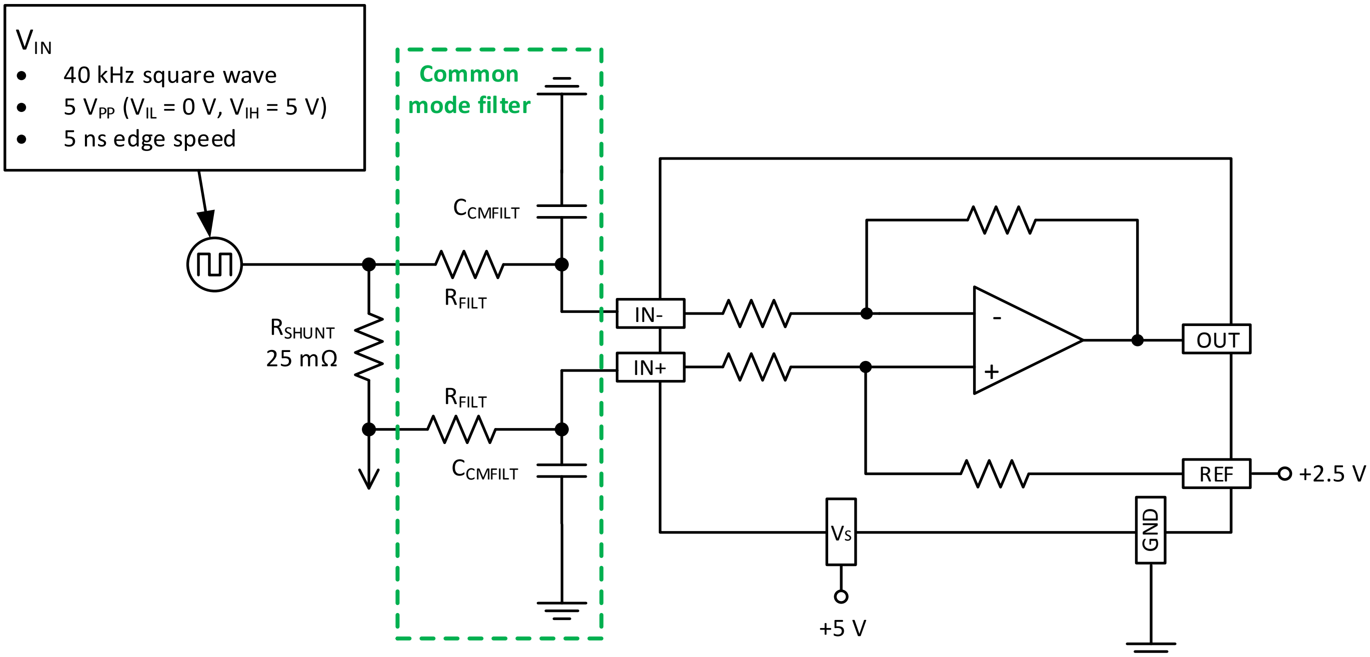

Figure 4: Common mode filtering solution schematic for the NCS21xR and NCS199AxR series current sense amplifiers; R_{FILT} and C_{CMFILT} sets up the common mode filter.

Using the equations provided above, f_{-3dB} and C_{CMFILT} are calculated by:

- $f_{-3dB} = \frac{0.35}{\text{Edge Speed}} = \frac{0.35}{5\ \text{ns}} = 70\ \text{MHz}$
- $C_{CMFILT} = \frac{1}{2\pi f_{-3dB} R_{FILT}} = \frac{1}{2\pi(70\ \text{MHz})(10\ \Omega)} = 227\ \text{pF}$

The 70 MHz is the -3dB bandwidth of V_{IN}, calculated from its rise time of 5 ns. At this point, the calculated 70 MHz is used in the capacitor calculation to arrive at a minimum capacitor value of 227 p. Through experimentation and observation, it was found that a minimum value of 300 pF for C_{CMFILT} was required to filter the falling edge overshoot transient from -1.5 V to -0.3 V, which puts the falling edge overshoot right at the ABS Max spec limit.

Figure 5 shows the effect of the implemented filter with 300 pF capacitors used for C_{CMFILT}. At this scale the overshoot is not clearly visible, so Figure 6 shows a zoomed in view of Figure 5. The cursor measurements show that the overshoot on the falling edge has been reduced to -0.3 V, meeting the spec limit.

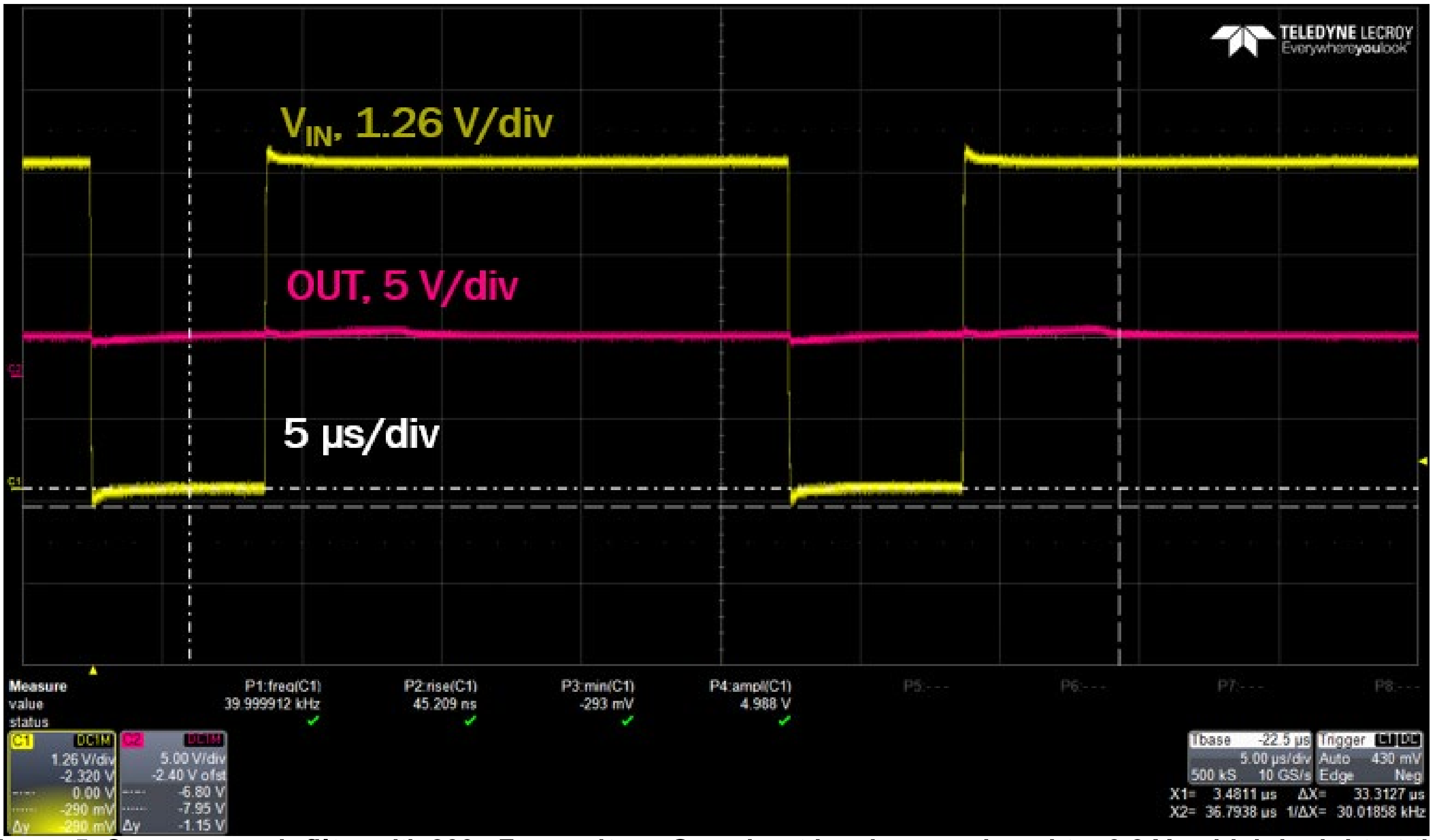

Figure 5: Common mode filter with 300 pF capacitors. Overshoot has been reduced to -0.3 V, which is right at the min spec limit.

Figure 6: Zoom view of Figure 5. Overshoot reduced to -0.3 V, which is right at the lower side of the ABS Max spec limit.

Table 1 below shows that with 100 pF capacitors, the overshoot is reduced by nearly half, but slowed the edge down to 22 ns. A 1000 pF (1 nF) capacitor value reduced the overshoot down to -0.2 V.

Table 1: Test Results; Filtering vs Overshoot and Edge Speed

Common Mode Input Filter Values	V_{IN} Falling Edge Overshoot (V)	V_{IN} Edge Speed (ns)
No Filtering	-1.5	5
R_{FILT} = 10 Ω, C_{CMFILT} = 20 pF	-1.36	11
R_{FILT} = 10 Ω, C_{CMFILT} = 100 pF	-0.945	22
R_{FILT} = 10 Ω, C_{CMFILT} = 200 pF	-0.37	34
R_{FILT} = 10 Ω, C_{CMFILT} = 300 pF	-0.3	45
R_{FILT} = 10 Ω, C_{CMFILT} = 1000 pF	-0.2	76

Table 2 below highlights the NCS21xR and NCS199AxR series current sense amplifiers. Customer evaluation boards for each part number can be ordered at their respective landing pages.

Table 2: NCS21xR and NCS199AxR Series Current Sense Amplifiers

Part Number	Gain (V/V)	Input Offset Voltage (μV)	Gain Error (%)
NCS210R	200	±35 Max	±1
NCS211R	500	±35 Max	±1
NCS213R	50	±100 Max	±1
NCS214R	100	±60 Max	±1
NCS199A1R	50	±150 Max	±1.5
NCS199A2R	100	±150 Max	±1.5
NCS199A3R	200	±150 Max	±1.5