TS Measurement & Discharge

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[Link to Altium Project]

1.0 TS Measurement Circuit

1.0.1 Our Approach

The [AMC1311B] takes in a voltage between 0 and $2V$ and outputs that voltage in differential pair form (i.e difference between pairs equals V_{IN}). Since our DC-link voltage is around $600V$, we divide our voltage using a 301:1 ratio voltage divider; our top resistor is $6\ M\Omega$ and the bottom resistor is $20\ k\Omega$. The MCU to which the differential pair feeds then re-scales the divided voltage back to the true value, "measuring" the DC-Link voltage.

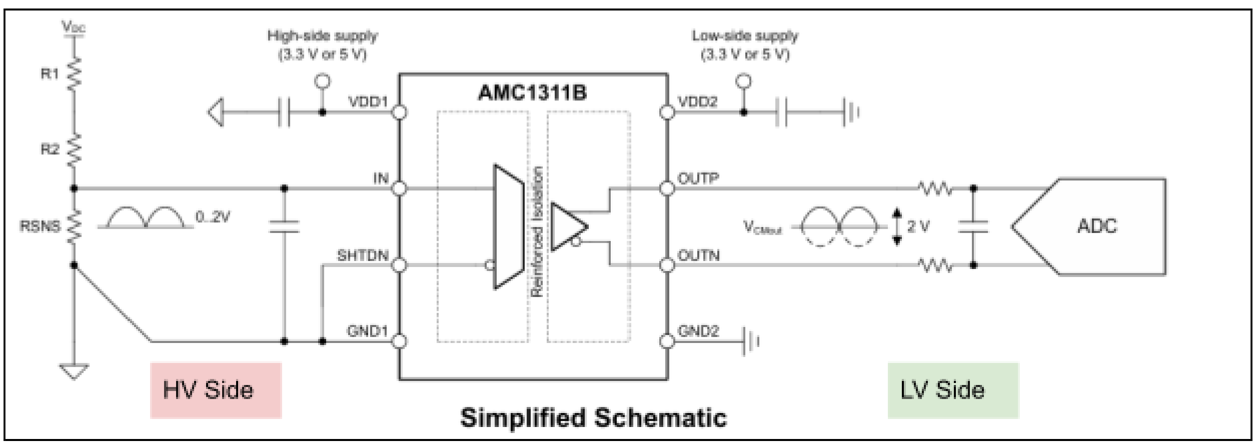

Figure 1 – AMC1311B + Schematic with Best Practices [AMC1311B Datasheet]

The input of the AMC1311B is **galvanically isolated** from the output, which prevents dangerous high voltage from reaching our low voltage electronics. The AMC1311B clamps voltages above $2V$. However, extra current still flows into the AMC1311B at higher input voltages. The AMC's maximum input current is 10mA, yet the AMC impedance is ~1 gigaohm, meaning we are resilient even to large transients.

Notice that we require a 3.3 or 5V supply on both sides of the AMC1311B (pins VDD1 and VDD2). This power will come from the **low voltage side**. We power the high voltage side by connecting the low voltage power supply to the high voltage side using a 5VDC to 5VDC

isolated converter [NME0505DC](). This keeps both sides galvanically isolated. Note that the [NME0505DC]() requires at least 10% of its fully rated load (200 mA) to work properly.

The AMC1311B chops the input signal at a rate of 20Mhz meaning we need a couple picofarads of capacitance in parallel with the voltage divider feeding into the AMC to ensure we have enough current to supply each switch. The AMC also steals about 3.5 nA of current from our divider; it has 1 gigaohm impedance in parallel with the 20 $k\Omega$; its effect on the voltage divider is negligible. Additional decoupling capacitors are also recommended for power supplies. See Figure 2.

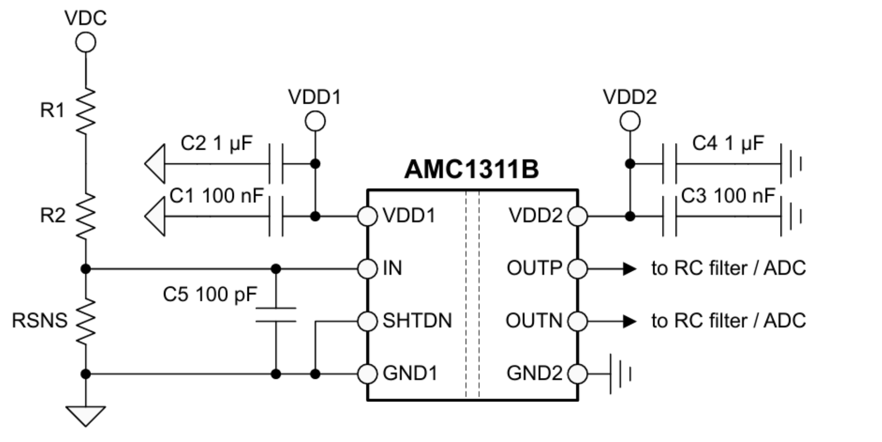

Figure 10-1. Decoupling of the AMC1311

Figure 2 – Recommended AMC1311 Decoupling Capacitor Layout

Some **STM32** MCUs accept differential pairs and some don't. If our MCU does not accept differential pairs, we can simply use an Op-Amp to get a 3.3V analog signal. See Figure 3 for an example on how to do this given by the datasheet, where *"For most applications, R1 = R2 = R3 = R4 = 3.3 kΩ and C1 = C2 = 330 pF yields good performance"*. More information can be found in [18-Bit, 1MSPS Data Acquisition Block (DAQ)]()

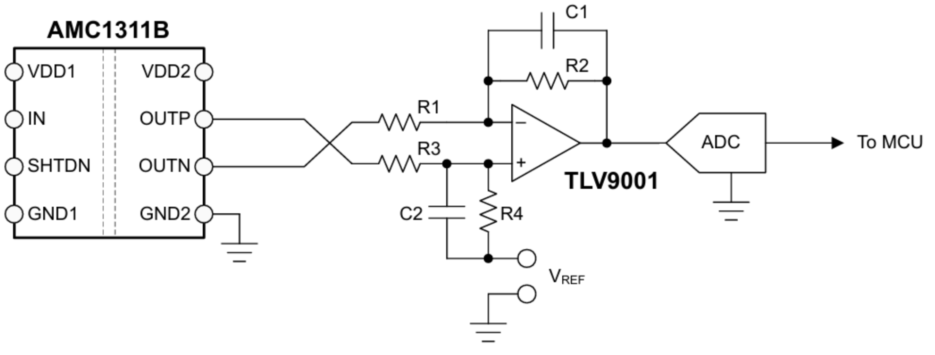

Figure 9-3. Connecting the AMC1311 Output to a Single-Ended Input ADC

Figure 3 – Converting AMC1311 Differential Pairs into Analog Signal.

1.0.2 Altium Schematic

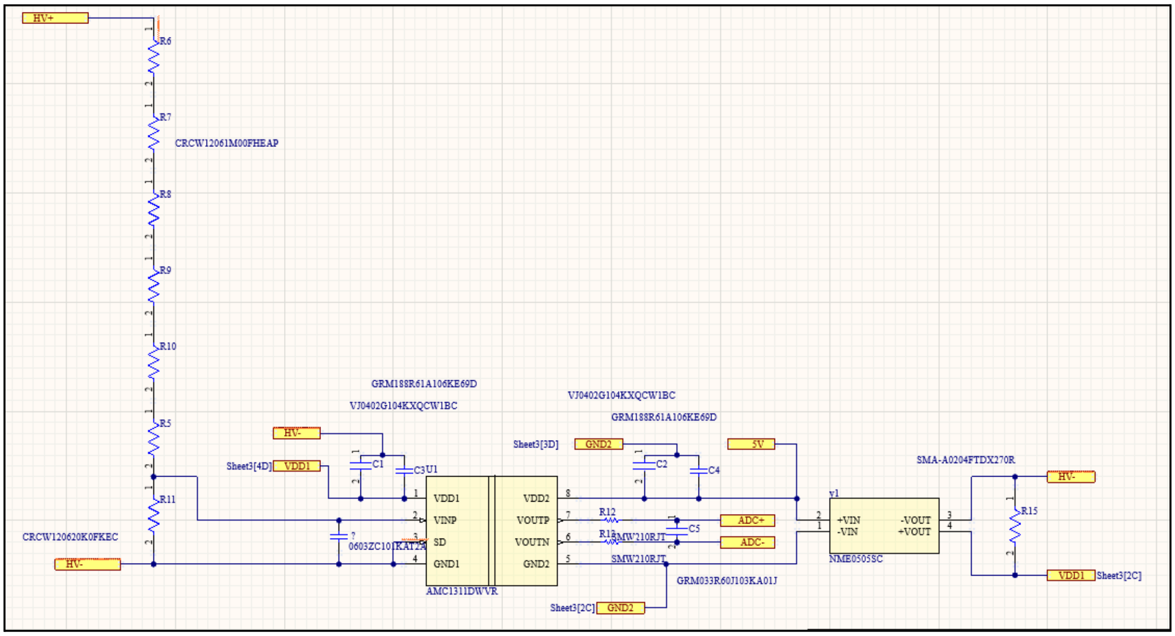

Figure 4 – Schematic of Measurement Circuit

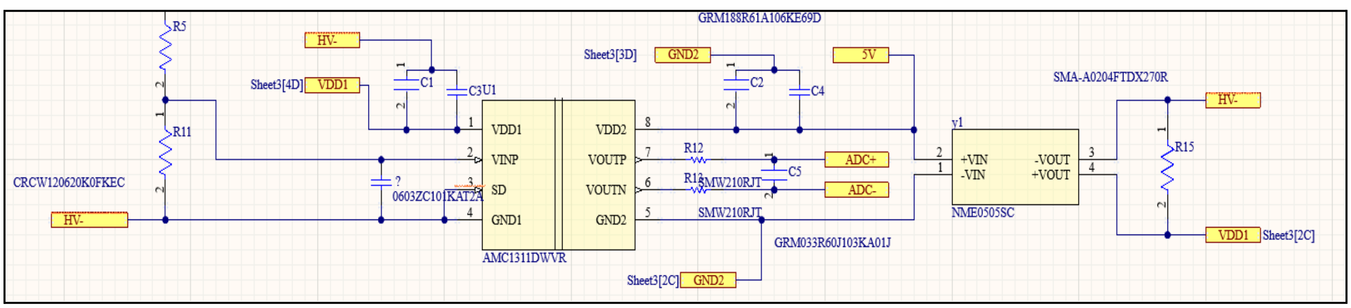

Figure 5 – Zoomed In Schematic of Measurement Circuit

Our schematic is based on *Figure 1* and *Figure 2*, which show best practices for implementing the AMC1311. We form the 6 $M\Omega$ top half of our 301:1 voltage divider using $6 \times 1M\Omega$ resistors in series.

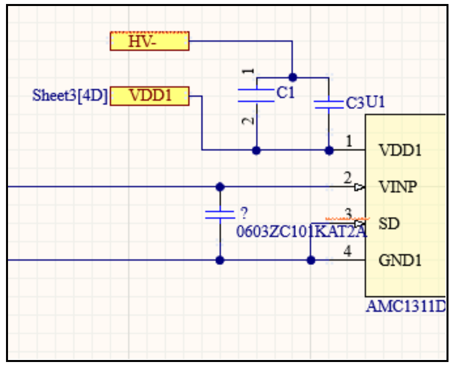

Figure 6 – Input of AMC1311DC

We place a capacitor between VDNP (the AMC1311 input) and its GND to ensure we can supply enough current to the 20 MHz switching of the AMC. Since our input impedance is 20 $k\Omega$, a $100pF$ input capacitance would yield a 2 microsecond time constant (10 microsecond settling time) and 80 kHz cutoff (-3dB reduction that increases as frequency grows higher). This agrees with the AMC datasheet's recommendations, which chose $100pF$ for a 20 $k\Omega$ input impedance as well (see Figure 2). The datasheet recommends a filter less than 1 order of magnitude of the sampling frequency (20 Mhz) so it does not interfere.

The average AMC input current is around $3.5\ nA$ (worst case $15\ nA$). The max charge drawn at each AMC switch is $\frac{I_{MAX}}{f_{switch}} = \frac{15\ nA}{20\ MHz} = 7.5 \times 10^{-16}\ C$ and the corresponding voltage drop across the capacitor is $\frac{7.5\times10^{-16}\ C}{100\ pF} = 7.5\ \mu V$ which is negligible.

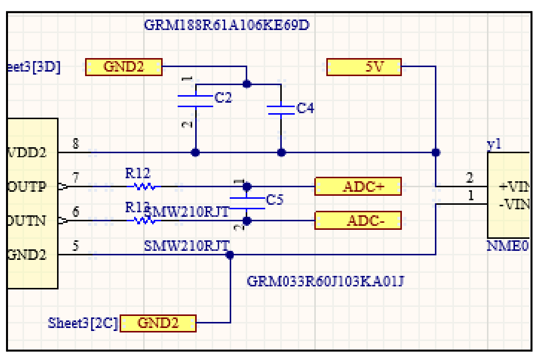

Figure 7 – Output of AMC1311DC

Following the Datasheet guidelines, we place a 22 nF capacitor between the AMC1311's differential pair in order to offer a low impedance path for high frequency differential noise to equalize. We place a 20 ohm resistor on each differential pair, creating a low pass on 330 kHz. This will dampen noise but not the differential pair frequency 100-220kHz. The transfer function magnitude for 100 kHz is 0.96. The phase shift is – 15 degrees, creating a signal delay of $\frac{\theta}{360}T = \frac{15}{360}\frac{1}{100\,kHz} = 416\,ns.$

$$|H(f)| = \frac{1}{\sqrt{1+\left[\frac{f}{f_c}\right]^2}} = \frac{1}{\sqrt{1+\left[\frac{100000}{330000}\right]^2}} = 0.96$$

$$\theta(f) = -\arctan(\frac{f}{f_c}) = -15\,deg$$

Common mode noise can be filtered using common mode choke, however, this is very likely overkill. Common mode amplification is much less than differential mode amplification when the differential pair is generated (ratio is 77 DB), and the signal likely won't travel over a long distance.

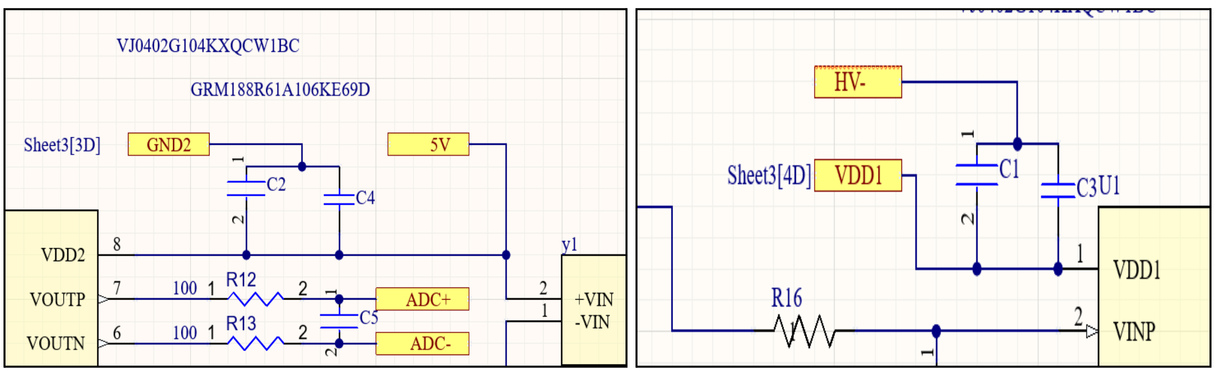

Figure 8 – High and Low Side Power Pins (VDD1, VDD2) of AMC1311DC

Finally, we place capacitors in parallel between low voltage supplies and ground to stabilize the power input. We use 10 µF (1-10 kHz filtering) and 0.1 µF (100+ kHz filtering) in parallel to handle a range of frequencies of noise and also have enough capacitance to supply instantaneous power.

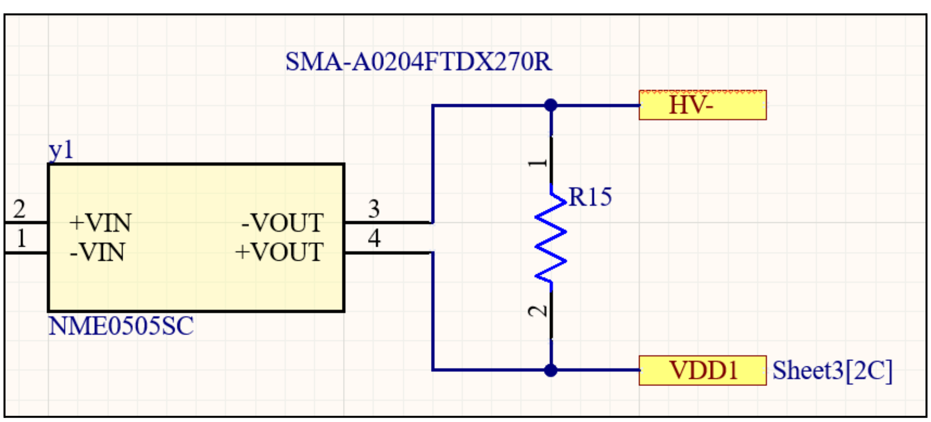

Figure 9 – Output of NME0505SC 5V-5V converter

Finally, recall that the NME0505DC requires at least 10% of its fully rated load (10% of 200 mA) to work properly. The AMC draws about 7.1 mA for VDD1 when supplied with 5V. We add a 270 Ohm resistor in parallel to VDD1 so that this number goes up to ~25 mA.

1.0.3 TS Measurement Circuit Parts & Justification

Part		Ratings	Purpose
AMC1311	Isolated input voltage to differential pair converter	0-2 V input range with 5 kV RMS isolation barrier	Converts 0-2V signal from 600 V divider into differential signal for MCU
NME0505SC	Isolated 5 DC to 5 DC converter	Input 4.5–5.5 V, Output: 5 V, 200 mA. Isolation: 1 kV	Connects 3.3/5V power from low voltage side to high voltage side to power AMC
CRCW12061M00FHEAP	1 $M\Omega$ resistor	Each is rated for 250 V, and sees 133V (max) in our circuit	6 are used in series to get the top half of the 301:1 voltage divider
CRCW120620K0FKEC	20 $k\Omega$ resistor	Rated for 70V (0.25 W). Sees < 2V in our circuit.	Bottom half of the 301:1 voltage divider
VJ0402G104KXQCW1BC	0.1 µF capacitor	10 V rating	High frequency denoising
GRM188R61A106KE69D	10 µF capacitor	10V rating	Lower frequency denoising and current supply
0603ZC101KAT2A	100 pF capacitor	10 V rating	Decoupling capacitor for AMC1311 input.
C0603C223K4RAC	22 nF capacitor	16V rating	Forms a quick responding RC circuit at the IN terminal of the AMC1311. Also used as a decoupling capacitor between differential pairs of AMC1311.
SMA-A0204FTDX270R	270 ohm resistor	10 V rating	In parallel with VDD1 so NME0505DC supplies sufficient current to work properly

2.0 Discharge Circuit

2.0.1 Altium Schematic

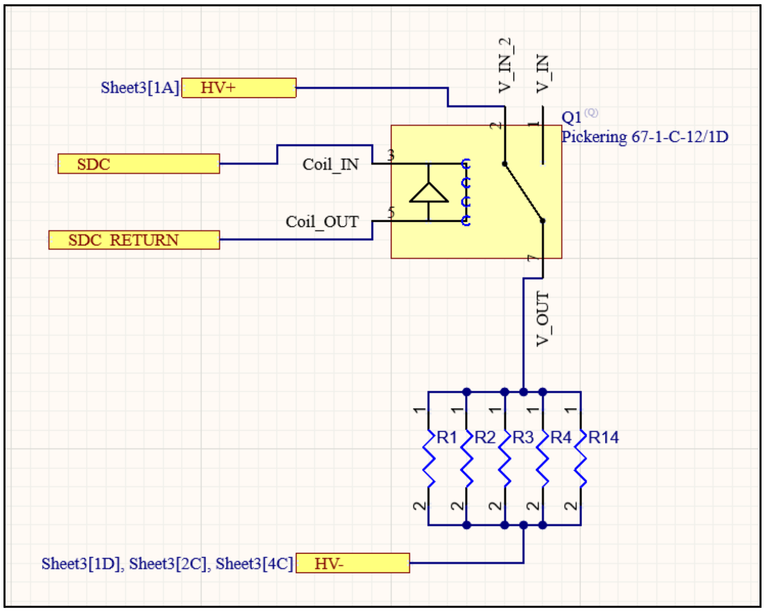

Figure 10 – Discharge Circuit

The five parallel resistors, [RH02530K00FC02](), are rated 30 kOhm and 25 W; collectively, they form 6 kOhm of resistance. Each resistor runs at 47% of its rating at 600V. The discharge takes less than 5 seconds, and only a small amount of energy is transferred to the resistors (~20 J), making the true factor of safety much larger. Rule EV4.9.1 is not clear in which mode the circuit must be able to handle the max TS voltage permanently; our circuit passes both cases.

Our normally closed relay is the [Pickering 67ES-1-C-24/1D]() which can handle voltages up to 2.5kV when switching and 5kV when steady. The rated current is 3A, yet, our circuit runs 0.13A at 600 volts. The shutdown circuit (SDC) powers the relay coil. The coil has a 24V limit with 18V minimum activation; **we will require a voltage divider** if our SDC voltage is greater than 24V as we are operating the coil continuously. *Note that the Pickering has a diode between the coil terminals built in and is normally closed on Pin 2 (see Figure 11)*

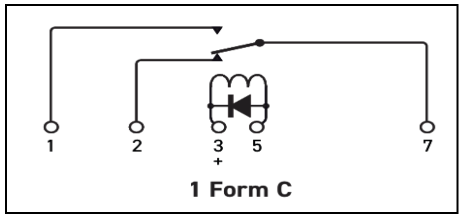

Figure 11 – 67ES-1-C-24/1D is normally closed on pin 2

2.0.3 Discharge Time

The DC link has a capacitance of 240 μF. The time constant of the shutdown circuit ($\tau = RC$) is thus 1.44s. The time it takes to discharge to 60 V falls within the 5 second requirement:

$$t = \tau\, ln(\frac{600}{60}) = 3.0\ s$$

3.0 PCB Layout

3.0.1 TS Measurement Circuit

Just like in a buck converter, we want low impedance between the voltage divider and AMC1311B input as di/dt is very high due to 20 MHz switching; even nanohenries could lead to massive voltage spikes. Also, remember to use differential pair routing for the differential pairs OUTP and OUTN. Finally, there must be no conductive material beside and below the AMC.

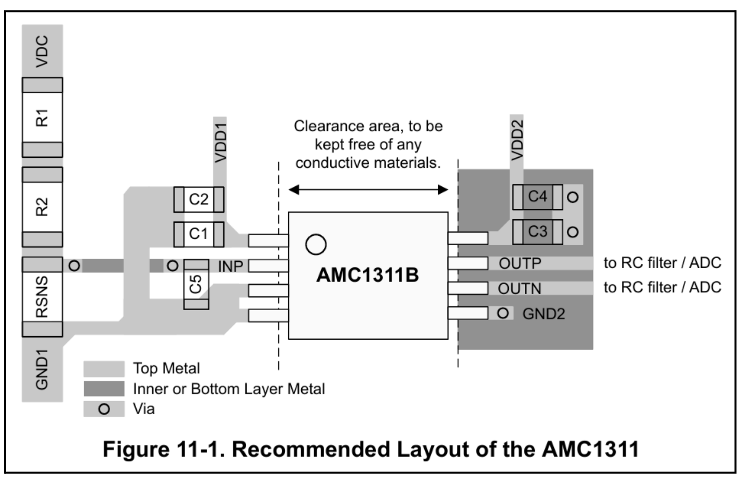

Figure 12 – Recommended AMC1311 Layout

The NME0505DC is a resonant converter and is galvanically isolated, so all “AMC1311B ” ytrouting/placement rules apply to this component also. Its switching frequency is 110 kHz.

3.0.2 Discharge Circuit

There isn't much to consider when placing+routing the shutdown circuit. We see 600V passing through 6 kOhm, yielding 10mA, meaning that any trace width works. Our lower limit is 1 mil width for 1oz copper if we wish to keep temperature rise under 10K; Trace Width Calculator.