THAT626x Common-Mode Operation

This document describes how THAT626x behaves to common-mode input signals. The typical bipolar power supply application circuit from the 626x datasheet is used as an example. Since the concern is about the common-mode signals, both phases of the differential path will respond the same way (assuming good matching between the phases). Hence, we'll examine the response in one phase of the differential path, i.e., the path marked with nodes N1 - N5 (Figure 1).

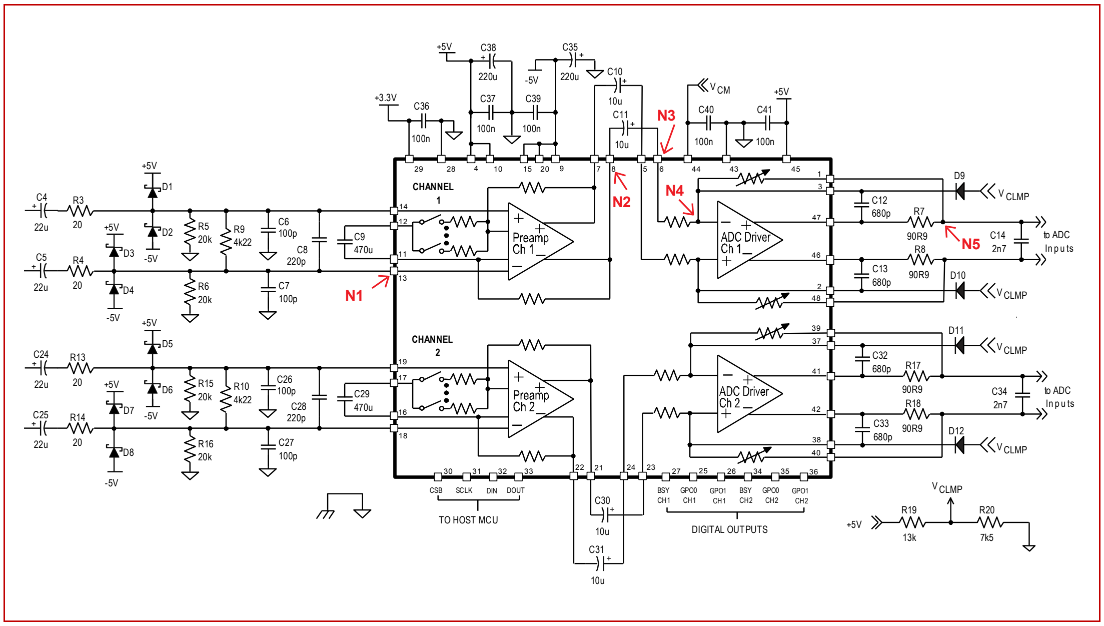

Figure 1. A typical 626x application circuit using bipolar power scheme.

THAT626x's inputs are ac coupled through capacitors C4 & C5, C24 & C25, so any dc common-mode input is blocked while ac signals are passed through. The 626x's preamp stage has unity common-mode gain, hence, the common-mode input (@ node N1) will show up at its output (@ node N2) without either attenuation or amplification (Figure 2), around the corresponding bias voltages, which is about ground at N1 and one V_{be} below ground at N2.

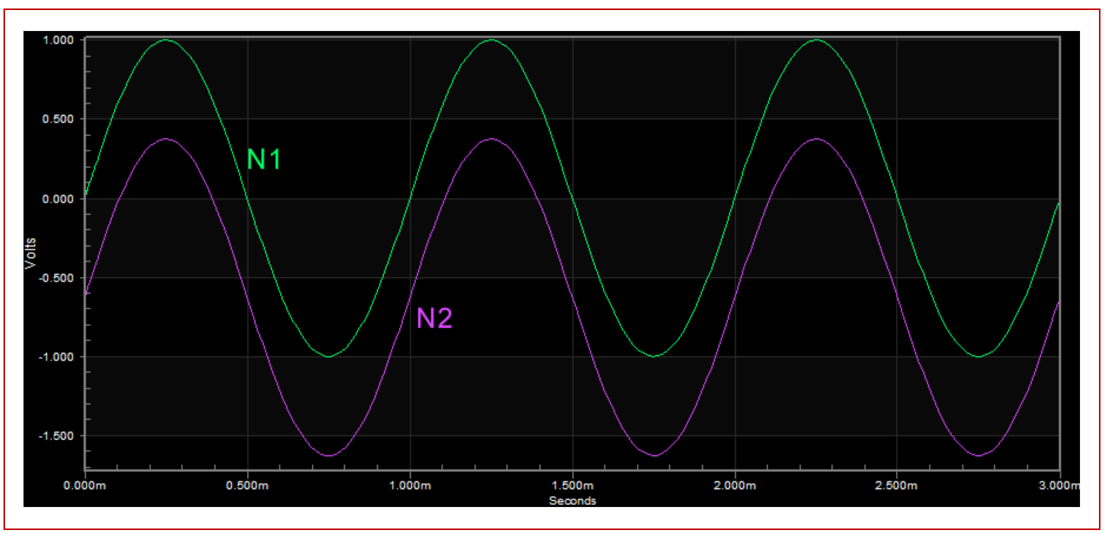

Figure 2. Common-mode waveforms at nodes N1 (green) and N2 (pink) of Figure 1.

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THAT Corporation Design Brief

The 626x's ADC driver stage, shown in Figure 3, suppresses any common-mode input at its output. This amplifier has a voltage swing constraint at the CFB+ and CFB- nodes. The minimum voltage is 1 V and the maximum voltage is V_{AD}, the positive supply voltage, so the tightest swing constraint with respect to the nominal 2.5 V bias level is on the low side. If the voltage at CFB+ or CFB- falls below 1 V, the driver opamp's differential input transistors will become misbiased and the opamp's common-mode feedback loop will stop working.

For a common-mode input at the DI+/- nodes, the voltage at CFB+/- nodes changes according to Equation 1. R_{ff} is the input resistor, which is 2 kΩ here. R_{fb} is the feedback resistor, whose value changes with the stage gain setting. For -8 dB gain, R_{fb} = 796 Ω, while for -5 dB gain, R_{fb} = 1125 Ω.

$$V_{cfb+} = \frac{R_{ff}}{R_{ff} + R_{fb}} V_{out+} + \frac{R_{fb}}{R_{ff} + R_{fb}} V_{di-} \quad (1)$$

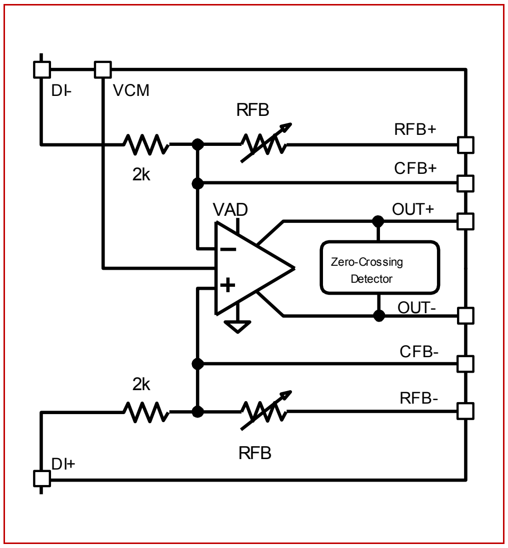

Figure 3. Block diagram of the 626x ADC driver stage.

When functioning properly, the common-mode feedback loop will force the common-mode level at OUT+/- to track V_{CM}., which is typically a fixed dc voltage. Assuming large common-mode loop gain, the small-signal response at CFB+/- from equation 1 can be simplified to:

$$V_{cfb+} \approx \frac{R_{fb}}{R_{ff} + R_{fb}} V_{di-} \quad (2)$$

For instance, if V_{CM} = 2.5 V, gain = -8 dB, for a 1 V_{peak} common-mode voltage at DI-, the swing on CFB+ is

$$V_{cfb+} \approx \frac{800}{2000 + 800} * 1 = 0.286\, V_{peak} \quad (3)$$

So CFB+ will see a voltage varying between 2.214 V (2.5 V – 0.286 V) and 2.786 V (2.5 V + 0.286 V), which is well above the required 1 V minimum. If the gain is at -5 dB, the swing at V_{cfb+} = 0.36 V_{peak}, hence, the absolute levels seen at CFB+ is between 2.14 V and 2.86 V, respectively.

Referring back to Figure 1, for the same common-mode input, the waveforms at N3 – N5 are as below. The amplitudes of the waveforms match the results from the above analysis reasonably well.

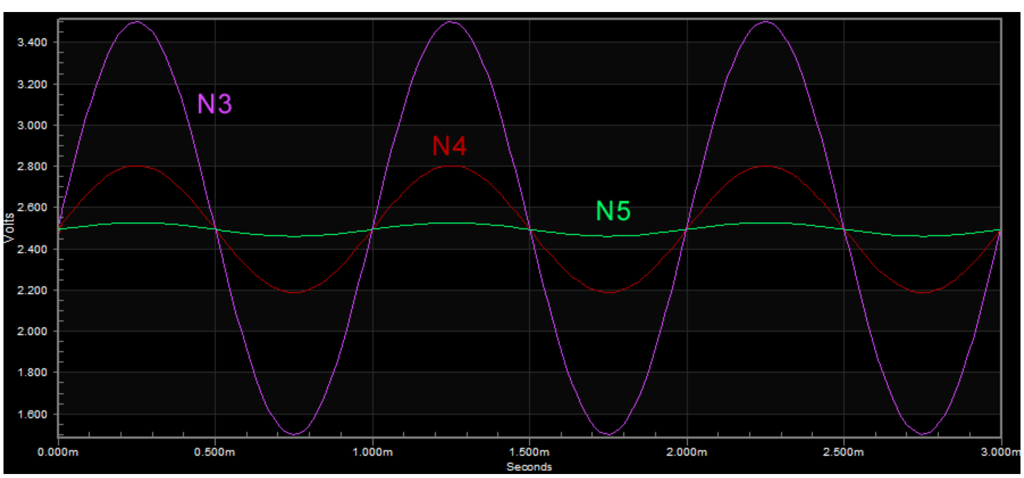

Figure 4. Common-mode waveforms at nodes N3 (pink), N4 (red) and N5 (green) of Figure 1.

Note that for any differential inputs within the specified range, the CFB+/- nodes are virtual grounds. Their voltage level will not change with the differential swing and will stay at about V_{CM}.

A transformation of equation 1 can be used to figure out the tolerable common-mode voltage swing at the ADC driver input, DI+/-.

$$V_{di-} = \left(1 + \frac{R_{ff}}{R_{fb}}\right) V_{cfb+} - \frac{R_{ff}}{R_{fb}} V_{out+} \quad (4)$$

This time, all the voltages include the dc bias component. During normal operation $V_{OUT+} = V_{CM}$. Again R_{ff} = 2 kΩ and R_{fb} varies with the gain setting. Equation 4 becomes:

$$V_{di-} = \left(1 + \frac{2000}{R_{fb}}\right) V_{cfb+} - \frac{2000}{R_{fb}} V_{cm} \quad (5)$$

This is where the formula for the 'Input Common-Mode Voltage' spec in the 626x datasheet comes from. For V_{CM} = 2.5 V, gain = -8 dB, when V_{cfb+} is at its minimum, i.e., 1 V, the minimum level at DI- is :

$$V_{di-} = \left(1 + \frac{2000}{796}\right) * 1 - \frac{2000}{796} * 2.5 \approx 3.5 - (2.5 * 2.5) = -2.75\,V \quad (6)$$

So the minimum common-mode level at DI+/- can be 2.75 V below ground. For the -5 dB gain setting, the level becomes -1.67 V, which implies that for V_{CM} = 2.5 V, the acceptable common-mode swing is about 4.17 V, i.e., 2.5 V – (-1.67 V), which easily exceeds the 626x preamp's input common-mode range of [-3.8 V, +3.8 V].

Users should note that V_{CM} voltages lower than 2.5 V will reduce the allowable common-mode swing at the ADC driver inputs. When V_{CM} is less than about 2.35 V the ADC driver becomes the limiting factor in allowable common-mode swing.

When phantom power faults occur, the input at DI+/- may be dragged much lower than -2.75 V, even lower than -5 V, which is the negative ESD protection reference for DI+/-. When that occurs, the ADC driver's outputs and inputs (@ CFB+/-) will be pulled to around ground and stay at that level. Diodes D9-12 (Figure 1) are added so that when such an incident occurs, the diodes will kick in and bring CFB+/- back to above 1 V. This allows the driver's bias condition to be reestablished and the circuit will function properly again.

Diodes D9-12 (Figure 1) are connected between voltage V_{clmp} and CFB+/-. During normal operation, D9-12 are off. Hence, $V_{clmp} < V_{cfb+\_min} + V_D$, where V_{cfb+_min} is the minimum allowable common-mode voltage at CFB+, and V_D is the diodes' forward voltage. When the maximum common-mode swing is known, V_{cfb+_min} can be figured out using equation 2. For the application in Figure 1, the maximum swing at DI+/- is 3.8 V (the preamp's common-mode range), using equation 2, we find that the corresponding maximum swing at CFB+/- is 1125 Ω / 3125 Ω * 3.8 V = 1.37 V at the worst-case gain of -5 dB. Hence, V_{cfb+_min} = 2.5 V – 1.37 V = 1.13 V. Assume V_D is 0.7 V, V_{clmp} < 1.13 V + 0.7 V = 1.83 V. In Figure 1, V_{clmp} = 7.5 kΩ / (7.5 kΩ + 13 kΩ) * 5 V = 1.829 V, which allows the full preamp common-mode range to be accommodated without the diodes turning on.