Application Report

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Precision Summing Circuit Supporting High Output Current From Multiple AFEs in Ultrasound Application

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ABSTRACT

This application report explains precision signal chain circuit for summing the outputs in "Current-Output" Medical Ultrasound Analog Front Ends (AFEs). Starting from the current-output AFE examples, this document highlights the requirements of the external summing circuit. The selection criteria and example circuit using Fully Differential Amplifiers (FDAs) is also explained.

NOTE: This application report is a companion to TI Design, TIDA-01351 (High-Resolution, High-SNR True Raw Data Conversion Reference Design for Ultrasound CW Doppler), which was designed to sum multiple AFEs with only voltage outputs from the same AFE58xx family of ultrasound receive AFEs. Once the signals are summed, TIDA-01351 then converts the summed CW I and Q phase signals with SNR greater than 101dB.

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1 Introduction

The Continuous Wave Doppler (CWD) is a key function in mid-end to high-end Ultrasound systems. The CW path must handle high dymanic range along wiht strict phase noise performance. For many of the Ultrasound AFEs from TI (AFE58xx series), the output in CW path is current signal. The output signals are differential and have I (In-phase) as well as Q (Quadrature-phase) signals for each channel. The output current is typically sum of all the channels within that AFE. For higher channel (like 64, 96, 128, 192 or 256) Ultrasound applications, multiple AFE outputs need to be added together externally to sum the echo energy.

Table 1 shows which AFEs support voltage or current or both output types.

Table 1. AFEs With Output Types (Voltage and/or Current Output)

AFE Part Number	Output Type	VOCM Requirement While Summing Output Currents	Maximum Current/Voltage	Number of Channels
AFE5805	Current	2.5 V	Dynamic CW current output: 2.9 mA(p-p) Static CW current output (sink): 0.9 mA	8
AFE5804	Current	2.5 V	Dynamic CW current output: 2.9 mA(p-p) Static CW current output(sink): 0.9 mA	8
AFE5808	Voltage/Current	1.5 V	Summing Amplifier Output: 4 V(p-p) Maximum output current: 20 mA(p-p)	8
AFE5808A	Voltage/Current	1.5 V	Summing Amplifier Output: 4 V(p-p) Maximum output current: 20 mA(p-p)	8
AFE5807	Voltage/Current	1.5 V	Summing Amplifier Output: 4 V(p-p) Maximum output current: 20 mA(p-p)	8
AFE5809	Voltage/Current	1.5 V	Summing Amplifier Output: 4 V(p-p) Maximum output current: 20 mA(p-p)	8
AFE5818	Voltage/Current	1.5 V	Summing Amplifier Output: 4 V(p-p) Maximum output current: 50 mA(p-p)	8
AFE5812	Voltage/Current	1.5 V	Summing Amplifier Output: 4 V(p-p) Maximum output current: 20 mA(p-p)	8
AFE5816	Current	0.9 V	4.8mApp per channel	16

AFE5816 supports 16-channels, so for 128-channel application, there will be eight AFEs required. Each AFE5816 can provide peak-to-peak output current of 1.5 mA (peak of 0.75 mA single-ended). For eight AFEs, the current requirement is 0.75*128 = 96 mA peak. For calculations, see Appendix A.

Design requirements for the summing circuit:

While designing the external summing circuit, the designer should look at specific requirements from the AFE's perspective. The requirements for the summing circuit:

- It should support the higher current as per the number of total channels.
- The summing circuit should be built with low-noise active components. The offset errors and noise can create a huge impact on the Continuous Wave (CW) Doppler I and Q signals.
- I & Q channels must be strictly symmetrical by using well-matched layout and high-accuracy components.
- Additional high-pass wall filters (20 Hz to 500 Hz) and low-pass audio filters (10 kHz to 100 kHz) with multiple poles are usually required as the noise under this range is critical because the CW Doppler signal ranges from 20 Hz to 20 kHz.

There are different approaches to handle such high current. since one FDA cannot be used for summing all the outputs (due to current capability of the FDA), using one Current-to-Voltage (I-to-V) converter for each AFEs (and then using the voltage outputs to sum before taking it to external ADC for conversion), is the simplest approach. This approach is also highlighted in the datasheet of AFE5816.

For a 32-channels system, on a block-diagram level, it will look like Figure 1.

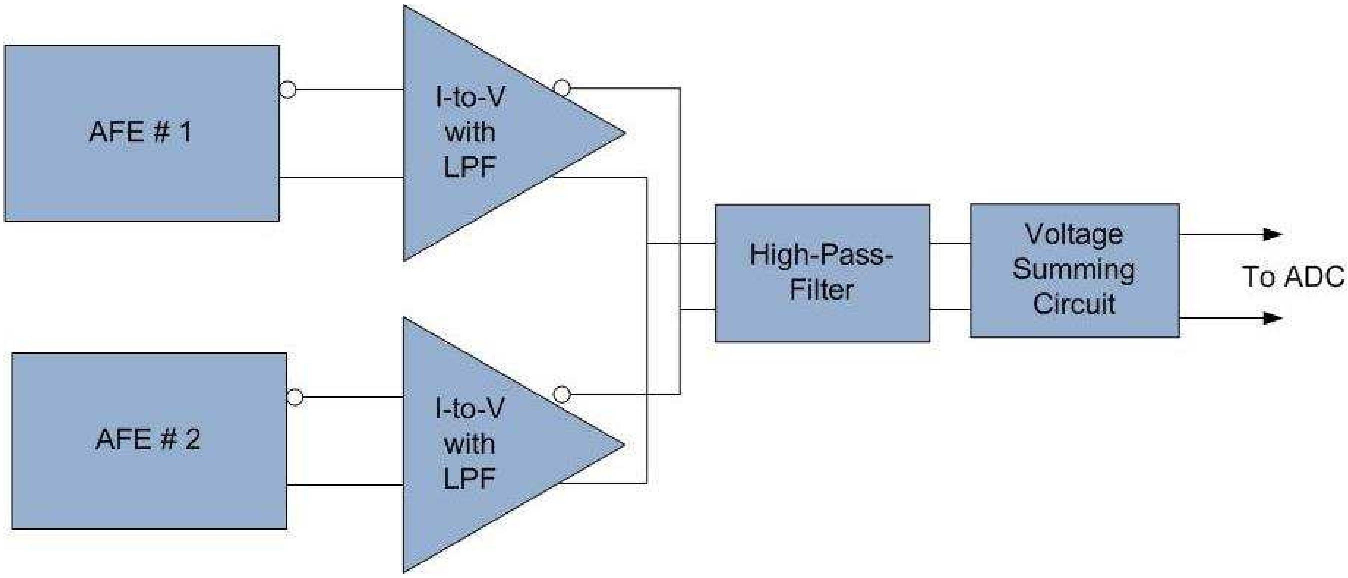


Figure 1. High Level Block Diagram for Multiple FDA Approach (32-channel system)

The I-to-V converter with a low-pass filter (LPF) is shown in Figure 2.

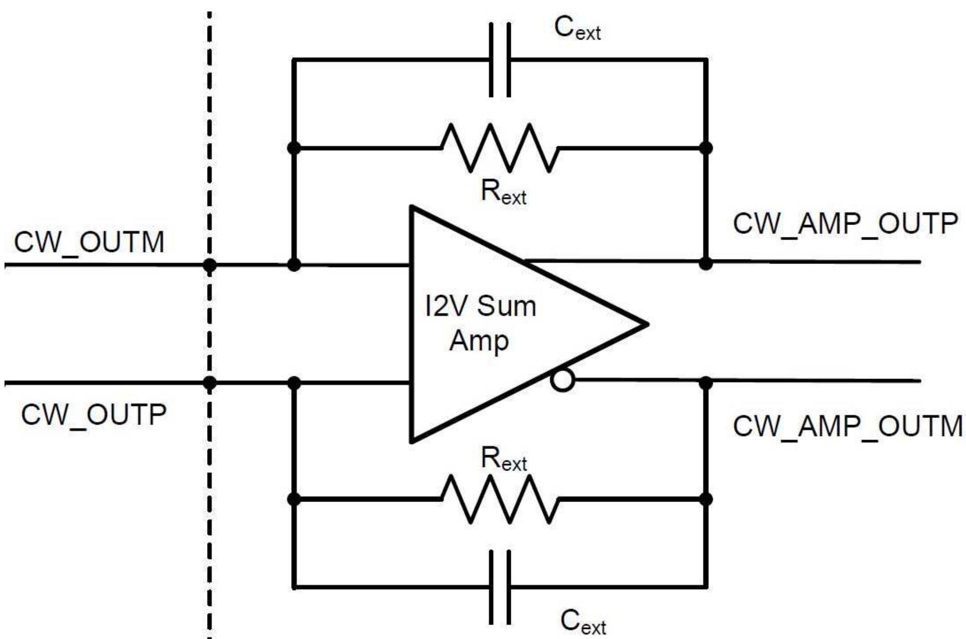


Figure 2. Single FDA I-to-V with LPF

For a given cut-off frequency (f_c), the calculation of R_{ext} and C_{ext} are given as shown in Equation 1.

$$f_C = \frac{1}{2 \times \pi R_{ext} \times C_{ext}} \quad (1)$$

This approach increases overall cost of the summing circuit as the Bill of Material (BoM) is higher. To scale up with the number of channels, the solution requires more number of FDAs. The number increases linearly with increase in total number of channels.

For the multiple FDA approach, the routing of signals can create offset errors, non-linearity and mismatch between the signals due to layout parasitic effects.

One other solution is to reduce the total number of components and provide low-noise summing circuit, the FDA and high-output current buffer can be used in composite loop to achieve both precision and current drive capability. Figure 3 shows an approach for summing the current outputs from multiple AFEs. The outputs from each of the AFEs can be combined together into one FDA and the composite loop is created by adding a high-output current buffer after the FDA.

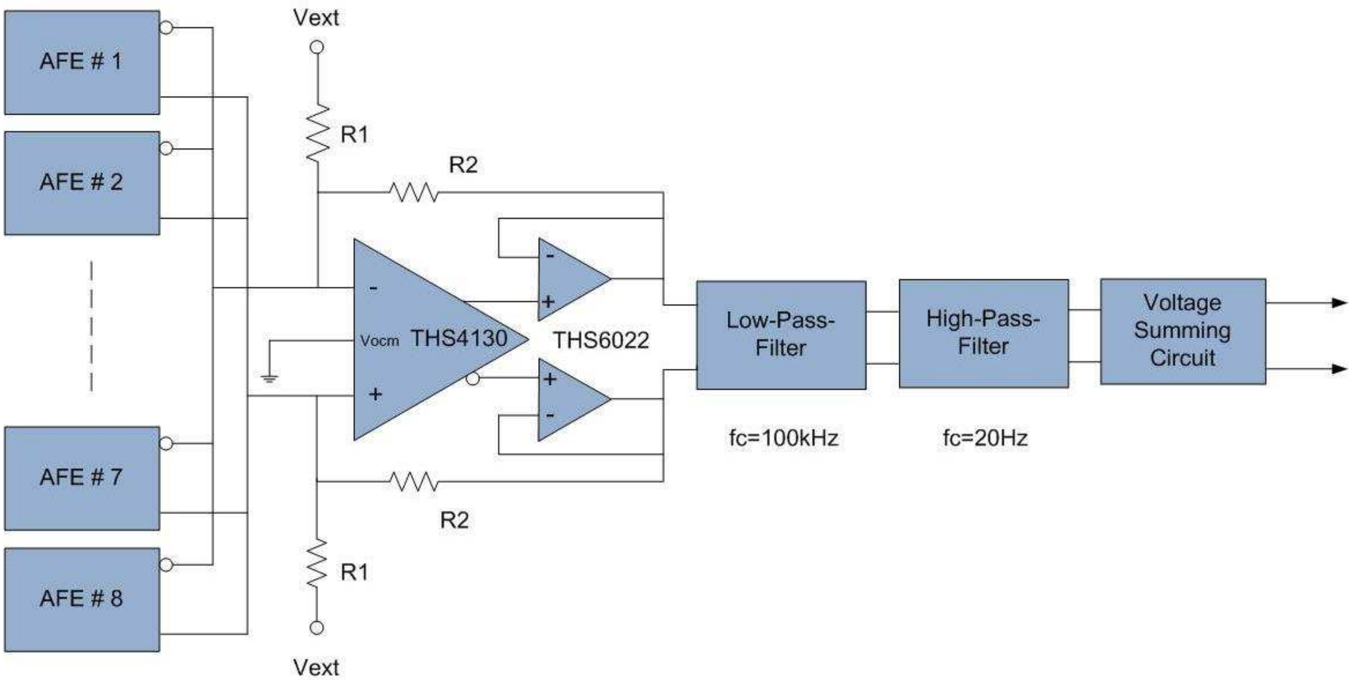


Figure 3. Using Buffer to Improve the Output Current Sink/Source Capability of THS4130

In composite loop scenario, the best qualities of both amplifiers are combined together to achieve the performance: FDA and current-output buffer. THS4130 has output current capability of 55 mA. To improve this limit, a current buffer THS6022 can be used. The input resistance for the circuit should be equal to Thevenin equivalent resistance (R_{th}) of 8 AFEs i.e. 3.9 Ω.

The external voltage V_{ext} helps in setting the common-mode voltage V_{ocm}, so that the AFE output does not get loaded. The value of R2 is decided based on the gain value required in I-to-V stage.

$$Gain\ of\ I-to-V\ Stage = \frac{R2}{R_{th}} \tag{2}$$

The value of R1 can be calculated using Equation 3.

$$V_{ocm}\ of\ AFE = \left(\frac{R2}{R1+R2}\right) \times V_{ext} \tag{3}$$

Let V_{ext} = 2.5 V, V_{ocm} = 0.9 V for AFE5816 and R2 = 39 Ω for gain of I-to-V stage as 10V/V, the value of R1 can be calculated as 69.3 Ω.

Figure 4 through Figure 7 show the simulation circuit and results in TINA-TI.

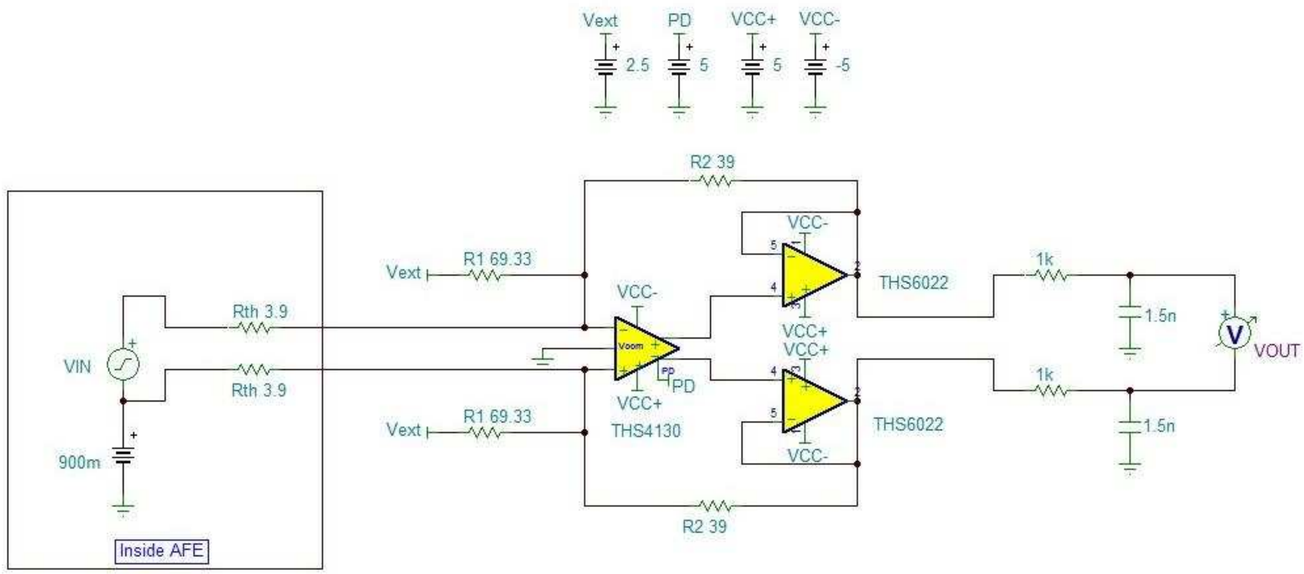


Figure 4. TINA Simulation for Circuit Using Buffer to Improve the Output Current Sink/Source Capability of THS4130

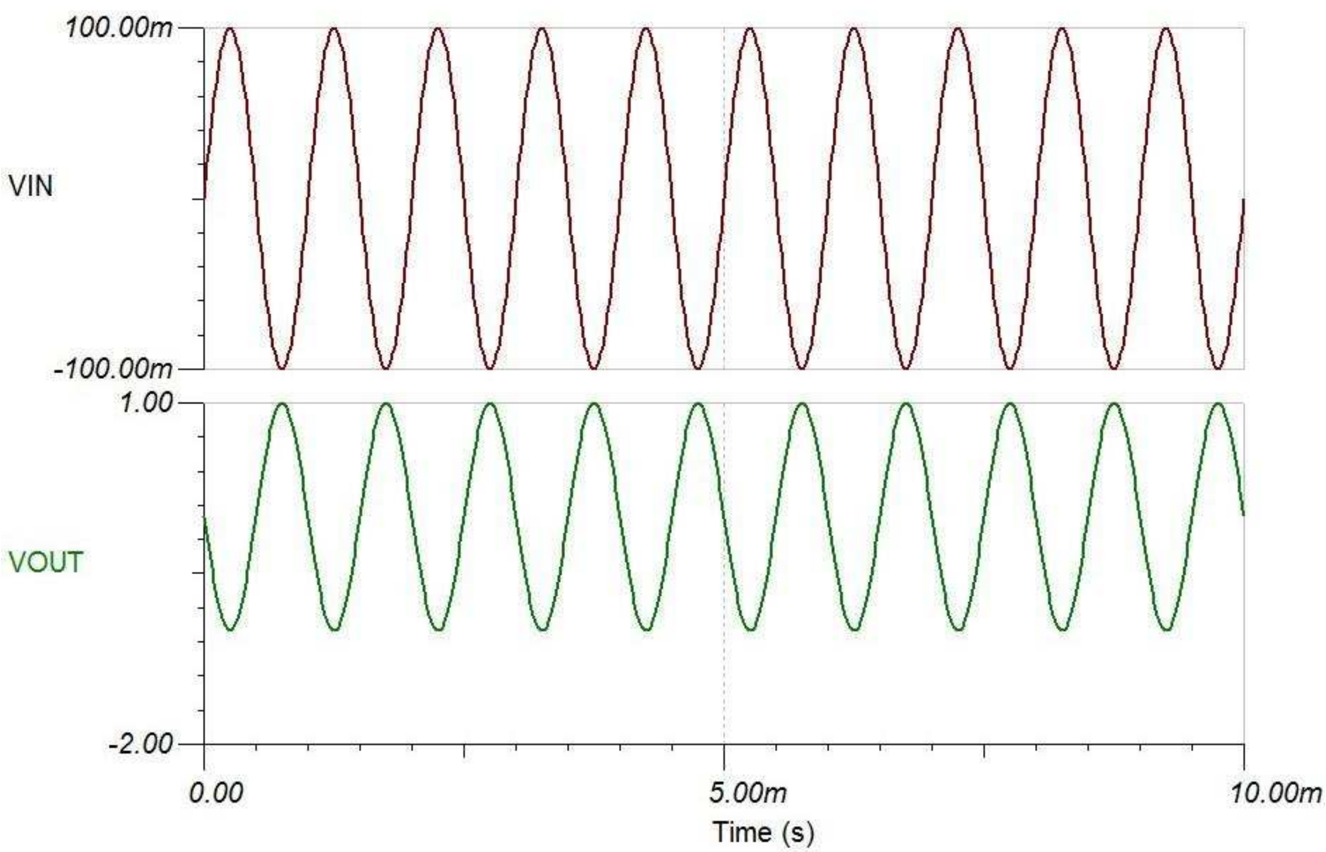


Figure 5. Output Waveform for Circuit Using Buffer

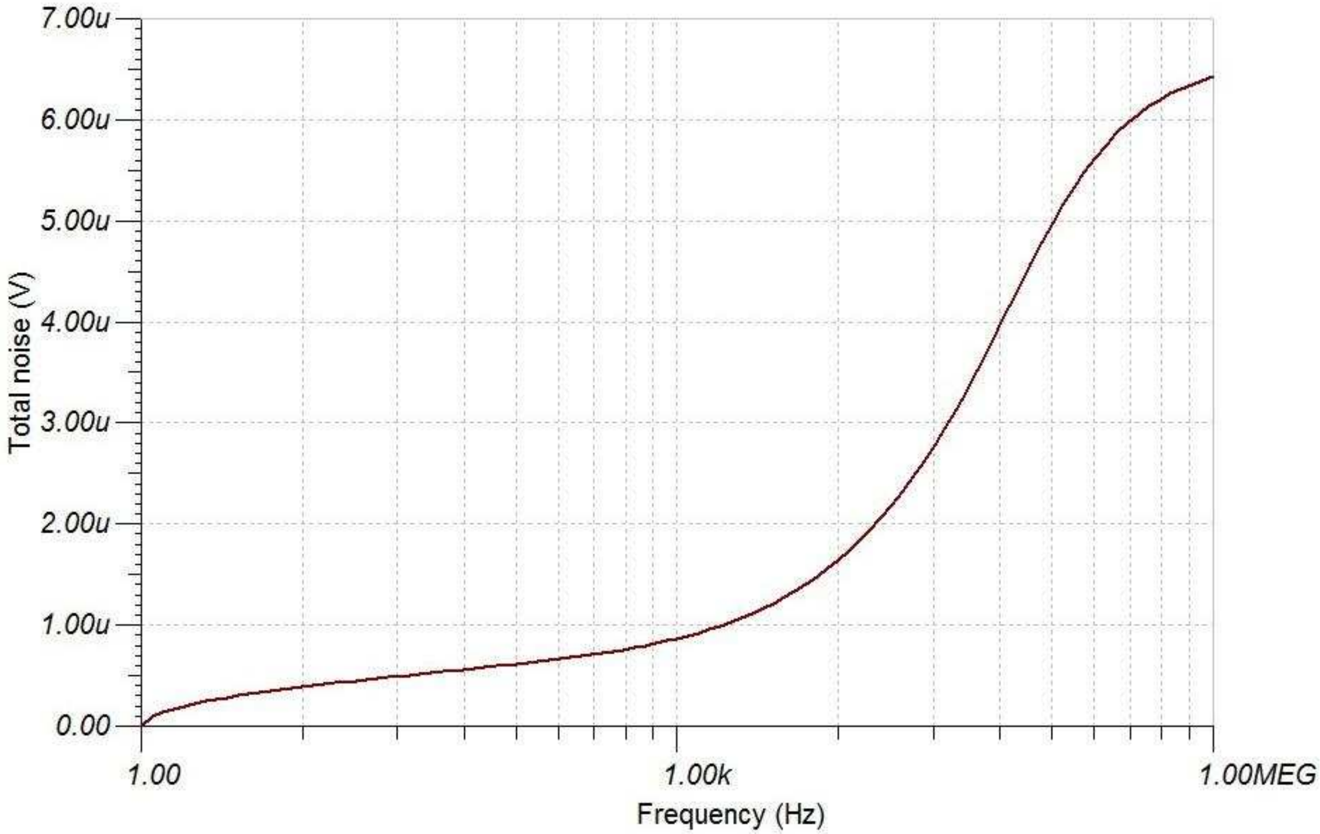


Figure 6. Noise Analysis

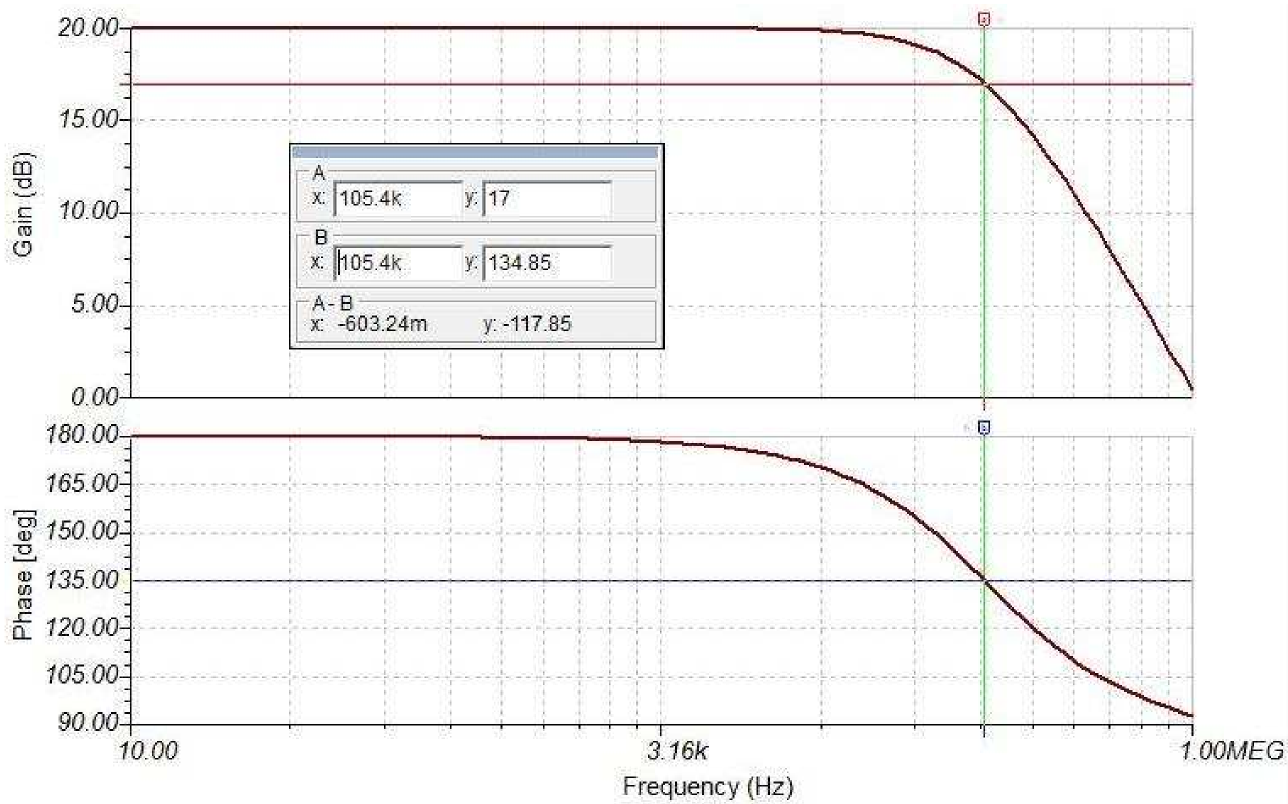


Figure 7. Frequency Response

This becomes a truly scalable solution for lower to higher number of channels without increasing the number of components in the input summing stage. To support higher number of channels the designer needs to change R1, R2 and the Buffer device (if the current limit exceeds) according to the number of channels.

2 Summary

Creating a composite loop using FDA and the high-current buffer helps to achieve better performance (nonlinearity from PCB is reduced, parasitic effects reduced) using lower cost, less bill of material (BoM) and space

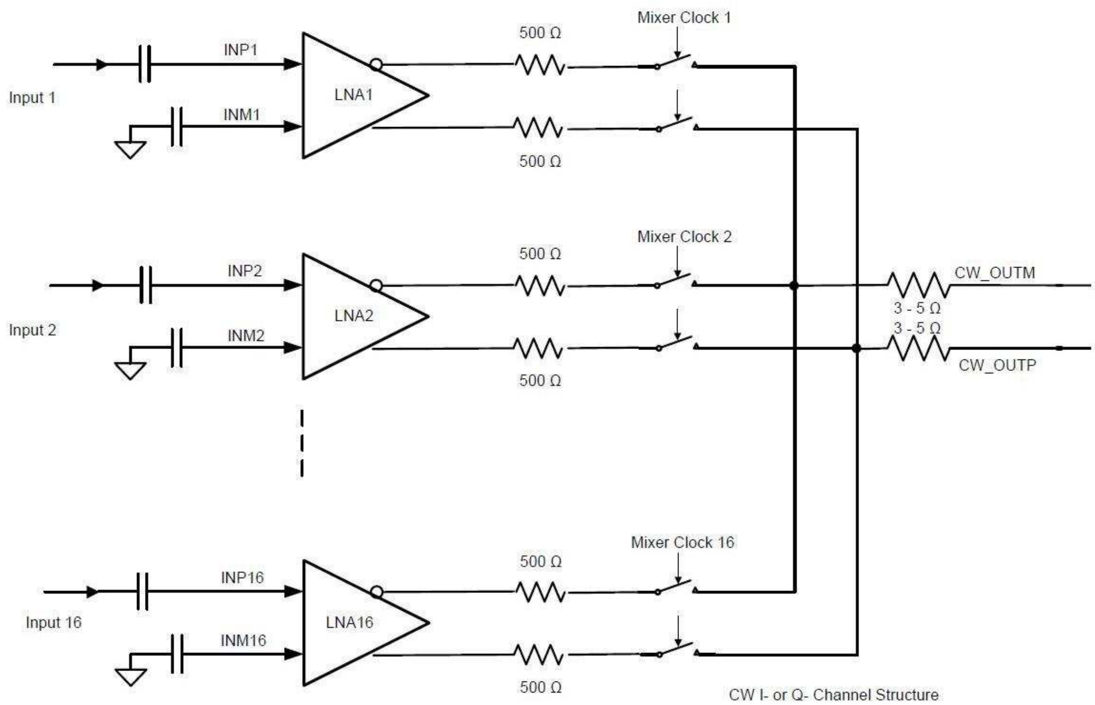
3 References

- *High-Resolution, High-SNR True Raw Data Conversion Reference Design for Ultrasound CW Doppler*
- *THS4551 Low Noise, Precision, 150 MHz, Fully Differential Amplifier*
- *THS4130 Fully Differential Input/Output Low Noise Amplifier With Shutdown*
- *THS6022 250-mA Dual Differential Line Driver*
- *THS6012 500-mA Dual Differential Line Driver*
- *AFE5816 Fully-Integrated, 16-Channel Ultrasound Analog Front-End With Passive CW Mixer, 0.95nV/rtHz*
- *AFE5816 16-Channel Ultrasound AFE With 90-mW/Channel Power, 1-nV/√Hz Noise, 14-Bit, 65-MSPS or 12-Bit, 80-MSPS ADC and Passive CW Mixer Data Sheet*

Calculation of the Output Current Signal

A.1 Calculation of the Output Current Signal

Note that all the figures and values in this section are taken from the *AFE5816 16-Channel Ultrasound AFE With 90-mW/Channel Power, 1-nV/√Hz Noise, 14-Bit, 65-MSPS or 12-Bit, 80-MSPS ADC and Passive CW Mixer Data Sheet*.



NOTE: The 3-Ω to 6-Ω resistors at CW_OUTP and CW_OUTM result from the internal device routing and can create a slight attenuation in the signal.

Figure 8. A Circuit Representation of I-Phase or Q-Phase Channel

As per the *AFE5816 16-Channel Ultrasound AFE With 90-mW/Channel Power, 1-nV/√Hz Noise, 14-Bit, 65-MSPS or 12-Bit, 80-MSPS ADC and Passive CW Mixer Data Sheet*, V_{MAX_CW} at the input of LNA = 300 mVp-p. The LNA gain is 18 dB (=7.94) and the mixer attenuation is 4 dB (=0.63).

$V_{MAX\_CW\_OUT}$ = 300 mV * 7.94 * 0.63 = 1.5 Vp-p (differential per channel)

The output current I = (1.5 Vp-p/500) = 3 mAp-p differential per channel = 1.5 mAp-p single-ended per channel = 0.75 mA peak per channel.

Table 2 shows the total summed output for multiple channel configurations.

Table 2. Total Summed Output Current for Multiple Channel Configurations

Number of Channels	Total Summed Output Current (mA peak per channel)
16	0.75 * 16 = 12
32	0.75 * 32 = 24
64	0.75 * 64 = 48
96	0.75 * 96 = 72
128	0.75 * 128 = 96
192	0.75 * 192 = 144
256	0.75 * 256 = 192

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