Application Report

SPRAC51 – September 2016

MEMS Microphone Direct PDM Input via I2S to a C5515 EVM With Software Decimation

ABSTRACT

This application report helps system designers demonstrate and understand the technique of directly feeding a MEMS mic output PDM stream into the Inter-IC Sound (I2S) lines of a C5515 EVM. This document is intended for audiences familiar with Digital Signal Processing, decimation and filtering techniques.

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1 Overview

A typical application that uses a MicroElectrical-Mechanical System (MEMS) microphone in its design requires a codec such as the TLV320AIC3204 in order to interface the system processor to the MEMS microphone. The AIC3204 has an I2S interface that provides the down-sampled audio stream utilizing a clock source from the codec. Alternatively, digital microphones with an I2S output can be used, but they tend to consume more power, which requires a larger PCB area and cost.

However, another technique to input a MEMS mic PDM stream into the system processor is to bypass a codec altogether and directly injecting the PDM stream to the processor's I2S lines.

This application report provides a significant advantage where the overall system design could eliminate the cost of a codec, thus, cost savings in the bill of materials (BOM). The power footprint of PDM mics are lower compared to their inter-IC sound (I2S) counterparts. It also demonstrates the steps on how to take a MEMS microphone direct PDM mono input via I2S to a C5515 EVM. The decimation of the captured audio is done in software (see Figure 1).

Note that this document illustrates this technique for evaluation purposes only. It is not intended for a production system without first understanding and evaluating the effects of clock jitter on the audio quality.

The source code discussed in this document can be downloaded from the following URL: https://git.ti.com/apps/c55x-digital-mic-decimation.

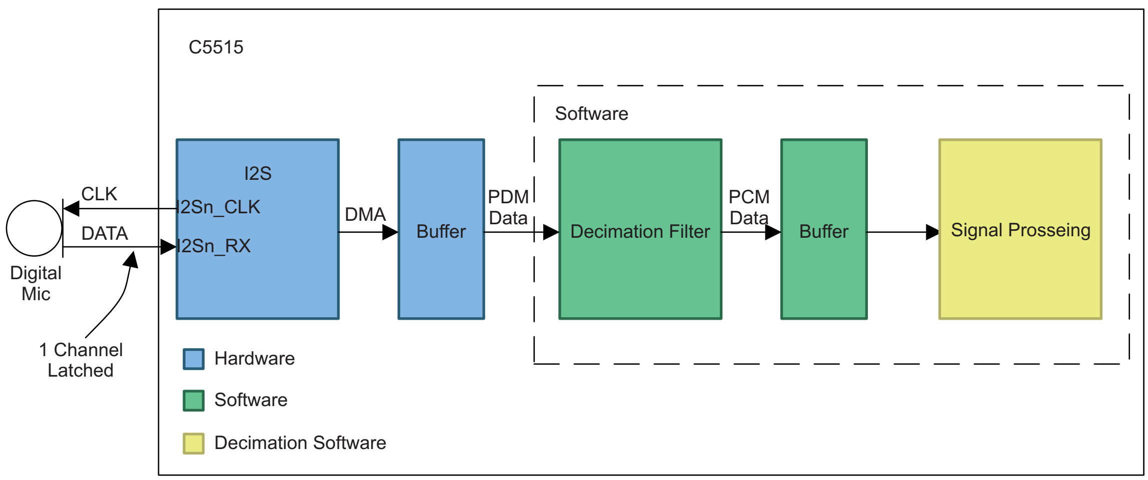

Figure 1. C5515 Audio Decimation System Overview

2 Introduction

Figure 2 shows an overview of the decimation process in the application note's demonstration. Separate DMA channels for "left" and "right" transfer into separate 32-bit buffers. The "Bit picking" block pulls correct bits for the "left" or "right" buffer for input to the Cascaded Integrated Comb (CIC) filter.

16 fractional bits are maintained in the data path to ensure staying below the noise floor of mic.

NOTE: "left" and "right" do not indicate positioning as in stereo microphones. This is a mono setup with 1 microphone. The terms are used to label the DMA buffers only.

The input PDM stream from the microphone is 1.024 Mbits/sec divided into two channels. The I2S hardware assembles the input data into 32-bit samples at a rate of 16KHz for each channel. The data is accumulated in a DMA ping-pong buffers. Every 20 ms a PDM stream snapshot contains 640, 32-bit words in each channel (total of 1280, 32-bit words every 200 ms). The "bit picking" block interleaves the data from two channels into 1 stream that is presented to the CIC filter.

The output from the CIC filter is then put through two finite impulse response (FIR) filters to complete the decimation process.

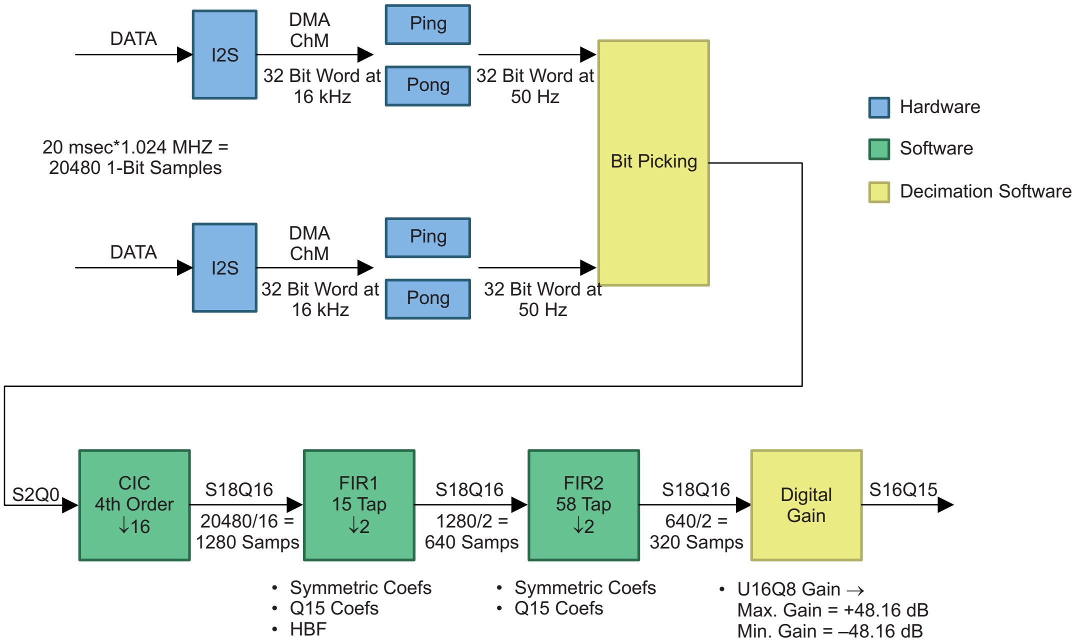

Figure 2. Overview of the Decimation Process

Output sampling rates of the various stages of decimation:

- Output from bit picking = 1 MHz
- Output from CIC = 64 KHz
- Output from FIR1 = 32 KHz
- Output from FIR2 = 16 KHz

Note that the above system supports mono audio single channel is supported since I2S uses single clock edge (rising or falling) to latch data. The typical oversampling ration is 64. For 16 KHz baseband sampling rate:

2Sn_CLK = 64 × 16KHZ = 1.024 MHz

The I2Sn_CLK is derived from the system clock, so this poses a limited I2S bit clock divider options. This can have implications for other peripherals in the system that would take the clock from the system clock.

Example:

- Fs = 16 kHz
- I2Sn_CLK = 1.024 MHz (64xFs)

Derived system clock frequencies:

- 2.048 MHz (/2)
- 4.096 MHz (/4)
- 8.192 MHz (/8)
- 16.384 MHz (/16)
- 32.768 MHz (/32)
- 65.536 MHz (/64)

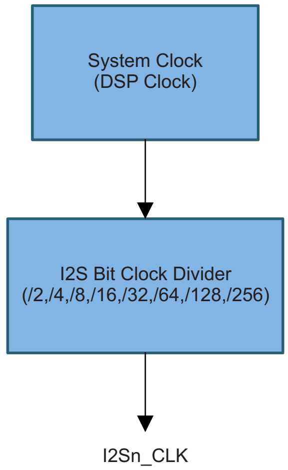

Figure 3. Examples of Various I2S Clock Frequencies Derived From the DSP Clock

2.1 These are the Tasks of the Decimation Block

The output of the “bit-picking” block is the input to the decimation block.

- Decimation: reduce sampling frequency (1.024 Mbps) to baseband Fs (16Kx32 M samples per seconds).
- Shape the signal and remove quantization noise
- Applying anti-aliasing filter; analog anti-aliasing filter rolls off gradually since ADC sampling frequency much higher than baseband Fs/2. Provide additional necessary aliasing rejection.

3 Stages of Decimation

Figure 4 through Figure 7 depict the sampling spectrum after each stage of the filtering processes.

3.1 Digital Mic Output Magnitude Spectrum

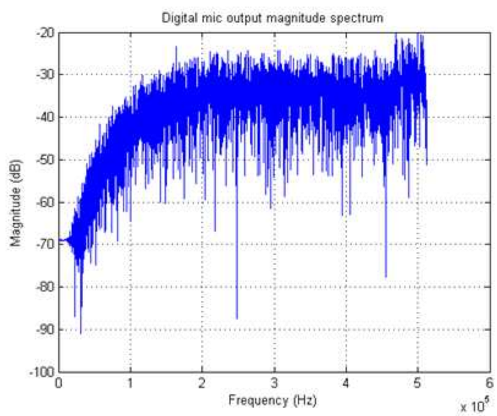

Figure 4. 1 kHz Tone in Baseband is Difficult to Observe, But Its Present at About -30 dB Magnitude

3.2 Cascaded Integrated Comb (CIC) Output Magnitude Spectrum

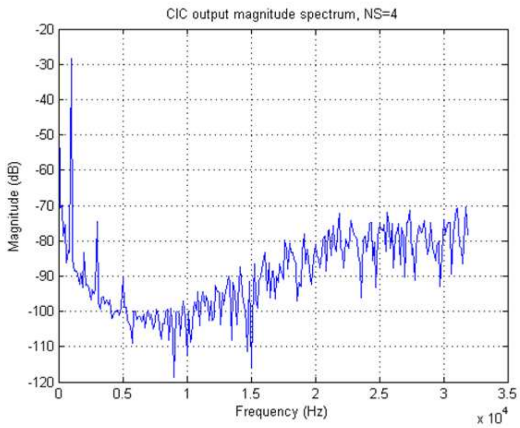

Figure 5. CIC Output With Significant Noise Spectrum Removed

3.3 Finite Impulse Response (FIR1) Output Magnitude Spectrum

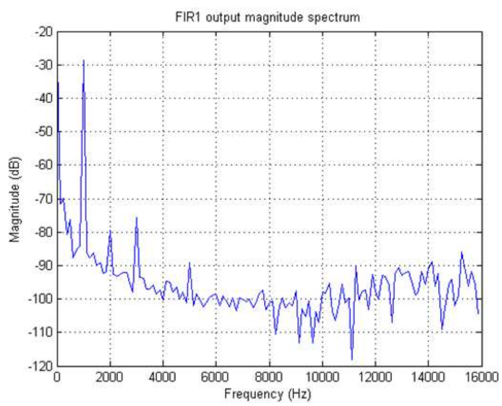

Figure 6. FIR1 Output Spectrum

15 taps, symmetric coefficients - such as, linear phase - S16Q15 coefficients

3.4 Finite Impulse Response (FIR2) Output Magnitude Spectrum

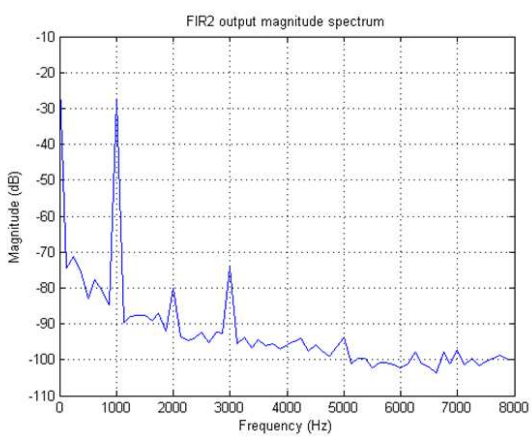

Figure 7. FIR2 Output Spectrum

At this point, a 0dB digital gain can be applied along with a high-pass filter for DC offset removal. 58 taps, symmetric coefficients - such as, linear phase. S16Q15 coefficients.

4 C5515 EVM Modifications

This application report is based on the use of a C5515EVM Rev B evaluation board. The board schematics are available at http://support.spectrumdigital.com/boards/evm5515/revb/.

The C5515 EVM hardware modifications to be made are:

- Attach wires to the NO-POP pad of R248 that is for I2S0_CLK
- Remove R240 from the EVM and attach a wire to the pad that connects to I2S0_RX (see Figure 8)
- R240 – I2S0_RX
- R248 – I2S0_CLK

NOTE: These pads are shared by the multimedia card/secure data memory card (MMC/SD), so removing R240 affects the SD card functionality.

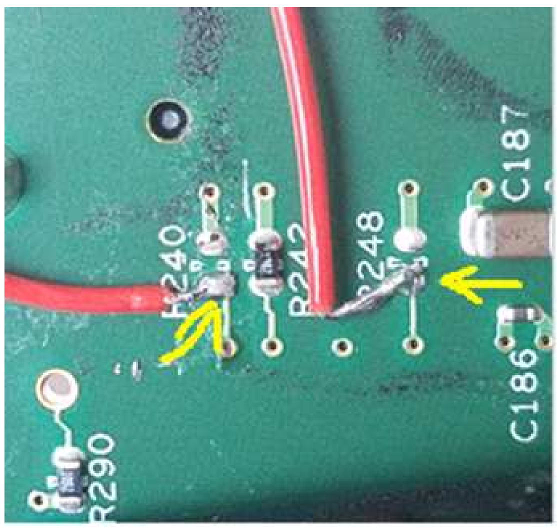

Figure 8. Close-Up of the Board Modifications and Attachment of Jumper Wires

Figure 9 details connecting the SPM1423HM4H-B MEMS microphone directly to the C5515 EVM.

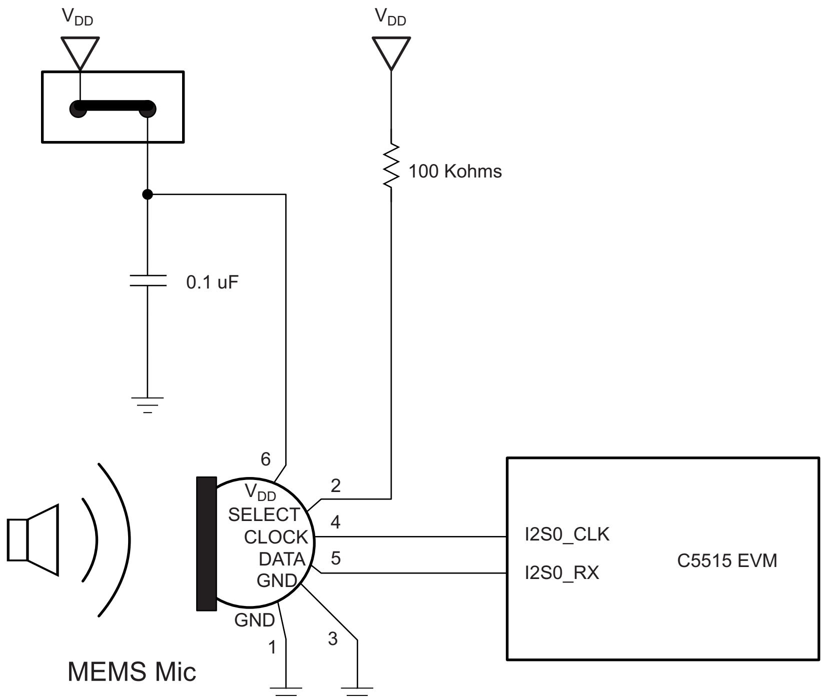

Figure 9. Connecting the MEMS Microphone to the C5515 EVM

5 Running the Demonstration

1. Download or clone the source code package from https://git.ti.com/apps/c55x-digital-mic-decimation.
2. If not already done, install the C55x Chip Support Library (CSL) from http://software-dl.ti.com/dsps/dsps_public_sw/dsps_swops_houston/C55X/latest/index_FDS.html. This document assumes that the CSL is installed at *C:\ti\c55_lp\c55_csl_3.06*.
3. Launch Code Composer Studio™ with a new workspace and import the CSL projects *C55XXCSL_LP* and *atafs_bios_drv_lib*.

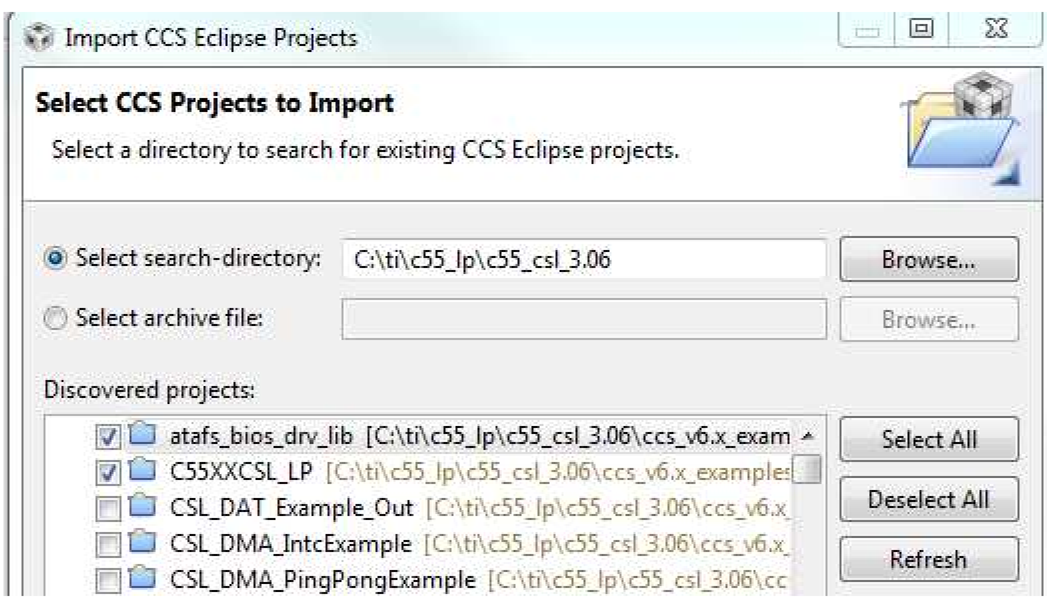

Figure 10. CSL Projects to Import Into the CCS Workspace

NOTE: Ensure that the correct macro for the C5515 device is enabled in *C:\ti\c55_lp\c55_csl_3.06\inc\csl_general.h* prior to compiling the project.

4. Import the target_test project from the software package downloaded in step 1 into the workspace.

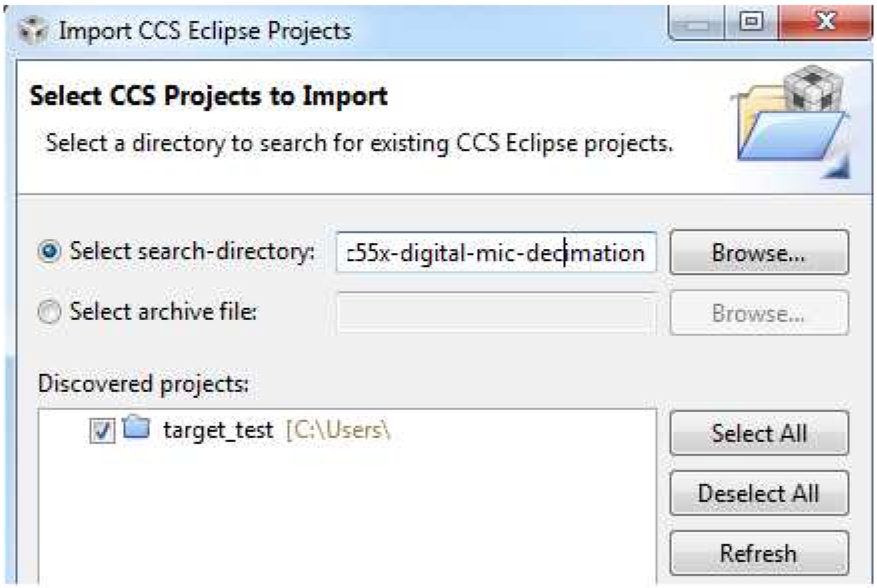

Figure 11. Importing the Main Decimation Project Into the CCS Workspace

5. Right click on the target_test project and build.

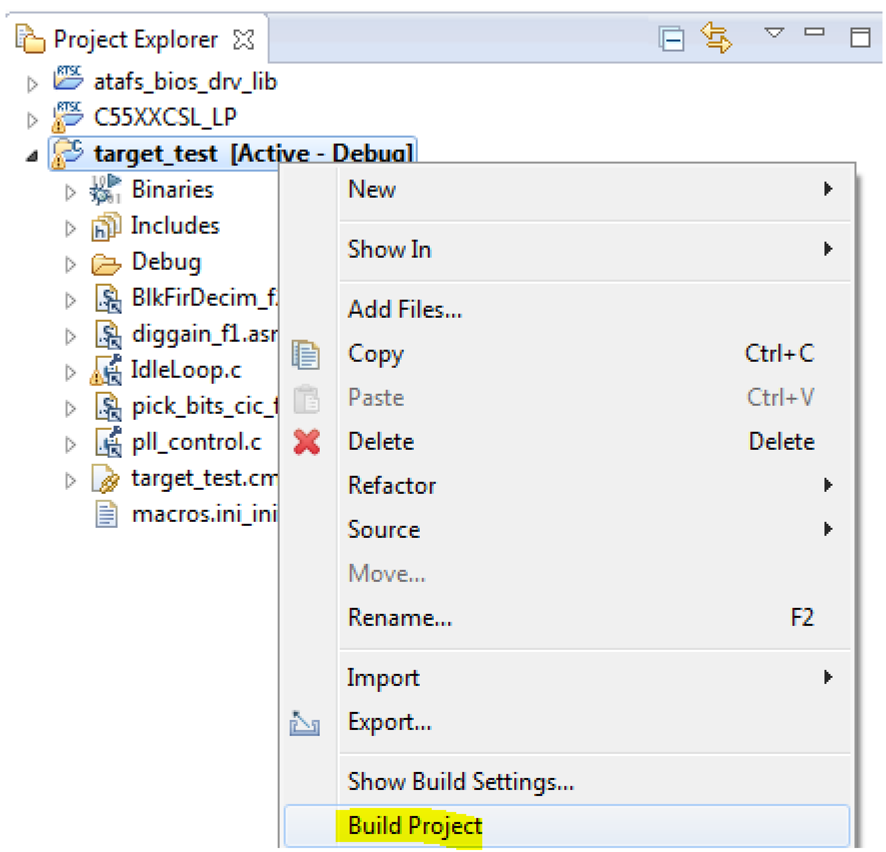

Figure 12. Building the CCS Project

6. Create a target configuration for the C5515 EVM and launch the session with a GEL file loaded on the core. For more information on setting up CCS (if not familiar), see the http://processors.wiki.ti.com/index.php/CCSv6_Getting_Started_Guide.

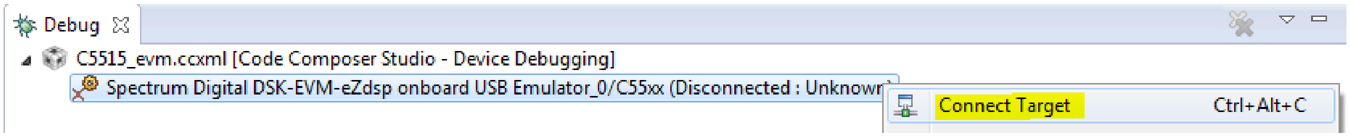

Figure 13. Connect Target

7. Once the core is connected, load target_test.out onto the core by going to Run → Load → Load Program then navigating to the .out file.

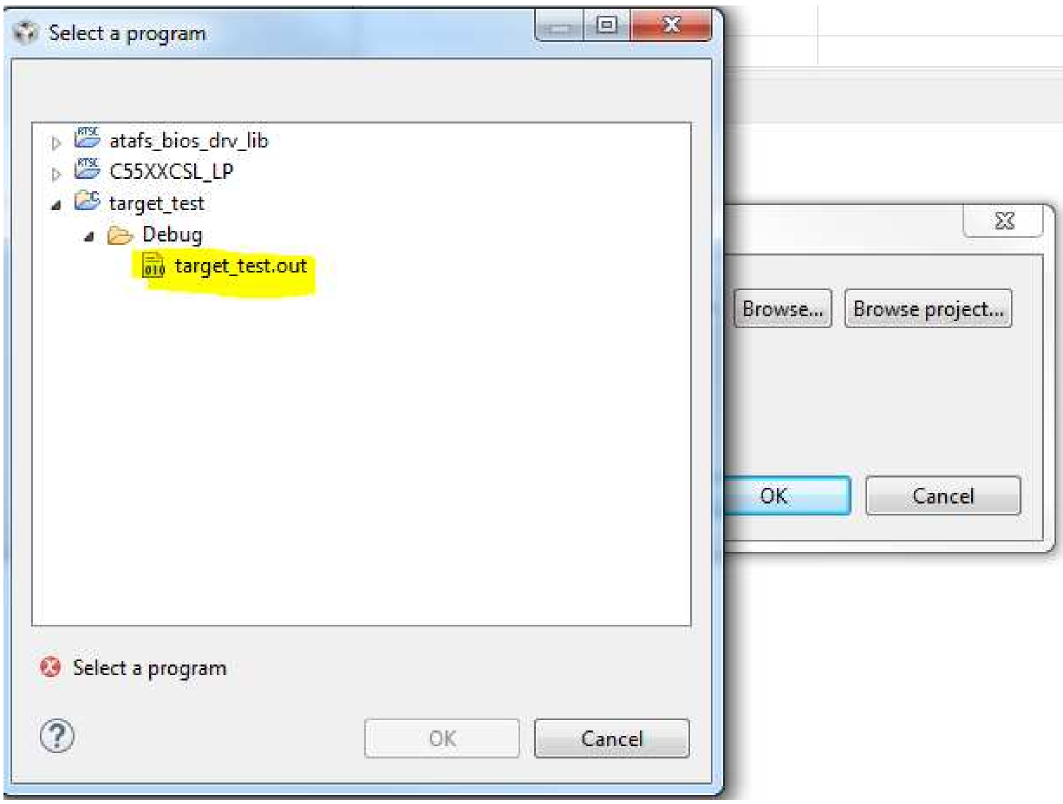

Figure 14. Loading the target_test.out File on the C5515 Core

8. Prior to running the program, create a watch expression for digGainOutFrame in the watch expression window. digGainOutFrame is the buffer that holds the final output of the decimation stages. The objective of having this expression in the watch window is to ascertain the memory location to grab the audio sample output from the test program. As seen in Figure 15, the location in this case is DATA 0x1246A. This location may vary, so ensure that the address is known before running the program.

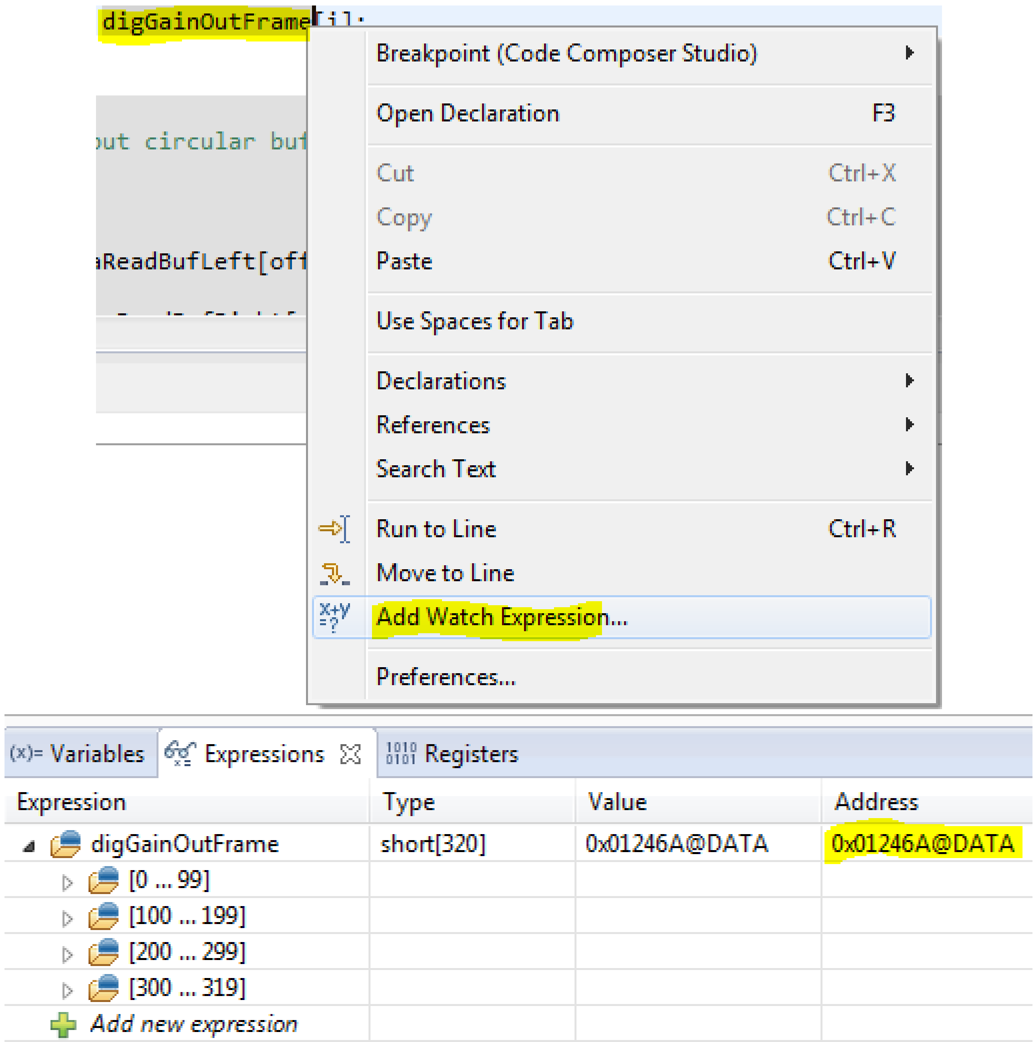

Figure 15. Adding a Watch Expression in CCS to Determine the Location of the Audio Buffers

9. In order to demonstrate the capture and decimation of the audio, an audio signal of known frequency needs to be played in front of the microphone. Audacity™ provides a quick way to generate a tone and is useful in analyzing the audio in later steps. For this demo, a Sine wave of 1KHz is used.

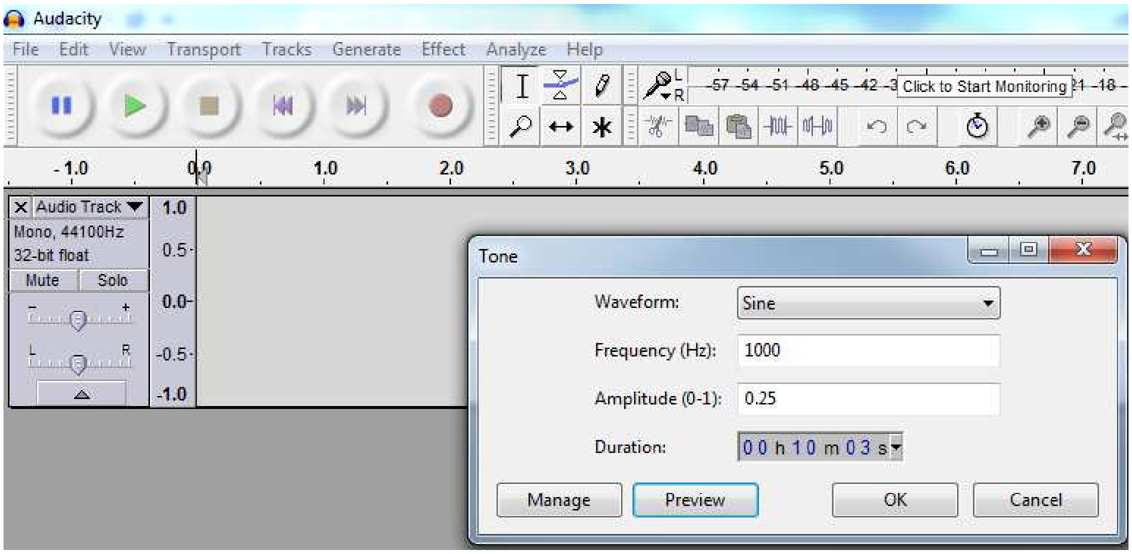

Figure 16. Audacity Tone Generation Tool

10. Play the audio tone through the speakers in front of the microphone.
11. Hit the Resume button or F8 to run the program while the tone is playing.

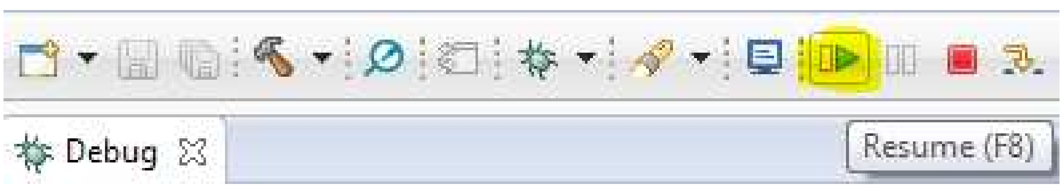

Figure 17. Executing the Program in CCS

12. Let the program run for a few seconds and then halt it.

Figure 18. Halting the Program in CCS

13. Open a memory browser window and observe the captured audio data at the memory location discussed in step 8.

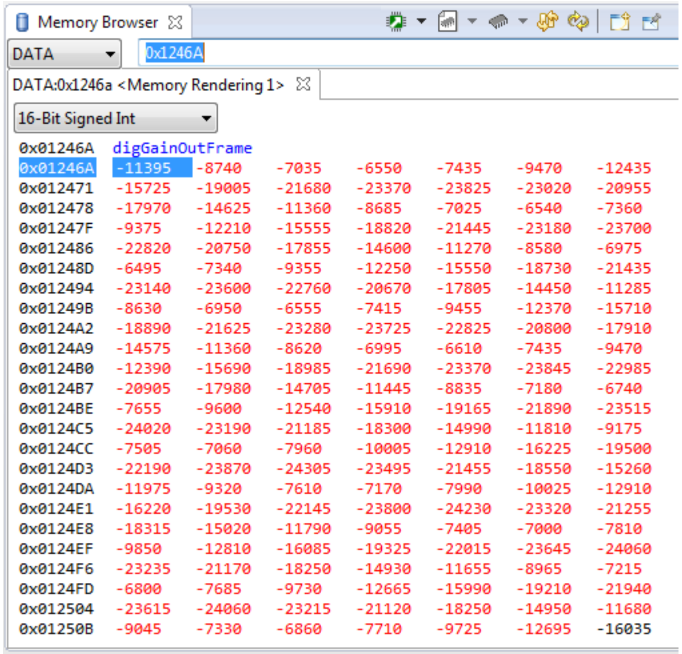

Figure 19. Memory Browser Window Showing 16-Bit Signed Audio Samples

14. Save the audio samples into a .dat file by right-clicking on the memory browser window as in Figure 20. Save the data at *\c55x-digital-mic-decimation\test_data\output\dig-mic-decimation_test_output.dat*, file type set as TI Data.

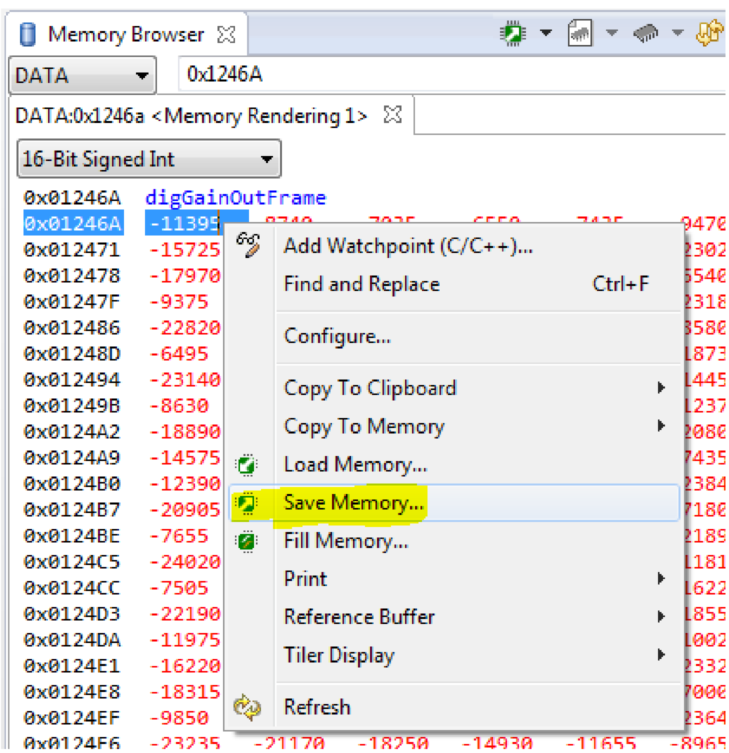

Figure 20. Saving the Captured Audio Samples to a .dat File

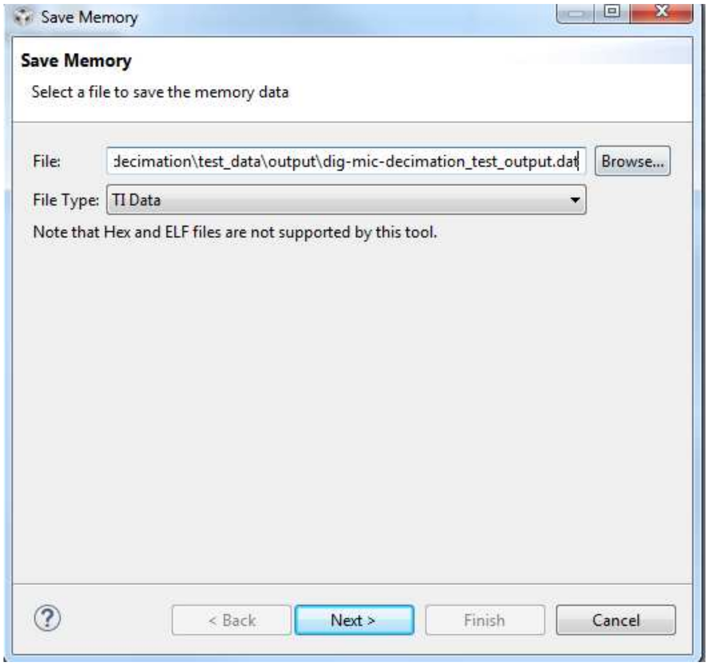

Figure 21. Saving Data From the Memory Browser to a .dat File

15. Save the data in the format as shown in Figure 22 and click Finish.

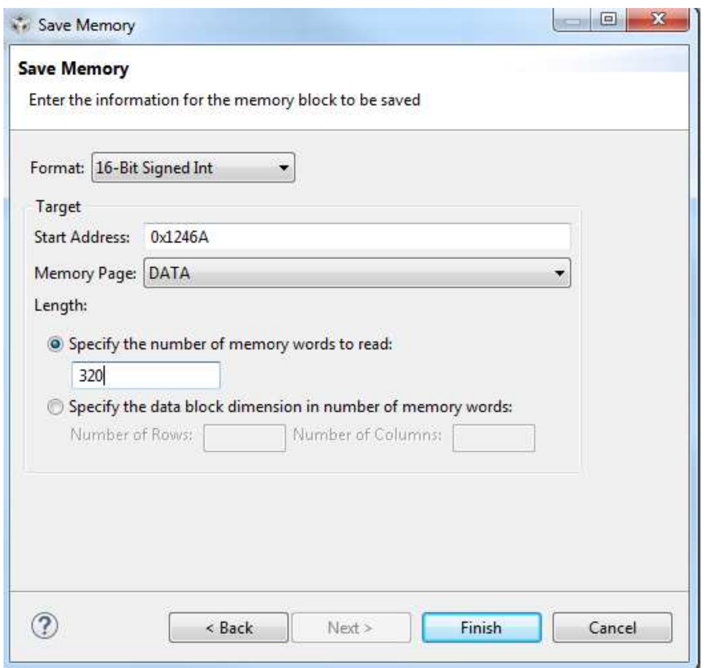

Figure 22. Format to Use to Save the Audio Samples in dig-mic-decimation_test_output.dat

16. At this point, the data is ready to be processed by the Matlab® script for .wav file conversion.
17. Open *\c55x-digital-mic-decimation\matlab_scripts\dig_mic_decimation_ConvertCCSbuf2wav.m* in Matlab.
18. Hit the Run button and a .wav file will be created: *\c55x-digital-mic-decimation\matlab_scripts\wavoutput_dig-mic-decimation_test.wav*.
19. Open *wavoutput_dig-mic-decimation_test.wav* in Audacity or any other audio software for analysis. As observed in Figure 23, an output with a 1KHz Sine wave would be observed.

NOTE: The sine wave has some DC offset. A high-pass filter (HPF) can be implemented in the decimation code to remove this offset. Alternatively, the audio can be scrubbed by using a HPF in Audacity as discussed in step 20.

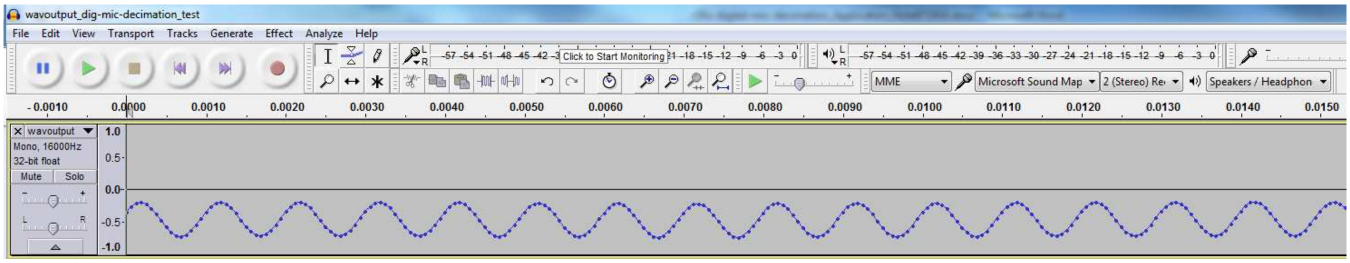

Figure 23. 1KHz Sine Wave Output Captured From the PDM Microphone and Decimated on the C5515 DSP

20. An HPF can be used in Audacity by going to Effect → High Pass Filter and choosing the suitable HPF parameters as seen in Figure 24.

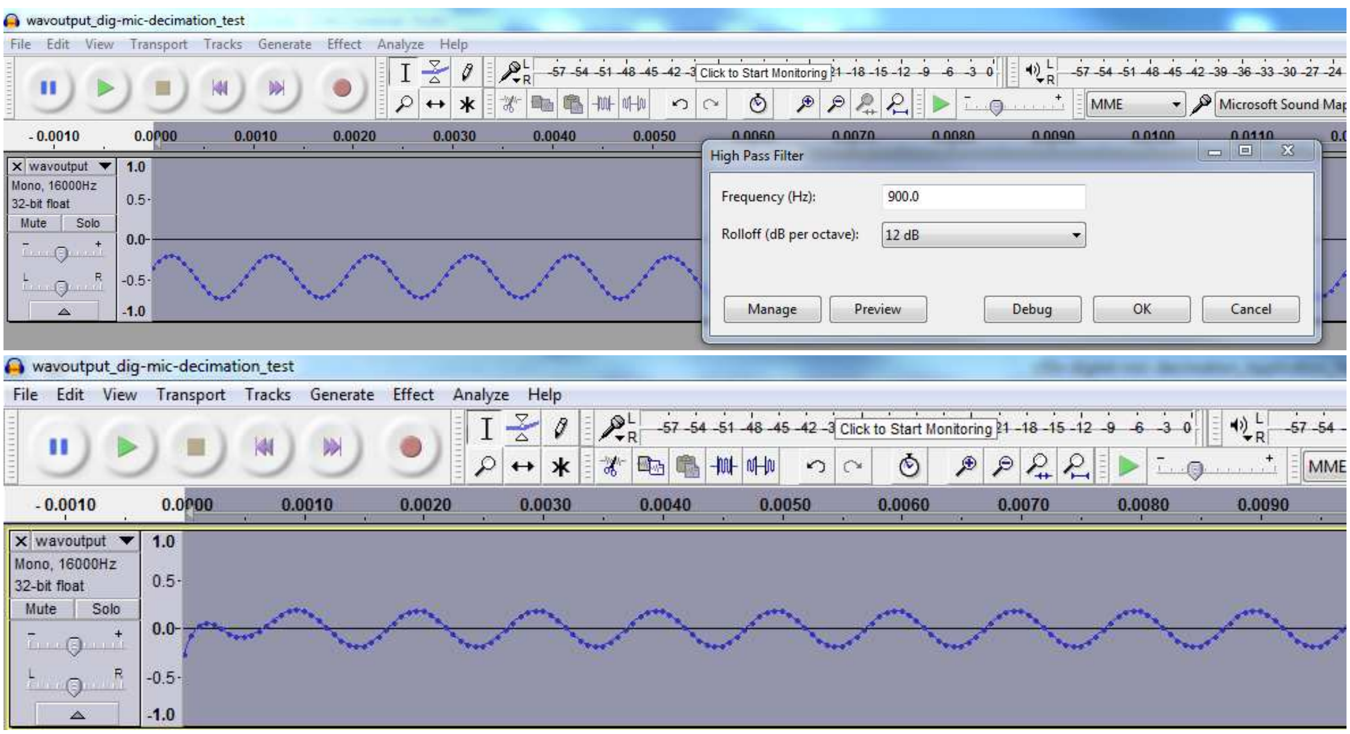

Figure 24. Applying a High-Pass Filter to the Audio Sample in Audacity to Remove the DC Offset

21. The audio spectrum can be plotted in Audacity to better analyze the signal Analyze → Plot Spectrum. As seen in Figure 25, the audio spectrum indicates a peak of a signal of approximately 1KHz.

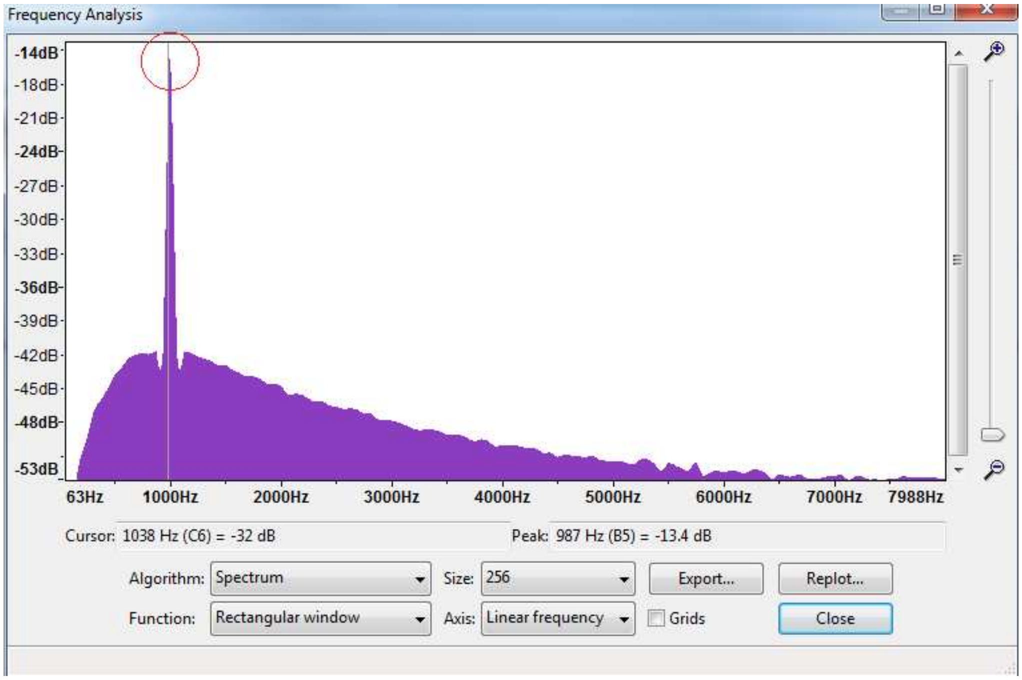

Figure 25. Spectrum Showing a Peak of Approximately 1KHz Signal

22. Further filtering techniques can be implemented as desired to refine the audio quality.

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