AN14177

Headset with Touch Function on MCX Nx4x

Rev. 1.0 — 20 January 2024

Application note

Document information

Information	Content
Keywords	AN14177, MCX Nx4x, gaming headset, USB audio, MICFIL, touch
Abstract	This application note describes how to use the MCX-N5XX-EVK to implement USB audio with touch control.

1 Introduction

Adding touch controls to the headset brings more operational diversity and convenience to users. This application note describes how to use the MCX-N5XX-EVK to implement USB audio with touch control.

The MCX Nx4x series microcontrollers combine the Arm Cortex-M33 TrustZone core with a CoolFlux BSP32, a PowerQuad DSP co-processor, and multiple high-speed connectivity options running at 150 MHz. MCX N54x and MCX N947 (VFBGA184) have high speed (HS) USB, SAI, DMIC, and TSI. Therefore, MCX Nx4x devices are suitable for the gaming headset solution.

Note: *The MCX N94x includes MCX N947 and MCX N946, among which MCX N946 and MCX N947 (100HLQFP) are not supporting DMIC.*

2 Implementation

The system block diagram of this application note is shown in Figure 1, which provides a brief overview of how the MCXN implements the headset with touch function.

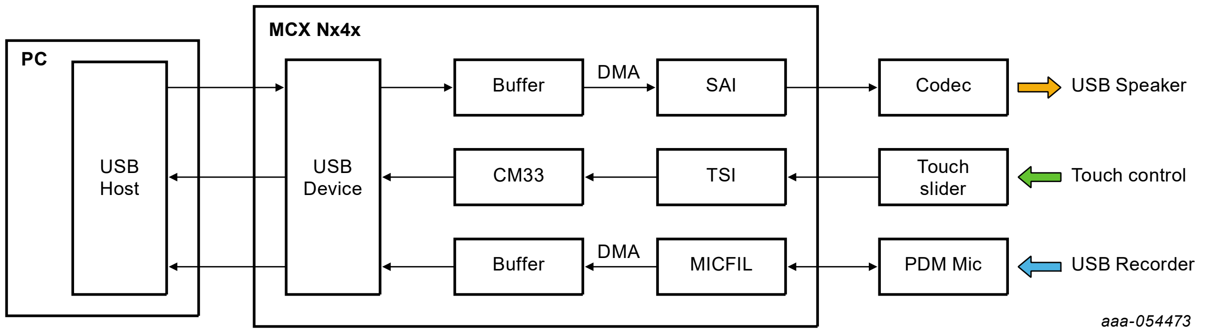


Figure 1. System block diagram

The code for this document is developed based on the `usb_device_composite_hid_audio_unified` example of MCX-N5XX-EVK SDK 2.13, and the IDE is IAR 9.40.1. To download the MCX-N5XX-EVK SDK 2.13, refer Build SDK for MCX-N5XX-EVK, and ensure to tick USB in the MCUXpresso SDK Builder.

The SDK example implements the USB speaker and recorder function. Based on this implementation, the document introduces how to enable the MICFIL module and touch control.

2.1 MICFIL introduction and use

The block diagram of the USB recorder is shown in Figure 1:

1. MICFIL module provides clock to PDM microphone and transforms the PDM data generated by the microphone into PCM data.
2. Then, the DMA transfers PCM data to the ring buffer.
3. Finally, the MCU sends the PCM data to the USB host via a high-speed USB interface.

MICFIL module transforms a pulse density modulated (PDM) microphone bitstream into a 24-bit PCM signal in the audio band, at a configurable output sample rate. Figure 2 shows the block diagram of MICFIL:

1. The internal time generator is used to generate a programmable clock for the PDM microphone. PDM data is converted into PCM data after the decimation filter.
2. Then, the PCM data is loaded into FIFO.
3. Finally, the PCM data in the FIFO can be read through interrupt or DMA.

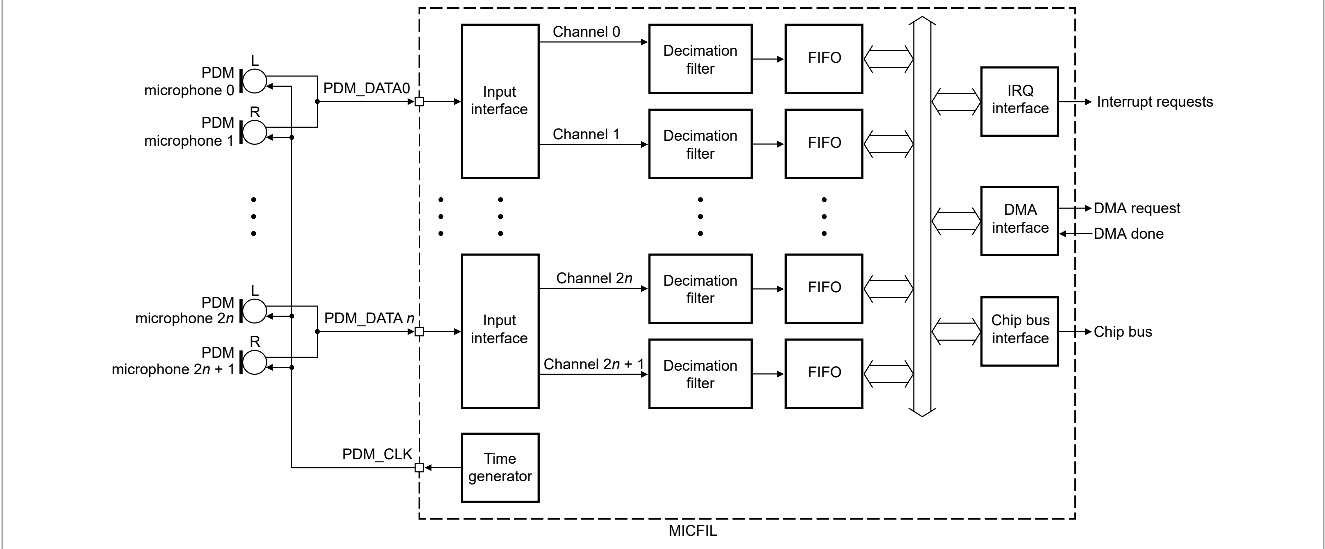


Figure 2. MICFIL block diagram

Figure 3 shows the timing diagram of the input interface signals when the clock divider is enabled. The bitstream incoming from the microphone data input "n" (PDM_DATAn) in the first half (right microphone) of the PDM_CLK is directed to channel "2n+1". The data generated during the last half (left microphone) is directed to channel "2n".

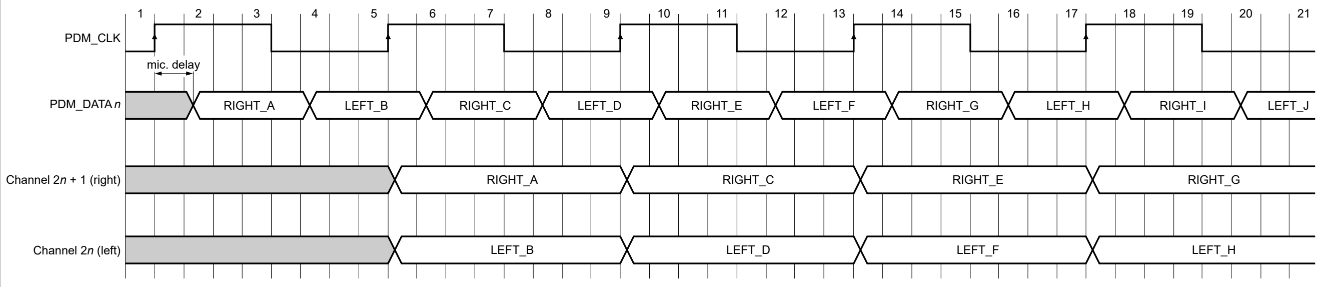
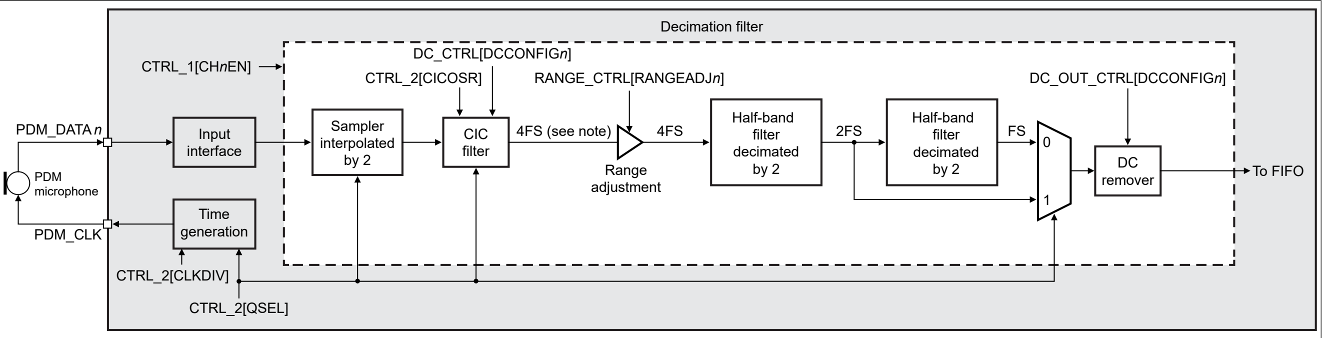


Figure 3. Input interface signals

Figure 4 shows the block diagram of the decimation filter:

- The cascaded integrator comb (CIC) filter converts PDM data from a digital microphone to PCM data at a given oversampling rate.
- Two half-band filters for each channel, which implement a low-pass digital filter with decimation by 2, can be used to compensate for the high CIC drop in passband.
- The DC remover is a high-pass filter that is used to remove the DC component of the processed signal with a configurable cut-off frequency.



Note: Throughout this diagram, *n*FS means *n*× the last-stage output rate (FS).

Figure 4. Decimation filter block diagram

OSR is the abbreviation of over sample rate. Equation (1) and Equation (2) show that CTRL_2[CICOSR] and quality mode selected define the CIC decimation rate:

$$OSR = 16 - \text{CICOSR} \tag{1}$$

$$CIC\ decimation\ rate = \begin{cases} 2\ x\ OSR\ ; If\ HQ,\ VLQ0 \\ OSR\ ; others \end{cases} \tag{2}$$

Table 1 shows the relationship between quality mode and coefficients in the decimation filter.

Table 1. Quality modes

Quality mode	CTRL_2[QSEL]	Sampler interpolation	CIC filter decimation	First-half band filter decimation	Second-half band filter decimation	PDM_CLK rate	Passband
High quality	001	-	: (2OSR)	: 2	: 2	Output rate x 8 x OSR	To ~ 0.5 x output rate
Medium quality	000	-	: OSR	: 2	: 2	Output rate x 4 x OSR	To ~ 0.5 x output rate
Low quality	111	x 2	: OSR	: 2	: 2	Output rate x 2 x OSR	To ~ 0.5 x output rate
Very-low quality 0	110	-	: (2OSR)	: 2	-	Output rate x 4 x OSR	To ~ 0.25 x output rate
Very-low quality 1	101	-	: OSR	: 2	-	Output rate x 2 x OSR	To ~ 0.25 x output rate
Very-low quality 2	100	x 2	: OSR	: 2	-	Output rate x OSR	To ~ 0.25 x output rate

As shown in Equation (3), the overall filter gain depends on quality mode, CIC decimation rate, and dynamic range adjustment of the CIC filter.

$$Overall\ filter\ gain\ (dB) = \begin{cases} 100\ x\ \log_{10}(32 - 2\ x\ CICOSR) + 6.02\ x\ RANGE\_CTRL[RANGEADJ_n] - 150.50\ ; if\ QSEL€\ [HQ,\ VLQ0] \\ 100\ x\ \log_{10}(16 - CICOSR) + 6.02\ x\ RANGE\_CTRL[RANGEADJ_n] - 150.50\ ; others \end{cases} \tag{3}$$

Table 2 shows the dynamic range adjustment in different quality modes.

Table 2. Channel range adjustment

QSEL	RANGEADJ$_n$
HQ, VLQ0	<=25-ceil(5log2(2OSR))

Table 2. Channel range adjustment *...continued*

QSEL	RANGEADJ$_n$
MQ, VLQ1	<=25-ceil(5log2(OSR))
LQ, VLQ2	<=24-ceil(5log2(OSR))

Equation (4) and Equation (5) show how to calculate the CLKDIV value and PDM_CLK value:

$$CLKDIV = \frac{MICFIL\_CLK\_ROOT\ \ rate}{8\ x\ \ OSR\ \ x\ \ (output\ \ rate)} \tag{4}$$

$$PDM\_CLK\ \ rate = \frac{MICFIL\_CLK\_ROOT}{2\ x\ \ floor\ (K\ \ x\ \ CLKDIV)} \tag{5}$$

Note: *The output rate represents the sample rate.*

For K factor value, refer Table 3.

Table 3. K factor value

Quality mode	K factor
High quality	1/2
Medium quality, very-low quality 0	1
Low quality, very-low quality 1	2
Very-low quality 2	4

The following is the main configuration code of MICFIL for reference. For more related code, refer to the `pdm_sai_edma` example in the SDK.

```
/* Watermark value for FIFO: half of PDM FIFO depth */
pdmConfig.fifoWatermark = DEMO_PDM_FIFO_WATERMARK;
/* Quality mode: high quality */
pdmConfig.qualityMode = DEMO_PDM_QUALITY_MODE;
/* CIC filter over sampling rate: 0 */
pdmConfig.cicOverSampleRate = DEMO_PDM_CIC_OVERSAMPLE_RATE;
/* output DC remover cut off frequency: Bypass */
channelConfig.outputCutOffFreq = DEMO_PDM_OUTPUTCUTOFFFREQ;
/* Configure filter dynamic range */
channelConfig.gain = DEMO_PDM_CHANNEL_GAIN;
/* Initializes the MICFIL peripheral */
PDM_Init(DEMO_PDM, &pdmConfig);
/* Configures the MICFIL channel */
PDM_TransferSetChannelConfigEDMA(DEMO_PDM, &s_pdmRxHandle, DEMO_PDM_ENABLE_CHANNEL_LEFT,
 &channelConfig);
PDM_TransferSetChannelConfigEDMA(DEMO_PDM, &s_pdmRxHandle, DEMO_PDM_ENABLE_CHANNEL_RIGHT,
 &channelConfig);
/* MICFIL set sample rate */
PDM_SetSampleRateConfig(DEMO_PDM, DEMO_PDM_CLK_FREQ, DEMO_AUDIO_SAMPLE_RATE);
/* Performs a non-blocking PDM receive using eDMA */
PDM_TransferReceiveEDMA(DEMO_PDM, &s_pdmRxHandle, pdmXfer);
```

In addition, the user has to change the USB description for the recorder interface in the project from 16 bit to 32 bit. The specific implementation can refer to the code in this application note attachment.

To reduce latency, DMA is used to transfer PCM data in the MICFIL FIFO. The following is the main configuration code of DMA for reference. For more related code, refer to the `pdm_sai_edma` example in the SDK.

```
#define DEMO_DMA                   DMA0
#define DEMO_PDM_EDMA_CHANNEL      0
#define DEMO_PDM_EDMA_SOURCE       kDmaRequestMuxMicfil0FifoRequest
/* Initializes the eDMA peripheral */
EDMA_Init(DEMO_DMA, &dmaConfig);
```

```
/* Creates the eDMA handle */
EDMA_CreateHandle(&s_pdmDmaHandle, DEMO_DMA, DEMO_PDM_EDMA_CHANNEL);
/* Set channel request source */
EDMA_SetChannelMux(DEMO_DMA, DEMO_PDM_EDMA_CHANNEL, DEMO_PDM_EDMA_SOURCE);
/* Initializes the PDM Rx eDMA handle */
PDM_TransferCreateHandleEDMA(DEMO_PDM, &s_pdmRxHandle, pdmCallback, NULL, &s_pdmDmaHandle);
/* Install EDMA descriptor memory */
PDM_TransferInstallEDMATCDMemory(&s_pdmRxHandle, s_edmaTcd, 2);
```

Table 4 shows the specific configuration of the TCD, considering two-channel MICFIL as an example.

Table 4. TCD configuration

Register	Field	Description	Value
TCDn_SADDR	SADDR	Source address	DATACH[channel]
TCDn_SOFF	SOFF	Source address offset	FIFO_Width
TCDn_DADDR	DADDR	Destination address	Buffer
TCDn_DOFF	DOFF	Destination address offset	FIFO_Width
TCDn_ATTR	SSIZE	Source data transfer size	FIFO_Width
	DSIZE	Destination data transfer size	FIFO_Width
TCDn_NBYTES	NBYTES	Number of bytes to be transferred for each service request of the channel	channelNums* FIFO_Width
TCDn_BITER	BITER	Starting major iteration count	Data_Size/NBYTES

2.2 Touch introduction and usage

Touch sensing input (TSI) module provides touch sensing detection on capacitive touch sensors. The TSI module supports Self-capacitance mode and Mutual-capacitance mode. TSI fully supports the NXP touch library based on the SDK, which provides a solid capacitive measurement module for the implementation of touch keyboard, rotaries, and sliders. The TSI module provides 25 input channels.

This application note introduces the use of the touch slider on MCX-N5XX-EVK to implement USB audio control.

2.2.1 USB host control codec volume

Based on the SDK code, we are going to introduce how to implement the USB host control codec volume.

1. First, set the volume control range to the range corresponding to the codec:

```
g_deviceAudioComposite->audioUnified.volumeControlRange.wMIN         =
 USB_VolumeConversion_ConvertVolumeToUsb(AUDIOCODEC_MIN_OUTPUT_VOLUME_DB);
g_deviceAudioComposite->audioUnified.volumeControlRange.wMAX         =
 USB_VolumeConversion_ConvertVolumeToUsb(AUDIOCODEC_MAX_OUTPUT_VOLUME_DB);
```

2. Then, add the following code to change the volume of the device codec:

```
int16_t range_volume_db = 0;
int16_t range_volume_USB = 0;
int16_t codec_min_USB = 0;
int16_t codec_max_db = (int16_t)AUDIOCODEC_MAX_OUTPUT_VOLUME_DB;
int16_t codec_min_db = (int16_t)AUDIOCODEC_MIN_OUTPUT_VOLUME_DB;
range_volume_db = codec_max_db - codec_min_db;
range_volume_USB = USB_VolumeConversion_ConvertVolumeToUsb(range_volume_db);
codec_min_USB = USB_VolumeConversion_ConvertVolumeToUsb(codec_min_db);
uint8_t limit_value = 80;
/*
    0xb300: covert Db-value(-77db) to USB-value
    0x4d00: covert Db-value(77db) to USB-value
*/
```

```
uint8_t volAdj = ((int16_t)ATOS(g_deviceAudioComposite->audioUnified.curSpeakerVolume20) -
 (int16_t)codec_min_USB) * limit_value / range_volume_USB;
usb_echo("vol_codec_val = %d\r\n", volAdj);
BOARD_SetCodecVol(volAdj);
```

2.2.2 Touch control USB host audio

To get the SDK touch demo, tick the NXP touch library in the MCUXpresso SDK builder. Then, refer to the `touch_sensing` demo code in the `demo_apps` folder.

Note: *MCX-N5XX-EVK SDK 2.13 does not support ticking the NXP touch library, and it is going to be supported in SDK 2.14. You can also tick NXP Touch Library in MCX-N9XX-EVK SDK 2.13 and refer to the corresponding demo code.*

The `aslider_callback` function in the `touch_sensing` demo code returns an analog slider event and position. By comparing the positions of the release event and initial touch event, determine the left/right sliding distance or signal touch event.

Update the USB device hid keyboard report descriptor for USB host audio control:

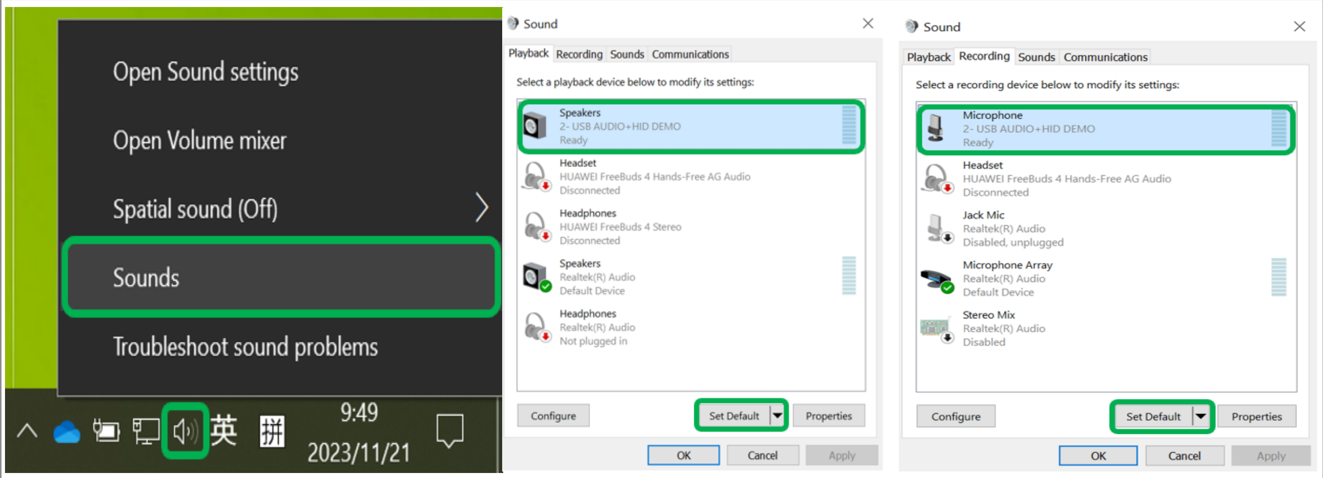
```
uint8_t g_UsbDeviceHidKeyboardReportDescriptor[] = {
    0x05, 0x0c,                   /* USAGE_PAGE (Consumer Devices) */
    0x09, 0x01,                   /* USAGE (Consumer Control) */
    0xa1, 0x01,                   /* COLLECTION (Application) */
    0x15, 0x00,                   /*   LOGICAL_MINIMUM (0) */
    0x25, 0x01,                   /*   LOGICAL_MAXIMUM (1) */
    0x05, 0x0c,                   /*   USAGE_PAGE (Consumer Devices) */
    0x09, 0xcd,                   /*   USAGE (Play/Pause) */
    0x09, 0xe9,                   /*   USAGE (Volume Up) */
    0x09, 0xea,                   /*   USAGE (Volume Down) */
    0x09, 0xb5,                   /*   USAGE (Scan Next Track) */
    0x09, 0xb6,                   /*   USAGE (Scan Previous Track) */
    0x09, 0xb7,                   /*   USAGE (Stop) */
    0x95, 0x06,                   /*   REPORT_COUNT (6) */
    0x75, 0x01,                   /*   REPORT_SIZE (1) */
    0x81, 0x02,                   /*   INPUT (Data,Var,Abs) */
    0x75, 0x02,                   /*   REPORT_SIZE (2) */
    0x95, 0x01,                   /*   REPORT_COUNT (1) */
    0x81, 0x03,                   /*   INPUT (Cnst,Var,Abs) */
    0xc0                          /* END_COLLECTION */
};
```

In `hid_keyboard.c`, the `USB_DeviceHidKeyboardAction` and `USB_DeviceHidKeyboardCallback` functions send corresponding device requests based on the sliding direction and distance.

3 Test

To test the basic USB audio playback function of the SDK demo code, perform the following steps:

1. Connect MCU Link (J5) and HS USB (J27) to the computer via USB cable.
2. After compiling and downloading the demo to the MCX-N5XX-EVK board, reset the MCU.
3. Plug the 3.5 mm headphones into J7 of the EVK.
4. Set a USB device as the default playback device and the default recording device as shown in Figure 5.
5. Right-click on the speakers icon, then click **Sounds**.
6. Select **Playback** or **Recording**, then select "USB AUDIO+HID DEMO" and click **Set Default**.
7. Now, the headphones on the USB device side (EVK) is going to hear the sound played on the USB host side (PC).



Select a playback device below to modify its settings:

Speakers
2- USB AUDIO+HID DEMO
Ready

Headset
HUAWEI FreeBuds 4 Hands-Free AG Audio
Disconnected

Headphones
HUAWEI FreeBuds 4 Stereo
Disconnected

Speakers
Realtek(R) Audio
Default Device

Headphones
Realtek(R) Audio
Not plugged in

Select a recording device below to modify its settings:

Microphone
2- USB AUDIO+HID DEMO
Ready

Headset
HUAWEI FreeBuds 4 Hands-Free AG Audio
Disconnected

Jack Mic
Realtek(R) Audio
Disabled, unplugged

Microphone Array
Realtek(R) Audio
Default Device

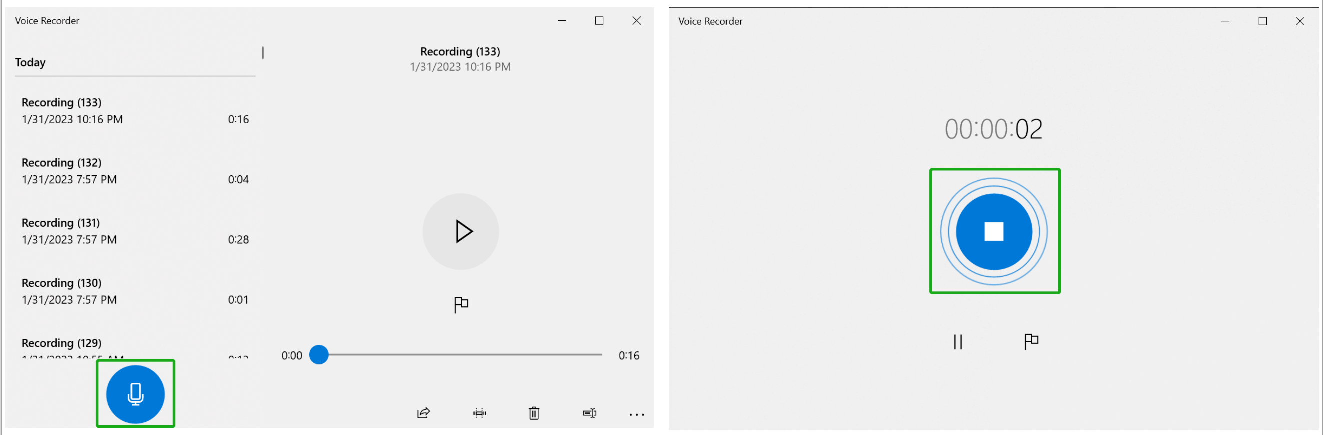
Stereo Mix
Realtek(R) Audio
Disabled

Figure 5. Set a USB device as the default device

3.1 Test USB device recording function

To test the USB device recording function, perform the following steps:

1. Change the jumper of JP7, JP8, JP10, and JP11 from the default to 2-3.
2. Click the Start button on Windows and search for "Voice Recorder", as shown in Figure 6.
3. Play the music closer to U30 and U32 on MCX-N5XX-EVK.
4. Play the recording and headphones on the USB device side (EVK) hear the sound acquired by DMIC (U30 and U32 on EVK).

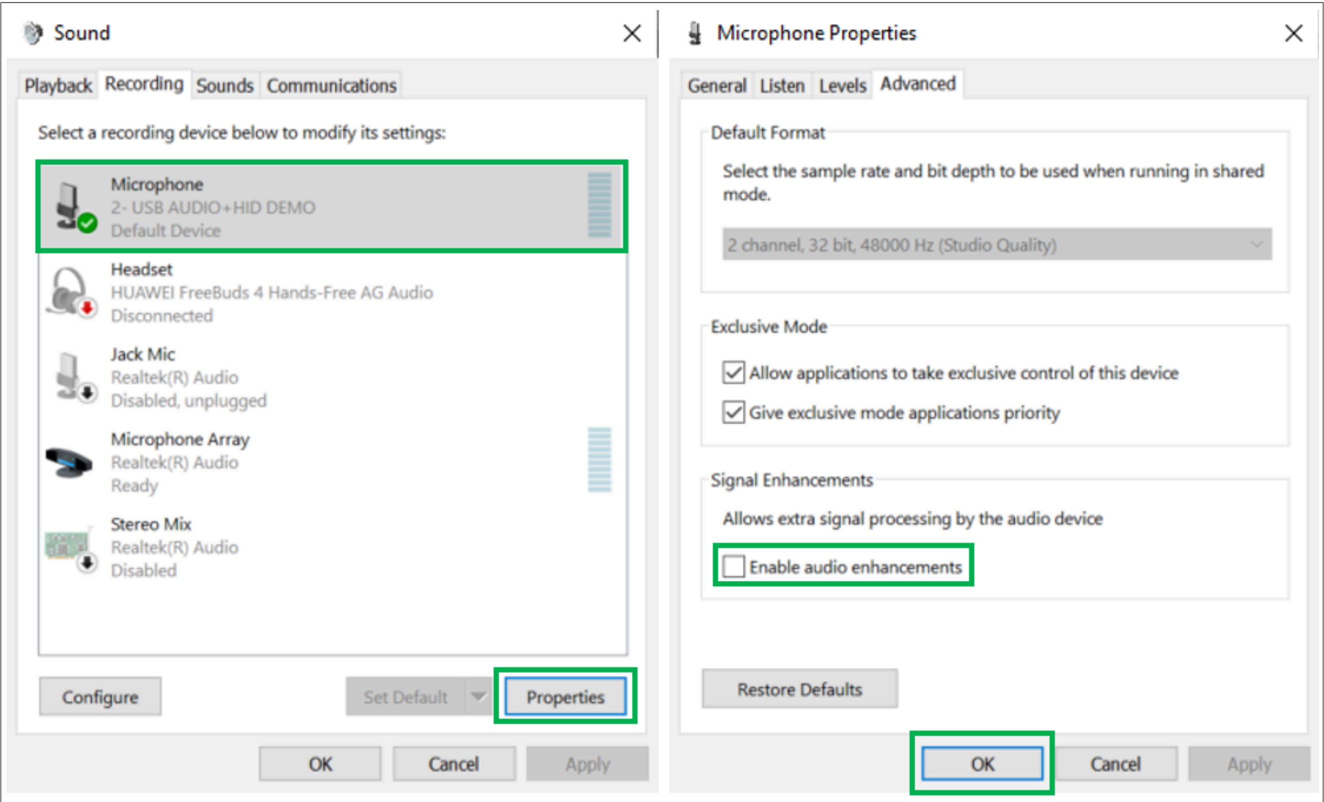


Recording (133)	1/31/2023 10:16 PM	0:16
Recording (132)	1/31/2023 7:57 PM	0:04
Recording (131)	1/31/2023 7:57 PM	0:28
Recording (130)	1/31/2023 7:57 PM	0:01
Recording (129)		

Recording (133)
1/31/2023 10:16 PM

Figure 6. Voice recorder

If only one DMIC acquires the sound (U30 or U32 on EVK), disable audio enhancements as shown in Figure 7. After resetting the MCU, the user can hear the sound acquired by the left and right channels.


Sound

Playback | Recording | Sounds | Communications

Select a recording device below to modify its settings:

Microphone
2- USB AUDIO+HID DEMO
Default Device

Headset
HUAWEI FreeBuds 4 Hands-Free AG Audio
Disconnected

Jack Mic
Realtek(R) Audio
Disabled, unplugged

Microphone Array
Realtek(R) Audio
Ready

Stereo Mix
Realtek(R) Audio
Disabled

Configure | Set Default | Properties

OK | Cancel | Apply

Microphone Properties

General | Listen | Levels | Advanced

Default Format

Select the sample rate and bit depth to be used when running in shared mode.

2 channel, 32 bit, 48000 Hz (Studio Quality)

Exclusive Mode

☑ Allow applications to take exclusive control of this device

☑ Give exclusive mode applications priority

Signal Enhancements

Allows extra signal processing by the audio device

☐ Enable audio enhancements

Restore Defaults

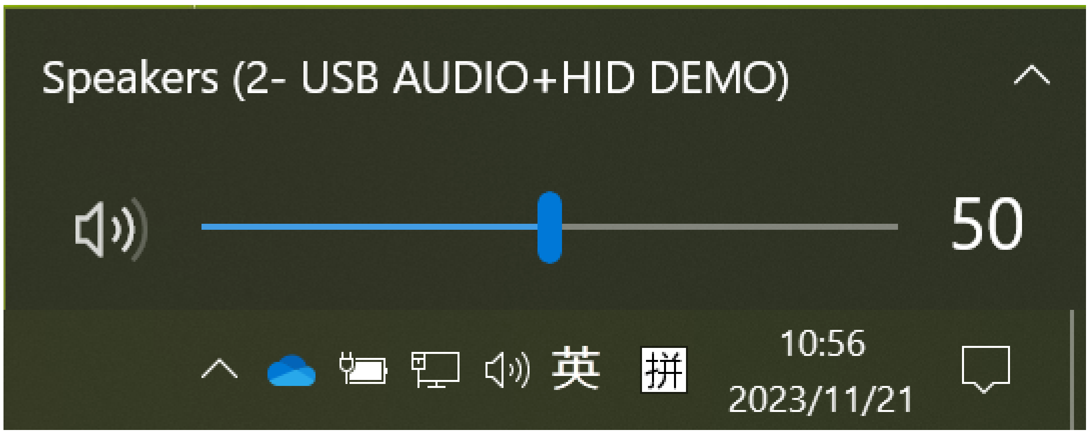
OK | Cancel | Apply

Figure 7. Disable audio enhancements

3.2 Test USB host change volume

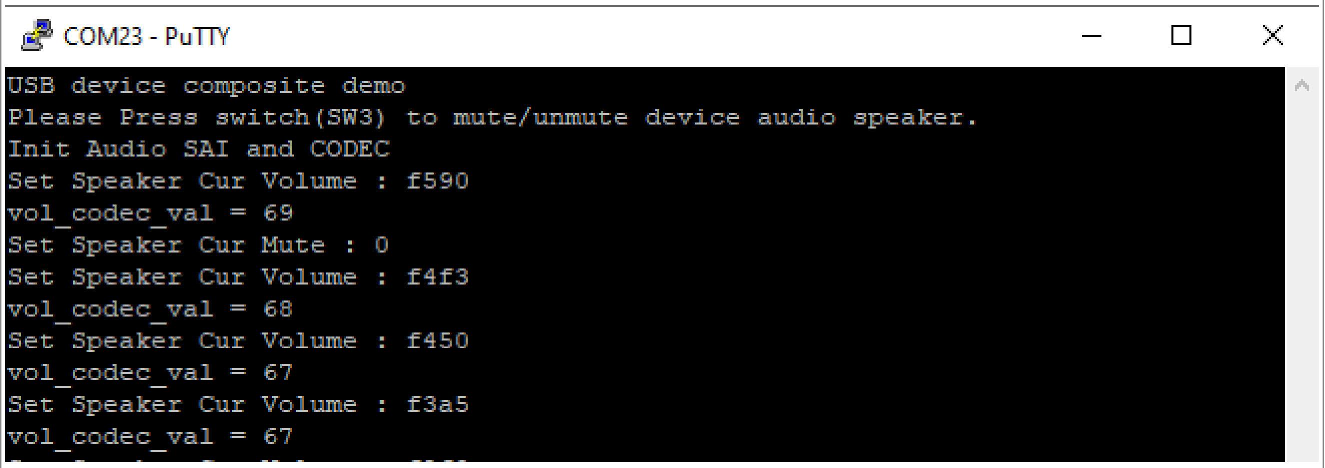
To test the USB host change volume, perform the following steps:

1. Change the volume on the USB host side (PC). The volume adjustment information is printed on the terminal, as shown in Figure 8.
2. At the same time, the volume changes are heard on the headset side (headphones on EVK).


Speakers (2- USB AUDIO+HID DEMO)

50

10:56
2023/11/21



```
USB device composite demo
Please Press switch(SW3) to mute/unmute device audio speaker.
Init Audio SAI and CODEC
Set Speaker Cur Volume : f590
vol_codec_val = 69
Set Speaker Cur Mute : 0
Set Speaker Cur Volume : f4f3
vol_codec_val = 68
Set Speaker Cur Volume : f450
vol_codec_val = 67
Set Speaker Cur Volume : f3a5
vol_codec_val = 67
```

Figure 8. USB host change volume

3.3 Test touch control USB host audio

To test touch control USB host audio, perform the following steps and the result is shown in Figure 9:

1. To adjust the volume, swipe the touch slider (E1) left or right on the EVK.
2. To play/pause the music, click the touch slider (E1) on the EVK.
   Note: *When sliding and clicking, make the contact area between the finger and the slider as large as possible, and don't slide too fast.*

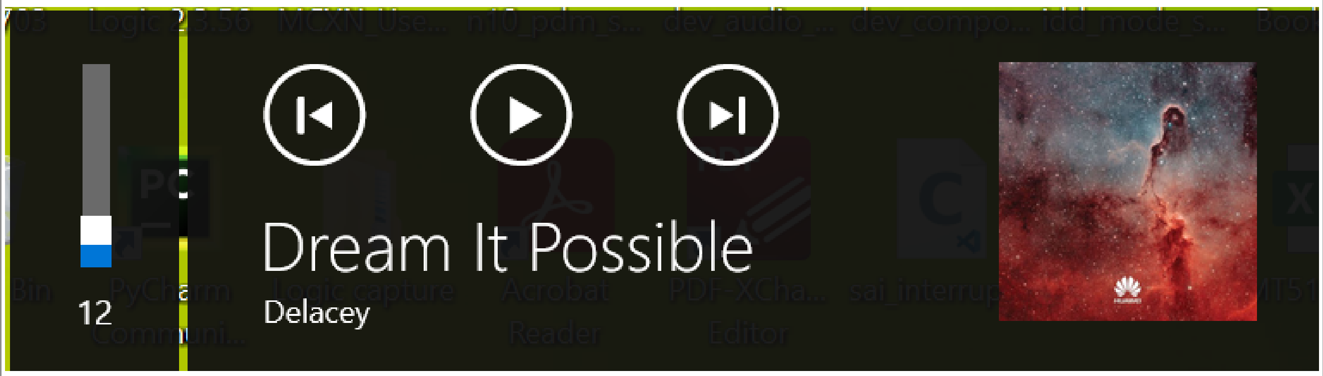


Figure 9. Touch control USB host audio

4 Summary

This application note based on the SDK example introduces how to enable the MICFIL module and use the TSI module to control the volume. It provides a reference for the gaming headset and brings more operational diversity and convenience to users.

5 Note about the source code in the document

Example code shown in this document has the following copyright and BSD-3-Clause license:

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6 Revision history

Table 5 summarizes the revisions to this document.

Table 5. Revision history

Document ID	Release date	Description
AN14177 v.1.0	20 January 2024	Initial public release

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NXP has a Product Security Incident Response Team (PSIRT) (reachable at PSIRT@nxp.com) that manages the investigation, reporting, and solution release to security vulnerabilities of NXP products.

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