

AN14177

采用MCX Nx4x触控功能的头戴方案

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应用笔记

文档信息

信息	内容
关键词	AN14177、MCX Nx4x、游戏头戴、USB音频、MICFIL、触控
摘要	本应用笔记介绍了如何使用MCX-N5XX-EVK实现带触控功能的USB音频方案。



1 介绍

在头戴上添加触控功能可提升用户操作的多样性和便利性。本应用笔记介绍了如何使用MCX-N5XX-EVK实现带触控功能的USB音频方案。

MCX Nx4x系列微控制器融合了Arm Cortex-M33 TrustZone内核、CoolFlux BSP32、PowerQuad DSP协处理器和以150MHz运行的多种高速连接选项。MCX N54x和MCX N947 (VFBGA184)提供了高速(HS) USB、SAI、DMIC和TSI接口。因此，MCX Nx4x芯片适用于游戏头戴解决方案。

注：MCX N94x包括MCX N947和MCX N946，其中MCX N946和MCX N947 (100HLQFP)不支持DMIC。

2 实施

本应用笔记的系统框图如图1所示，此框图简要介绍了MCXN如何实现带触摸功能的头戴。

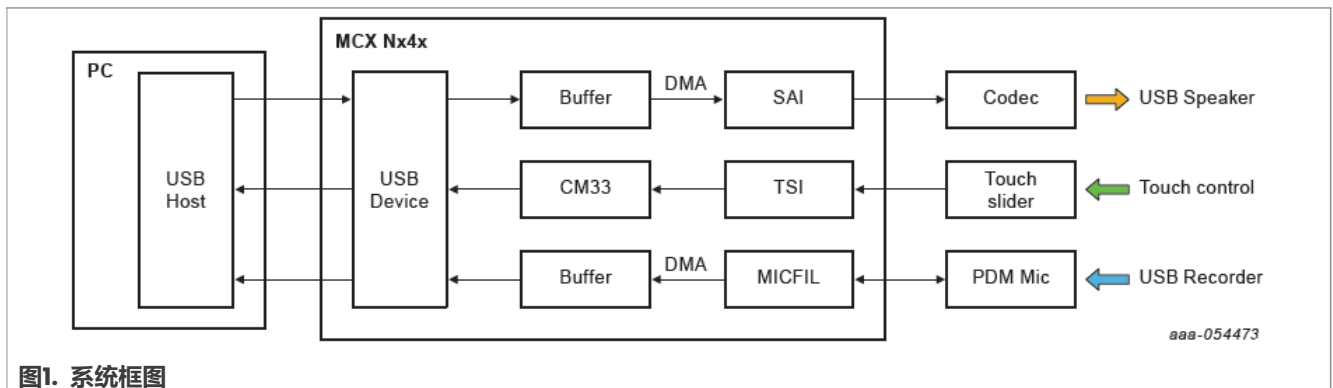


图1. 系统框图

本文的代码基于MCX-N5XX-EVK SDK 2.13的usb_device_composite_hid_audio_unified示例进行开发，IDE为IAR 9.40.1。要下载MCX-N5XX-EVK SDK 2.13，请参见[Build SDK for MCX-N5XX-EVK](#)，并确保在MCUXpresso SDK Builder中勾选了USB。

此SDK示例实现了USB扬声器和录音功能。基于此实施方案，本文将介绍如何启用MICFIL模块以及触摸控制。

2.1 MICFIL的介绍及使用

USB录音功能的框图如图1所示：

1. MICFIL模块为PDM麦克风提供时钟，并将麦克风生成的PDM数据转换为PCM数据。
2. 然后，DMA将PCM数据传输到环形缓冲区。
3. 最后，MCU通过高速USB接口将PCM数据发送到USB主机。

MICFIL模块以一个可配置的输出采样率，将脉冲密度调制（PDM）麦克风的比特流转换为音频波段的24位PCM信号。图2所示为MICFIL的框图：

1. 内部的时间发生器用于为PDM麦克风生成可编程时钟。PDM数据经过抽取滤波器后转换为PCM数据。
2. 然后，将PCM数据载入到FIFO中。
3. 最后，可通过中断或DMA读取FIFO中的PCM数据。

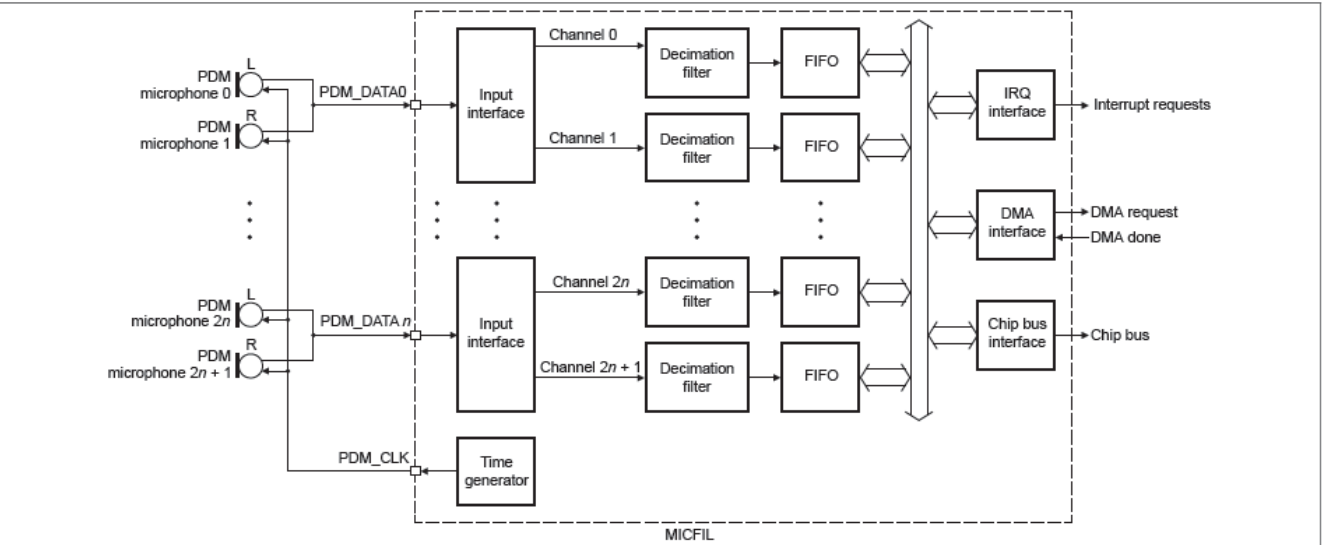


图2. MICFIL的框图

图3所示为启用时钟分频器时输入接口信号的时序图。在PDM_CLK的上升沿（对应于右侧麦克风），从麦克风数据输入“n”(PDM_DATA n)的比特流被分配到通道“2n+1”。而在下降沿（对应于左侧麦克风）产生的数据被分配到通道“2n”。

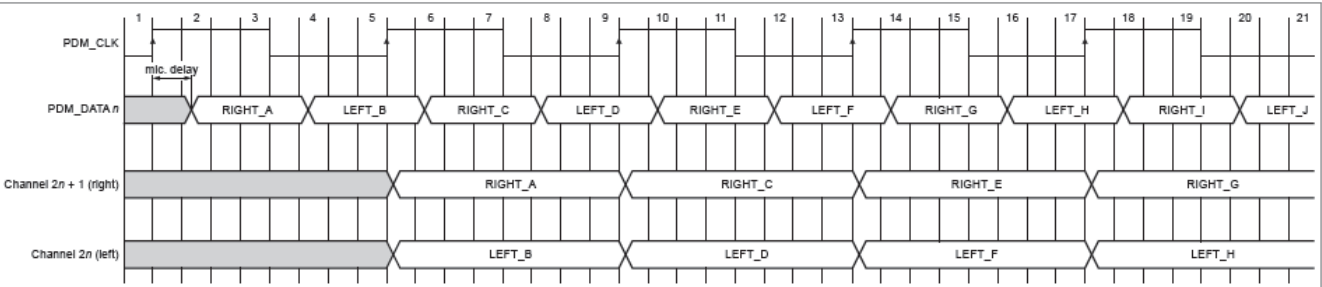


图3. 输入接口信号

图4所示为抽取滤波器的框图：

- 级联积分梳状（CIC）滤波器以给定的采样率将来自数字麦克风的PDM数据转换为PCM数据。
- 每个通道都配备了两个半带滤波器，实现了低通数字滤波器的2倍抽取率，可用于补偿通带中的高CIC衰减。
- 直流消除器是一个高通滤波器，用于消除已处理信号中的直流分量，其截止频率可配置。

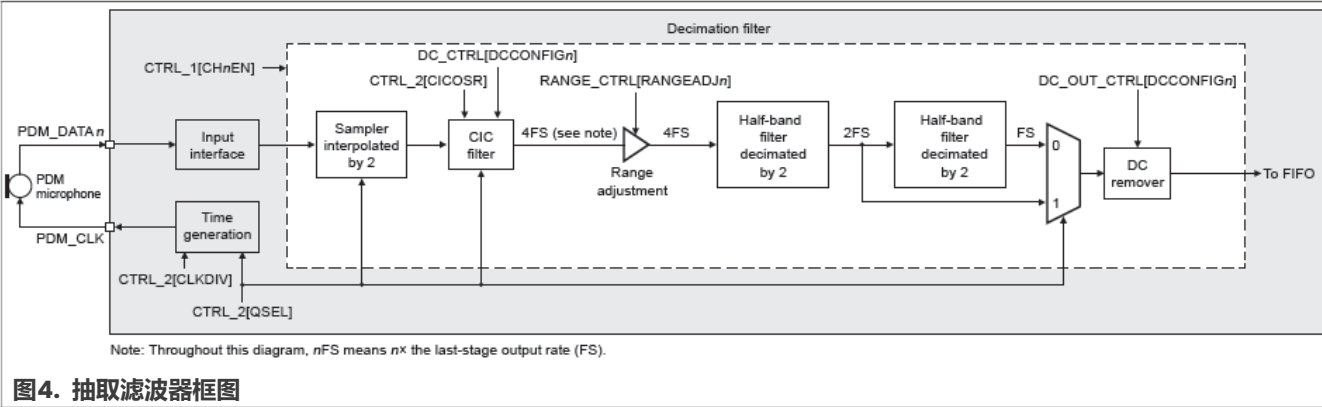


图4. 抽取滤波器框图

OSR是过采样率的缩写。公式(1)和公式(2)所示为由CTRL_2[CICOSR]和所选的质量模式定义CIC抽取率：

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

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

表1所示为质量模式与抽取滤波器中系数之间的关系。

表1. 质量模式

质量模式	CTRL_2[QSEL]	采样器插值	CIC滤波器抽取因子	前半带滤波器抽取因子	后半带滤波器抽取因子	PDM_CLK速率	通带
高质量	001	-	: (2OSR)	: 2	: 2	输出速率 x 8 x OSR	至约0.5倍输出速率
中等质量	000	-	: OSR	: 2	: 2	输出速率 x 4 x OSR	至约0.5倍输出速率
低质量	111	x 2	: OSR	: 2	: 2	输出速率 x 2 x OSR	至约0.5倍输出速率
极低质量0	110	-	: (2OSR)	: 2	-	输出速率 x 4 x OSR	至约0.25倍输出速率
极低质量1	101	-	: OSR	: 2	-	输出速率 x 2 x OSR	至约0.25倍输出速率
极低质量2	100	x 2	: OSR	: 2	-	输出速率 x OSR	至约0.25倍输出速率

如公式(3)所示，总体的滤波器增益取决于质量模式、CIC抽取率和CIC滤波器的动态范围调整。

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

表2显示了不同质量模式下的动态范围调整。

表2. 通道范围调整

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

表2. 通道范围调整 (续)

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

公式(4)和公式(5)所示为如何计算CLKDIV值和PDM_CLK值:

$$CLKDIV = \frac{MICFIL_CLK_ROOT \text{ rate}}{8 \times OSR \times (\text{output rate})}$$

(4)

$$PDM_CLK \text{ rate} = \frac{MICFIL_CLK_ROOT}{2 \times \text{floor}(K \times CLKDIV)}$$

(5)

注: 输出率代表采样率。

有关K因子的值, 请参见表3。

表3. K因子值

质量模式	K因子
高质量	1/2
中等质量、极低质量0	1
低质量、极低质量1	2
极低质量2	4

以下是MICFIL的主要配置代码, 供参考。更多相关代码, 请参考SDK中的pdm_sai_edma示例。

```
/* 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_OUTPUTCUTOFFREQ;
/* 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);
```

此外, 用户还需将工程中录音器接口的USB描述符从16位改为32位。具体实现方法可参考本应用笔记附件中的代码。为了降低延迟, 使用DMA传输MICFIL FIFO中的PCM数据。以下是DMA的主要配置代码, 供参考。更多相关代码, 请参阅SDK中的pdm_sai_edma示例。

```
#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);
```

表4所示为TCD的具体配置，以双通道MICFIL为例。

表4. TCD配置

寄存器	字段	描述	值
TCDn_SADDR	SADDR	源地址	DATACH[channel]
TCDn_SOFF	SOFF	源地址偏移	FIFO_Width
TCDn_DADDR	DADDR	目的地址	Buffer
TCDn_DOFF	DOFF	目的地址偏移	FIFO_Width
TCDn_ATTR	SSIZE	源数据传输大小	FIFO_Width
	DSIZE	目的数据传输大小	FIFO_Width
TCDn_NBYTES	NBYTES	通道的每次服务请求的传输字节数	channelNums* FIFO_Width
TCDn_BITER	BITER	开始主迭代计数	Data_Size/NBYTES

2.2 触控功能的介绍和使用

触摸感应输入（TSI）模块提供对电容式触摸传感器的触摸感应检测。TSI模块支持自电容模式和互电容模式。TSI完全支持基于SDK的恩智浦触摸库，为触摸键盘、旋转环和滑条的实现提供了可靠的电容测量模块。TSI模块提供了25个输入通道。

本应用笔记介绍了如何使用MCX-N5XX-EVK上的触摸滑条来实现USB音频的控制。

2.2.1 USB主机控制编解码器音量

基于SDK代码，以下将介绍如何实现用USB主机控制编解码器音量。

1. 首先，将音量控制范围设置为编解码器对应的范围：

```
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. 然后，添加以下代码来更改设备编解码器的音量：

```
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 用触摸控制USB主机的音频

要获取SDK触摸演示，请在MCUXpresso SDK构建器中勾选恩智浦触摸传感软件库。然后，参考demo_apps文件夹中的touch_sensing演示代码。

注：MCX-N5XX-EVK SDK 2.13不支持勾选恩智浦触摸传感软件库，SDK 2.14将支持此库。您也可以在MCX-N9XX-EVK SDK 2.13中勾选恩智浦触摸传感软件库，并参考相应的演示代码。

touch_sensing演示代码中的aslider_callback函数会返回一个模拟滑条事件和位置。通过比较释放事件和初始触摸事件的位置，来确定左/右滑动距离或信号触摸事件。

更新USB设备隐藏键盘报告描述符，可实现USB主机音频控制：

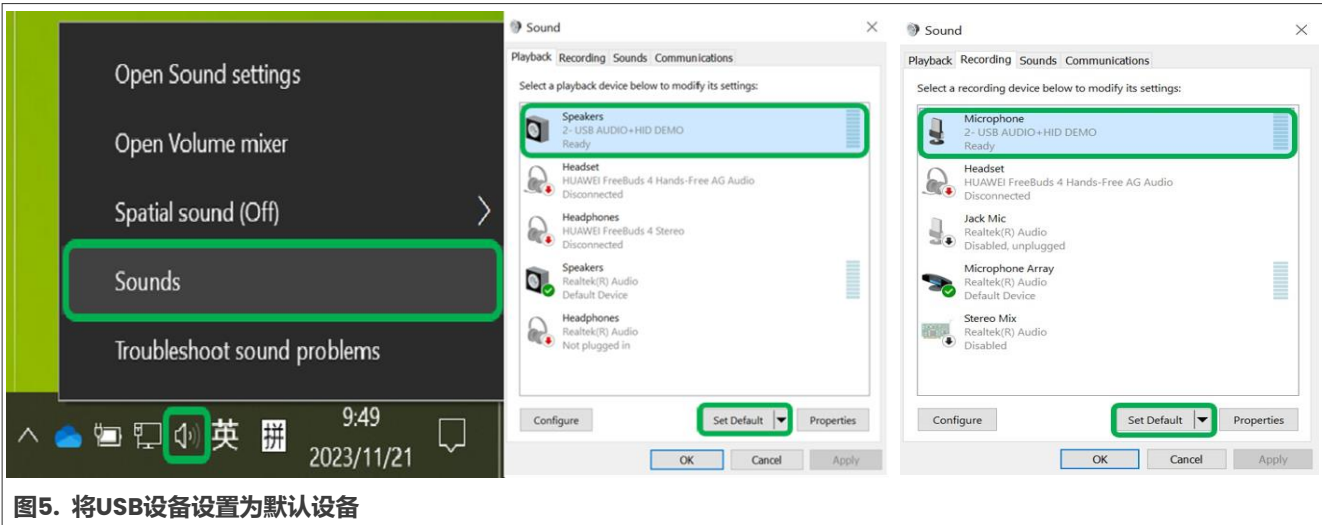
```
uint8_t g_UsbDeviceHidKeyboardReportDescriptor[] = {  
    0x05, 0x0c, /* USAGE_PAGE (Consumer Devices) */  
    0x09, 0x01, /* USAGE (Consumer Control) */  
    0xa1, 0x01, /* COLLECTION (Application) */  
    0x15, 0x00, /* LOGICAL_MINIMUM (0) */  
    0x25, 0x01, /* LOGICAL_MAXIMUM (1) */  
    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 */  
};
```

在hid_keyboard.c中，USB_DeviceHidKeyboardAction和USB_DeviceHidKeyboardCallback函数会根据滑动方向和距离发送相应的设备请求。

3 测试

要测试SDK演示代码的基本USB音频播放功能，请执行以下步骤：

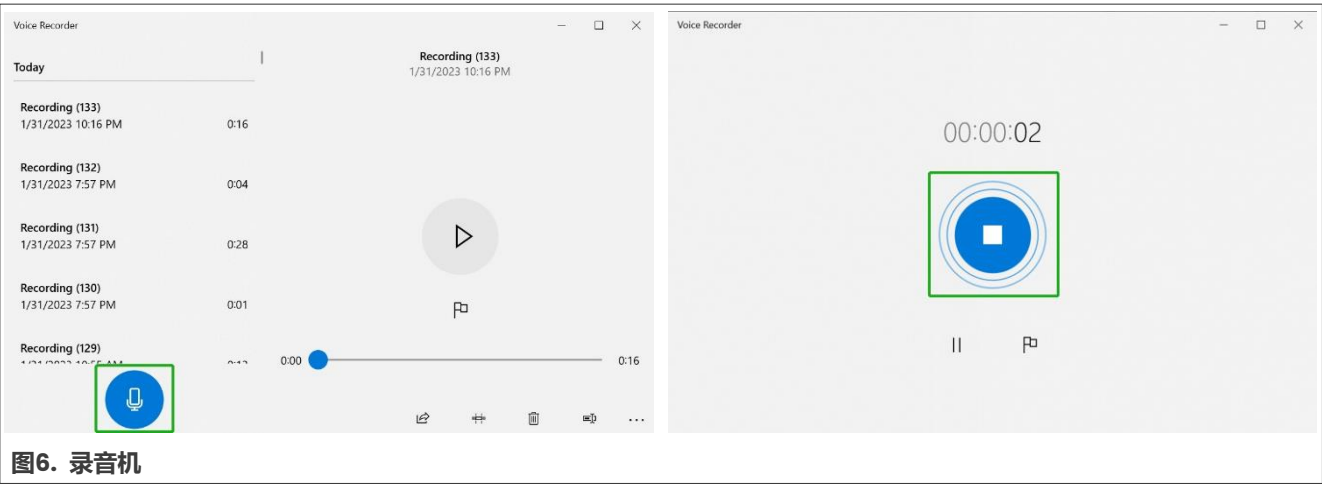
1. 通过USB电缆将MCU Link (J5)和HS USB (J27)连接到计算机。
2. 编译演示程序并将其下载到MCX-N5XX-EVK板后，复位MCU。
3. 将3.5 mm耳机插入EVK的J7。
4. 将USB设备设置为默认播放设备和默认录音设备，如图5所示。
5. 右键单击扬声器图标，然后单击**Sounds**。
6. 选择**Playback**或**Recording**，然后选择“USB AUDIO+HID DEMO”并单击**Set Default**。
7. 现在，USB设备端（EVK）的耳机将听到USB主机端（PC）播放的声音。



3.1 测试USB设备录音功能

要测试USB设备录音功能，请执行以下步骤：

- 1. 将JP7、JP8、JP10和JP11的跳线从默认值更改为2-3。
- 2. 点击Windows的Start按钮，搜索“Voice Recorder”，如图6所示。
- 3. 靠近MCX-N5XX-EVK上的U30和U32，播放音乐。
- 4. 播放录音，通过USB设备端（EVK）的耳机会听到DMIC（EVK上的U30和U32）采集到的声音。



如果只有一个DMIC（EVK上为U30或U32）采集声音，请关闭音频增强功能，如图7所示。复位MCU后，用户可以听到左右声道采集的声音。

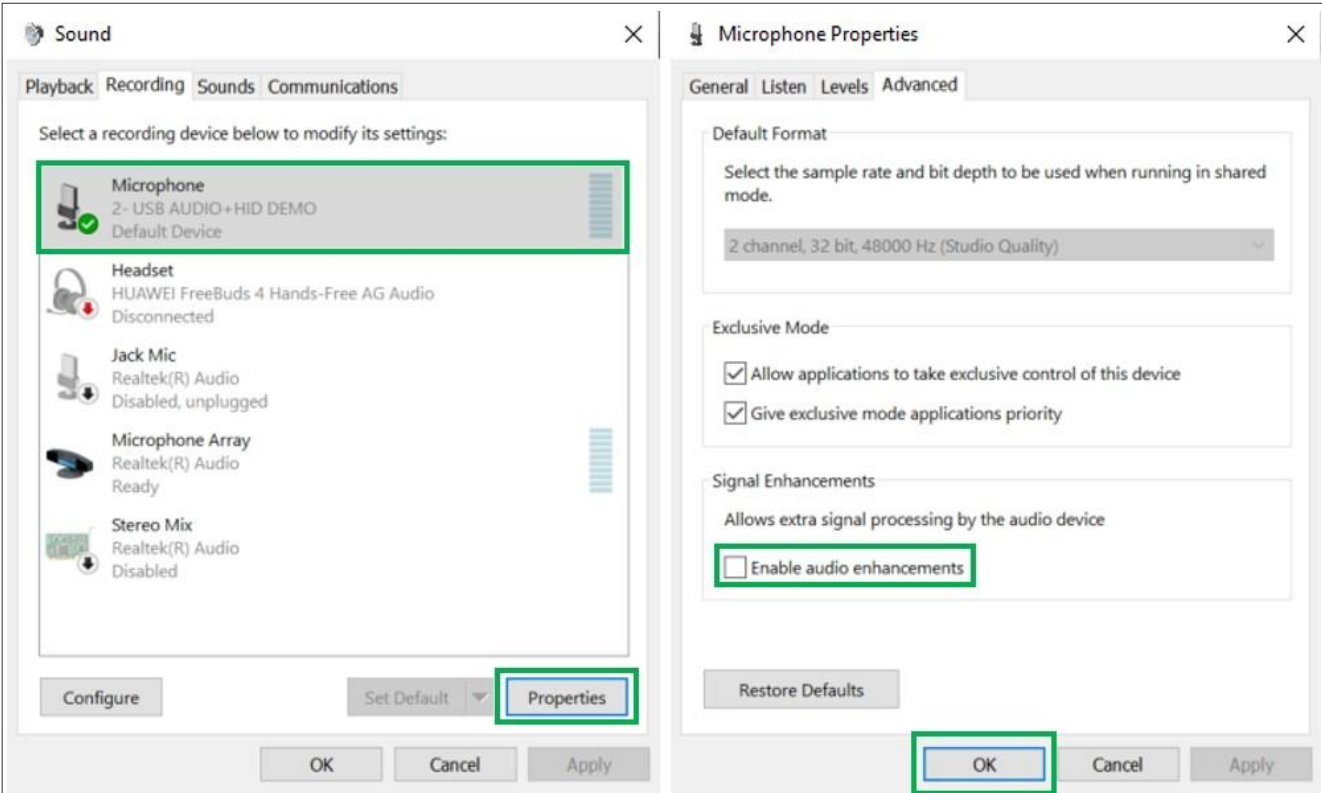


图7. 禁用音频增强功能

3.2 测试USB主机更改音量功能

要测试USB主机更改音量功能，请执行以下步骤：

- 1. 更改USB主机端（PC）的音量。终端打印音量调节信息，如图8所示。
- 2. 同时，通过耳机端（EVK上的耳机）可听到音量的变化。



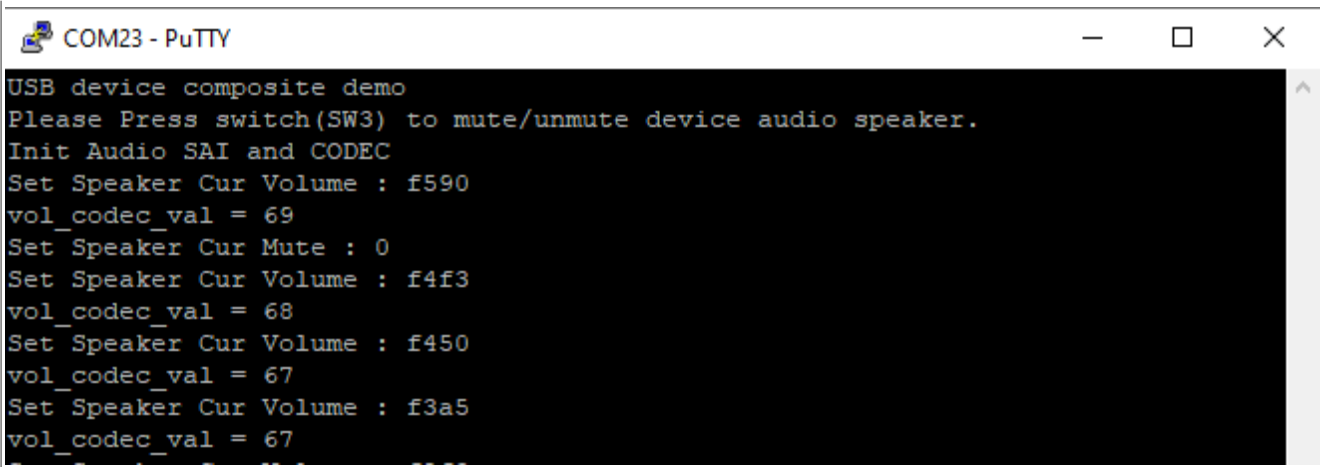


图8. USB主机更改音量功能

3.3 测试USB主机音频触控功能

要测试USB主机音频触控功能，请执行以下步骤，结果如图9所示：

1. 要调节音量，请左右滑动EVK上的触摸滑块（E1）。
2. 要播放/暂停音乐，请单击EVK上的触摸滑块（E1）。

注：当滑动或点击时，手指与滑块的接触面积要尽可能大，且滑动速度不要太快。

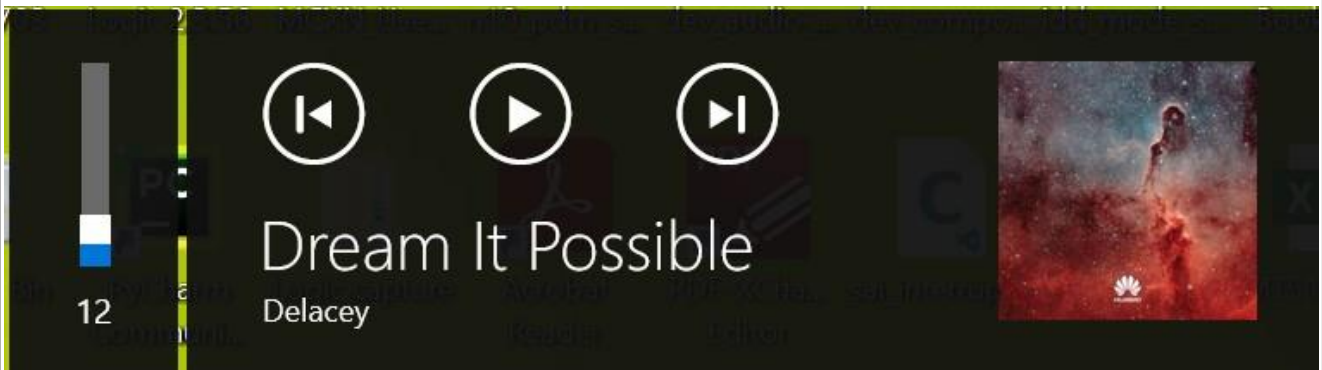


图9. USB主机音频触控功能

4 总结

本应用笔记基于SDK示例，介绍了如何启用MICFIL模块以及使用TSI模块来控制音量。为游戏耳机提供了技术参考，并给用户带来了更多的操作多样性和便利性。

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6 修订历史

[表5](#)总结了本文的修订情况。

表5. 修订历史

文档ID	发布日期	说明
AN14177 v.1.0	2024年1月20日	初版发布

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