ECE 445: Senior Design Laboratory

M.E.L.O.D.I.C Project Proposal

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1 Introduction

1.1 Problem

A common problem associated with live performing is the rats' nest of audio and control cables required to run front-of-house (FOH) equipment, digital effects, and instruments. However, In recent times UHF, VHF, and ISM systems have taken mainstay in the industry. For a large performance, having a $10,000+ rack dedicated to wireless audio systems makes sense. For the performing musician on a budget, such as a small house band or coffee shop artist, professional UHF, VHF, and ISM systems are not feasible to operate. Although low-cost or used legacy systems are popular amongst amateur musicians, they often suffer from problems such as data packet collisions from co-existing network protocols, interference from existing UHF and VHF television bands, and/or lack of scalability or configurability.

1.2 Solution

In order to combat this, we are developing M.E.L.O.D.I.C. A low-cost, scalable, configurable, and high-fidelity wireless audio link that will be compatible with any system or instrument. We intend to use a COTS RF SOC (TI CC8530) commonly found in wireless headphones and karaoke systems. This chip is an attractive choice due to its operation in the ISM band, use of adaptive frequency hopping techniques for co-existence with other ISM devices, and configurable to either be an audio transmitter or receiver. Due to the configurability and low cost of the chip, our transmitter and receiver will have very similar circuit schematics, which will make it cheaper to manufacture multiple sets of transmitter and recievers.

1.3 High-level Requirements

- Able to transmit lossless CD quality audio between an audio source and sink.
- Co-existence with other 2.4 Ghz protocols.
- Co-existence with two instrument links.

- Human-friendly enclosure with LCD displaying battery status, network statistics, and unique device ID with paired device ID.

2 Design

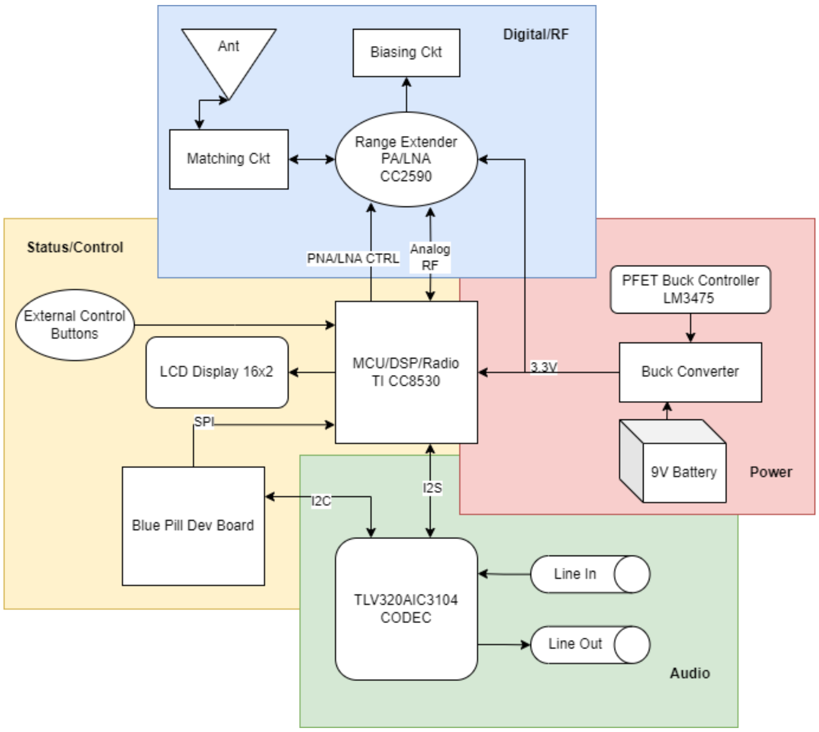

Figure 1: Block Diagram

2.1 Subsystem Overview

2.1.1 Power

The main power supply for our device will be a 9V battery. This will then be brought down to the 3.3V that the CC8530 RF SoC needs, using a variable duty ratio buck converter. The buck will operate using TI's 10-V hysteretic PFET buck controller, LM3475. This will allow the system to operate for an extended time with a constant output as the 9V slowly loses charge. In order to minimize noise created by the converter an ample sized output capacitor must be selected as well as a slightly lower operating frequency. In addition to this a PGate resistor as well simple RC filter across the output diode will help keep noise levels minimal.

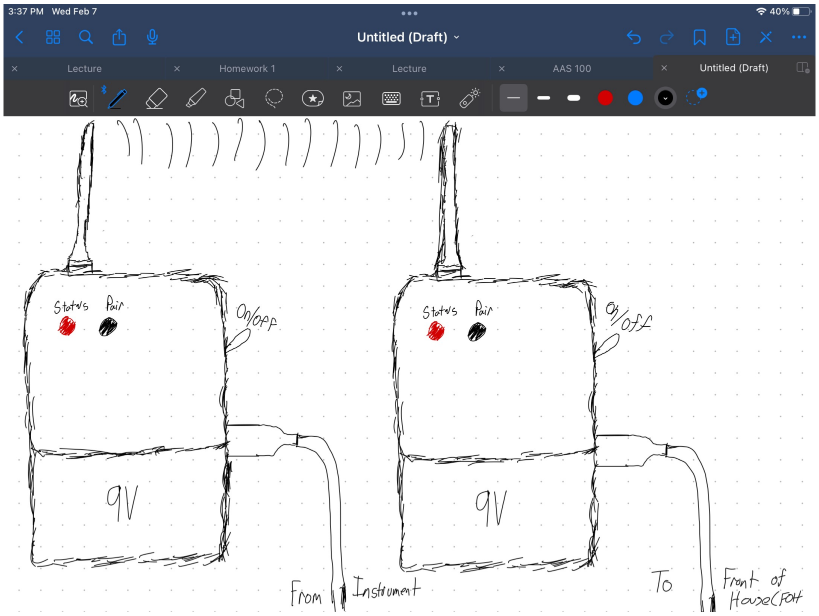

Figure 2: Sketch of M.E.L.O.D.I.C. Device (Initial Concept)

2.1.2 Audio

In order to be compatible with a wide range of instruments and devices, the M.E.L.O.D.I.C will take in both line and instrument level inputs. Line level is typically between 4 & -10dB, while the instrument level is around -30dB. Because of this, we will implement a pre-amp as well as bypass switch before the signal reaches the CODEC.

We are considering two different formats of audio streaming for the M.E.L.O.D.I.C device, both supported by the CC8530. PCM16 offers uncompressed, lossless CD-quality 16-bit data. PCME24 offers compounded 24-bit data and a 15-bit signal-to-noise ratio. Both formats implement error concealment mechanisms in marginal RF conditions so that no break in audio is heard. In theory, PCME24 allows for more dynamic range as opposed to PCM16, but the PCM16 offers a better signal-to-noise ratio. We will decide on which format to use based on testing.

We will be using Texas Instruments' TLV320AIC3204 Ultra Low Power Stereo Audio Codec to convert our analog audio into digital audio. This is done through the use of the codec's built-in DAC. The stereo audio DAC provided by the codec supports data rates ranging from 9khz to 198khz. As one our requirements, we wanted to be able to transmit CD quality audio (44.1khz/16-

bit). As explained in the previous paragraph, the CC8530 supports 16-bit audio transmission and up to 198khz data rates. We are confident that we will be able to meet our requirement with these specifications.

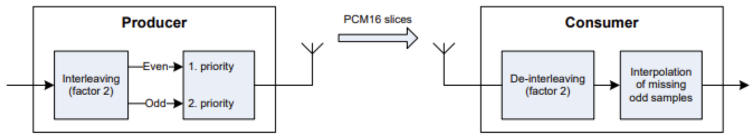

Figure 3: PCM16 Processing Diagram

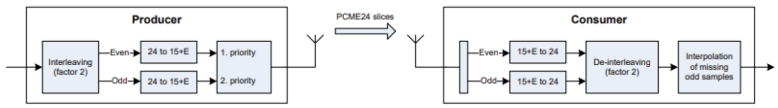

Figure 4: PCME24 Processing Diagram

2.1.3 Digital/RF

The Digital/RF subsystem is composed of CC8530 RF SoC, CC2590 BLE range extender, RF matching/balancing circuitry, and RF amplifier biasing circuitry. The CC8530 would provide the needed components to act as both a host for the audio subsystem and the digital radio. The included Cortex ARM-M3 processor core will handle general management functions and act as a host to the radio co-processor, audio co-processor, and audio codec.

The CC8530 can perform in autonomous mode, which will decrease the amount of needed components by acting as both the micro-controller and radio peripheral. The included GPIO pins on the SOC are directly connected to the Cortex ARM-M3 processor, so we would be able to control the device by including status LEDs and buttons. The SoC also features pin-outs for an I2S and I2C connection, which are needed to control and receive audio data from the codec.

The SOC features a digital radio that will perform normal digital communications functions and output an analog wireless signal to the CC2590 BLE range extender. It will also act as a host for the BLE range extender and determine whether a power amplifier or a low noise amplifier will be needed to perform the transceiver's assigned function. Care will be taken to ensure that we have a simultaneous conjugate match between the high-frequency circuit components of the system. Some of the considerations would be the transmission line type, width and thickness of the strip, and length of the strip.

From the CC2590, there would possibly be circuitry for balancing and matching the output to the antenna, the inclusion of this would be determined by 1-port S-Parameter readings of the device while it is active. If both the antenna and CC2590 are conjugate matched, then we would not need to include this circuitry. However, if they are not, a T-network or Pi-network would be needed to have a conjugate match over the required bandwidth.

2.2 Subsystem Requirements

Power

- The buck converter must provide stable 3.3V from the 9V battery.
- The output of the buck must have minimal noise and ground noise as to not interfere with device operations.
- The battery must be easily accessible to be able to be replaced when needed.
- The battery must be able to last a minimum of 12hrs with adequate charge.

Audio

- Convert line in analog audio into digital audio that can be transmitted by the RF subsystem.
- Convert digital audio provided by the RF subsystem into an analog CD-quality audio stream.

Digital RF

- Successfully utilize AFH to minimize frequency dependent interference from coexisting wireless protocols and data packet collisions between multiple devices.
- Coherent human-device interface, ease of use utilizing only LED's, buttons, and encoders for simplistic operation.
- The RF SOC acts as the audio CODEC master, and handles all aspects of digital audio transmission without extra IC's.
- Ability to perform with 2 instrument links at the same time.

3 Tolerance Analysis

3.1 RF Subsystem

In order for M.E.L.O.D.I.C to solve the issue of frequency dependent interference with FSK, we must use AFH to spread the spectrum to decrease the probability of frequency dependent interference. The AFH technique still uses FSK as the main form of modulation, however, it varies the carrier frequency as function of time as opposed to fixing the carrier frequency to a single channel. Our chosen metric for proving that AFH has successfully decreased frequency dependent interference compared to using FSK is decreasing the probability of interference by a factor of two.

3.1.1 Justification for AFH

Typical systems in the UHF and VHF range utilize M-Ary frequency shift keying or M-FSK to modulate the digital signal in the base-band. Our motivation to use AFH, a subset of FHSS, is the high probability of frequency dependent interference from other devices in the ISM band. Our choice of using the ISM band for this device is solely based on working around FCC licensing for the device, as the ISM band is 'open waters' in the FCC band plan [**?**].

In order to formulate the devices band-plan, we must find the minimum amount of channels needed for each stream to hop around the band plan. The Pure-Path Wireless protocol specifies 18 channels over a 4 MHz bandwidth, with each time slot taking up 222.2 KHz of bandwidth. [**?**].

Within each time-slot, 198 KHz of bandwidth is used for the FSK modulation, with the remaining side-bands around the frequency used as guard frequencies. However, we must specify how many channels we would like available for all time-slots to take up.

3.1.2 Mathematical background of FHSS/AFH and FSK

For our calculation of the minimum amount of channels needed for the band plan, we will consider two different time domain signals using FSK as the form of modulation.

$$x_1(t) = A * Re\{e^{j2\pi f_c t} e^{j2\pi \Delta f_m \int_0^t m(\tau)\, d\tau}\} \tag{1}$$

and

$$x_2(t) = A * Re\{e^{j2\pi f_{hop} t} e^{j2\pi \Delta f_m \int_0^t m(\tau)\, d\tau}\} \tag{2}$$

Where A is the maximum amplitude of the carrier signal, f_m is the max frequency deviation of the frequency modulated message, $m(t)$ is an arbitrary continous message and f_{hop} and f_c is the carrier frequency for the FSK and FHSS signals respectively.

For f_{hop} in equation 4, the relationship between carrier frequency f_c and f_{hop} is

$$f_{hop+1} = (f_{hop} + hop) mod(x) \tag{3}$$

Where hop is some psuedo-random sequence and x is the number of total channels we could choose.

Using this intuition, we can formulate a frequency domain simulation of each of these signals and calculate the probability of frequency dependent interference.

3.1.3 Simulation of AFH/FHSS and FSK co-existing with WLAN

Since the AFH algorithm uses extra processing outside of traditional FHSS systems to dynamically change the bands, we will not be modeling true AFH. Instead, we will use FHSS as a place holder to prove that it is better than using just FSK and calculate the minimum amount of channel bands needed to reach our performance metrics.

Using the equations in section 3.1.2, we can quantatively justify that FHSS is better than FSK and empiracally calculate the minimum amount of channels needed to avoid frequency dependent interference by creating a simple MATLAB simulation of the spectra.

For the simulation, we chose f_c and the initial f_{hop} to be centered around the same center frequency of some random WLAN spectra. We set $A = 1$ and $\Delta f_m = 222.222$ KHz for both $x_1(t)$ and $x_2(t)$. In order to calculate the frequency dependent probability given different values of SNR, we treat the WLAN spectra as both artificial noise and another co-existing protocol and increase it for every five sets of FHSS hop in the simulation. This simulation considers SNR to be the ratio between the transmit power of the WLAN spectra and the FSK or FHSS spectra. We set $m(t) = u(t)$ where $u(t)$ is the Heaviside step function. For five steps of f_{hop} within each step of WLAN transmit amplitude, we calculate the frequency dependent interference by taking the P$(|x_2(t)| < |WLAN|)$ and plotting the average of each probability over the different values of WLAN transmit amplitude. Similarly, for five different instances of FHSS, we calculate the P$(|x_1(t)| < |WLAN|)$ and plot those values over WLAN transmit amplitude.

In order to figure out how many channels out of the 18 possible channels we should use, we start with one channel and keep adding more channels until we are confident that the probability of interference with FHSS is half that of probability of interference with FSK.

Figure 5 shows the results from the simulation given the amount of channels is six. This result was the first result where the probability of interference with FHSS is half that of FSK for 20 dB of relative WLAN transmit power. This validates that our simulation is correct, since the device needs a minimum of 6 channel bands to operate properly. [?] Therefore, in order to reach our tolerance of decreasing the probability of interference by a factor of two, we must have at least six channel bands used out of the 18 we could possibly use.

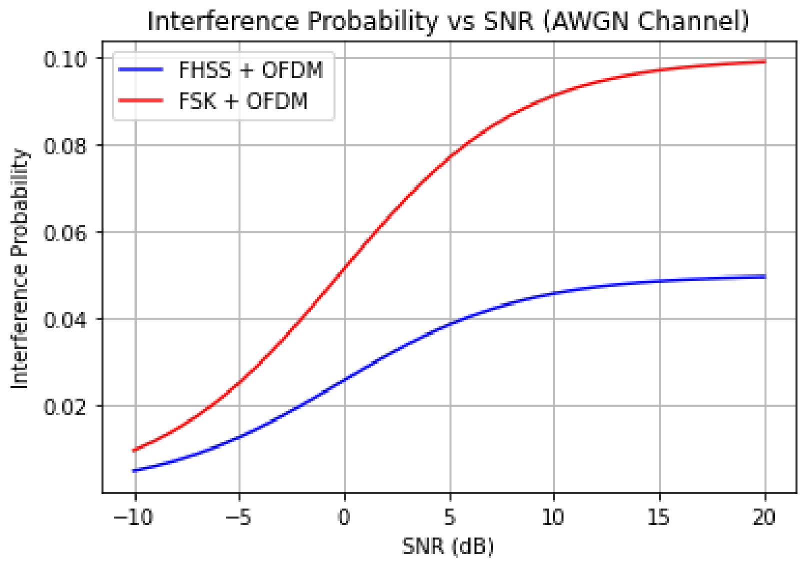

Figure 5: Probability of Frequency Dependent Interference versus SNR

4 Ethics and Safety Considerations

4.1 FCC Regulations

One concern with designing a digital wireless communication system was aligning with FCC regulations and the FCC band plan. If we were to design our system around the same frequencies as existing systems, we would need to license our device to work in that band. Specifically, UHF and VHF equipment used in the live audio industry either have privately licensed bands with the FCC or are licensed around the same bands as terrestrial television [**?**]. Since we are using an RF SOC specifically made for wireless digital audio streaming, we do not have to worry about licensing the device with the FCC since the device has already been tested and approved to be used in the ISM band.

4.2 Environmental Concerns

One concern with using a 9V battery is the potential environmental damage that it might cause when it is thrown away. We plan on using Alkaline 9V batteries which are a safer alternative to lithium ion batteries, which are known to have a greater negative impact on the environment when thrown away.

4.3 Safety Concerns

We will ensure that the device itself is safe to use before we demo the project through thorough analysis of the device's power consumption. Mainly, all components (resistors, capacitors, SOCs, etc.) should be within their allowed power consumption tolerance. Most of the devices we are using do not draw a substantial amount of current except for the STM32, which varies based on the programs it is running. We will do thorough electrical analysis to determine how much current the device is drawing when we run the programs.