Technical Reference Material

Updated

May 16th 2024

Details in this document supersede other details provided in Call for Proposals and Request For Proposal, and previous updates of this document. As new information is added to this document, it will be highlighted in green.

The 2024 International Future Energy Challenge (IFEC 2024)

A student competition sponsored by the

The Institute of Electrical and Electronics Engineers (IEEE)

Competition Topic: Switch-mode Audio Power Amplifier

Updated August 2023

Vision Statement and Intent of the Competition:

> *It is important for students to understand the intent of the committee and what they are looking for from competing teams. We state here that the committee is particularly interested in seeing innovations in the amplifier power stage electronics, its modulation, and particular attention will be given to metrics that quantify high-quality audio performance. Any team that creates a design with an off-the-shelf power stage and/or other components that bypass the key engineering effort to create a high performance power stage and its closed-loop modulator will receive lower scores. It is particularly important to note that the committee decided to provide an external 48 V supply so that students can focus on the power stage, modulation, and output filtering. Moreover, designs that use excessively bulky filtering components to achieve high quality waveforms can expect to receive lower scores with regards to metrics that quantify weight and volume. An ideal design would have an innovative power stage, high-bandwidth closed-loop performance, a modest-sized output filter, and sound exceptional to an audio professional.*

This remainder of this document is intended to provide an overview of the technical requirements for the design, realization and testing of the prototype switch-mode audio power amplifier. The document is a guide to provide a frame of reference for the competing teams to stay within a set of common guidelines and use their creative skills to meet the challenge.

It is a live and working document that may be updated as new questions arise and we develop additional guidelines. All updates will be posted on the website for the competition. When a particular question is not addressed in the guideline, you are free to make suitable assumptions. You are of course welcome to pose your question to the technical team who can provide clarifications.

1. Each team will have to submit a design proposal outlined under item 17 in this document.
    a. First round finalists are required to submit a progress report and make a

presentation at the IFEC 2024 workshop to be held at APEC 2024 in Long Beach, CA on Sunday the 25th of February 2024. After this presentation second round finalists will be announced.

b. Selected second round finalist teams will have to present their hardware prototype for the final challenge competition to be held in Austin, TX.

c. The team will have to bring only their amplifier hardware prototype for performance testing to the competition. Test conditions for the competition are outlined in this document, and will be continuously updated.

2. Continuous output maximum power rating: 135 W per output channel. The output will have 3 channels for left, right, and subwoofer signals. This implies a total power rating of approximately 400 W. Note that actual tests may be conducted at lower power levels as described in the remainder of this document. The continuous power rating is the maximum power level that your converter should be expected to work at. It should also be emphasized that this power rating pertains to the converter output.
3. Left/right stereo speakers model: DALI - Oberon 3 Bookshelf Speakers.
   - Available at: Dali - Oberon 3 Bookshelf Speakers (Pair) - Music Direct
4. Subwoofer model: Dayton MKSX4 Passive Subwoofer
   - Available at: Dayton - MKSX4 Four 4" Driver Low Profile Passive Subwoofer
5. Nominal input and output ratings: Notice that these are *nominal* ratings. Motor operating conditions may exceed these ratings during transient and dynamic conditions. Extended continuous and sustained operation outside these ratings will lead to increased temperature rise and should be avoided. We will not be testing against these ratings. Test conditions for the hardware are specified further in this document.

   a. Input voltage: A fixed 48 V dc voltage will be provided by a power supply. For the final competition in Austin, each team will be provided the dc supply specified below and must use this supply during the competition. Teams are encouraged to use the same power supply during their hardware development.

      i. Dc power supply model: Keysight E36155A

   b. Input audio format: WAV format digital audio files will be standardized across the

team. Files and/or download links will be posted on the IFEC website. The data will be formatted in 24-bit and will have a sample rate between 44.1 kHz and 96 kHz. Under item 10 below, we describe the three audio formats teams will need to able to receive these signals at their amplifier input.

c. Load characteristics: For listening tests, the teams may refer to the speaker and subwoofer models described above. To facilitate high sound quality, teams are expected to understand and implement crossover filters that shape the sound which goes to the main left/right speakers and the subwoofer. In particular low frequencies should go to the subwoofer and frequencies above that will go to the main left/right speakers. Teams may design the crossover filter however they see fit and they may need to consider the nonlinear properties of their speakers to get a desired response. Electrical characterization tests will be conducted using wirewound 6 Ohm ceramic resistive loads.

d. Output frequency range: Output audio tests will be conducted across the 20 Hz - 20 kHz range.

6. Power connector to dc supply
    a. Anderson power pole connector (contact: MFR# 261G3)
    b. Red (MFR# 1327), Black (MFR# 1327 G6), color terminals to be stacked in the same order
    c. Red corresponds to + terminal of power supply
    d. Black corresponds to – terminal of the supply
    e. Dc power cable (12 AWG) 30cm-35cm long
7. Audio output connectors to speakers and resistive loads
    a. The converter enclosure must have 3 pairs of panel-mounted jacks for the three speaker connections (see below for panel-mount plate model). Each set of speaker terminals will have one black and red Anderson connector. Speaker cable must be at least 20 feet to facilitate speaker placement, and the cables must be outfitted with load-side connections that are compatible with the speaker models described above.

i. Anderson Panel Mount Plate: Manufacturer # 1462G1

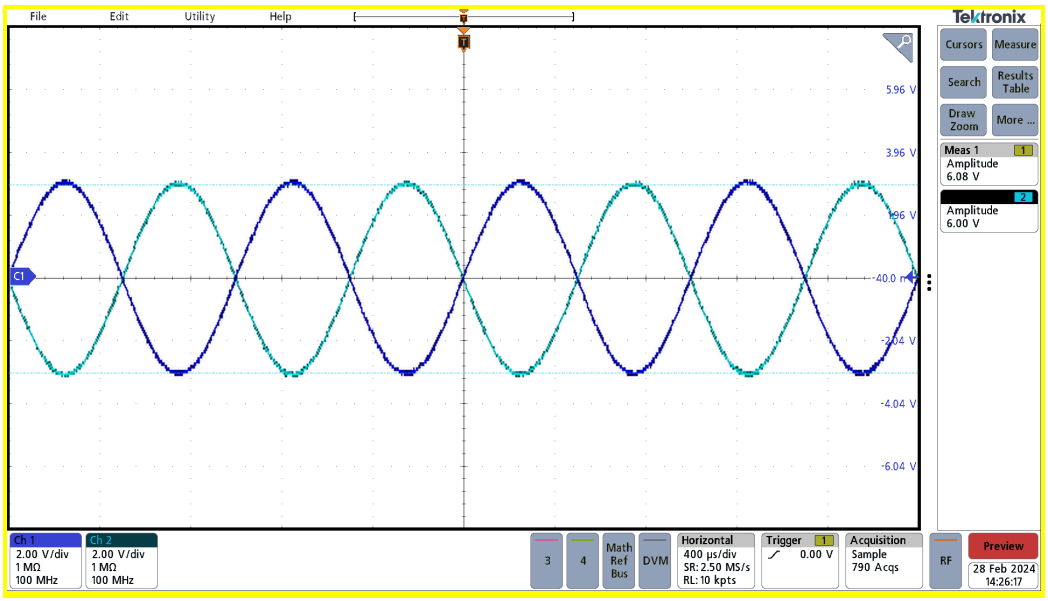
8. Mechanical and mounting details
    a. An electrically touch-safe enclosure with a grounded chassis is required.
    b. A grading scheme will be formulated that penalizes designs in proportion to their weight and volume above certain thresholds.
    c. Target box volume 1500 cm^3. This is a target. There are no specifications.
9. Operational and volume controls
    a. A power-indicator LED with a label is required.
    b. Rotary or linear control mechanisms must be used to control volume between 0% and 100% power. There must be one volume knob that controls the stereo Left and Right channels and a second volume knob that adjusts the Subwoofer channel output. Audio-grade logarithmic potentiometers must be used.
10. Audio input ports:
    a. In accordance with standardized for professional audio applications, the hardware unit must accept differential-balanced stereo analog signals via XLR plugs.
11. Over-voltage protection
    a. The teams should anticipate that the power supply may provide a voltage above the nominal 48 V value if not adjusted properly. If this occurs, the converter should protect itself for the full peak voltage of 60 V that the Keysight E36155A can provide.
12. Safety:
    a. No live electrical elements are to be exposed when the unit is fully configured. The system is intended for safe, routine use by non-technical customers.
13. Thermal consideration: Case should be touch-safe for prolonged operation (<48°C)
14. Cooling: Natural convection or fans are allowed. If fans are used, they must be quiet to avoid a scoring penalty.
15. **Final Competition:** The final competition hardware tests will be carried out at the University of Texas at Austin, USA. Tests can be categorized into *Electrical Tests* and

Subjective Listening Tests. Electrical Tests will be carried out using Audio Precision (AP) brand audio analyzer. During such tests, the audio analyzer will provide the balanced analog input signals to your converter which will deliver power to resistive loads. For all Electrical Tests, the AP audio analyzer and its software will generate audio signals. In contrast, the Subjective Listening Tests will be carried out in a studio where the audio amplifier will deliver power to actual speakers. For these tests, an iFi brand Zen DAC V2 will provide analog musical waveforms to the converter. These tests will be strictly focused on assessing performance with music audio files. Below is a description of these two test categories.

a. Electrical Tests Description:

i. **Overview:** Tests will be carried on an Audio Precision AP2722 with an AUX-0025 unit and a laptop configured with appropriate software. Five complete setups (each setup includes one AP2722, AUX-0025, and laptop with AP software) will be provided and available for the teams to use. Three resistors (6 Ohms for Left, 6 Ohms for Right, and 4 Ohms for Subwoofer outputs) will be connected to the outputs of your converter during these tests.

ii. **Definition of Decibel Scale**: All decibel scalings align with the signals provided by the iFi brand Zen DAC V2, and these will act as inputs to your converter. Specifically, all instances of 0 dB in the text below correspond to a balanced waveform with a 4.2 Vrms differential output. Below is a measurement of the L+ and L- pin voltages with respect to the ground pin on the Left channel XLR connector when the DAC is producing a full scale 4.2 Vrms output. In other words, this measurement corresponds to a 0 dB set of balanced waveforms on one of the input channels. The Audio Precision audio analyzer will be configured so that its amplitudes in decibels align with these waveform amplitudes.



Measured output of ifi Zen DAC V2 left channel balanced outputs with respect to ground.

iii. Left and Right Channel Tests:

1. Crosstalk amplitude sweep test: This test will be fixed at 1 kHz. First, the Left channel input will be provided with fixed amplitude input at -10 dB while the Right channel input will be given zero input from the AP unit (approximately -99 dB). The right channel output will be measured and should ideally show minimal output. The test will be repeated by swapping the excitation signal to the Right channel input and measuring the Left channel output.
2. THD+N versus frequency test: First, teams are encouraged to read this to gain a deeper understanding of what the THD+Noise (THD+N) metric is. Identical sinusoidal excitations will be given to both the Left and Right channel inputs. These input signals will be fixed at -10 dB while the frequency is swept from 20 Hz to 20 kHz. The THD+N will be measured across this frequency range.
3. THD+N versus amplitude test: Identical sinusoidal excitations will be given to both the Left and Right channel inputs. Input signal amplitudes will be swept from -10 dB to -60 dB. This test will be

conducted at 1 kHz, 3 kHz, and 6 kHz. THD+N will be measured during each of the tests at these three frequencies.

4. THD+N at low amplitude output: This test is designed to assess performance when low amplitude output waveforms are generated by your converter. The AP unit will generate a -10 dB signal and your converter volume knob will be adjusted until 1 W of power is delivered to the Left and Right outputs. THD+N will be measured from 20 Hz to 20 kHz and the judges will pay special attention to the measurements at 1 kHz, 3 kHz, and 6 kHz.
5. (Bonus points test) THD+N at high power stress test: This test is designed to assess performance when your converter delivers high power. The AP unit will generate a -3 dB signal and your converter volume knob will be adjusted to maximum volume so that high power is delivered to the Left and Right outputs. THD+N will be measured at 1 kHz, 3 kHz, and 6 kHz. This test introduces risk that may lead to converter failure with improper thermal management. Accordingly, this test is optional and teams that successfully complete it will be given bonus points.
6. Intermodulation distortion test: The AP unit will be configured to create a superposition of 1 kHz and 1.1 kHz sinusoids at the same time with -10 dB amplitude. The 100 Hz frequency component will be measured at the output. Ideally, the 100 Hz component should be highly attenuated. Read this page to learn more about intermodulation distortion.

iv. Subwoofer Test:

1. THD+N versus amplitude sweep test: The Left and Right channel inputs will be provided with an identical 40 Hz sinusoid that is swept across the amplitude range of -60 dB to -10 dB. THD+N will be measured across the amplitude range.
2. THD+N versus frequency sweep test: The Left and Right channel

inputs will be provided with an identical sinusoid fixed at -10 dB amplitude. The input signal will be swept across the frequency range of 20 Hz to 200 Hz. THD+N will be measured across the amplitude range.

3. THD+N at low amplitude output: This test is designed to assess subwoofer channel performance when a low amplitude output waveform is generated by your converter. The AP unit will generate a -10 dB signal and your converter volume knob will be adjusted until 1 W of power is delivered to the subwoofer output channel. THD+N will be measured at 40 Hz.

v. **Idle Channel Noise:** The AP unit will be configured to produce the minimal possible input signal (approximately -99 dB) to your converter inputs. The amplitude of the outputs will be measured using the A-weighted scale. This test will be carried out on the Left, Right, and Subwoofer channels.

vi. **Crossover Test:** A fixed amplitude identical sinusoid will be provided to both the Left and Right inputs and fixed at a -20 dB amplitude. The frequency will be swept from 20 Hz to 20 kHz. The outputs will be measured on the Left, Right, and Subwoofer channels. Results should verify that the crossover filters have been properly implemented so that frequencies above approximately 200 Hz and above are routed to the Left and Right channels. Frequencies below approximately 200 Hz should go to the Subwoofer channel.

vii. Efficiency Test:

1. Efficiency test up to 75% power: Efficiency will be measured with a 1 kHz input signal with fixed -3 dB amplitude. The volume knob will be adjusted until the output power levels are 25%, 50%, and 75% of the converter power rating. Power will be delivered into resistive loads (6 Ohms for Left, 6 Ohms for Right, and 4 Ohms for Subwoofer outputs) for each channel.

2. (Bonus points test) Efficiency test at 100% power: Efficiency will be measured with a 1 kHz input signal. The amplitude of the input and converter volume knobs will be adjusted until the output power levels are at 100% of the converter power rating (135 W per channel). Efficiency will be computed at this operating point. This test introduces risk that may lead to converter failure with improper thermal management. Accordingly, this test is optional and teams that successfully complete it will be given bonus points.

b. Subjective Listening Tests Description:

   i. More details will be provided here shortly.

~~c. The EMI generated by the audio amplifier will be measured and it must adhere to typical FCC requirements that limit emissions.~~

~~d. A sequence of tests will be prescribed using a Audio Precision analyzer unit as shown here: https://www.ap.com/audio-analyzers/~~

16. Design proposal (PDF file submission upload details will be posted online soon)

    a. Not more than 25 pages and 11-point Times New Roman Font, including all the figures, charts, references, charts, etc.

    b. Information page (On-line entry details TBD)

    c. Letter of support (On-line upload details TBD)

    d. Narrative document:

       i. Introduction

       ii. Overall block diagram

       iii. Circuit topology

       iv. Modulation method

       v. Controller

          1. Block diagram

          2. Hardware realization

       vi. Design/Analysis

1. Power circuit components (including gate drives)
2. Losses, efficiency and thermal analysis
3. Sensing, control, interface hardware

vii. Time-domain simulation results, including ideal switch model for the inverter, block-diagram level controller for the system, model showing steady state waveforms with the provided audio test signals.

1. Input current
2. Output voltage and current at load
3. Switch-level waveforms

viii. Cost: Bill of materials cost information for production of 1000 units, using the price information from online distributors.

17. Progress Report: Submission details will be updated soon. The progress report must include following contents:

a. Names and email address of all team members including faculty advisor, graduate student assistants, and undergraduate students

b. Technical Approach

c. Design Methodology and Procedure

d. Simulation Results

e. Preliminary Experimental Results

f. Future Work Plan

g. The progress report must conform to the following requirements:

i. The progress report must be written in English.

ii. The progress report must not exceed 25 pages in length including cover page, figures, tables and references.

iii. The page size must be 8.5" x 11" or A4 with margins not less than 25 mm on every side.

iv. Double space all text and use Times New Roman typeface, and a font size

of 12 point or larger.

18. Workshop presentation: Submission details will be updated soon.
    a. The workshop presentation only can be presented by undergraduate students.
    b. Each team will have 15 minutes for presentation and 5 minutes for Q&A. There is no slide limit for presentation. However, it is highly recommended to prepare a presentation with less than 20 slides.
    c. The workshop presentation must include following contents:
        i. Technical Approach
        ii. Design Methodology and Procedure
        iii. Preliminary Experimental Results
        iv. Future Work Plan