Comparing the Effects of Efficiency and Distortion in Audio Power Amplifiers with and without Tracking Power Supply Circuit Design

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Abstract. This research aims to compare the effects of efficiency and distortion in Audio Power Amplifiers with and without Tracking Power Supply (TPS) circuit design. The TPS circuit design is known for enhancing power efficiency while keeping low distortion in the amplifiers. This paper examined the performance of Class-A type Audio Power Amplifiers with and without a TPS circuit. The performances are evaluated for power efficiency and distortion levels using standard tools and procedures. The results show the amplifier with a TPS circuit design exhibits significantly higher power efficiency than one without a TPS. The TPS in the Audio Power Amplifier will increase the power efficiency from 34% to 51 % for the Class-A type. Moreover, the TPS implementation demonstrates the little effect on the total harmonic distortion (THD) of the 20 W amplifier to an 8 Ω load with THD 0.0027% at a 1 kHz audio operating frequency. These findings highlight the potential of TPS circuit design in improving efficiency with low distortion characteristics on the Audio Power Amplifiers.

Keywords: Tracking Power Supply, Audio Power Amplifier, Power Efficiency, Total Harmonic Distortion, Hysteresis Comparator.

1. Introduction

Audio Power Amplifiers are essential in sound systems in various applications such as home theaters, concert halls, and public address systems. The performance of an audio amplifier is indicated by its output power, efficiency, and the distortion level. In a conventional audio power amplifier, the maximum available output power is generally limited by at least two factors: the voltage swing available at the amplifier output, and the load impedance. The voltage swing is itself typically limited by the amplifier supply rail voltage. One technique for increasing output voltage is known as bridging and another technique is to employ a switching power supply to raise the power supply voltage to the amplifier [1].

A Tracking Power Supply (TPS) for an amplifier includes one or more cascaded sets of power boost circuits configured (voltage buffer, switching supply, comparator, etc) to temporarily boost positive and/or negative power supply rails [2]. In recent years, Tracking Power Supply circuit design has gained popularity in the audio amplifier

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industry due to its ability to increase power efficiency and keep low distortion. However, the effectiveness of TPS circuit design in enhancing audio amplifier performance is not well documented. This research aims to compare the effects of efficiency and distortion in Audio Power Amplifiers with and without TPS circuit design.

The research will involve designing and implementing a TPS circuit on an Audio Power Amplifier and comparing the performances with and without the TPS circuit. The study and implementations will use standard testing equipment to measure the amplifier's power efficiency, distortion level, and frequency response. The research findings will provide valuable insights into the effectiveness of TPS circuit design in enhancing audio amplifier performance. This study will help audio amplifier manufacturers and designers to make informed decisions on designing a TPS circuit to improve amplifier performance.

2. Research Methodology

2.1. The Concept System

By conducting a comprehensive literature review on TPS circuits [3][1] and their application in audio amplifiers, also review the principles of Class-A amplifiers [4][5] and the methods used to power efficiency and reduce distortion [2], the founded concept system used in this study shows in the system block configuration diagram in Fig. 1., which contains: Driver, Positive and Negative polarity Tracking Power Supply, and feed to the output stage of the Class-A type Audio Power Amplifier. Based on the concept system, the TPS circuit should include cascaded voltage buffer as High-Speed Voltage Buffers (HSVB), Switching Supplies, and a Hysteresis Comparator, as shown in Fig. 4.

The circuit simulation is needed using simulation software to ensure that it meets the design requirements and is suitable for implementation. The simulation conducted on this concept is by doing the simulation using NI Multisim 14.1 for all blocks in the concept system block diagram.

Based on the simulation, Printed Circuit Board (PCB) Layout and fabrication is done using a PCB design software to make sure that the layout meets the design requirements, and all components are correctly placed. Afterward, fabricate the PCB for all components, such as Driver circuit PCB, Power Amplifier circuit PCB and two PCBs for TPS circuit for the positive voltage supply and negative supply voltage.

For circuit implementation, all PCB components are assembled in an audio amplifier system with audio signal input and output using an 8-ohm speaker load, tested, and measured using the appropriate test tools device. Test and measurement is done on the audio amplifier system are the amplifier's power efficiency, distortion level, and frequency response. Compare the results with those obtained with and without the TPS circuit. Standard test equipment is used such as an oscilloscope, signal generator, and multimeter.

Analyzing the test results is done to evaluate the effectiveness of the TPS circuit in enhancing power efficiency and reducing distortion in the audio amplifier system. Use statistical analysis techniques and graphs to determine the significance of the results.

The conclusion is drawn based on testing, analyzing, comparing, and finding the result of the effectiveness of the TPS circuit in improving the power efficiency and reducing distortion in the audio amplifier.

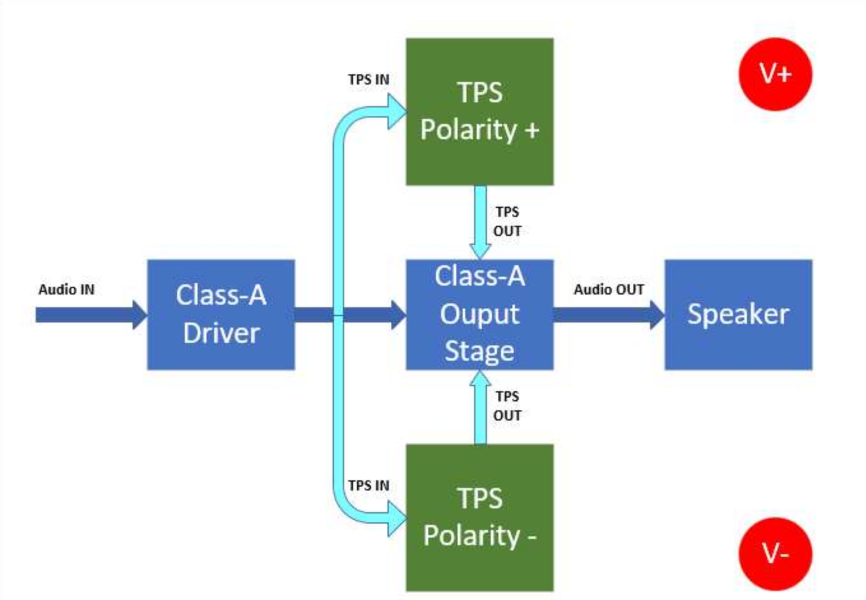

Fig. 1. Configuration Block Diagram of Audio Power Amplifier with TPS

2.2. Tracking Power Supply

Tracking Power Supply in audio amplifiers is a technique that involves adjusting the amplifier's power supply voltage to match the audio signal's amplitude. The goal is to ensure that the amplifier operates in its most efficient range, which can improve the amplifier's linearity and increase the power efficiency with less distortion.

One way to enhance power efficiency and reduce distortion in Audio Power Amplifiers is through a TPS circuit by combining the linear power supply with a switching-mode supply. A hybrid power amplifier is formed that maintains a high quality output while having a high efficiency [3]. The TPS circuit can adjust the supply current to match the audio signal's amplitude, ensuring the amplifier operates in its most efficient range. This technique improves the amplifier's linearity and increases power efficiency with little distortion, leading to better audio quality.

The TPS method combines the HSVB and the Switching Supply method [6] to respond to fast voltage changes and supply power with higher efficiency by controlling the electrical current required by the output stage of the Audio Power Amplifier. The TPS circuit uses the switching supply technique to adjust its output electrical current as the variation of the voltage signal of the power amplifier as the input. The TPS block diagram is shown in Fig. 4. TPS will get the input signal in the form of an audio signal from the power amplifier stage. Based on the input audio signal, the TPS will give an output signal as an electrical current with an additional DC offset to the BJT or FET as the main component of the output stage amplifier circuit.

We use a Class-A type Audio Power Amplifier which is theoretically an amplifier with low power efficiency but has high linearity with low distortion. According to Boylestad [7], Class-A type Power Amplifiers have a maximum power efficiency of only 25% for a single polarity supply or 50% achieved on a dual supply operation method with push-pull. As for the issue of distortion, Douglas Self has designed a Class-A type power amplifier with 20W of power to a capable 8 Ω load distortion as low as 0.0005% in THD value [4].

2.3. Audio Power Amplifier with TPS

The Audio Power Amplifier designed by Leo Simpson and Peter Smith [5] that is based on a design by Douglas Self [4] is able to provide a power output of 20 W to an 8 Ω load. The schematic drawing shown in Fig. 2. Several modifications or developments need to be done on the schematic to make it can be integrated with the TPS circuit. The developments and modifications development carried out are:

- Adding two capacitors and a 2.2 kΩ resistor for the feedback from the output stage power amplifier to the Voltage Amplifier Stage (VAS) to reduce the distortion in high frequencies.
- Change in the value of the Resistors, on the Emitter of the transistor VAS buffer, on the Collector of the transistor multiplier, on the Base resistor for each output stage driver transistors, and the speed-up resistor of the output stage.
- Add an emitter degeneration resistor to VAS transistors to improve linearity of the transistor. [4]
- Change the value of the input low-pass filter capacitor to make it easier to find the capacitor on the market.
- Adding diodes to differential transistors pair to prevent reverse bias.
- Changes in the model of transistors to BD and MJE due to the given schematic model are not available in the library of the Multisim simulator.

The Audio Power Amplifier input is fed by sine-wave input at 1 kHz audio frequency, the output response is measured using an Oscilloscope. The measurement result of the input and output response is shown in Fig. 3. As shown in Fig. 3., the shape of the sine-wave audio is in good linearity between the input and output voltage, and they are also in phase (no phase shift between input and output voltage) and the signal voltage gain is about 36.

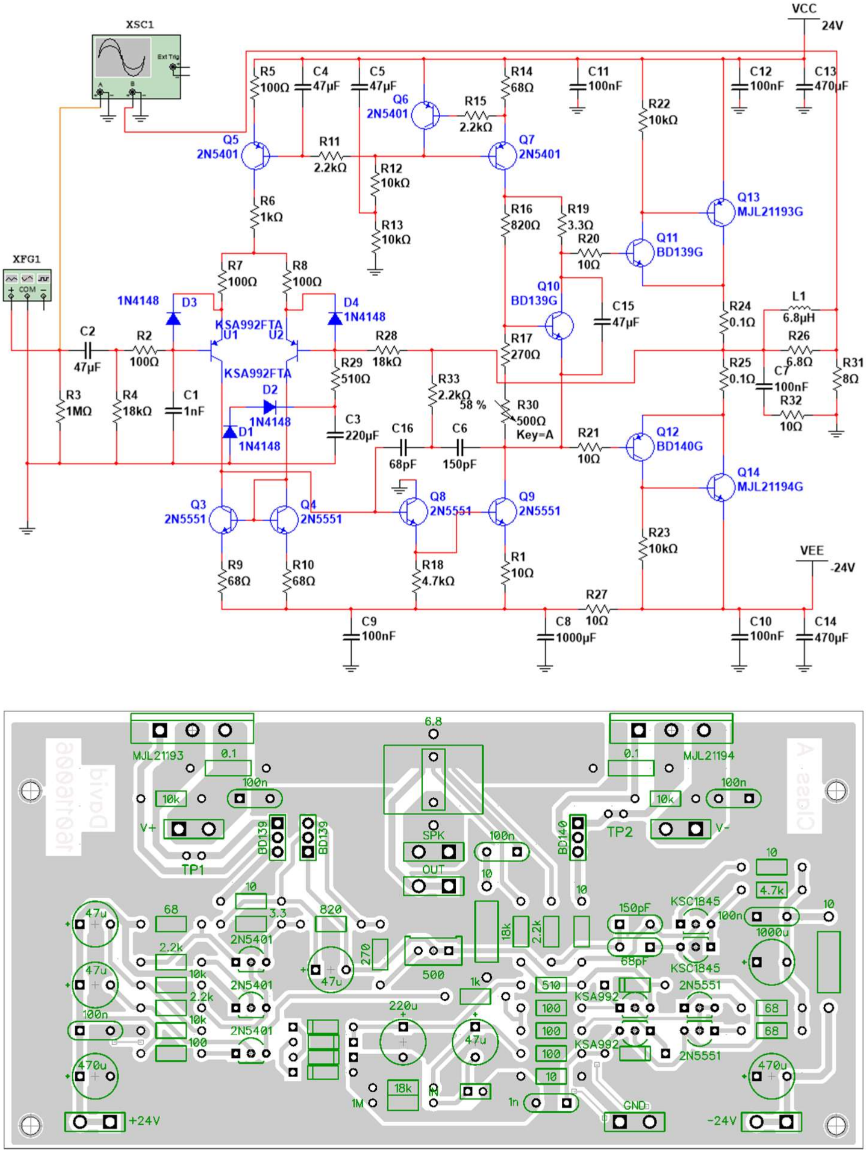

Fig. 2. Audio Power Amplifier Schematic and Fabricated PCB

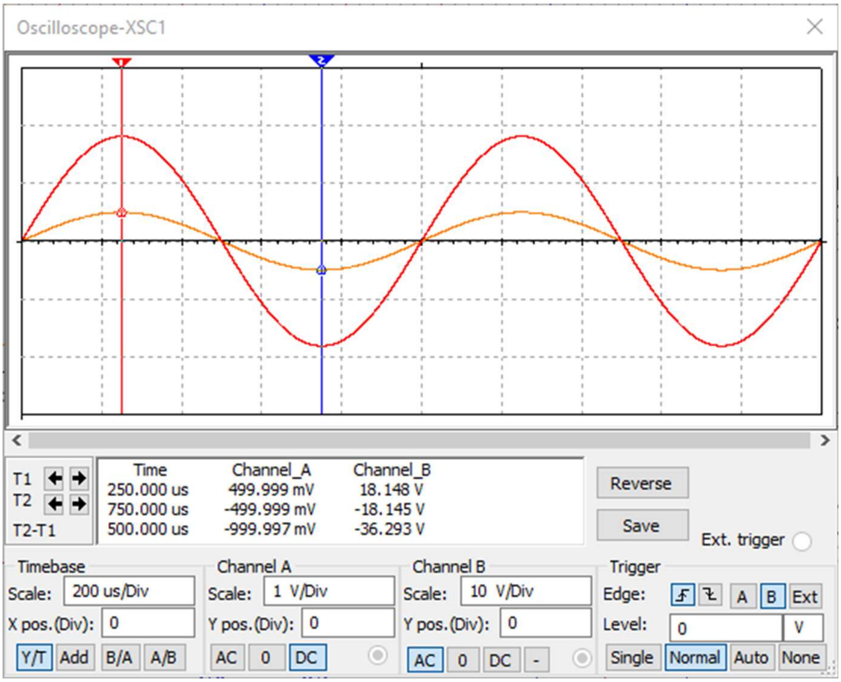

Fig. 3. Input and Output Waveforms of Audio Power Amplifiers

2.4. The TPS Design

The TPS circuit design is based on Masao Noro [8] design making for Yamaha, in which there are circuits of the positive and negative polarity side of the TPS. Both polarity circuits have the same working principle. Fig. 4. shows the block diagram of the TPS, while Fig. 5. shows the schematic electronic circuit.

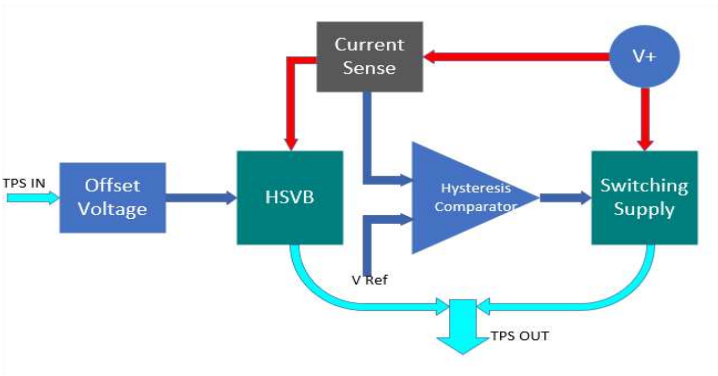

Fig. 4. TPS Block Diagram.

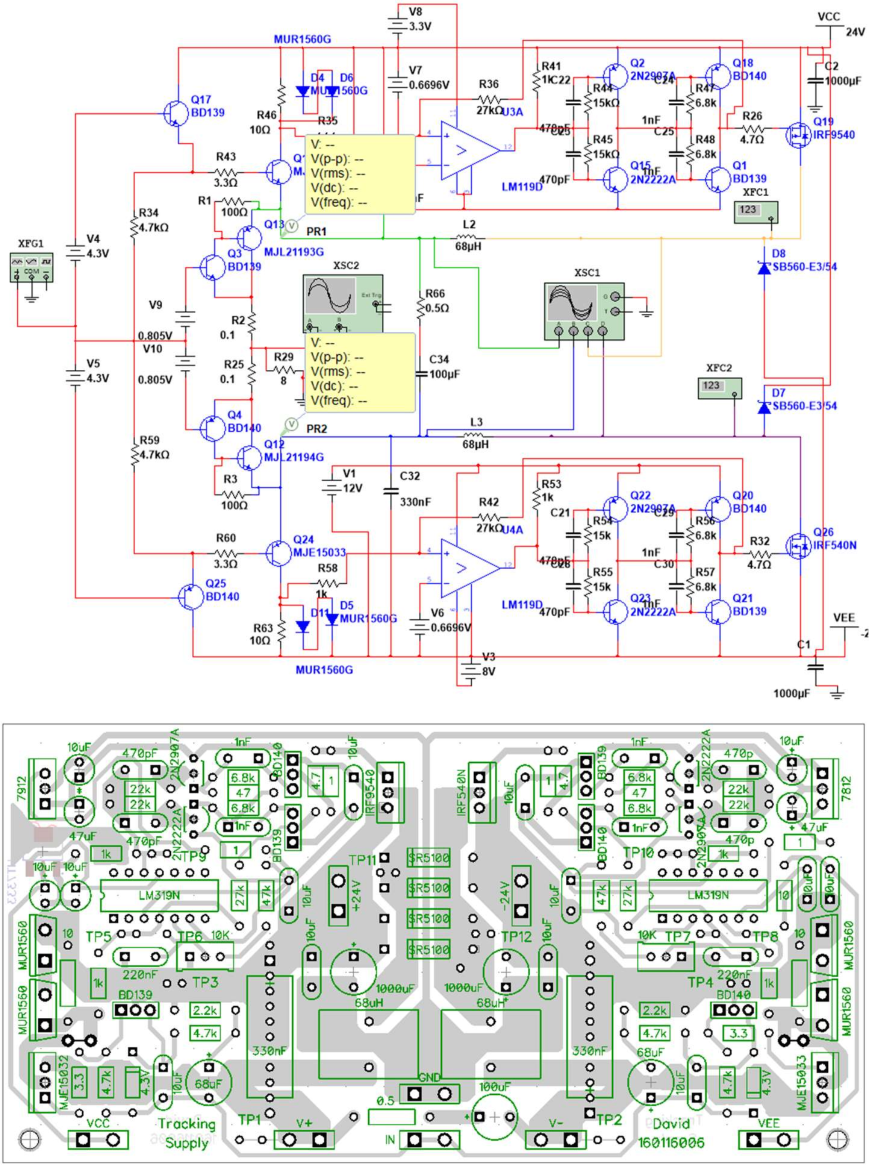

Fig. 5. Complete TPS Circuit Schematic and Fabricated PCB

The main component parts of TPS are the block circuits of the Switching Supply, HSVB, Current Sense as the control part of the HSVB, and High-Speed Comparator. There is also an Offset Voltage circuit used for assigning an offset reference voltage to the input signal of the TPS. Fig. 6. shows the offset voltage of the TPS. The green and blue line in the graph denotes for both polarity of the TPS input.

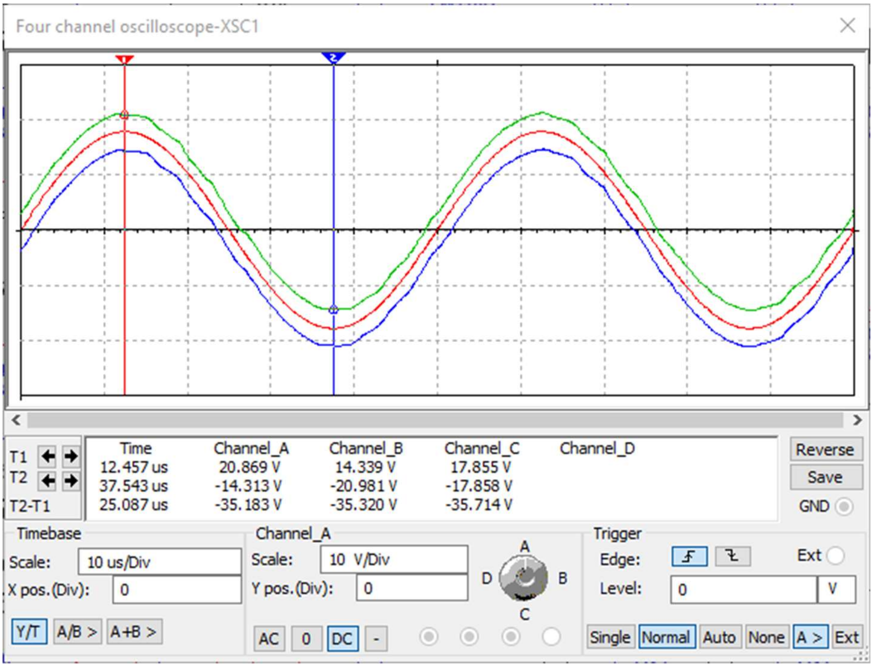

Fig. 6. Waveform of Signal and Positive side TPS.

HSVB is a high-speed voltage buffer allowing it to draw the required output current without distortion or loss of input signal quality. It is an electronic circuit that is designed to provide a high-impedance input to signal source, preventing loading effects that could degrade the input signal quality. HSVB is also designed with low-impedance output to load, allowing it to draw the load current with minimal distortion.

The HSVB block of this TPS is based on Noro circuit design [8]. Besides buffering the signal voltage, HSVB also serves to supply the additional current while responding to the changes in the input voltage. This HSVB circuit will trace the audio voltage signal of the power amplifier input voltage and supply the additional current to the output stage of the power amplifier. The HSVB circuit uses double emitter followers configuration for each polarity side to give high current gain with low output impedance (no voltage gain).

To overcome the large ripple current at high frequencies (200 kHz to 400 kHz), this circuit uses a high-performance transistor to minimize distortion. On the positive side, it uses a BD139 NPN driver transistor, and MJE15032 as the transistor output, as well as on the negative side, using a PNP BD140 driver transistor, and MJE15033 as output transistors.

The Switching Supply block cannot supply the current when there is a fast transient or changes at the input because the Switching Supply response is not as fast as HSVB. The function of HSVB is to supply the current which cannot be supplied totally by the main Switching Supply to the load of the power amplifier stage.

The amount of current that passes through HSVB is measured by the voltage across the resistor on Current Sense. The Current Sense circuit is made using parallel resistors and diodes. This circuit is used by Hysteresis Comparator [7][9]), measuring the voltage on the Current Sense Resistor and comparing it with a reference voltage. If the measuring current passing through the HSVB exceeds the upper reference limit, switching will occur at the output of the comparator to activate the Switching Supply circuit. Otherwise, if the measuring current passes through the HSVB below the lower reference limit, the output of the comparator activates the HSVB circuit.

If the Switching Supply circuit is active, the current passing through the HSVB will decrease. This matter is detected on the Hysteresis Comparator, which then will deactivate the Switching Supply circuit when the current is less than the lower limit of the reference voltage. On the other hand, if the Switching Supply is not active, it will cause the current passing through HSVB to increase until it reaches the upper limit of the reference voltage to activate the Switching Supply circuit. This cycle of events will repeat continuously.

To test effectiveness and tracking capabilities of TPS, The Audio Power Amplifier circuit is used and merged with the TPS circuits. The circuit is simulated using Multisim and measured using an Oscilloscope at 20 kHz sine-wave input. The results of the Multisim simulation of the power amplifier output are shown in Fig. 6. with the blue line. While the output from the TPS circuit (positive side only) is shown with a red line. This figure also shows the linearity and low distortion between the TPS output voltage and the audio output signal of the power amplifier. This situation indicates that the TPS circuit is running according to the expectations.

3. Comparison Results

The result of the simulation stage of Audio Power Amplifier with attached TPS circuit implemented practical electronic circuits on PCBs for all blocks of TPI components, such as Power Supply, Driver circuit PCB, Power Amplifier circuit PCB, and TPS PCB circuits for the positive voltage supply and negative supply voltage.

All PCB components are assembled in an audio amplifier system with audio signal input and output using an 8-ohm speaker load, tested, and measured using the appropriate test tools device. The test tools devices are Power Meter, Oscilloscope, Multimeter, and a laptop computer as Audio Spectrum Analyzer and THD Meter. The measurement tools configuration for testing and measuring the system test is shown in Fig. 7. The measurements taken are measuring the power efficiency and the distortion produced by the system.

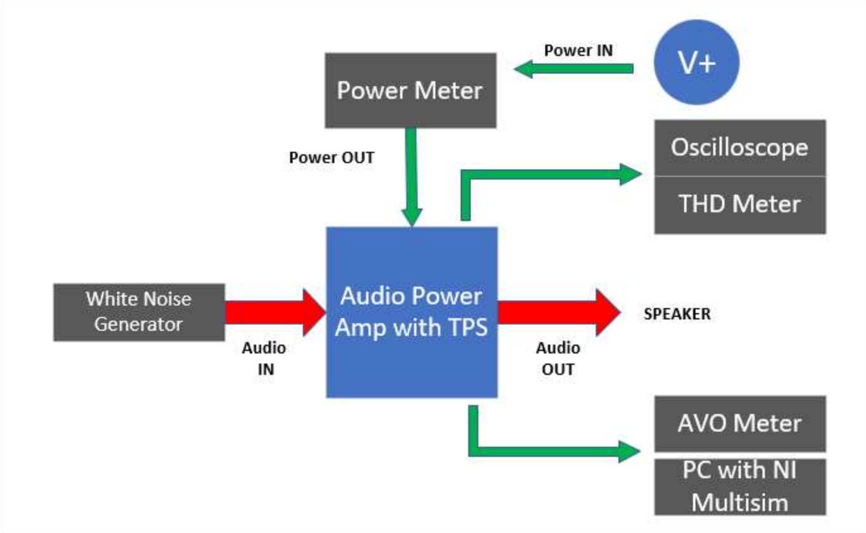

Fig. 7. Measurement Tools Configuration

Measuring THD is carried out by comparing the distortion in Audio Power Amplifier with TPS and without TPS. The THD value is measured in the audio frequency range, namely at 20 Hz, 50 Hz, 100 Hz, 200 Hz, 500 Hz, 1 kHz, 2 kHz, 5 kHz, and 10 kHz. Note that the THD measurements were not taken at 20 kHz frequency, this is due to the occurrence of sufficient distortion measured at a frequency of 20 kHz. It happens due to the influence of the low-pass filter on the laptop microphone input used for measuring. So, this THD measurement is not done for a frequency of 20 kHz.

THD measurements are also carried out at various power outputs i.e., for output power of 1 W, 2 W, 5 W, 10 W, and 20 W to 8 Ω speaker load. Fig. 8. shows THD Audio Power Amplifier measurement results without TPS. Fig. 9. shows THD measurement results of Audio Power Amplifier using a TPS circuit. And for the comparison result for the THD Audio Power Amplifier without TPS and with TPS simultaneously with variations frequency for 20 Watt output power is shown in Fig. 10.

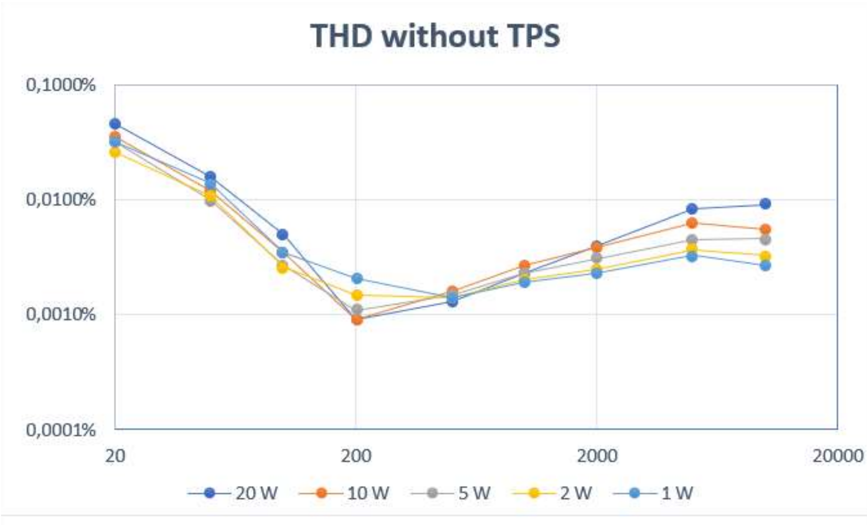

Fig. 8. THD without TPS

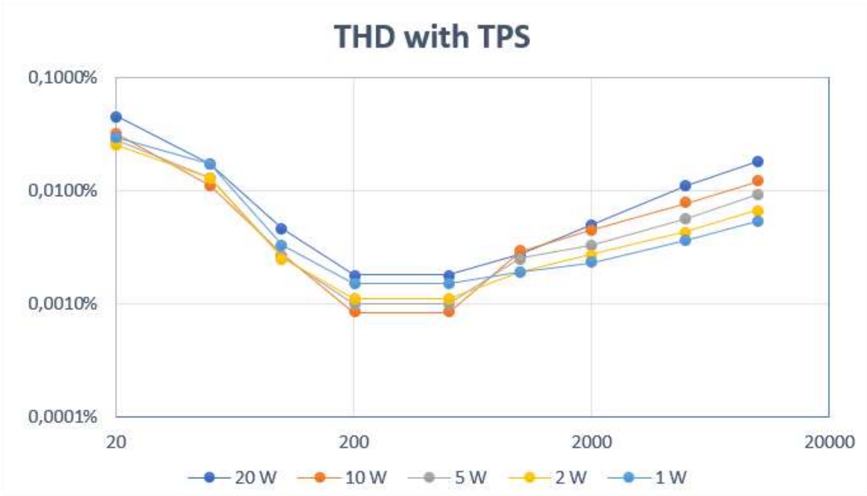

Fig. 9. THD with TPS

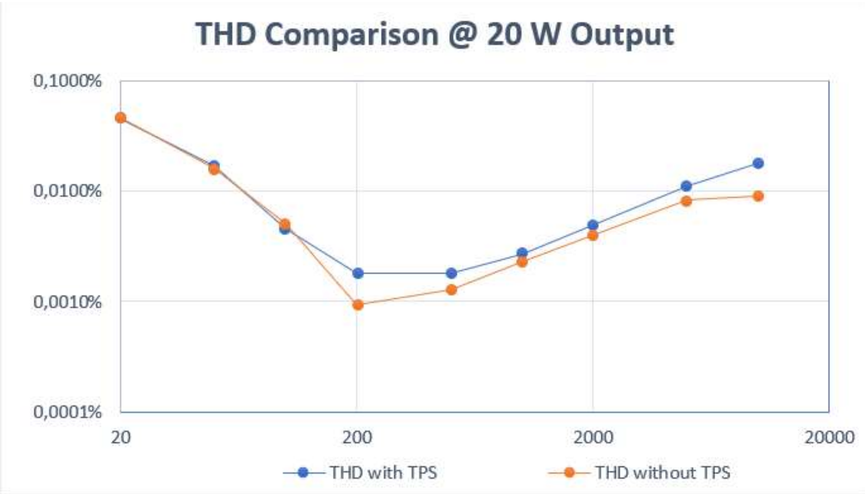

Fig. 10. THD Comparison at 20 W Output

Power efficiency measurements on power amplifier systems measured at 20 Hz, 50 Hz, 100 Hz, 200 Hz, 500 Hz, 1 kHz, 2 kHz, 5 kHz, 10 kHz, and 20 kHz. For each frequency, power efficiency measurements are carried out for the output power of 1 W, 2 W, 5 W, 10 W, and 20 W to 8 Ω load. Power input is measured using a Power Meter. Fig. 11. shows the results of the efficiency measurement of the Audio Power Amplifier without TPS. Fig. 12. shows the results of efficiency measurements of Power amplifier audio with a TPS. While Fig. 13. shows a comparison of measurements of Audio Power Amplifier efficiency with and without TPS in a single graph for convenience comparison.

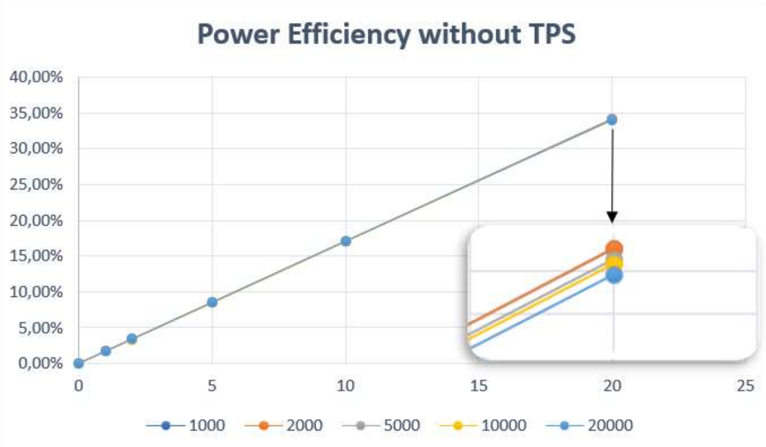

Fig. 11. Power Efficiency without TPS

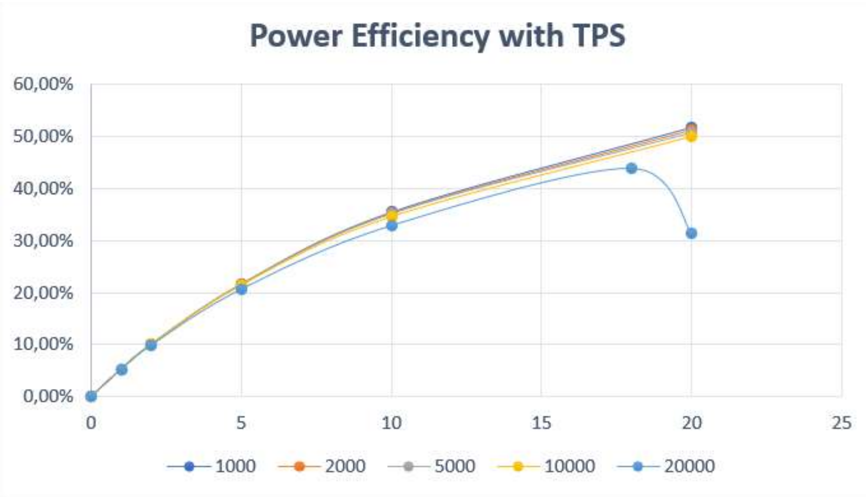

Fig. 12. Power Efficiency with TPS

Fig. 13. Power Efficiency Comparison at 1 kHz

In Fig. 12. for a 20 kHz frequency and 20W output power, it is seen as a significant decrease in efficiency. This is due to the tracking speed TPS not being enough for full tracking at 20 kHz. TPS tracking speed is only able to follow the signal Audio Power Amplifier output at the maximum output power of 18 W at 20 kHz frequency. For this condition, power efficiency is obtained at 43.78%.

Based on the comparison, results can be seen in Fig. 13. which shows the addition of TPS on a Class-A type Audio Power Amplifier managed to improve efficiency power from the Audio Power Amplifier. It can be seen that the Audio Power Amplifier's maximum power without TPS is found at approx. 34%, while the maximum power efficiency of an Audio Power Amplifier with TPS can be obtained up to 51% at 20 W maximum power. It is proven that a TPS will increase power efficiency from 34% to 51%, or there was an increase in efficiency of 17%.

4. Conclusions

Several conclusions can be drawn after performing simulation, design, testing, and analysis measurements as follows:

1. Audio Power Amplifier with TPS has been successfully simulated and realized on the printed circuit board PCB. Based on testing, Audio Power Amplifier with TPS can give a sine-wave output with a power of 20 W to the 8 Ω loudspeaker in the audio frequency range.
2. Based on the comparison of power efficiency in Fig. 13., shows that an Audio Power Amplifier without TPS achieves maximum efficiency at 34%, while with a TPS the efficiency of an Audio Power Amplifier can reach the maximum of 51%. This means there is a 17% increase in efficiency.
3. The increased power efficiency of an Audio Power Amplifier with a TPS, will also increase the value of its harmonics. It is shown in Fig.10. the increase in the THD value. This can be seen in the THD comparison chart in Fig. 10., which shows the THD value of an Audio Power Amplifier without TPS at 20W output power with a 10 kHz frequency is 0.009%, while if with a TPS the THD value is 0.018%. This means there is an increase of 0.009% in THD value.
4. The THD values of the Audio Power Amplifier tend to increase along with the increase in the audio working frequency. It is shown in Fig.10. the THD comparison chart for 200 Hz to 18kHz range frequencies.
5. Based on the TPS testing result, the efficiency of the Audio Power Amplifier with a TPS is decreased significantly on a working frequency of 20 kHz for 20 W output power, as shown in the graph of Fig. 12. This is caused by the limited maximum switching speed on the TPS for high audio range frequencies.

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