WP DISCRETE OPERATIONAL AMPLIFIER SERIES

CONVERGENCE AUDIO ADVANCEMENT

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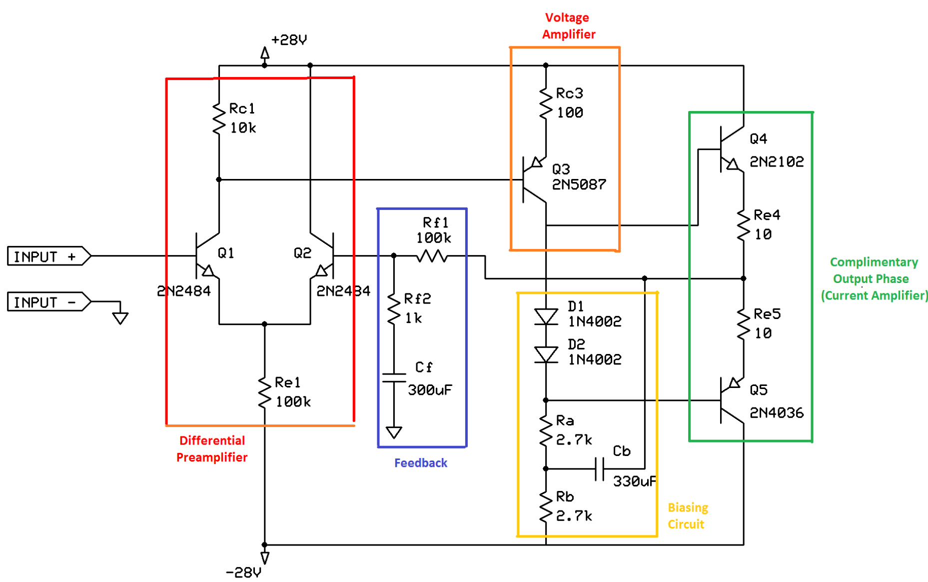
DESCRIPTION

The WP series are audio power amplifiers designed to provide amplification with low levels of noise and distortion. Each amplifier in the series consists of three stages: the differential preamplifier, voltage amplification, and current amplification. Each operational amplifier has a positive and negative input pin, with the difference amplified using a differential amplifier.

The WP6T9 was the original amplifier of the series, released in 1970. Each successive amplifier has been improved to eliminate noise, increase reliability, and increase gain. Examples include constant current sources, current mirrors, bypass and bootstrapping capacitors,

The amplifiers provide 40dB of gain (WP6T9) to 120 dB of gain (WP421/520) in the open loop gain configuration.



WP6T9

The original and most economical amplifier in the series has 40dB of open-loop gain and linear operation even without external feedback.

Differential Preamplifier:

Using a differential preamplifier as the first stage is useful because it allows negative feedback to be utilized. It is important for the preamplifier to be free of noise and errors, as these will be amplified in the later stages of the circuit. The differential preamp uses a shared emitter resistor, known as a long tailed pair, to link the current of the two amplifiers together. Because the current through the emitter resistor is held constant by the resistor and the voltage sources, the current going through each transistor (I_{c1} and I_{c2}) will affect each other.

The differential preamplifier incorporates negative feedback from the output of the amplifier to the second input of the amplifier. The level of feedback is controlled by a voltage divider.

When only one collector is driving the next stage, the opposite collector resistor can be shorted, as is the case with the preamplifier stage of the WP6T9. I_{c1} and I_{c2} can be made equal by appropriately setting R_{C1} relative to R_{E1}.

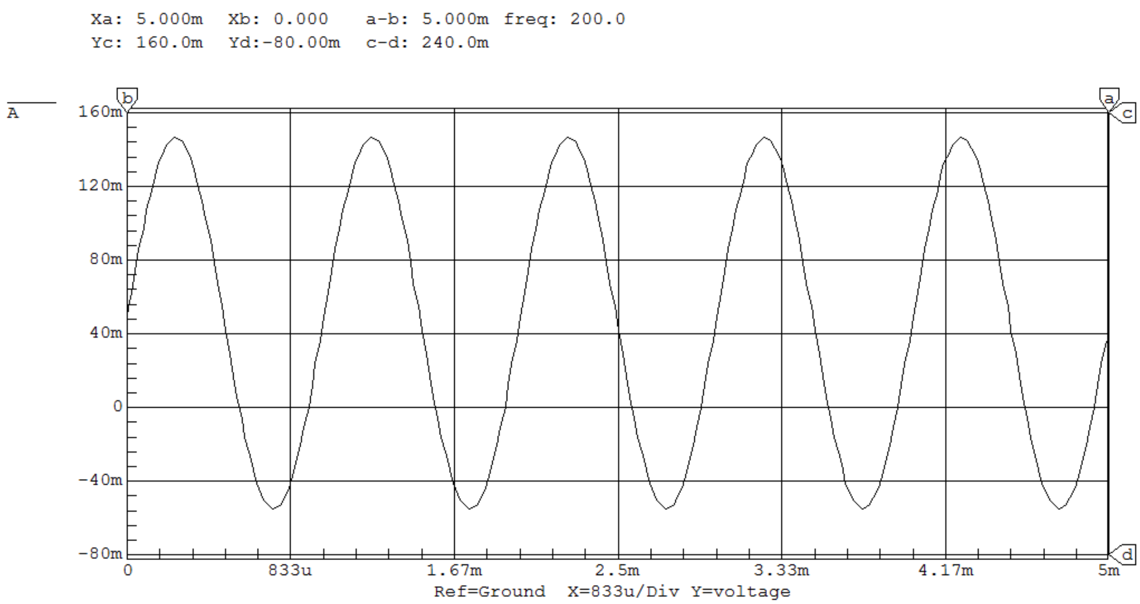
Voltage Amplification: Because power is the product of voltage and current, effective power amplification requires amplification of both voltage and current. The output stage primarily amplifies current, while adding a voltage amplification stage prior to the output stage will allow effective power amplification as well as driving the output stage. Because bipolar junction transistors are already effective at amplifying voltage, the voltage amplification consists of only a single transistor.

The voltage amplification stage also includes biasing so the input of the output stage is properly biased to prevent crossover distortion. Biasing can be done with resistors or diodes, but the WP6T9 uses diodes, which is the preferred method. The turn on voltage of the bipolar junction transistor changes as temperature changes. By placing diodes of the same material as the transistors physically close to the transistors, the diodes will heat up to the same temperature and the voltage drop will be the same.

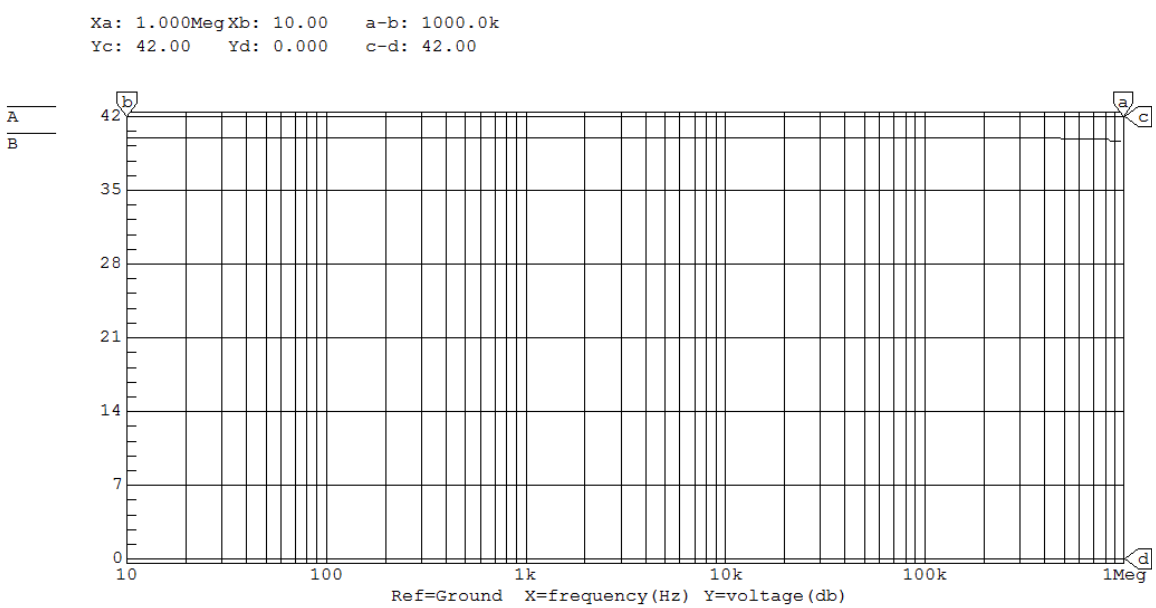
Complimentary Output Stage: The last stage of the amplifier is the complimentary output stage, which also functions as a current amplifier. The stage contains one PNP and one NPN transistor, which are biased to operate for either the positive or negative half of the signal, summing the two together at the output. The biasing diodes from the voltage amplification stage overcome the turn on voltage of each transistor, so that the turn on voltage for each transistor will be 0 volts instead of 0.7 or -0.7 volts. Having the turn on voltage be 0 volts prevents crossover distortion, which is highly undesirable in power amplifiers.

Additional Compensation: Without proper compensation, there is an impedance mismatch between the voltage amplifier stage and the current amplifier stage. The output impedance of the voltage amplifier should be 1/10th the input impedance of the current amplifier to prevent loading. However, the output resistance of the voltage amplifier is R_{c3}, while the input resistance of the current amplifier is $\beta(r_e+R_E)$. The output resistance is not sufficiently small, so there must be a method to preserve the impedance at DC values, but make the output impedance low for AC signals. This is done by adding a bootstrapping capacitor. This involves splitting the collector resistor into two values and placing a capacitor that connects the output of the circuit to the split of the two resistors. Adding the bootstrap capacitor effectively matches impedance of the stages, while maintaining the biasing of the transistor in the voltage amplification stage.

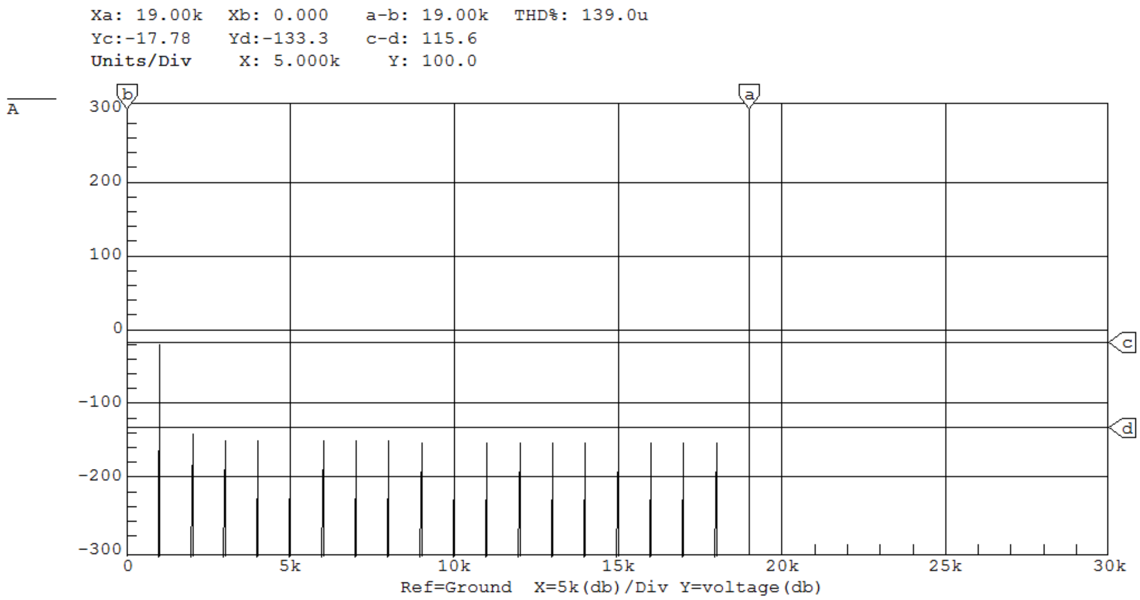
Transient Response:



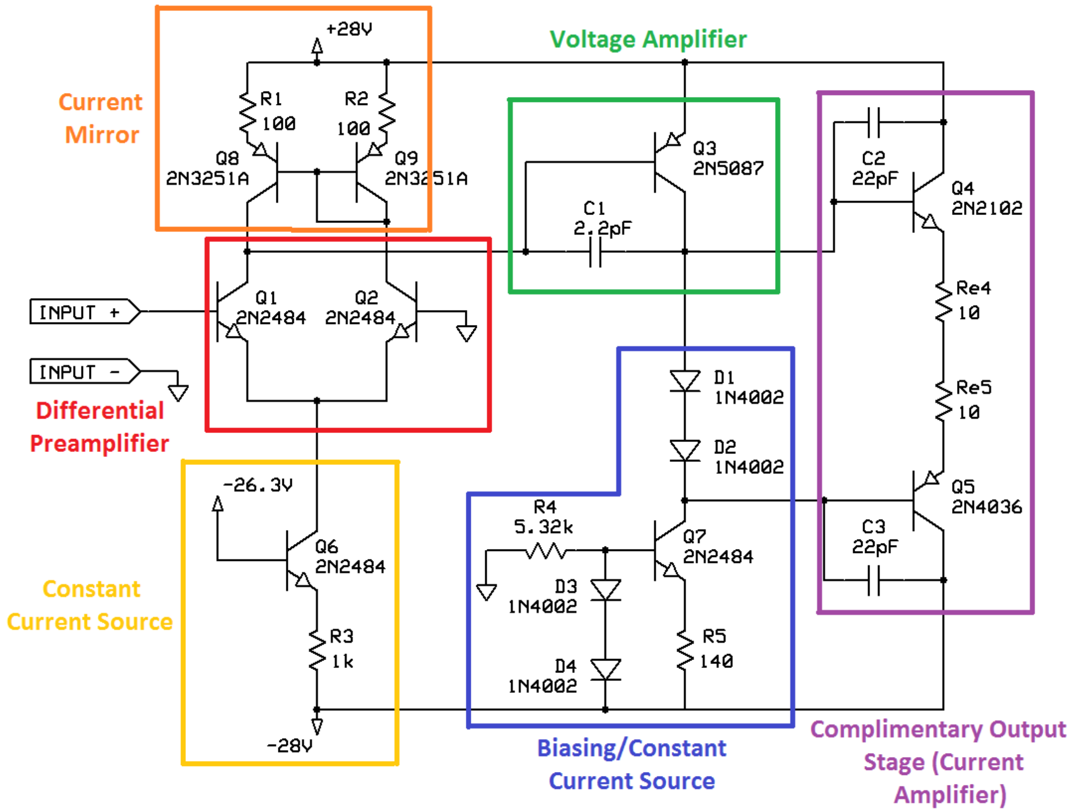
Frequency Response



Fourier Response:



The above plots outline typical operation of the WP6T9, showing its linear output and flat frequency response, both of which are due to the internal feedback path in the amplifier. The internal feedback path limits the open loop gain of the amplifier, which prevents distortion due to the limits of the power supplies being reached. As the open loop gain is lowered, the bandwidth of the amplifier is larger, as seen in the frequency response plot.



WP421

The WP421 has many upgrades to improve stability, as well as overall voltage gain. In open loop mode, the has 115 dB of gain.

Differential Preamplifier: Two major improvements were made to the preamplifier stage in the WP421: the replacement of the long-tailed pair with a constant current source, and addition of a current mirror to improve the common mode rejection ratio.

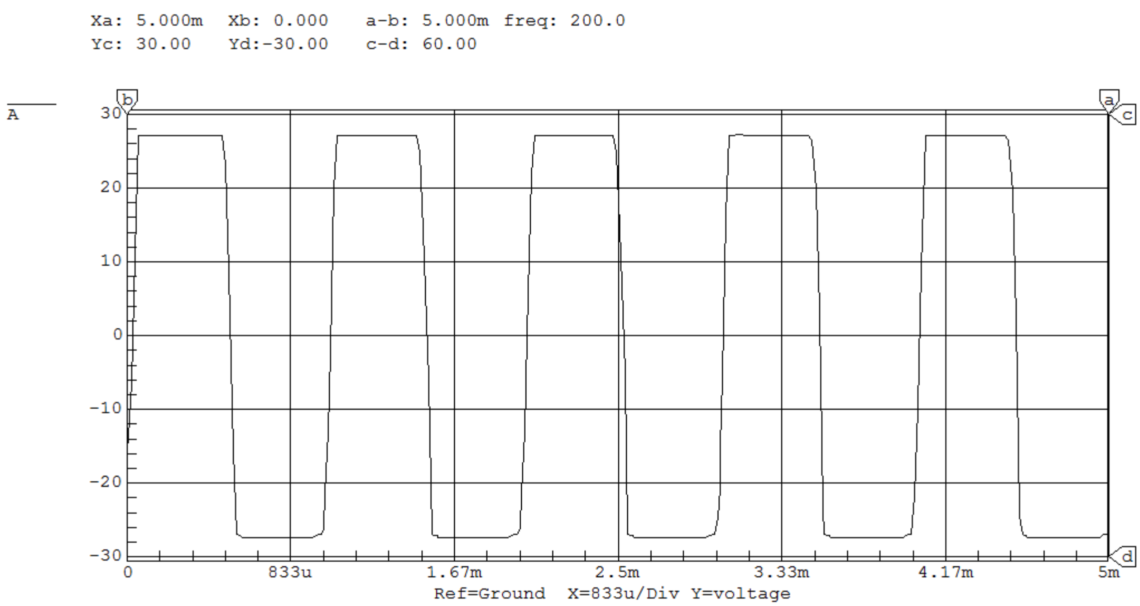
The long-tailed pair fixes the current I_E based on the power supply and emitter resistor. However, any noise or sag generated by the power supply will be present in the output, because the output currents are dependent on I_E being constant. The constant current source works by locking a transistor into a state of conductance at a specific current, which is less noisy than depending directly on the power supply for a constant current. Diodes are used to bias the base terminal into a conducting state and the resistor is used to set the current. The resistance of the current source is much higher than that of the long tailed pair, which also improves the common mode rejection.

The second improvement is use of a current mirror to exactly match the current through the two transistors of the differential preamplifier. In the WP6T9, this is done through proper matching of R_{C1} and R_E. However, any errors in the actual resistance of a resistor will result in the currents being different. Noise from the positive power supply will also be amplified. Use of the current mirror forces the two currents to be exact regardless of noise or resistor values. This is done by linking the two bases of the transistors in the current mirror. If the base current, β, and collector resistors are all matched, then I_{C1} and I_{C2} must be the same.

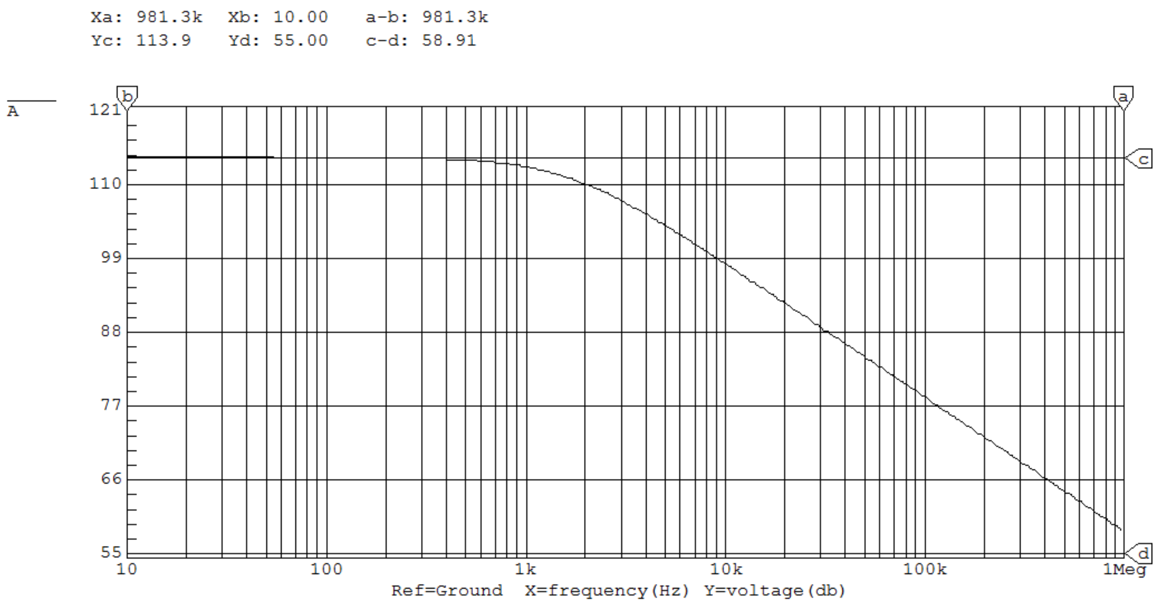
Voltage Amplifier: An improvement made in the voltage amplifier of the WP421 from the 6T9 is the inclusion of a constant current source. In the 6T9, the bias current is set by the collector resistor of the voltage amplifier. However, it can be replaced by a constant current source circuit to set the bias point. By replacing the emitter resistor with a constant current source, the need for a bootstrap capacitor is eliminated. The original purpose of the bootstrapping capacitor was to lower the AC impedance of the collector resistor, but the constant current source has a low input impedance, which eliminates this problem.

Additional Compensation: The transistors present in the circuit have parasitic capacitances, which can combine with resistors to create high frequency oscillations. Placing another small capacitor between the emitter and base terminals of the transistor suppresses high frequencies and these anti-squeal capacitors are present in the WP421.

Transient Response:



Frequency Response:



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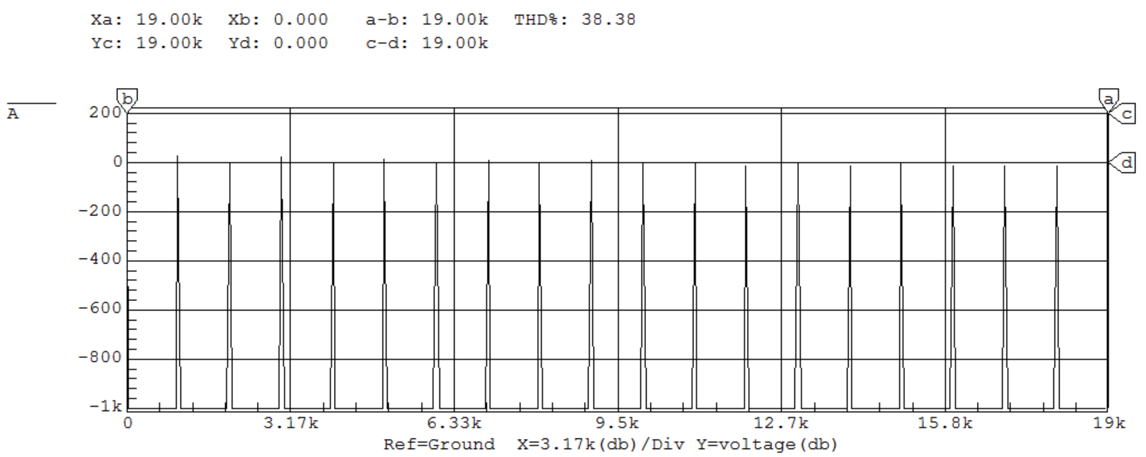
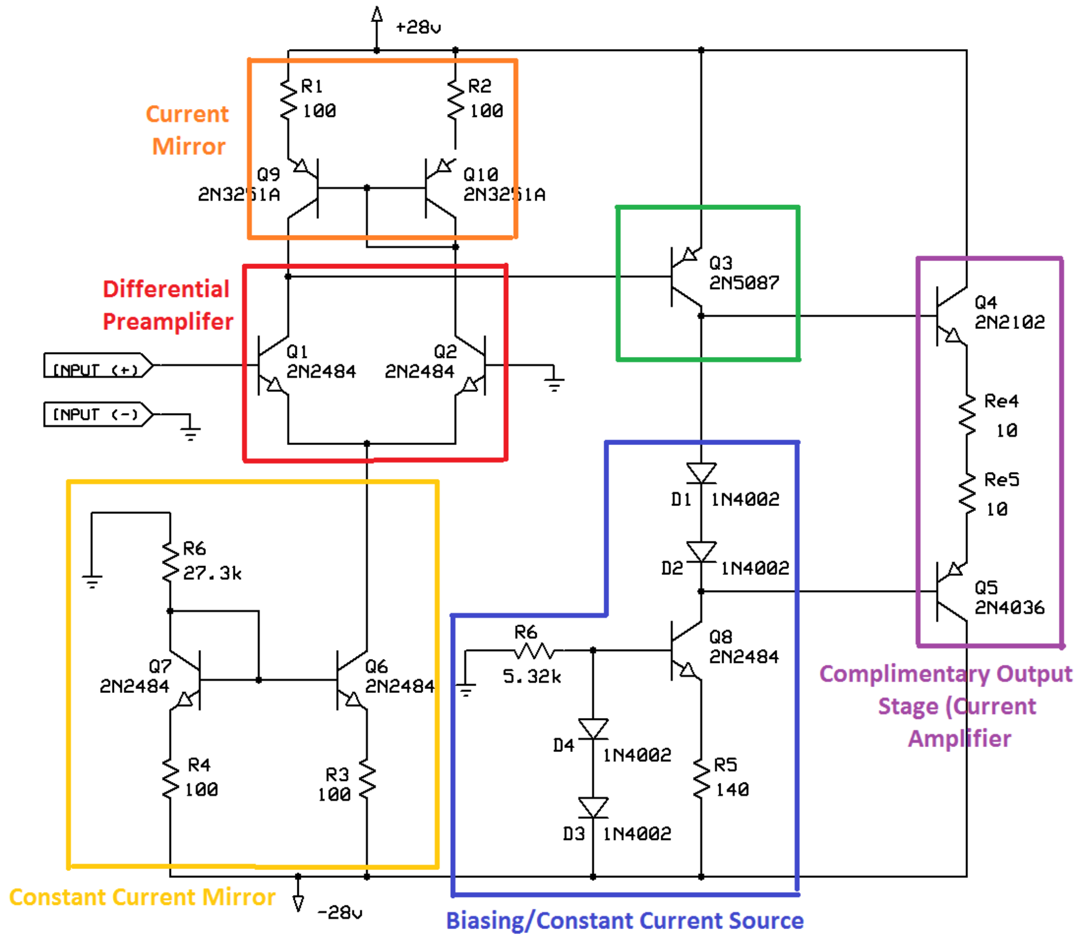


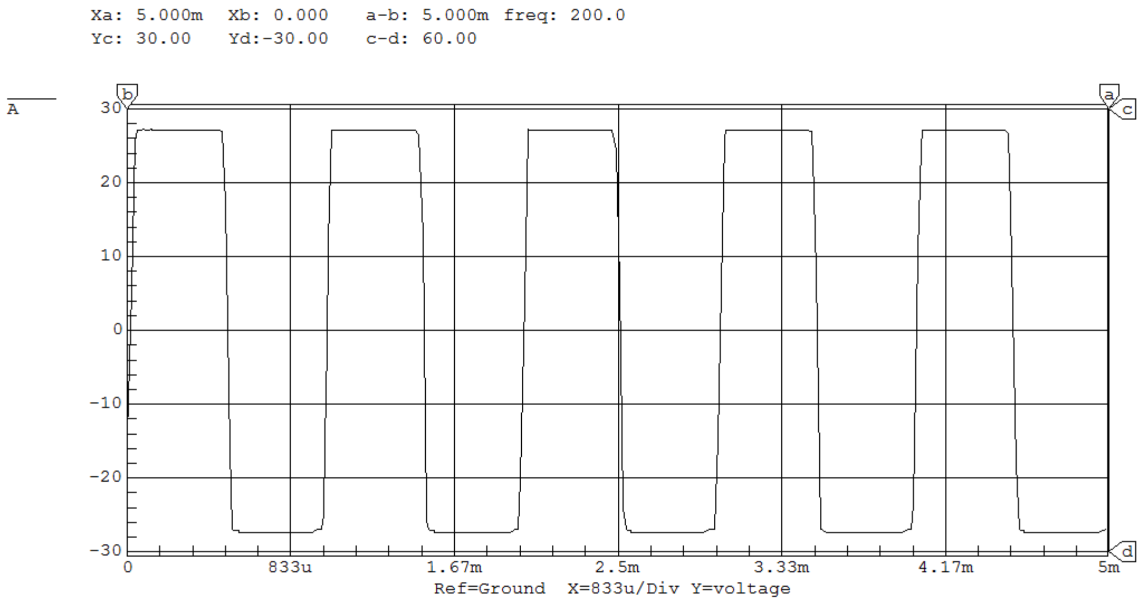
The elimination of the internal feedback path greatly increases the open loop gain of the WP421 amplifier. As the voltage supply is reached, the output distorts, creating a square wave output. The tradeoff of higher gain is that the bandwidth is much lower, as seen in the frequency response plot. The low pass cutoff frequency is well within the audible range of frequencies. However, eliminating the internal feedback path allows the WP421 greater versatility, as it can also be used as a comparator in open-loop mode. By attaching external negative feedback, the gain will be reduced, the bandwidth increased, and the linear will operate linearly.



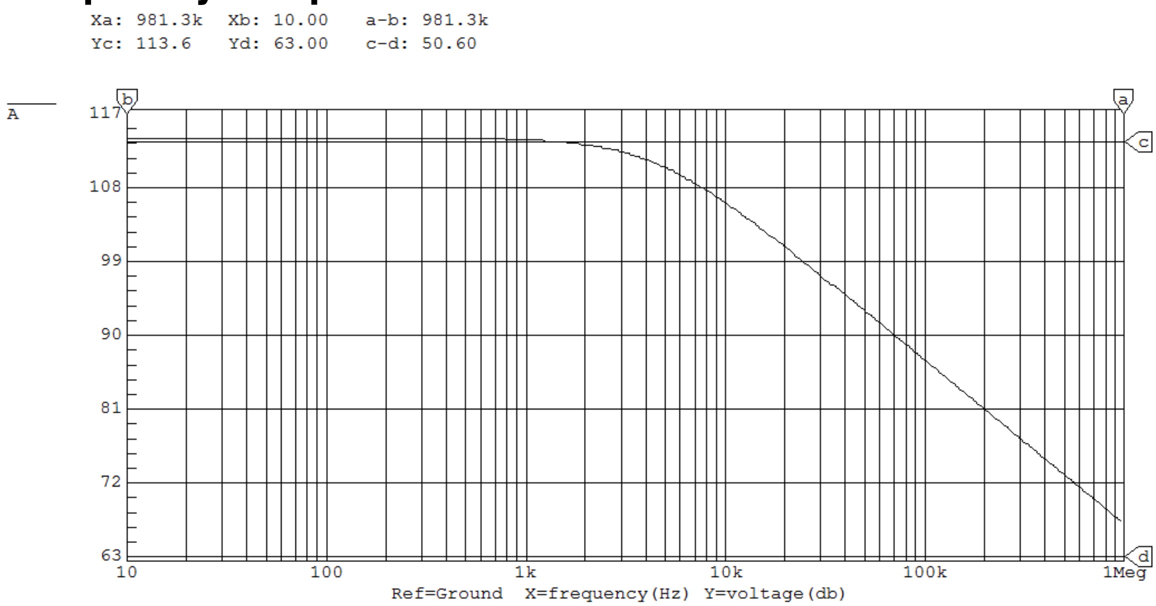
WP520

The major addition to the WP520 is replacing the diode biasing of the current source in the differential preamplifier with a current mirror, increasing the stability of the circuit and eliminating the need of anti-squeal capacitors present in the WP421.

Transient Response:



Frequency Response:



Fourier Response: