AN66

Designing with shunt regulators – *AC amplifier*

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Introduction

A three terminal shunt regulator can be used to make a simple and effective single-supply AC amplifier. The solution offers cost and space saving advantages. This application note presents the details.

The amplifier

The amplifier is shown in Figure 1. The DC gain is set by R1,R2. R3 sets up reference/load current which is its normal function. The input and output from the amplifier are necessarily AC coupled by C1 and C2 respectively.

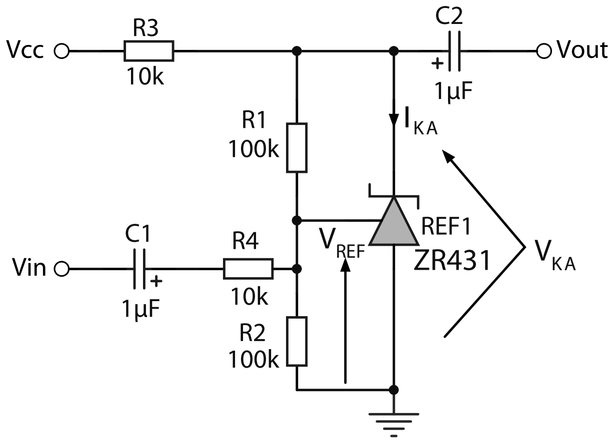

Figure 1 - Gain of 10 amplifier using a 3-terminal shunt regulator

The gain calculation uses the principle that the reference terminal voltage of the shunt regulator is fixed by the feedback network and also draws negligible current. Hence a change in V_{IN} produces equal current change in R4 and R1.

$$\Delta I_{IN} = \frac{\Delta V_{IN}}{R4} = -\frac{\Delta V_{OUT}}{R1}$$

Therefore the AC gain within the pass band, G_{AC}, is given by,

$$G_{AC} = \frac{\Delta V_{OUT}}{\Delta V_{IN}} = -\frac{R1}{R4}$$

Design procedure

1. Set up DC conditions

a. Choose V_{CC} from $(2 \cdot V_{REF} + V_{KA(\min)}) < V_{CC} \geq (V_{OUT(pk-pk)} + V_{KA(\min)})$

b. Choose R2. A value of the order of 100k and up is recommended.

c. Calculate R1 from

$$R1 = R2 \cdot \left(\frac{V_{CC} - V_{KA(min)}}{2 \cdot V_{REF}} - 1 \right)$$

This ensures that V_{KA} is biased at half of V_{CC}.

d. Determine maximum load (minimum R_{LOAD}) on the output and calculate R3 from

$$R3 \leq \left(\frac{V_{CC} + V_{KA(min)}}{2 \cdot V_{OUT(pk-pk)}} \cdot R_{LOAD(min)} \right)$$

2. **Set up AC conditions**

a. Determine R4 from $R4 = \frac{R1}{G_{AC}}$ where G_{AC} is the required AC gain.

R4, R1 and R2 can be scaled up or down to obtain a desired impedance gain

b. Determine the 6dB (low corner frequency cut-off) point of the amplifier, f_{CL}, and calculate C1 from

$$C1 \geq \frac{1}{2 \cdot \pi \cdot f_{CL} \cdot R4}$$

c. Calculate C2 from

$$C2 \geq \frac{1}{2 \cdot \pi \cdot f_{CL} \cdot R_{LOAD(min)}}$$

Note that $V_{KA(min)}$ is usually not a quantified parameter for shunt regulators. However it is usually less than 1.5V for most devices.

Input impedance

If the design steps above have been followed, then the input impedance, Z_{IN}, is given by $Z_{IN} \approx R4$. The user therefore has full control of the input impedance.

Output impedance

The output impedance of the amplifier, Z_{OUT}, provided the design steps above have been followed, is the dynamic slope resistance of the reference used and given by $Z_{OUT} \approx R_Z$. R_Z for most references is typically a few hundred milliohms and therefore will not be a problem in most applications.

Bandwidth

The amplifier behave like an operational amplifier in that it has a constant Gain-Bandwidth Product (GBP). In a practical test carried out using the ZR431, a GBP of 1MHz was obtained. This will vary depending on which device is used.

Drive capability

The shunt regulator amplifier, by definition, is a Class A amplifier. This means that, even when it is not delivering power, it is consuming 50% of the total available power. It is therefore best suited for signal or low power applications such as driving earphones or headphones.

Nevertheless, the amplifier's peak-to-peak current drive capability is quantified by the $I_{KA(max)}$ rating of the shunt regulator. If the application demands it, this rating can be boosted by an external transistor as shown below. Refer to AN57 for details on current-boosting a shunt regulator.

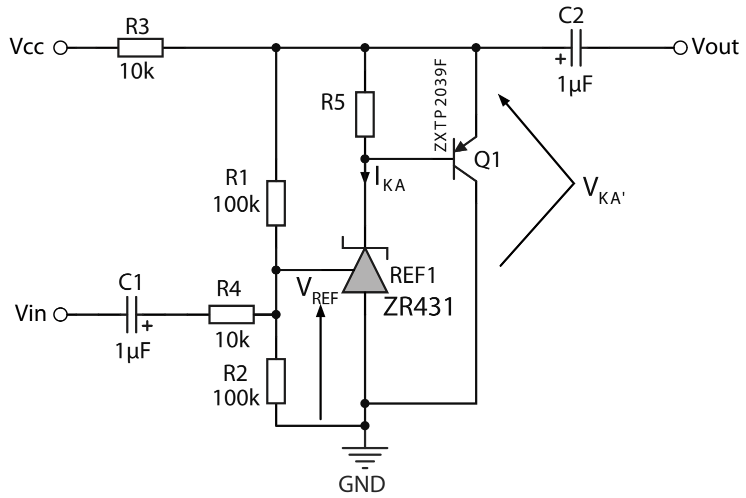

Figure 2 - Gain of 10 shunt regulator amplifier with current-boosted output

Stability

Some shunt regulators can become unstable when only lightly loaded. In this case it may be necessary to preload the output with a resistor in order to maintain this minimum load requirement. Doing this modifies $R_{LOAD(min)}$ and it is this modified $R_{LOAD(min)}$ that should be used in the procedure when calculating R3 and C2.

Simplified circuit

If the output voltage requirement is within V_{REF} and $V_{KA(min)}$ of the shunt regulator, i.e. $V_{OUT(pk-pk)} \leq (V_{REF} - V_{KA(\min)})$, then the simplified circuit below may be used instead. This circuit gets rid of R2 to give the amplifier a unity DC gain. The AC gain remains the same being determined by R1/R4.

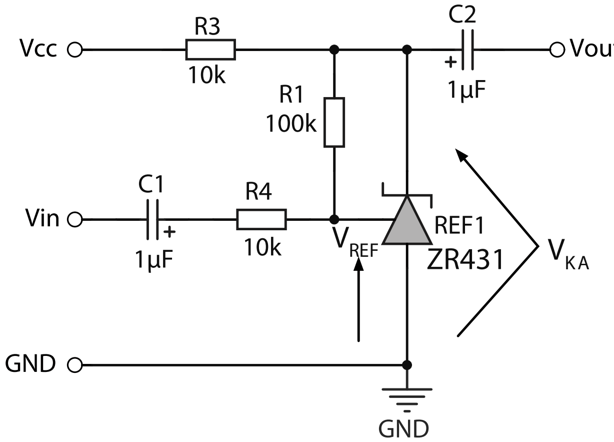

Figure 3 - Gain of 10 amplifier with unity DC gain

Bench Tests

The circuit in Figure 1 was built using the ZR431 shunt regulator. The following graphs show the obtained performance. In all cases, the top trace is the input and the bottom trace output.

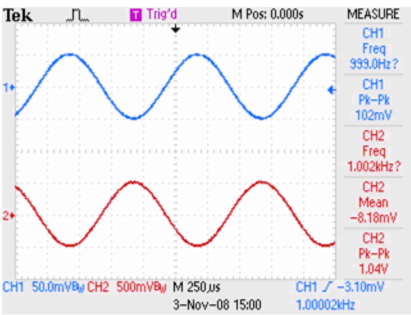

Figure 4 G = 10, V_{IN} = 50mV 1kHz sine wave, load = 10k

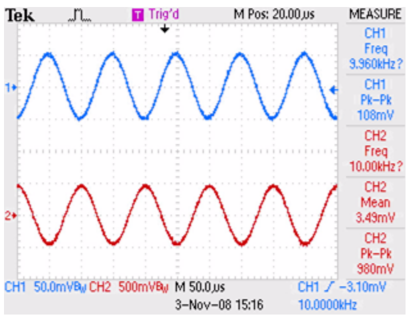

Figure 5 G = 10, V_{IN} = 50mV 10kHz sine wave, load = 200R

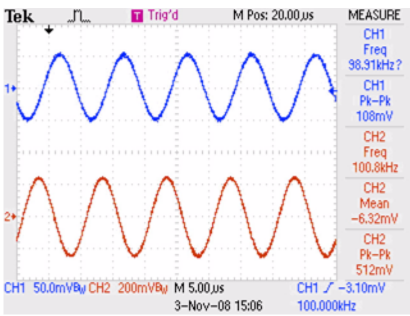

Figure 6 G = 10, V_{IN} = 50mV 100kHz sine wave, load = 10k

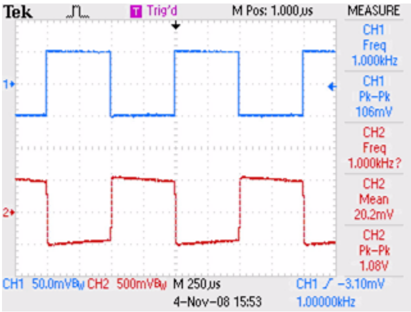

Figure 7 G = 10, V_{IN} = 50mV 1kHz square wave, load = 10k

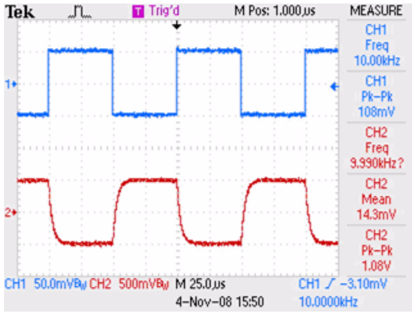

Figure 8 G = 10, V_{IN} = 50mV 10kHz square wave, load = 10k

The graph below shows test result for Figure 3.

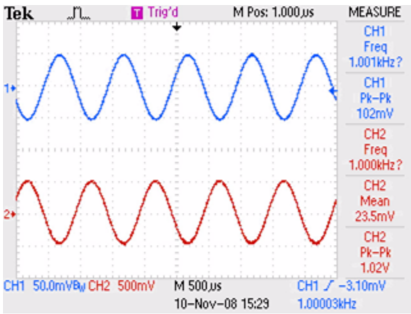

Figure 9 G = 10, V_{IN} = 50mV 1kHz sine wave, load = 10k

Conclusion

This application note has shown that a shunt regulator can be used as an AC amplifier and that it offers practical benefits in terms of parts rationalisation, space and cost savings.

Recommended further reading

AN67 - Designing with Shunt Regulators – *mixing, adding or summing*

AN57 - Designing with Shunt Regulators – *Shunt Regulation*

AN58 - Designing with Shunt Regulators – *Series Regulation*

AN59 - Designing with Shunt Regulators – *Fixed Regulators and Opto-Isolation*

AN60 - Designing with Shunt Regulators – *Extending the operating voltage range*

AN61 - Designing with Shunt Regulators – *Other Applications*

AN62 - Designing with Shunt Regulators – *ZXRE060 Low Voltage Regulator*

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