AN67

Designing with shunt regulators – *mixing, adding or summing*

Peter Abiodun A. Bode, Snr. Applications Engineer, Diodes Incorporated

Introduction

This application note demonstrates how a three-terminal shunt regulator may be used to implement a simple summing circuit or mixer. It is an extension of the subject first introduced in AN66 which shows how a shunt regulator can be used as an AC amplifier.

The proposal

Figure 1 shows the AC amplifier. Because feedback through R1 maintains the reference pin at a constant DC value, this point represents an AC virtual earth or "*ve*". It means that this point can be used as a summing junction for several independent inputs. This is shown in Figure 2.

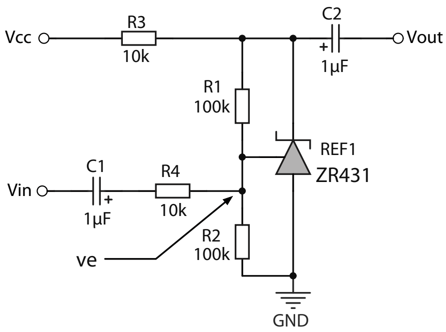

Figure 1 - AC amplifier using a reference

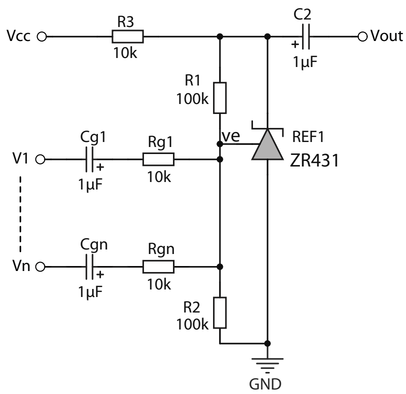

Figure 2 - Shunt regulator as a general multi-input summing amplifier

The transfer function of the circuit is given by

$$V_{out} = R1 \cdot \left(\frac{V_1}{Rg1} + \frac{V_2}{Rg2} + \ldots + \frac{V_n}{Rgn} \right)$$

This is the basic idea of the summing amplifier. The nature of the output depends on the nature of the inputs. Consider, for example, the 2-input amplifier shown in igure 3

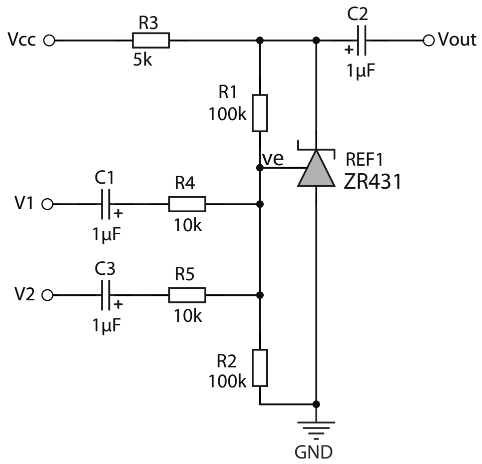

Figure 3 - Two-input amplifier

$f1 = f2$

If both v1 and v2 are of similar bandwidth then the output is a straightforward amplified phasor sum of the two inputs.

For example, suppose v_1 and v_2 are given by:

$$v_1 = V_1 \cdot \sin \omega t$$

$$v_2 = V_2 \cdot \sin(\omega t + \alpha)$$

The output voltage, v_O, is of the form

$$v_O = -V_O \cdot \sin(\omega t + \theta) \qquad \text{Equation 1}$$

where

$$V_O = G_{AC} \cdot \sqrt{V_1^2 + V_2^2 + 2V_1V_2.\cos\alpha} \qquad \text{Equation 2}$$

and

$$\theta = \cos^{-1}\left(\frac{V_1 + V_2.\cos\alpha}{\sqrt{V_1^2 + V_2^2 + 2V_1V_2.\cos\alpha}}\right) \qquad \text{Equation 3}$$

(see Appendix)

The result is shown in Figure 5, based on a simulation of Figure 4:

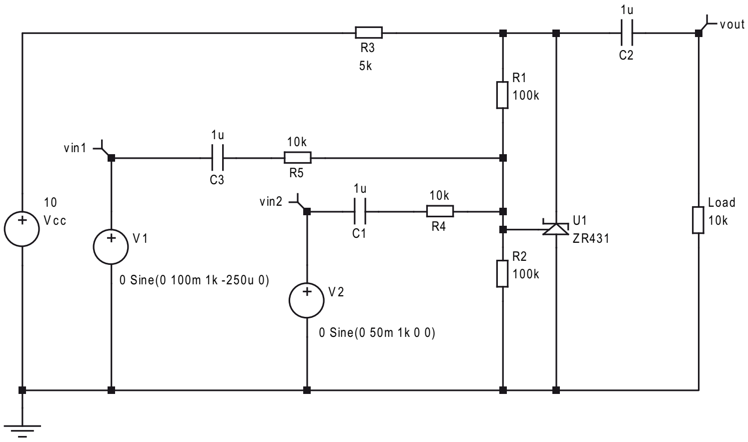

Figure 4 - Simulation circuit demonstrating summing or adding

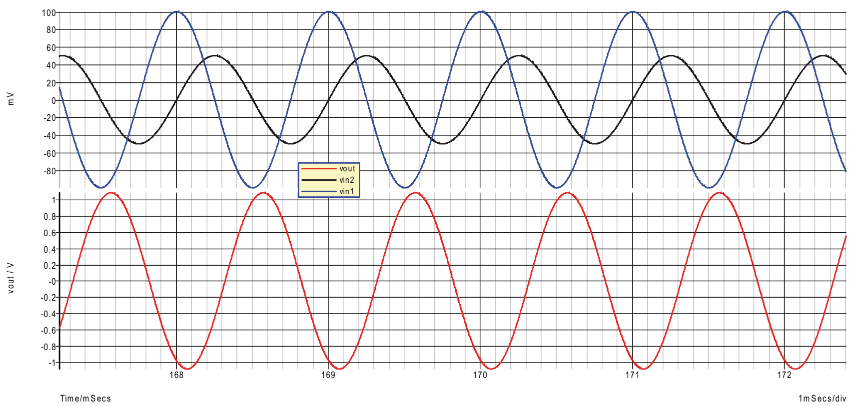

Figure 5 - Simulation result of figure 4

Figure 5 shows $v_{in1} = 100mV \cdot Sin\omega t$ - blue trace (f = 1kHz)

And $v_{in2} = 50mV \cdot Sin(\omega t + \frac{\pi}{2})$ - black trace (f = 1kHz)

AC gain, $G_{AC} = 10$

Therefore, $V_O = \sqrt{(10 \cdot 0.1)^2 + (10 \cdot 0.05)^2}$ - red trace (f = 1kHz)

$\sqrt{1^2 + 0.5^2} = 1.118V$

$\theta = \cos^{-1}\left(\frac{0.5}{\sqrt{1^2 + 0.5^2}}\right) = 1.107Rads$

Hence $v_O = -1.118Sin(\omega t + 1.107)$ i.e. v_O leads v_{in1} by 1.107 radians or about 63.43° and is inverted.

If v1 and v2 are of different frequencies, one of two things will happen as follows.

$f2 < f1 < 2.f2$

If *f1* and *f2* are different but the ratio of separation is less than 2, the two frequencies will "beat" together. "Beating" is interference between two slightly different frequencies which manifests as a periodic variation in amplitude of a higher frequency. This is illustrated in the simulation results in Figure 7

If $v_1 = V \sin \omega_1 t$

and $v_2 = V \sin \omega_2 t$

The output voltage v_O is given by;

$$= -2V \cos\left(\frac{\omega_1 - \omega_2}{2}\right)t \cdot \sin\left(\frac{\omega_1 + \omega_2}{2}\right)t \qquad \text{Equation 4}$$

The cosine term contains half the frequency difference between *f1* and *f2* but, due to its interaction with the sine term, the waveform envelope it produces is that of *f1-f2*, or beat frequency. The sine term behaves like a carrier signal (for the beat frequency) whose frequency is the average of *f1* and *f2*.

The beat frequency can produce interesting acoustic effects when used for mixing audio frequencies when it is perceived as a third tone. This is because beating can also occur with complex waveforms due to harmonics of one signal interacting with close harmonics of another – known as inter-modulation distortion.

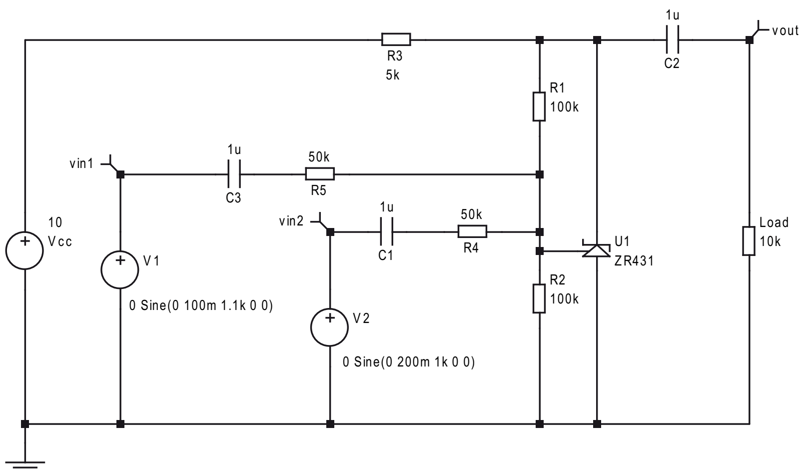

Figure 6 - 2-input shunt-regulator mixer illustrating beat frequency phenomenon

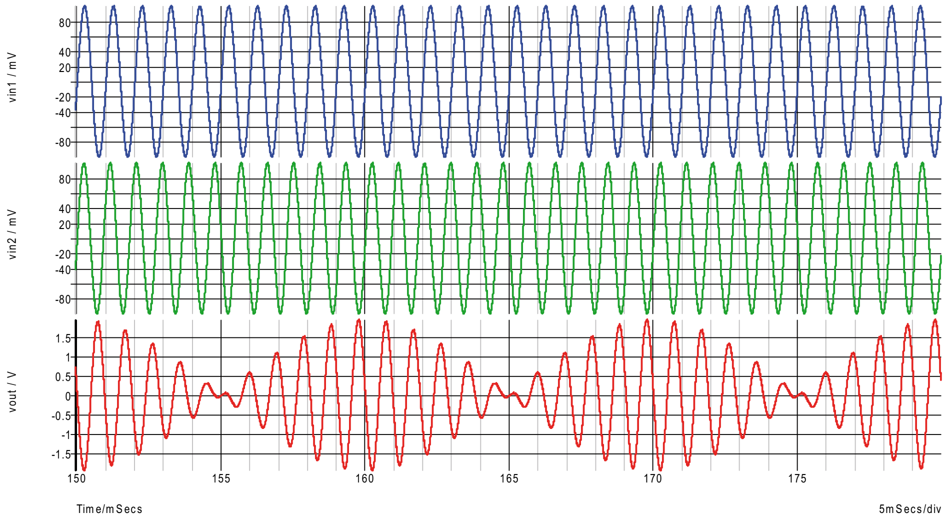

Figure 7 - Beat frequency output

In the above example v_1 has a frequency of 1.1kHz and v_2 1kHz. This generates a beat frequency of 100Hz. In audio processing, these non-harmonic tones are sometimes referred to “off-key notes”.

$f1 > 2f2$

If the two signals have widely different frequencies, then they simply add together in a manner where the two signals are visibly combined.

This is illustrated in Figure 8 and Figure 9.

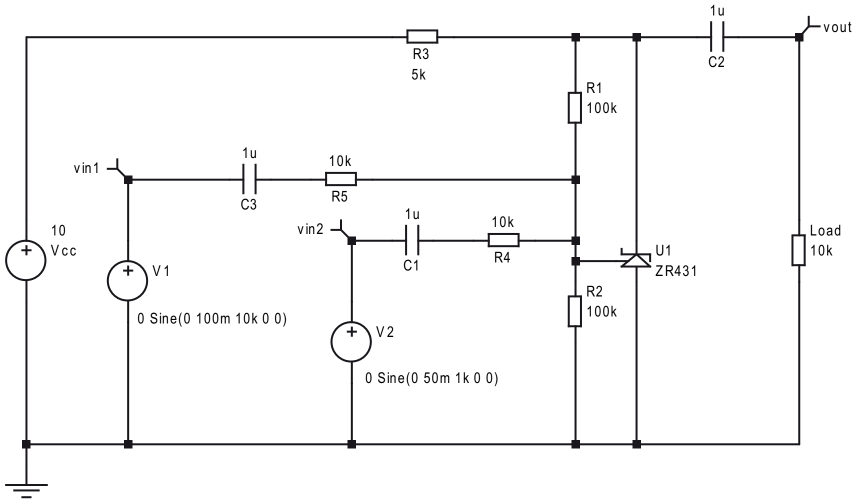

Figure 8 - Shunt regulator summing amplifier – *f1 > 2f2*.

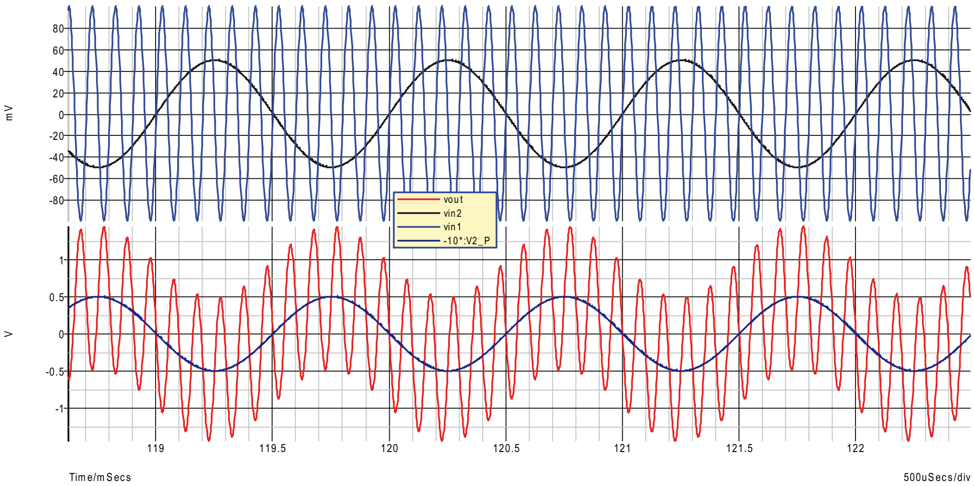

Figure 9 - Simulation result of summing amplifier – *f1* > *2f2* - Figure 8

The two input signals v_1 and v_2 (100mV@10kHz and 50mV@1kHz respectively) are shown together on the top trace (blue and black). An inverted copy of v_2 is displayed on the output to show the relationship between the output and the inputs.

Conclusion

This application note shows that a shunt regulator can be used as a summing amplifier or mixer using the same basic configuration. This demonstrates the flexibility of a shunt regulator.

Recommended further reading

AN66 - Designing with Shunt Regulators – *AC Amplifier*

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*

Appendix - Proof of Equation 1

Given $v_1 = V_1 \cdot \sin \omega t$

$v_2 = V_2 \cdot \sin(\omega t + \alpha)$

and $v_O = -(v_1 + v_2) = -V_O \cdot \sin(\omega t + \theta)$

Determine V_O and θ

Solution

Represent v_1, v_2 and v_O on a phasor diagram as shown below.

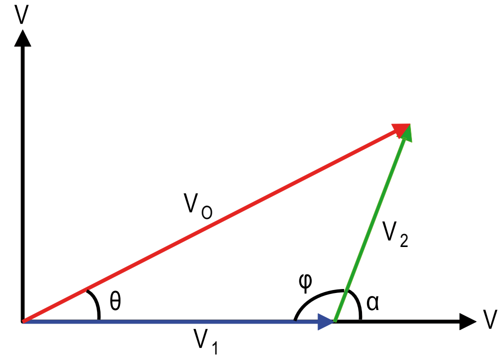

Figure 10 - Phasor diagram representation of v_1, v_2 and v_O

$$V_O^2 = V_1^2 + V_2^2 - 2V_1V_2 \cos\phi$$ - applying cosine rule

$$\cos\phi \equiv \cos(\pi - \alpha) \equiv -\cos\alpha$$ - identity

Gives $$V_O^2 = V_1^2 + V_2^2 + 2V_1V_2 \cos\alpha$$

Equals $$V_O = \sqrt{V_1^2 + V_2^2 + 2V_1V_2 \cos\alpha}$$ - as required.

$$\cos\theta = \frac{V_1 + V_2 \cos\alpha}{V_O}$$

After substitution $$\theta = \cos^{-1}\left[\frac{V_1 + V_2 \cos\alpha}{\sqrt{V_1^2 + V_2^2 + 2V_1V_2 \cos\alpha}}\right]$$ - as required.

Definitions

Product change

Diodes Incorporated the right to alter, without notice, specifications, design, price or conditions of supply of any product or service. Customers are solely responsible for obtaining the latest relevant information before placing orders.

Applications disclaimer

The circuits in this design/application note are offered as design ideas. It is the responsibility of the user to ensure that the circuit is fit for the user's application and meets with the user's requirements. No representation or warranty is given and no liability whatsoever is assumed by Diodes Inc. with respect to the accuracy or use of such information, or infringement of patents or other intellectual property rights arising from such use or otherwise. Diodes Inc. does not assume any legal responsibility or will not be held legally liable (whether in contract, tort (including negligence), breach of statutory duty, restriction or otherwise) for any damages, loss of profit, business, contract, opportunity or consequential loss in the use of these circuit applications, under any circumstances.

Life support

Diodes Zetex products are specifically not authorized for use as critical components in life support devices or systems without the express written approval of the Chief Executive Officer of Diodes Incorporated. As used herein:

A. Life support devices or systems are devices or systems which:
   1. are intended to implant into the body

or

   2. support or sustain life and whose failure to perform when properly used in accordance with instructions for use provided in the labelling can be reasonably expected to result in significant injury to the user.

B. A critical component is any component in a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or to affect its safety or effectiveness.

Reproduction

The product specifications contained in this publication are issued to provide outline information only which (unless agreed by the company in writing) may not be used, applied or reproduced for any purpose or form part of any order or contract or be regarded as a representation relating to the products or services concerned.

Terms and Conditions

All products are sold subjects to Diodes Inc. terms and conditions of sale, and this disclaimer (save in the event of a conflict between the two when the terms of the contract shall prevail) according to region, supplied at the time of order acknowledgement.

For the latest information on technology, delivery terms and conditions and prices, please contact your nearest Diodes' sales office .

Quality of product

Diodes Zetex Semiconductors Limited is an ISO 9001 and TS16949 certified semiconductor manufacturer.

To ensure quality of service and products we strongly advise the purchase of parts directly from Diodes Inc. or one of our regionally authorized distributors. For a complete listing of authorized distributors please visit: **www.diodes.com**

Diodes Zetex does not warrant or accept any liability whatsoever in respect of any parts purchased through unauthorized sales channels.

ESD (Electrostatic discharge)

Semiconductor devices are susceptible to damage by ESD. Suitable precautions should be taken when handling and transporting devices. The possible damage to devices depends on the circumstances of the handling and transporting, and the nature of the device. The extent of damage can vary from immediate functional or parametric malfunction to degradation of function or performance in use over time. Devices suspected of being affected should be replaced.

Green compliance

Diodes Zetex Semiconductors is committed to environmental excellence in all aspects of its operations which includes meeting or exceeding regulatory requirements with respect to the use of hazardous substances. Numerous successful programs have been implemented to reduce the use of hazardous substances and/or emissions.

All Diodes Zetex components are compliant with the RoHS directive, and through this it is supporting its customers in their compliance with WEEE and ELV directives.

Product status key:

"Preview"	Future device intended for production at some point. Samples may be available
"Active"	Product status recommended for new designs
"Last time buy (LTB)"	Device will be discontinued and last time buy period and delivery is in effect
"Not recommended for new designs"	Device is still in production to support existing designs and production
"Obsolete"	Production has been discontinued

Datasheet status key:

"Draft version"	This term denotes a very early datasheet version and contains highly provisional information, which may change in any manner without notice.
"Provisional version"	This term denotes a pre-release datasheet. It provides a clear indication of anticipated performance. However, changes to the test conditions and specifications may occur, at any time and without notice.
"Issue"	This term denotes an issued datasheet containing finalized specifications. However, changes to specifications may occur, at any time and without notice.

Sales offices

The Americas	Europe	Taiwan	Shanghai	Shenzhen	Korea
3050 E. Hillcrest Drive Westlake Village, CA 91362-3154 Tel: (+1) 805 446 4800 Fax: (+1) 805 446 4850	Kustermann-Park Balanstraße 59, D-81541 München Germany Tel: (+49) 894 549 490 Fax: (+49) 894 549 4949	7F, No. 50, Min Chuan Road Hsin-Tien Taipei, Taiwan Tel: (+886) 289 146 000 Fax: (+886) 289 146 639	Rm. 606, No.1158 Changning Road Shanghai, China Tel: (+86) 215 241 4882 Fax (+86) 215 241 4891	ANLIAN Plaza, #4018 Jintian Road Futian CBD, Shenzhen, China Tel: (+86) 755 882 849 88 Fax: (+86) 755 882 849 99	6 Floor, Changhwa B/D, 1005-5 Yeongtong-dong, Yeongtong-gu, Suwon-si, Gyeonggi-do, Korea 443-813 Tel: (+82) 312 731 884 Fax: (+82) 312 731 885