**AN67**

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

\[
\text{The transfer function of the circuit is given by}
\]

\[
v_{\text{out}} = R_1 \left( \frac{v_1}{R_{g1}} + \frac{v_2}{R_{g2}} + \ldots + \frac{v_n}{R_{gn}} \right)
\]

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 Figure 3.
Figure 3 - Two-input amplifier

If both \( v_1 \) and \( v_2 \) 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

\[
v_O = -V_O \cdot \sin(\omega t + \theta)
\]

Equation 1

where

\[
V_O = G_{ac} \cdot \sqrt{V_1^2 + V_2^2 + 2V_1V_2 \cdot \cos \alpha}
\]

Equation 2

and

\[
\theta = \cos^{-1} \left( \frac{V_1 + V_2 \cdot \cos \alpha}{\sqrt{V_1^2 + V_2^2 + 2V_1V_2 \cdot \cos \alpha}} \right)
\]

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**

If $v_1$ and $v_2$ are of different frequencies, one of two things will happen as follows.

$\omega < f_1 < 2f_2$

**Figure 5 - Simulation result of figure 4**

- blue trace ($f = 1\text{kHz}$)
- black trace ($f = 1\text{kHz}$)

AC gain,

Therefore,

Hence

i.e. $v_O$ leads $v_{in1}$ by 1.107 radians or about 63.43° and is inverted.
If \( f_1 \) and \( f_2 \) 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:

\[
V = -2V \cos\left(\frac{\omega_1 - \omega_2}{2}\right) t \cdot \sin\left(\frac{\omega_1 + \omega_2}{2}\right) t
\]

Equation 4

The cosine term contains half the frequency difference between \( f_1 \) and \( f_2 \) but, due to its interaction with the sine term, the waveform envelope it produces is that of \( f_1 - f_2 \), or beat frequency. The sine term behaves like a carrier signal (for the beat frequency) whose frequency is the average of \( f_1 \) and \( f_2 \).

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”.

\[ f_1 > 2f_2 \]

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 – $f_1 > 2f_2$. 
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 \( \theta \)

Solution
Represent \( v_1 \), \( v_2 \) and \( v_O \) on a phasor diagram as shown below.

\[ V_1 \]
\[ V_2 \]
\[ V_O \]
\[ V \]

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
\[ \cos \phi = \cos(\pi - \alpha) = -\cos \alpha \]
- 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.
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