Setting the Shunt Voltage on an Adjustable Shunt Regulator

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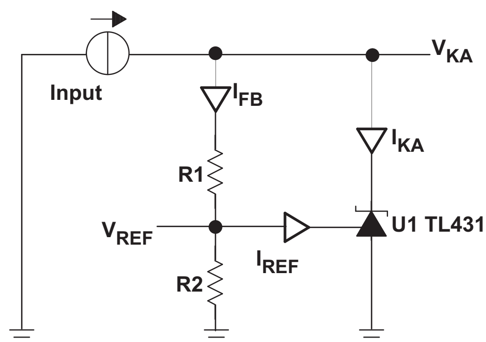
ABSTRACT

The ability to set the shunt voltage, V_{KA}, to any voltage between V_{REF} and the maximum rated voltage for the shunt regulator provides a lot of flexibility. It takes two resistors to set the shunt voltage. In an ideal common anode shunt regulator, the shunt voltage would be $V_{REF} \times (R_1/R_2 + 1)$. A few shunt regulators have a common cathode where the feedback voltage is relative to the cathode and are not covered in this document. The TL430, TL431, TL432, TLV431, TLVH431, TLVH432, and TL1431 are covered.



However real world shunt regulators have limited gain, non-zero reference input current, and suffer from cathode voltage modulation. This application report derives comprehensive formulas that accurately represent the relationship between the shunt voltage and feedback resistors. It also shows a practical example.

Shunt Regulator Limitations

Real world shunt regulators have three parameters that should be taken into account.

1. Dynamic impedance, Z_{KA}
2. Reference pin current, I_{REF}
3. Ratio of change in reference voltage to the change in cathode voltage, $\Delta V_{REF}/\Delta V_{KA}$.

The first parameter will cause a V_{REF} shift for all V_{KA} values and the last two only apply when V_{KA}, is set greater than V_{REF}.

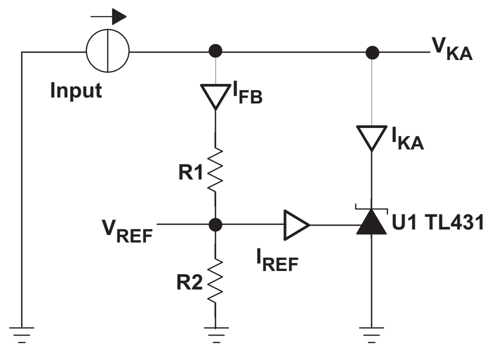
Z_{KA} offsets the V_{REF} in direct proportion to the cathode current. The data sheet generally specifies V_{REF} at a specific current. At any other current Z_{KA} impacts V_{REF}.

I_{REF} causes an inequality in the feedback resistor currents which changes the effective DC feedback ratio. This factor is often included in data sheet formulas.

$\Delta V_{REF}/\Delta V_{KA}$ specifies how much the V_{REF} voltage changes when the cathode voltage changes. This is a frequently ignored factor although the effect can be significant.

General Design Example

To calculate the values for resistors R_1 and R_2, it is required that the feedback current, I_{FB}, cathode current, I_{KA}, and desired shunt voltage, V_{KA}, are known.



electrical characteristics over recommended operating conditions, T_A = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		TL431C, TL432C MIN	TYP	MAX	UNIT
V_{ref}	Reference voltage	$V_{KA} = V_{REF}$, I_{KA} = 10 mA		2440	2495	2550	mV
$V_{I(dev)}$	Deviation of reference voltage over full temperature range	$V_{KA} = V_{REF}$, I_{KA} = 10 mA, T_A = 0°C to 70°C	SOT23-3 and TL432 devices		6	16	mV
			All other devices		4	25	
$\Delta V_{ref}/\Delta V_{KA}$	Ratio of change in reference voltage to the change in cathode voltage	I_{KA} = 10 mA	ΔV_{KA} = 10 V – V_{REF}		–1.4	–2.7	mV/V
			ΔV_{KA} = 36 V – 10 V		–1	–2	
I_{ref}	Reference input current	I_{KA} = 10 mA, R1 – 10 kΩ, R2 = ∞			2	4	μA
$I_{I(dev)}$	Deviation of reference input current over full temperature range	I_{KA} = 10 mA, R1 – 10 kΩ, R2 = ∞, T_A = 0°C to 70°C			0.4	1.2	μA
I_{min}	Minimum cathode current for regulation	$V_{KA} = V_{REF}$			0.4	1	mA
I_{off}	Off-state cathode current	V_{KA} = 36 V, V_{REF} = 0			0.1	1	μA
$\lvert Z_{KA}\rvert$	Dynamic impedance	$V_{KA} = V_{ref}$, f ≤ 1 kHz, I_{KA} = 1 mA to 100 mA			0.2	0.5	Ω

The table specifies when $V_{KA} = V_{REF}$ and I_{KA} is 10 mA the nominal V_{REF}, (labeled V_{NOM}) is 2.495 V. The reference voltage varies with cathode voltage at two different rates; it is –1.4 mV/V from V_{REF} to 10 V then –1 mV/V above 10 V. The reference pin current is 2 μA.

The Z_{KA} parameter offsets V_{REF} by $(I_{KA} – I_{NOM})$ x Z_{KA}

In addition, the $\Delta V_{REF}/\Delta V_{KA}$ parameter offsets V_{REF} by either –1.4 mV x (V_{KA} – 2.5 V) if V_{KA} ≤ 10 V or –10.5 mV –1 mV/V x (V_{KA}–10 V) if V_{KA}>10 V. The "–10.5 mV" constant is the V_{REF} offset as V_{KA} changes from V_{NOM} to 10 V, (10 V–2.495 V) x –1.4 mV/V.

Therefore:

If V_{KA} ≤ 10 V then;

$V_{REF} = V_{NOM} + (I_{KA} – I_{NOM}) \times Z_{KA} + (V_{KA} – V_{NOM}) \times –1.4$ mV/V

If V_{KA} > 10 then;

$V_{REF} = V_{NOM} + (I_{KA} – I_{NOM}) * Z_{KA} + (V_{KA}$ – 10 V) x –1 mV/V –10.5 mV

Now that V_{REF} is solved, R_1 and R_2 can be determined.

$R_1 = (V_{KA} – V_{REF}) / I_{FB}$

$R_2 = V_{REF} / (I_{FB} – I_{REF})$; Note that R_2 has less current than R_1

Practical Example

Design goal; TL431 cathode set to 12 V, cathode current 2 mA, and feedback current 0.2 mA.

Using the formula derived in the general example for V_{KA}>10 V.

$V_{REF} = V_{NOM} + (I_{KA} – I_{NOM}) \times Z_{KA} + (V_{KA} – 10\ V) \times -1\ mV – 10.5\ mV$

$V_{REF} = 2.495\ V + (2\ mA – 10\ mA) \times 0.2\ \Omega + (12\ V – 10\ V) \times –1\ mV – 10.5\ mV$

$V_{REF} = 2.4809\ V$

$R_1 = (V_{KA} – V_{REF}) / I_{FB}$

$R_1 = (12V – 2.4809\ V) / 0.2\ mA$

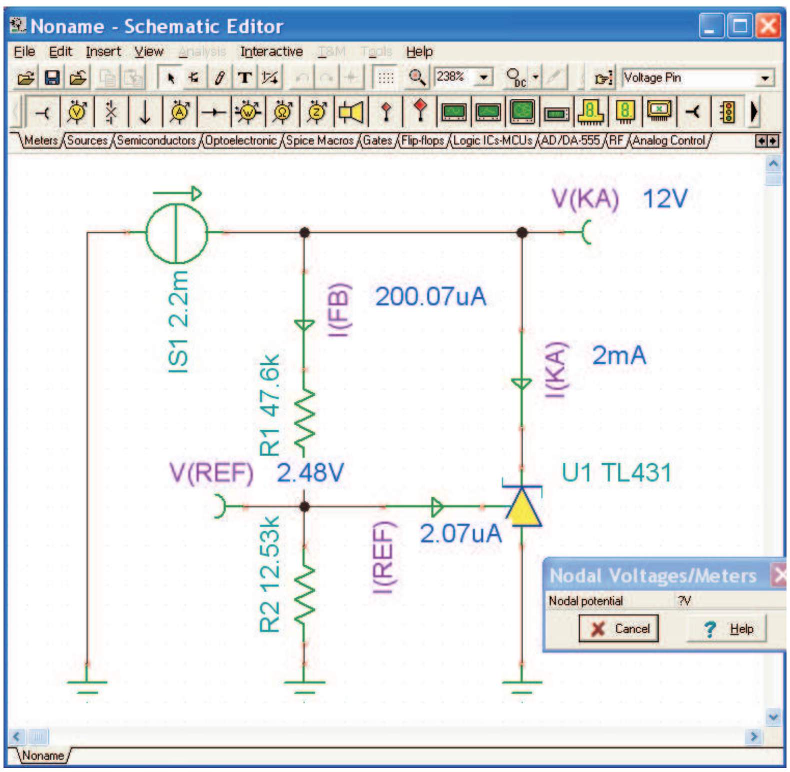
$R_1 = 47.596\ k\Omega$

$R_2 = V_{REF} / (I_{FB} – I_{REF})$

$R_2 = 2.4809\ V /(0.2\ mA–2\ \mu A)$

$R_2 = 12.530\ k\Omega$

Simulation using **TI-TINA** agrees with the solution.



The closest standard 1% resistor values are R_1 = 47.5 kΩ and R_2 = 12.4 kΩ. This results in a shunt voltage of 12.08 V which is a 0.66% error. Other resistor combinations may provide a shunt voltage that is centered better. A formula to test for R_1 values that may be closer to standard values using standard R_2 resistors is $R_1 = (V_{KA} – V_{REF})/(V_{REF}/R_2 + I_{REF})$. Moving R_2 up and down the resistor table five values revealed the best resistor pair was R_1 = 43.2 kΩ and R_2 = 11.3kΩ. This produced a more centered shunt voltage of 12.05 V and I_{FB} marginally increased to $(V_{KA}–V_{REF})/R_1$ = 0.22 mA.

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