FINE TUNING OF XTR75011 AND XTR75012 OUTPUT VOLTAGE

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ABSTRACT

This Application Note describes how to fine tune the output voltage of XTR75011 and XTR75012 regulators form the XTR75010 family based on very simple measurements.
This allows using the XTR75011 and XTR75012 as accurate voltage references in applications where the intrinsic spread of these parts cannot be afforded.
The detailed equations are provided for the user to determine the optimized set of tuning resistor values for the final application, based on a part-by-part highly accurate tuning method.
This application note also references a spreadsheet implementing all equations, where the user is guided to carry out each needed measurement and fill in the corresponding values in order to get the values of the external resistors needed.

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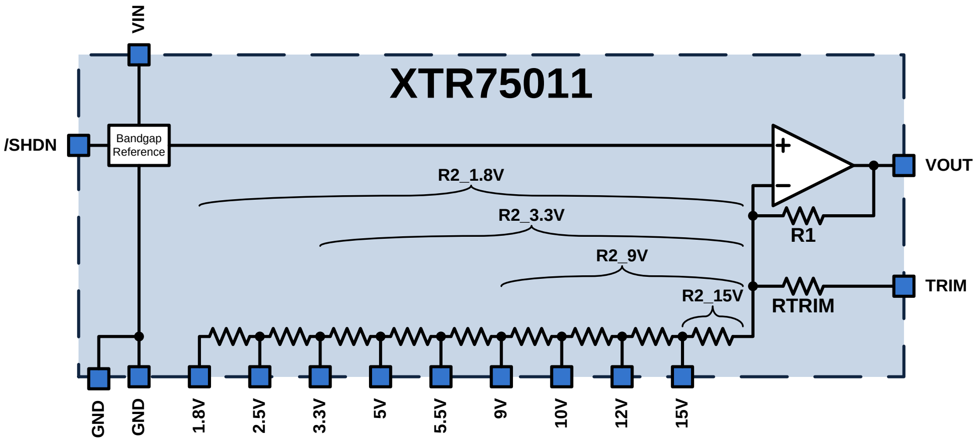
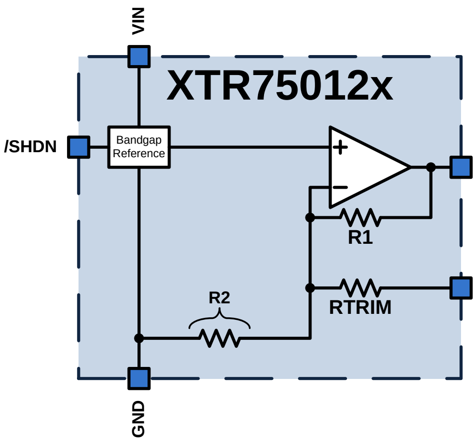
INTRODUCTION

XTR75011 and XTR75012 devices, in spite of being non-trimmed during fabrication or assembly, present a quite fair intrinsic accuracy better than 2%. However, in applications where a more accurate output voltage is needed, these devices offer the user the possibility to fine tune the output voltage by means of the TRIM terminal.
In order to fine tune the output voltage, an external resistor divider is needed in order to slightly change the feedback factor to compensate for the normal spread of the internal voltage reference.
The following sections provide an insight view of the XTR75011 and XTR75012 devices followed by a detailed procedure on how to obtain the needed information to fine tune the output voltage.

INTERNAL VIEW OF THE XT75011 AND XTR75012

Figure 1 shows the simplified block diagram of XTR75011 and XTR75012 (any package). In these diagrams the internal 1.2V voltage reference is shown as well as the output amplifier and the feedback network setting the output voltage. XTR75011 is a monolithic 16-pin device where any voltage from ten different choices (1.2V / 1.8V / 2.5V / 3.3V / 5V / 5.5V / 9V / 10V / 12V / 15V) can be obtained by grounding the appropriate terminal in the final application. XTR75012 is an 8-pin monolithic device where the output voltage is preset during the assembly stage.





Product Reference	Variant	Vout
XTR75012	A	1.2V
	B	1.8V
	C	2.5V
	D	3.3V
	E	5V
	F	5.5V
	G	9V
	H	10V
	I	12V
	J	15V

Figure 1. Simplified block diagrams of XTR75011 and XTR75012 showing internal feedback network.

As it can be seen for the XTR75011, the internal R_2 is formed by a multi tapered resistor, where each tap is used to get the different nominal output voltages. If all R_2 are left open (corresponding to $R_2=\infty$), the output voltage is 1.2V. From VOUT equation it can be seen that only voltages equal or greater than 1.2V can be obtained.

From Figure 1, neglecting the offset voltage and the finite gain of the error amplifier, the nominal output voltage can be obtained from

$$V_{OUT\_NOM} = V_{REF\_NOM} \cdot \left(1 + \frac{R_1}{R_{2\_VOUT}}\right) \qquad (1)$$

where V_{OUT_NOM} is the nominal (ideal) output voltage, V_{REF_NOM} represents the nominal (ideal) reference voltage 1.2V and R_1 (ideally 100kOhm) together with R_{2_VOUT} are the feedback resistive network determining the reference multiplying factor to get the desired V_{OUT_NOM}.

As it can be seen in Figure 1, the value of R_2 to obtain a given nominal output voltage, for R_1 fixed and equal to 100kOhm (ideally), depends on which resistor tap is connected to GND. The following table shows the equivalent value of R_2 as a function of the obtained nominal output voltage for R_1=100kOhm.

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Nominal Output Voltage (V)	Ideal Equivalent R2 for an Ideal R1 (100kOhm) (Ohm)
1.2	Infinite (open)
1.8	200000
2.5	92308
3.3	57143
5	31579
5.5	27907
9	15385
10	13636
12	11111
15	8696

In the previous paragraph, it is assumed that the internal reference voltage (1.2V) value, the feedback resistor R_1, the feedback ratio R_1/R_2 and the trimming resistor R_{TRIM} are all error free, thus producing an infinitely accurate output voltage equal to the selected nominal output voltage.

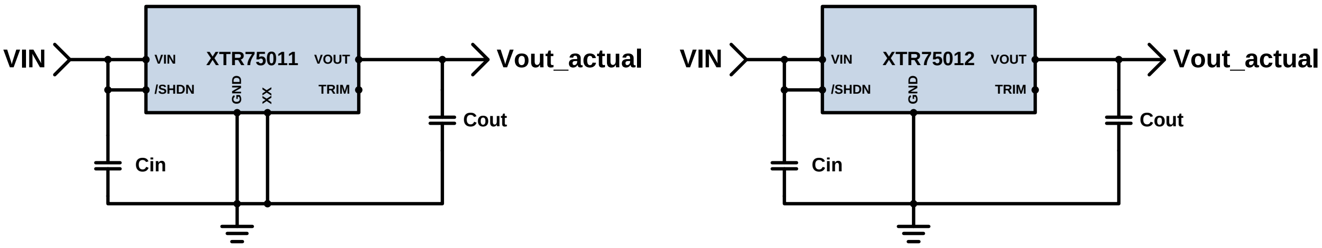

Figure 2. Untrimmed applications of the XTR75011 and XTR75012.

In the untrimmed application as shown in Figure 2, equation (1) can be rearranged to

$$\frac{R_1}{R_{2\_VOUT}} = \frac{V_{OUT\_NOM}}{V_{REF\_NOM}} - 1 \qquad (2)$$

where all parameters have their nominal values.

In integrated circuits, the absolute value of resistors is accurate to only ±15%, though the ratio between two resistors can be quite precise (about ±0.1%). Hence, the ratio of nominal resistors can be expressed as the ratio of actual resistors and vice versa.

This last sentence means that, for the untrimmed application shown in Figure 2, equation (2) can be rewritten as

$$\frac{R_{1\_NOM}}{R_{2\_VOUT\_NOM}} = \frac{R_{1\_ACTUAL}}{R_{2\_VOUT\_ACTUAL}} = \frac{V_{OUT\_ACTUAL}}{V_{REF\_ACTUAL}} - 1 = \frac{V_{OUT\_NOM}}{V_{REF\_NOM}} - 1 \qquad (3)$$

In the real life, the internal reference voltage, as well as the feedback and trimming resistors have some spread which makes the output voltage to be slightly different (within ±2%) for products in the XTR75010 family.

In the next section it is derived a general equation that provides the actual output voltage as a function of the actual internal reference voltage, R_1, R_2 and R_{TRIM}.

FINE TUNING THE OUTPUT VOLTAGE

The XTR75010 product family has available a TRIM pin which is intended for slightly changing the feedback ratio, thus fine tuning the output voltage. Figure 3 shows how two external resistors RA and RB can be connected in order to fine tune the output voltage.

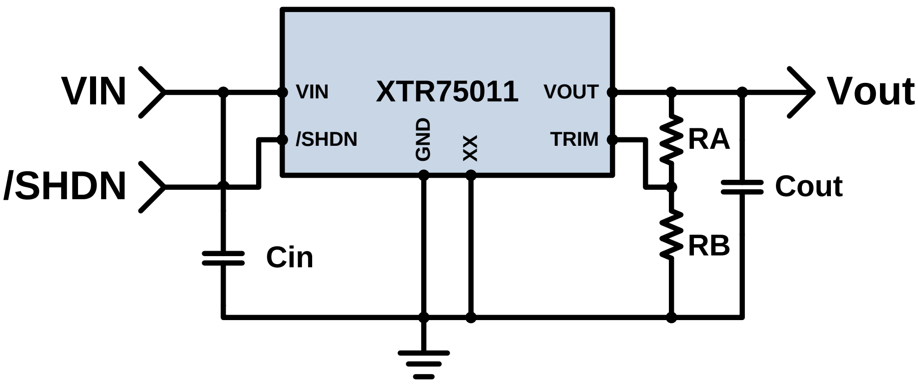

Figure 3. Simplified schematic showing the use of external resistors RA and RB to fine tune the output voltage of a XTR75012.

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When R_A and R_B are present in the feedback network, the actual trimmed output voltage is given by

$$V_{OUT\_TRIMMED} = \frac{(R_{A//B} + R_{TRIM\_ACTUAL})\frac{V_{OUT\_NOM}}{1.2V} + R_{1\_ACTUAL}}{R_{TRIM\_ACTUAL} + R_{A//B}\left(1 + \frac{R_{1\_ACTUAL}}{R_A}\right)} V_{REF\_ACTUAL} \quad (4)$$

In equation (4) V_{OUT_NOM} is the desired nominal output voltage (1.2V, 1.8V, 2.5V, etc), 1.2V represents the ideal value of the internal reference voltage, V_{REF_ACTUAL} is the actual value of the internal reference voltage of the used part, $R_{A//B}$ is the parallel of R_A and R_B, R_1 and R_{TRIM} are the feedback resistors.

Equation (4) shows that to retrieve the actual output voltage, given R_A and R_B, the actual value of internal components (R_1 and R_{TRIM}) as well as the actual value of the internal reference (V_{REF_ACTUAL}) must be known. Also, the trimmed output voltage does not depend on the value of R_A or R_B, but on their parallel value $R_{A//B}$. Hence, to fine tune the output voltage, it is needed to find the value of $R_{A//B}$ that makes the output voltage equal to the desired nominal output voltage. That is

$$R_{A//B} = \frac{R_{TRIM\_ACTUAL}\left(\frac{V_{OUT\_NOM}}{1.2V} - \frac{V_{OUT\_TRIMMED}}{V_{REF\_ACTUAL}}\right) + R_{1\_ACTUAL}}{\left(1 + \frac{R_{1\_ACTUAL}}{R_A}\right)\frac{V_{OUT\_TRIMMED}}{V_{REF\_ACTUAL}} - \frac{V_{OUT\_NOM}}{1.2V}} \quad (5)$$

The goal of fine tuning the part is to have the actual output voltage (V_{OUT_ACTUAL}) equal to a given nominal output voltage (V_{OUT_NOM}). In equation (5), if now it is considered that $V_{OUT\_TRIMMED}=V_{OUT\_NOM}$ (a perfectly tuned output voltage) we obtain

$$R_{A//B} = \frac{R_{TRIM\_ACTUAL}\left(\frac{V_{OUT\_NOM}}{1.2V} - \frac{V_{OUT\_NOM}}{V_{REF\_ACTUAL}}\right) + R_{1\_ACTUAL}}{\left(1 + \frac{R_{1\_ACTUAL}}{R_A}\right)\frac{V_{OUT\_NOM}}{V_{REF\_ACTUAL}} - \frac{V_{OUT\_NOM}}{1.2V}} \quad (6)$$

After some algebra, equation (6) can be rearranged as

$$R_{A//B} = \frac{R_{TRIM\_ACTUAL}\left(\frac{V_{REF\_ACTUAL}}{1.2V} - 1\right) + R_{1\_ACTUAL}\frac{V_{REF\_ACTUAL}}{V_{OUT\_NOM}}}{1 + \frac{R_{1\_ACTUAL}}{R_A} - \frac{V_{REF\_ACTUAL}}{1.2V}} \quad (7)$$

In the following, for the sake of simplicity, we have removed the "_ACTUAL" subscript from the "actual" values.

In order to obtain the unknown variables of equation (7) (R_1, R_{TRIM} and V_{REF_ACTUAL}), some direct measurements must be carried out on the part.

R_1+R_2 can be measured with an ohmmeter[1] from VOUT to the R_2 tap corresponding to the desired nominal output voltage. Let us call this value $(R_1+R_2)_{MEASURED}$. Hence, using equation (3) for the actual values of R_1 and R_2, we can then deduce the actual values of R_1 and R_2, as given by the equation system

$$R_1 - \left(\frac{V_{OUT\_NOM}}{V_{REF\_NOM}} - 1\right) R_{2\_VOUT} = 0 \quad (8)$$

$$R_1 + R_{2\_VOUT} = (R_1 + R_{2\_VOUT})_{MEASURED} \quad (9)$$

with solutions

$$R_1 = \frac{(R_1 + R_{2\_VOUT})_{MEASURED}}{\frac{V_{OUT\_NOM}}{V_{REF\_NOM}}} \quad (10)$$

$$R_{2\_VOUT} = (R_1 + R_{2\_VOUT})_{MEASURED} - R_1 \quad (11)$$

Once that R_1 and R_2 are known, we can proceed quite in the same way to obtain R_{TRIM}. To do so, it is needed to measure with an ohmmeter[1] R_{TRIM}+R_2 from the TRIM pin to the R_2 tap corresponding to the desired nominal output voltage. Let us call this value $(R_{TRIM}+R_2)_{MEASURED}$. As R_{2_VOUT} is already known from equation (11), it is obtained that

$$R_{TRIM} = (R_{TRIM} + R_{2\_VOUT})_{MEASURED} - R_{2\_VOUT} \quad (12)$$

[1] The part must be removed from the test fixture or application with no supply voltage applied nor any other component connected to the part.

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The only missing variable in equation (7) to know the value of $R_{A//B}$ (for a given R_A) providing the desired nominal output voltage V_{OUT_NOM} is V_{REF_ACTUAL}.

The actual reference voltage inside a part can be obtained from the direct measurement of the untrimmed output voltage (see Figure 2) and equation (3).

$$V_{REF\_ACTUAL} = \frac{V_{OUT\_NOM}}{V_{REF\_NOM}} V_{OUT\_ACTUAL} \quad (13)$$

At this time, all variables of equation (7) are known and the value of $R_{A//B}$ to obtain the desired nominal output voltage can be obtained.

Either R_A or R_B can now be freely selected in order to get the other from the value of $R_{A//B}$. We recommend choosing R_A under 200kOhm. Indeed, as R_A is an external resistor connected to the TRIM pin, the leakage currents (mainly at high temperatures) flowing through the ESD protections of the TRIM pin can buildup a voltage through R_A thus detuning the output voltage of the application.

PRACTICAL EXAMPLE

In the following example we use a spreadsheet that implements all equations above in which we need to fill in the measured values of (R_1+R_2), (R_{TRIM}+R_2) and the untrimmed V_{OUT}. This spreadsheet can be downloaded from the link AN-00166-12 Fine Tuning of XTR75011 and XTR75012 Output Voltage.

In this example, it is supposed that a 5V output voltage is desired. Implementing the schematics of Figure 2 with the “XX” pin being the “5V” pin of the XTR75011, we obtain a measured untrimmed output voltage of 5.083V. Removing the XTR75011 from the test fixture and measuring the resistance between pin VOUT and 5V, we obtain (R_1+R_2)=138.8kOhm. Repeating the operation between pins TRIM and 5V it is obtained (R_{TRIM}+R_2)=44.0kOhm. Selecting R_A=100kOhm and entering all values in the corresponding cells of the spreadsheet it is obtained that the needed R_B is 33.261kOhm. The closest value to 33.261kOhm from the E192 resistor series is 33.2kOhm. In the “Validation” section of the spreadsheet it is calculated the trimmed output voltage obtained with a valid value of R_B.

RESISTOR SIZING		
Parameter	**Value**	**Description**
Vref_nom	1,2	Nominal reference voltage.
Vout_nom	5	Nominal desired output voltage. Select from drop down list.
Vout_act	5,083	Enter value of actual measured output voltage without trimming.
R1/R2	3,17	Theoretical value of R1/R2 to get the desired nominal output voltage.
R1+R2	138800	Enter value of measured value of R1+R2 between VOUT and ground corresponding to the desired nominal voltage.
R1	105488,00	Internal feedback resistor.
R2	33312,00	Internal feedback resistor. Calculated from Vref_nom, Vout_nom and R1.
Rtrim+R2	44000	Enter value of measured value of Rtrim+R2 between TRIM and ground corresponding to the desired nominal voltage.
Rtrim	1,07E+04	Internal trimming resistor.
Vref error	2%	Error on actual Vref with respect to Vref_nom.
RA	1,00E+05	Enter value of external RA feedback resistor. Choose RA between 100kOhm and 200kOhm.
RA//RB	24959,36	Parallel reduction of RA and RB.
RB	**33261,12**	Needed RB to get the desired nominal voltage.
Vout_ideal	5,00	Verification of obtained ideal output voltage.
VALIDATION		
RB_actual	**33200,00**	Needed RB to get the desired nominal voltage.
RA//RB_actual	**24924,92**	Actual parallel of RA and RB.
Vout_trimmed	5,003	Verification of obtained actual output voltage with actual RB.

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