Temperature coefficient compensation of standard resistance (Beta coefficient compensation)

This post was created by lymex

http://bbs.38hot.net/thread-167995-1-1.html

(translated by Dipl.-Ing. André Bülau)

The first part, Q&A Introduction

Q1. What is the temperature coefficient of resistance?A1. It is temperature drift. Simply put, the resistance value changes with temperature. For precision resistors and standard resistors, the temperature drift is of course as small as possible.

Q2. What are Alpha coefficient and Beta coefficient?Hereinafter referred to as A and B. The A coefficient is the slope of the tangent line at a certain temperature point, and the B coefficient represents the overall curved resistance value/nominal value = 1 + D + A*(t-23) + B*(t-23)^2 where D is a A very small coefficient represents the deviation. The nominal value is the nominal resistance value at a standard temperature (23 degrees in the West).This formula shows that A is the coefficient of the first term of the temperature curve, and B is the coefficient of the second term of the temperature curve. For the sake of convenience, after this post, the unit of D is ppm, the unit of A is ppm/C, and the unit of B is ppm/C² (the same below) A is at a certain temperature, after a slight temperature change, how much resistance changes A metric. Since B is mostly non-zero, A changes with temperature. B indicates the speed at which A changes with temperature. For every degree of temperature change, A changes twice as much as B.

Q3. Which is important, A or B? Should we pursue A small or B small? For professional, A is important, because people have a constant temperature bath, and a small A is at the peak of the conic, so even if the temperature changes a little, the resistance change is very small, the so-called sweet spot. For amateurs, most of them do not have a constant temperature measure, and the temperature of the resistor changes with the room temperature, so that A also changes at any time, and it is meaningless to pursue a small A. Even if A=0 (under 23 degrees), A at 24 degrees is equal to 2B! For example, for a standard resistance, A=0.01 is very small, B=-0.6, that is, the temperature drift at 23 degrees is 0.01, but the temperature drift at 22 degrees is 1.2, and A at 24 degrees is -1.2. If the temperature deviation is larger, A will larger, -2.4 at 25 degrees, -4.8 at 28 degrees, far greater than 0.01 at 23 degrees. Therefore, for amateur conditions, B is more important.

Q4. How big are A and B? How young is ideal? A typical Evanohm can be compared. A is in the range of -0.1 to 0.1, which is a good indicator, and B is around -0.03, which is also acceptable. After compensation, it would be ideal for A to be in the range of -0.01 to 0.01, and of course B should be in the range of -0.002 to +0.002. From the point of view of the window temperature coefficient, it is ideal that it can reach within 0.05ppm (18 degrees to 28 degrees) after compensation. After all, some SR104 have a window temperature drift of 1.5ppm.

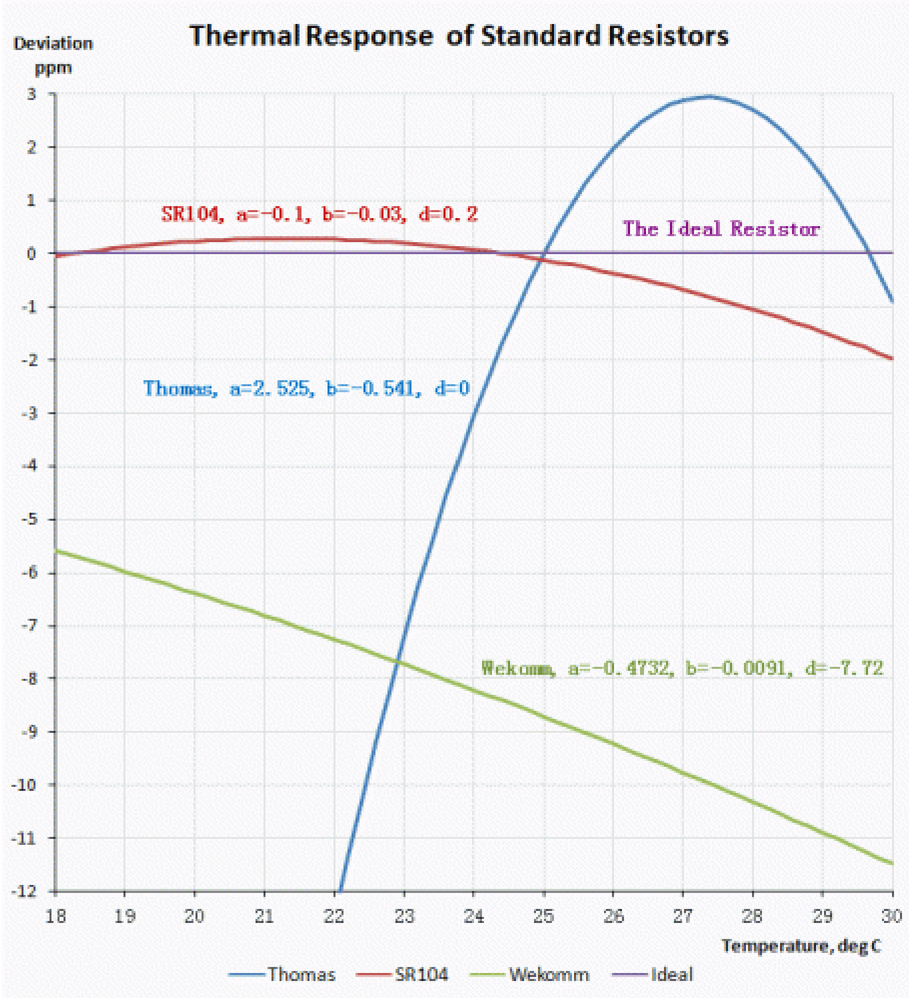
Q5. What determines A and B? Simply put, it is the quality of the resistor, but more specifically, it depends on the material, form, and manufacturing process. Since A is variable, for the same resistance, A can be very large, or it can be very small or even zero. The speed of change depends on B. Therefore, B is the decisive factor, and A will not be considered for the time being. B is mainly determined by the material: common manganese copper, B=-0.55, which is relatively large; Evanohm is a good resistance material, most standard resistors currently use this, B=-0.03, which is relatively small; Metal foil resistance, due to the special process, B is generally around -0.01, which is very small. In addition, the long-term stability of gold-sealed metal foil is good, so it is adopted by some recent standard resistors (such as Wekomm, Transmille, USR and ASR of AE, and myself).

Of course, if B is small, the size of A is important, but often the A of the metal foil resistor is not small and needs to be compensated. In addition, it can be seen that the B values of the above-mentioned types of resistors are all negative. Of course, there are some occasions, such as the rare K-shaped metal foil B value is positive.

Q6. Can A be compensated? Yes and No. Yes means that the original negative A resistance can be compensated by enameled wire (copper resistance, which has a large positive temperature drift and is relatively linear);
No, it means the resistance of positive A, it is difficult to find a suitable linear negative temperature drift compensation resistance; in addition, when B is very large, only compensating A is not very useful (in amateur without constant temperature conditions).
General rule: A of a large part of gold-sealed metal foil resistors is negative, which is convenient for compensation. However, A of a large part of the manganin resistance is positive, which is not easy to compensate.

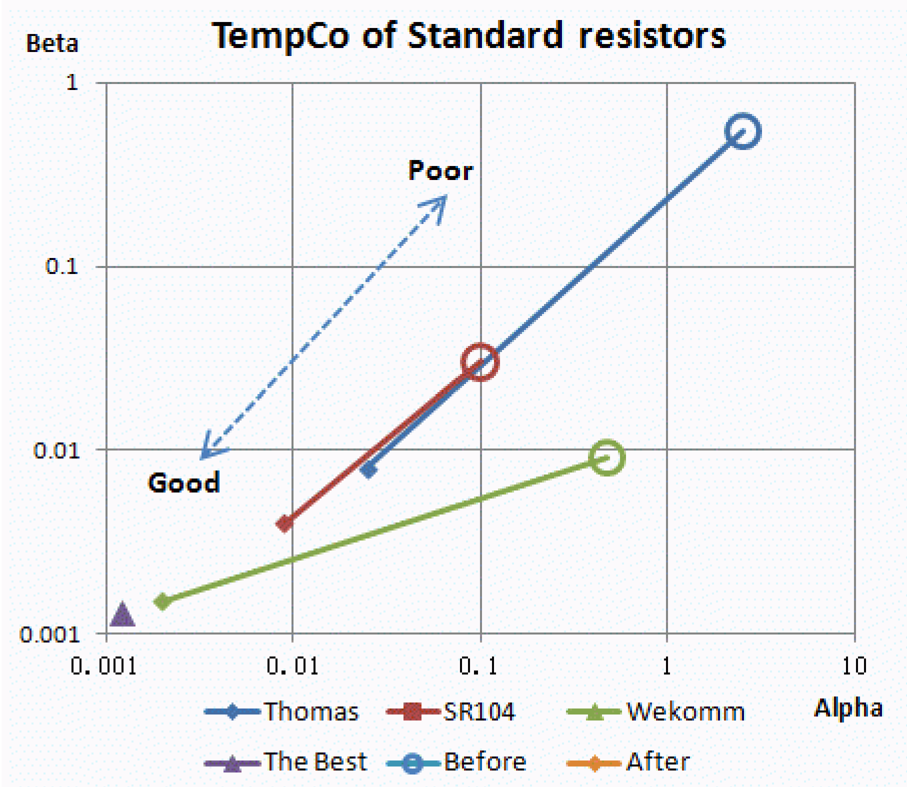
Q7. Can B be compensated?
This is what this topic mainly involves, the simple answer: most of them can.
First of all, B compensation must include A compensation at the same time, otherwise the temperature curve will be compensated to be very straight, but not flat, meaningless.
Secondly, the B coefficient of most resistors is negative, that is to say, the curve is convex. To compensate, you must find a concave resistor that changes rapidly with temperature.
Fortunately, NTC (negative temperature coefficient thermistor) just has a concave shape, and the resistance changes very quickly with temperature, the resistance range is also large, and it is stable and mature, making B compensation possible. B compensation is a problem that I have been discussing for several years. I have written a post before (http://bbs.38hot.net/thread-4928-1-1.html), but the B compensation there is not thoughtful. , The NTC used is not good. This time, a simpler, more reliable, and more complete method has been found to make B compensation realistic.
Simpler: one less compensation resistor, the circuit can be considered as the simplest;
more reliable: the use of temperature measurement type glass seal NTC that can be easily purchased, the weakening coefficient is improved; more complete: the relationship between the compensation range and the compensation parameters is given, Gives weakening calculations.

Q8. Why is compensation required?
Without compensation, the temperature drift may be relatively large. The following figure is the temperature curve (actual curve) of three very typical and very good standard resistances

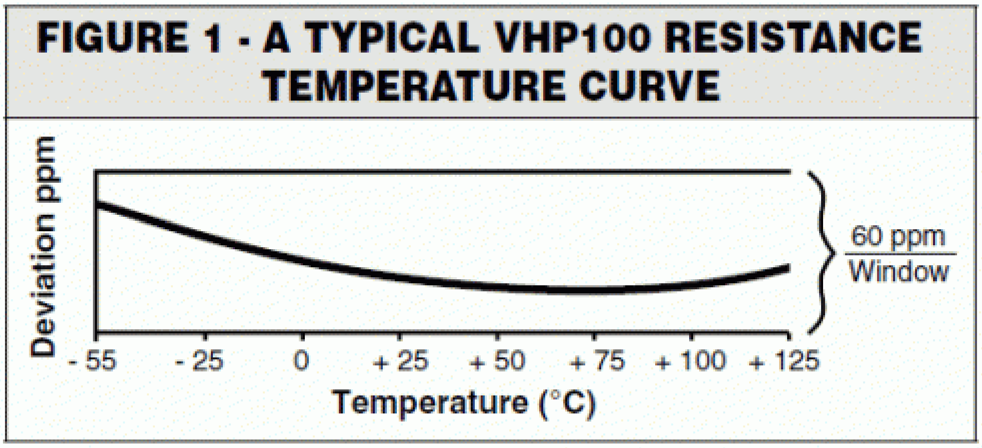


The horizontal axis is temperature, from 18 degrees to 30 degrees, which is common in amateur measurements. The vertical axis is the deviation/change of resistance in ppm.
The blue line is a Thomas 1 ohm resistor (http://www.nist.gov/calibrations... s-of-resistance.pdf). This kind of resistance has been the national standard of the United States before, and the national standard resistance of our country There is also one that has a large temperature drift, but people have a high-precision constant temperature oil tank, so they are not afraid of large temperature drift.

The green line is a recent Wekomm 10k standard resistor from Germany (EEVBLOG blogger Dave: http://v.youku.com/v_show/id_XMTQzMzQ0MDAxNg==.html), and the Vishay gold-sealed metal foil is used inside, although the curves are compared Straight (the B coefficient is small), but the tilt is very severe (the A coefficient is not small), and the deviation is relatively large.
How do you think the temperature drift of these two resistors is good? Is the influence of large temperature changes acceptable?
The red line is my own SR104, using Evanohm, this is obviously much better, but the resistance is reduced by 2ppm at 30 degrees, and the window change exceeds 2ppm, which is not too small.
The purple line is ideal, which is our ultimate goal for temperature drift compensation.
In fact, it is impossible to achieve the ideal after compensation, but some indicators can be increased by 10 times or even higher, and it is even difficult to measure the temperature drift. This is the reason for compensation.

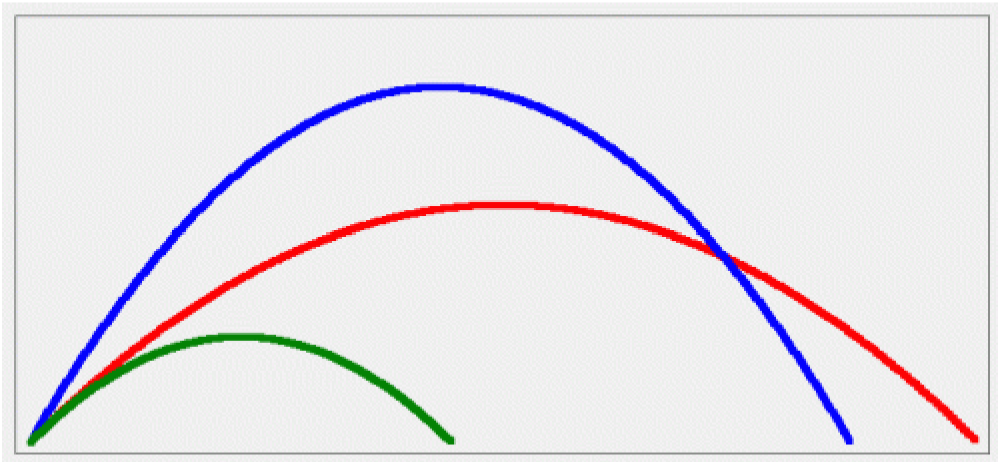


The purple triangle in the lower left corner represents the ideal compensation. After the blue Thomas resistance compensation, A and B can be reduced by several tens of times or nearly a hundred times. After the green Wekomm compensation, A is reduced by a hundred times, and the A and B of SR104 are also greatly reduced. Q9. How does B compensate? Will there be stability problems after compensation? With NTC compensation, there are only two methods: series and parallel. In fact, standard resistors with small and medium resistance are connected in parallel, and resistors with higher resistance are connected in series. Of course, when connecting in parallel, it cannot be connected directly. It is necessary to connect a resistor in series before connecting, otherwise there will be insufficient low-end compensation and excessive high-end compensation. In the end, how large the resistance value of NTC is, and how large the series resistance is, it is more troublesome to calculate. This is the next part to discuss. As for the issue of stability, as long as the parameters are appropriately selected, it will not. The temperature drift of NTC itself is very large. As long as there is a small compensation, the required effect can be achieved, so the weight is not large; in addition, the temperature measurement type NTC technology is very mature, and the glass-sealed NTC is consistent, curve conforming and stable. Reliable models can be found in terms of sex. Q10. Apart from A and B, are there other ways to express temperature drift? Yes, for example, the rectangle method, or box method, window method, is to draw the smallest rectangle that can include the temperature curve in the appropriate temperature range on the temperature-resistance curve. The height of the rectangle divided by the width is the temperature. Drift, Vishay often uses this method to express the temperature drift of its metal foil resistance:



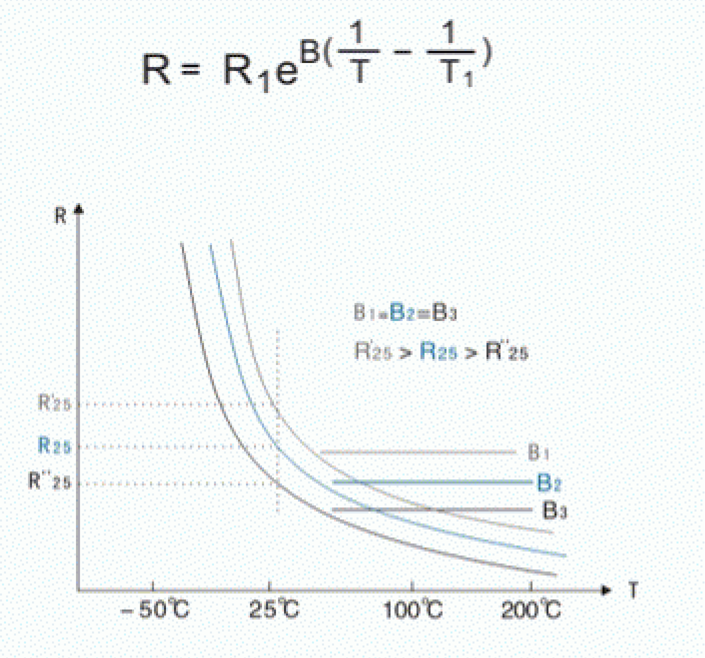
Part 2: Beta temperature coefficient compensation principle.

First, the resistance B to be compensated is all negative, that is, the temperature curve is convex, that is, the shape of a parabola:



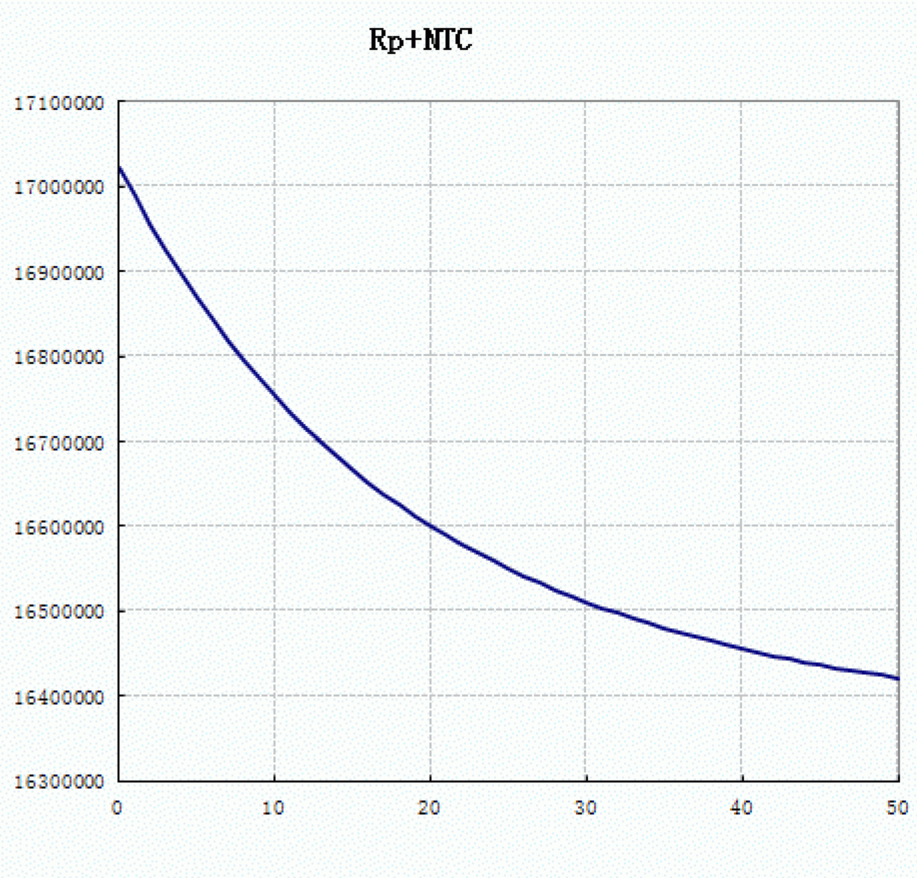
(It should be noted that the actual resistance curve in the normal temperature range may be only a part of the above curve)

So, what is the shape of the NTC temperature curve? The NTC resistance is an exponential curve, which is obviously concave when drawn, but it slopes downward:

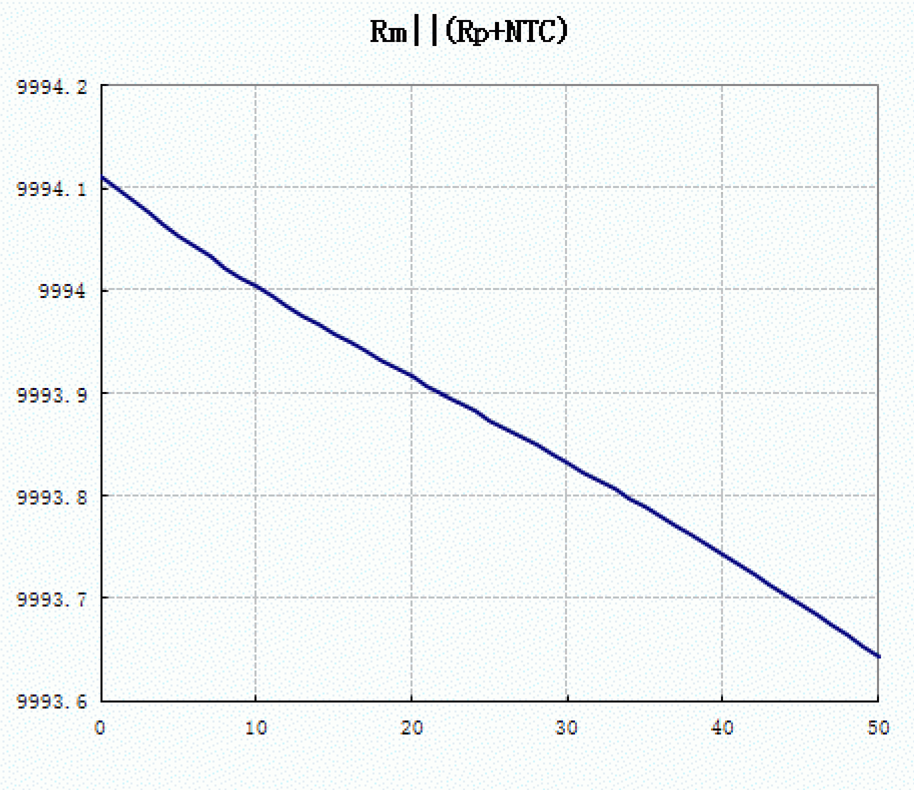


(1) B 值相同，阻值不同

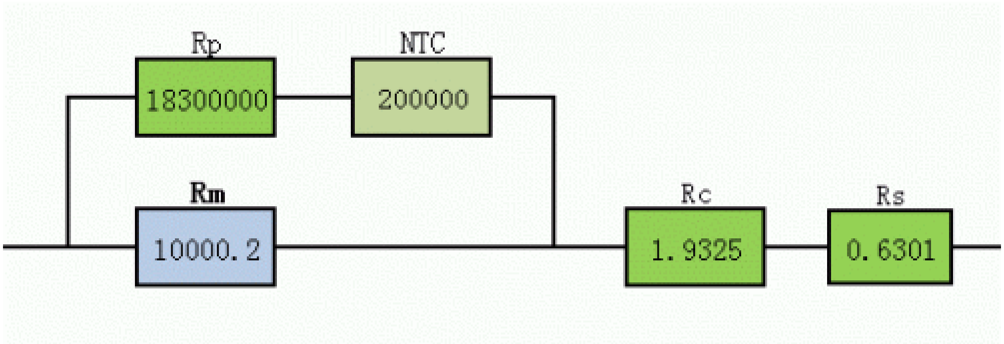
If NTC is connected in parallel with the compensated resistance Rm, it is expected that the unevenness can be canceled. However, NTC will decrease quickly at higher temperatures, and direct parallel connection will overcompensate. Therefore, a resistor Rp must be connected in series first. The curve is as follows, which is still concave:



After the adjustment of RTC and Rp, this compensation resistor is ideal. When connected in parallel to the main resistor Rm, it can be offset with the convex type of negative B coefficient, and an approximate straight line is obtained, indicating that the B coefficient compensation is good:

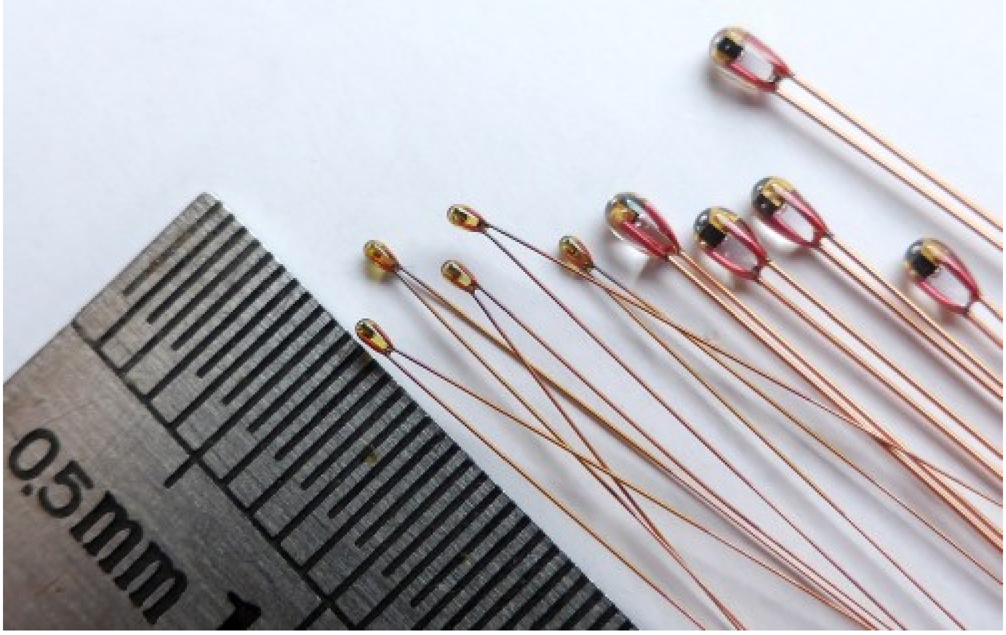


Of course, this line is sloping downwards, which means that the A coefficient is negative. This is not afraid, you can use copper resistance Rc to compensate back.



Didn't I say that positive A coefficient resistance is not easy to compensate? By appropriately choosing NTC and Rp, it can be ensured that A is negative, and this problem does not exist. So far, the B compensation principle has been explained. Of course, there are still some problems left, which will be explained one by one below. What if the B coefficient is positive? This does not matter, because I have never seen a standard resistor with positive B. The B of most resistance elements is also negative, and only a few of the hard-to-see K-type metal foils are positive. How does NTC choose? According to a large number of own experiments, NTC can achieve a good compensation effect in a very wide range (1 times to 180 times the main resistance Rm). The NTC is selected as small, and the Rp that needs to be connected in parallel is also small. In this way, Rs is relatively large in order to make up the nominal value, which is not conducive to the weakening of these resistances. Therefore, from this perspective, the NTC should be selected as large as possible. Of course, although the larger Rp has a large weakening factor, the stability of a high-resistance resistor is also worse, which will offset the increase of the weakening factor. On the other hand, NTC that is too large will not be compensated for the B value, and the compensation characteristics will also change in the extreme state. At the same time, because the overall resistance of Rp+NTC is large, the resistance becomes limited after being connected to the main resistance, so Rc and Rs are not left. There is enough margin (the disadvantage of positive deviation Rm, negative A). Therefore, it is generally appropriate to choose between 100 times and 150 times the main resistance of NTC. For a standard resistance of 10k, NTC is between 1M and 1.5M. If the negative value of A cannot be compensated, the NTC resistance should be appropriately reduced, for example, 10 to 50 times the main resistance. NTC's B value (not Beta coefficient) is generally better to choose a larger value, such as 3950, 4250, 4700, so that a larger relative compensation amount can be obtained, or if the B value is larger, the Rp will be larger. Of course, for a relatively large resistance with a small B coefficient (Beta) and a negative A coefficient, a larger Rc is required to compensate. In this way, it is hoped that Rp should be smaller, and NTC with a smaller B value can be used at this time. The NTC resistance range is actually very wide, and temperature measurement types from 1k to 1.5M are easy to buy, and there is no problem with the compensation of standard resistances near 1k to 10k. Even for a 1 ohm resistor, the required 150 ohm NTC can be obtained through multiple parallel connections.

As for the type of NTC, glass-encapsulated temperature measurement type is preferred. This type of NTC has high accuracy, good consistency, high stability, and is not affected by humidity. For example, a large number of MF58, DO-35 package similar to 1N4148 diode, or Japanese Shibaura brand single-ended package:



What is the most suitable standard resistance range for this compensation method? It is most suitable for 1k and 10k, 100 ohm and 100k are also very good, 10 ohm is also good, 1 ohm is slightly difficult (practical difficulty, not calculation difficulty), 1M and above require additional compensation methods.

So, how to calculate the key parameter Rp? This is indeed more difficult, because it involves exponential curves and solving nonlinear equations. However, I found an experiment-observation method. By manually adjusting Rp and observing the final curve to make it as straight as possible, I can get Rp conveniently and quickly. If the curve is convex, it means that the compensation is insufficient and Rp should be reduced; on the contrary, if the curve is concave, it means that the compensation is over-compensated and Rp should be increased. When adjusting Rp, not only the curve shape can be observed, but also the relevant numerical table can be seen to see the qualitative results after compensation. These specific adjustments will be specified in the example, and I will attach all the Excel files. Similarly, the resistance Rc is also adjusted manually-observe the curve, so that the curve is not only straight, but also flat, so that the A coefficient is also compensated. When the curve is downhill, it means that the compensation is insufficient and Rc should be increased; when the curve is uphill, it means that the compensation is over-compensated and Rc should be reduced. In addition, there is a series of Rs not drawn, which is used to compensate for the resistance deviation. This adjustment is easy, and the final resistance can reach the nominal value. It should be noted that after the B coefficient is compensated, the curve is no longer a quadratic curve, so it is meaningless to talk about the B value. In view of this, in addition to the partial retention of the A parameter, the overall effect of the compensation is expressed by the rectangle method, to see how many times the height of the rectangle has dropped.

Improved, times	
Deviation	1,539
Box variation	415
Alpha23	168
Box TC	415

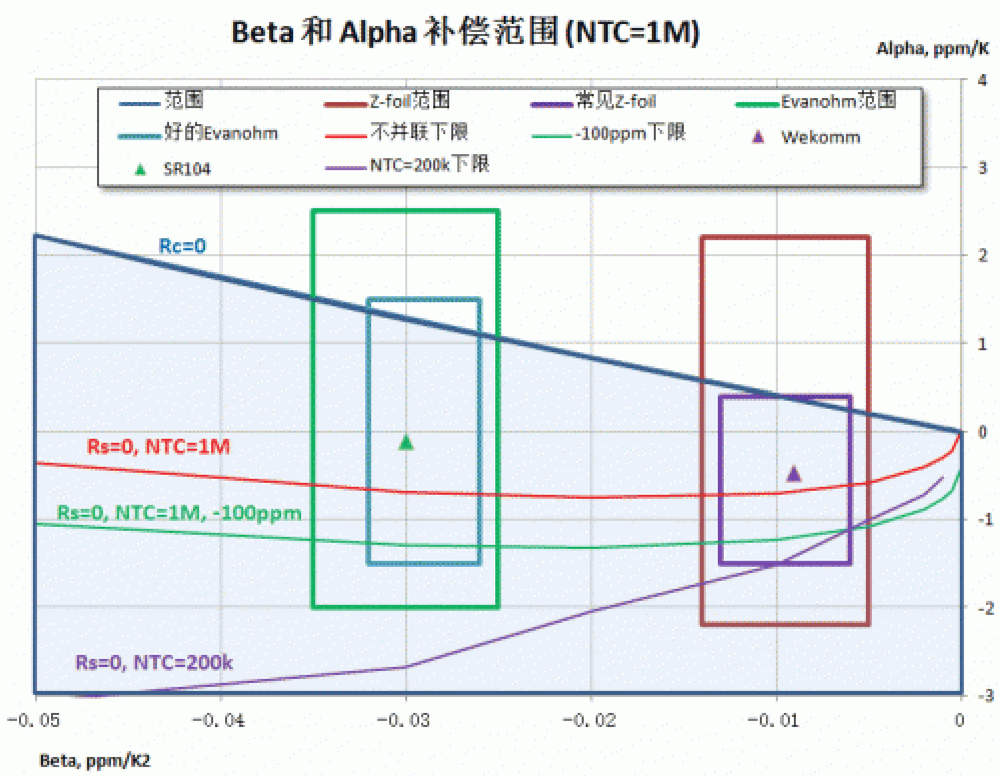
The above table shows how many times the various parameters have been improved after compensation. The values in the table will change at any time after adjusting each parameter. Deviation 1539 shows that the deviation has been improved by more than 1500 times;

Alpha23 168 shows that the A parameter has been improved by 168 times; Box TC 415 shows that the rectangular temperature coefficient (window temperature coefficient, box temperature coefficient) has been improved by more than 400 times. There is another very important question: How to choose Rp, Rc, Rs? What effect does the addition of these resistors (including NTC) have on the final result? This is actually a question of the **weakening factor** , that is, how much of the contribution of these resistance changes to the total resistance? This is also a **sensitivity analysis** , which can be obtained through partial derivatives, and is given in two ways in a table. One way: when Rp changes by 100ppm (other parameters are similar), how much does the total resistance change? Another way: the final resistance is allowed to change by 0.1ppm, how much is the corresponding change in Rp? The following table is an example of Wekomm resistance compensation. The values are calculated and will change with the changes of various parameters:

Sensitivity Analysis		
Param	100ppm	allowed
Rm	99.921	0.1
Rp	0.038	265.3
NTC	0.001	13,530.8
Rc	0.020	506.8
Rs	0.017	571.8

Rm 99.921 means that a 100ppm change in Rm has an effect of 99.921ppm on the final result, which is almost 100%; Rm 0.1 means that a change of 0.1ppm in Rm has an effect of 0.1ppm on the result, and the weakening factor is 1 (no weakening).
Rp 265.3 shows that the Rp weakening factor is 2653 times, which is very large, that is, the change of Rp 265.3ppm will have an impact of 0.1ppm on the final result.
NTC 13530.6 shows that NTC has been weakened by more than 130,000 times, and the long-term stability of NTC has negligible influence on the final result.
Rc 506.6 shows that the copper resistance has been weakened by more than 5000 times, and the aging of the enameled wire is very small, so the effect of this Rc can also be ignored.
Rs 571.8 shows that this series of small resistance has also been weakened by more than 5000 times, just choose a piece of resistance wire to be a wire wound resistor. Since these additional resistances are weakened greatly, the contribution of their own temperature drift to the final resistance is relatively small, so the temperature drift of these resistors is not included in the calculation.

Temperature coefficient compensation range A and B compensation, not any resistance can be compensated, but there is a certain range of compensation. In brief, if B is positive, it cannot be compensated, but if B is negative, the amount of compensation is relatively small. After NTC compensation, a large negative temperature drift cannot be produced, so A cannot be large. Specifically, for the metal foil resistance (set B=-0.01), it can only be suitable for A not greater than 0.41 (it can be negative). Fortunately, the gold-sealed metal foils I tested have a negative temperature drift, so there is no problem with compensation.



In the figure, the light blue shaded range is the range that this method can compensate, which is calculated based on the NTC 100 times the main resistance (for Rm=10k, NTC=1M, B=3950). The red line frame is the Z foil range specified by Vishay, most of which are within the compensation area, and most of the measured ones are within the compensation area (purple wire frame).

The green box is the common Evanohm area, most of which can be compensated, and the blue is the excellent Evanohm area, indicating that as long as it is a good Evanohm resistor, it can basically be compensated.

The manganese copper near B=0.55 is not drawn, and the compensation range A can reach +48 without any problems.

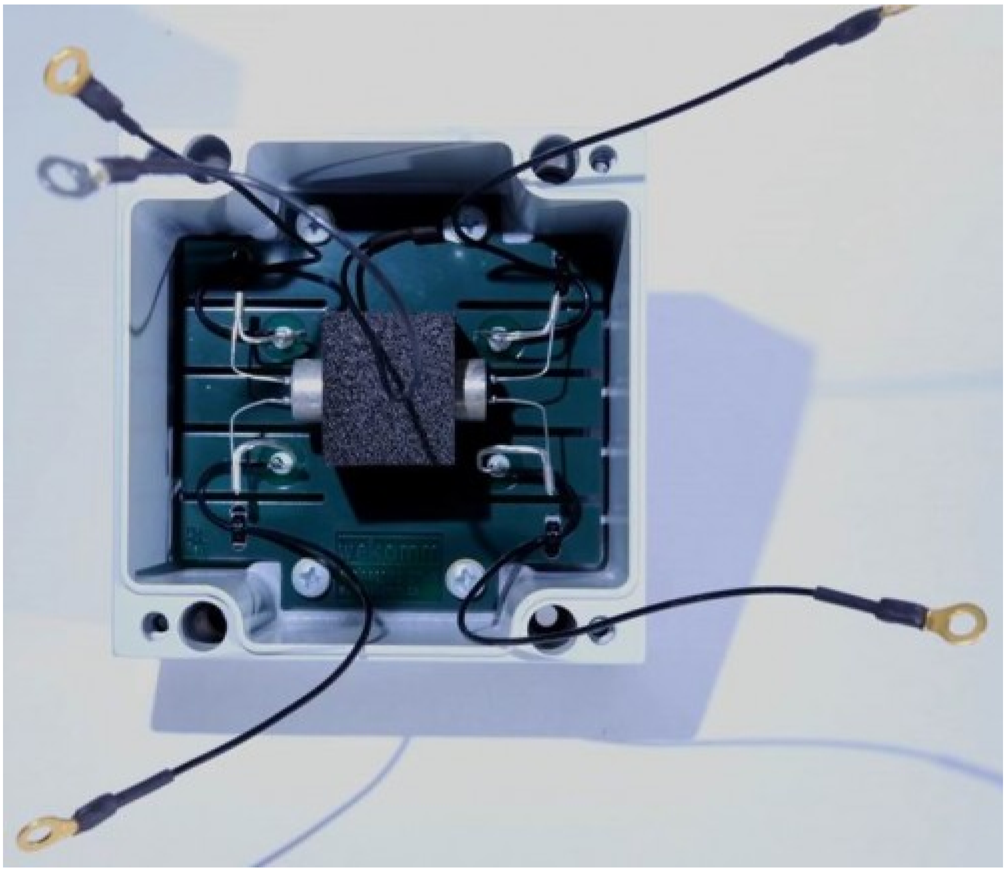
On the other hand, if the negative value of A is relatively large, then a larger copper resistor is needed in series, so the total resistance may exceed the nominal value. The above connection method will not work. The red thin line is the smallest A. The compensation range cannot be smaller . However, two methods can be used to expand at this time, one is to connect a large resistor in parallel, or the Rm is smaller when the reservation is started. The green thin line is to book -100ppm (that is, the 10k resistor is booked as 9.999k). It is equivalent to a 100M resistor in parallel with a 10k resistor, so there will be more series margin, and the compensation range will be increased to a thin green line. Another way is to reduce NTC. The purple thin line is the lower limit of compensation when NTC is 20 times the main resistance (NTC is 200k when Rm=10). In addition, you can see a green triangle and a purple triangle, which represent the SR104 and Wekomm respectively. They are both relatively good Evanohm and metal foil resistors, and they are naturally within the range that can be compensated. For example, if the metal foil resistance B=-0.01, the range of A that can be compensated is -0.6 to +0.4. If it is greater than 0.4, it cannot be compensated, but even if A=-3, it can be compensated. Just connect one in parallel with Rm. The resistance value is 15M to 16.7M, or Rm is 9994 ohms

In fact, Vishay's metal foil resistance A is basically not lower than -2, so Rm is required to be -340ppm (Rm=9996.6), that is, a 29M resistor is required in parallel for 10k.

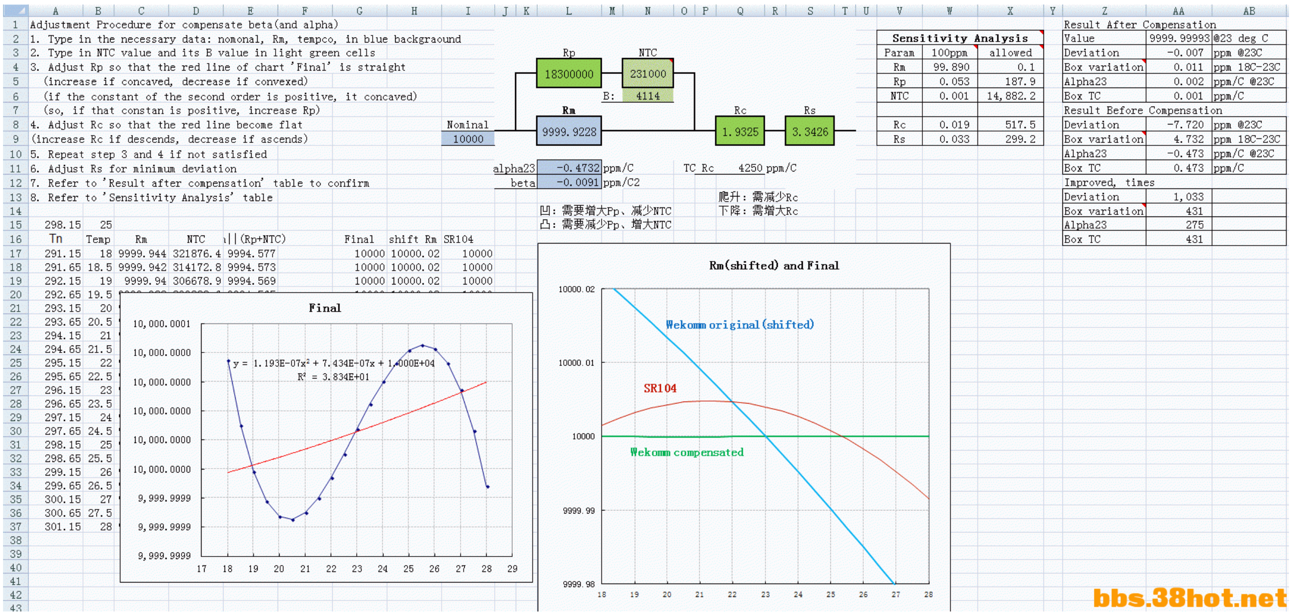
Part 3: Temperature coefficient compensation example: Wekomm RS9010A 10k standard resistance

The first step of the compensation process is to obtain D, A, and B of the compensated resistance.
D is the deviation, and A and B are two temperature coefficients. The formula is shown in the first post.
For this Wekomm resistor, these three parameters have been accurately determined when leaving the factory:

D=-7.72 (large enough) A=-0.4732 (not small) B=-0.0091 (very good) D and A are relatively large. The reason is that Wekomm adopts the doctrine when making this standard. The resistance core is A Vishay VHA518-7 gold-sealed metal foil resistor was led out intact without any correction or compensation.



If DIY standard resistance, these three parameters are unknown, then it needs to be tested first, which is the basis of compensation.
As for how to measure these three parameters, please refer to other posts in this forum, so I won’t repeat them here.
The second step of the compensation process: written compensation is paper compensation, rather than actual physical compensation. I am doing it in Excel here.



After compensation, A was reduced from 0.47 to 0.002, and the window drift was also reduced from the original 0.47 to almost negligible 0.001.

The upper left part is the operation prompt, the upper middle part is the structure diagram and the original data input part, and the upper right part is the two result tables.
The final chart on the lower left is the result of compensation, where blue is the actual curve and red is the quadratic fitted trend line.
The middle and lower chart is the comparison before and after compensation, and SR104 has been added. The process of writing compensation is as follows: 1. Enter the original data into the 4 blue background grids: nominal value, original resistance value, A, B 2. Select SHIBAURA Pxx-312 thermistor, the NTC is at 25 degrees 231k, B value 4112, fill in the light green grid; Rc=0, Rs=0, Rp choose 10 times NTC, first fill in the green grid 3. Change Rp so that the red line in the Final table is a straight line. Increase Rp when the red line is concave and decrease Rp when the red line is convex. This step does not need to be accurate for the first time. 4. Change Rc so that the red line in the Final table is horizontal. When the red line drops, Rc is increased, and when the red line rises, Rc is decreased. 5. After changing Rc, it will affect the unevenness of the red line. Go back to step 3 to re-adjust Rp, and then repeat step 4 to adjust Rc. The purpose of these 2 steps is actually to make the AA4 unit a minimum of 6. Finally, the red line is flat and straight. At this time, you can change Rs to make the deviation (see AA3 unit) the smallest . 7. Refer to the upper right table to confirm the value 8. Refer to the upper right Sensitivity analysis table, confirm the value so that the Excel written compensation has been completed. The actual Excel sheet has been filled in with my own compensation data. It can be seen that the A coefficient has improved by 275 times, the window temperature coefficient has improved by 431 times, and the deviation has improved by 1033 times.
In addition, when I was compensating, the red line was not very flat but upturned. The reason was to take care of the window temperature (AA4) instead of blindly pursuing a small A parameter.
The sky blue curve in the middle and lower graphs is before compensation and has been shifted, otherwise the curve will be worse. The green curve is compensated, it is very close to the ideal X axis, and it is much better than the SR104.
Of course, this is only written compensation. Actual compensation may not be so ideal due to various factors. Therefore, written compensation does not necessarily have to be very accurate.

The third step of the compensation process, physical compensation
is to obtain (purchase or make) the required resistance (NTC, Rp, Rc, Rs) according to the results of the written compensation, and actually assemble it.
Since this Wekom resistor is not mine, it can't be implemented to this step, so I can only talk about it here.
In addition, the resistance core used in this Wekomm resistor is 4-wire, which is not suitable for compensation.
Rp is 18.3M, which is weakened by 1879 times. It only needs a resistance whose annual change does not exceed 200ppm. You can choose a resistance such as RN55 for series connection, 10M+7.5M+750k+50k.
Rc is 1.9325 ohms, and you can use 0.15 enameled wire Production, double wires are wound in parallel, the end is welded to fine-tune Rs to 3.3426 ohms, and it needs to be wound with manganese copper wire of about 0.15.

The fourth step of the compensation process, testing
is to re-test the compensated D, A, and B if they are satisfied, the end. If you are not satisfied, that is, you feel that a certain value of D, A, B is still too large, you need to modify

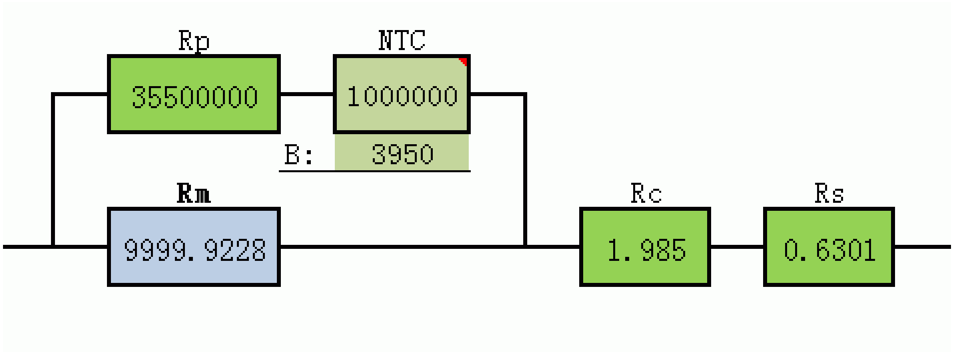
the fifth step of the compensation process.
The reasons for modifying the compensation are not ideal, and it may be the original test D, A, B Inaccurate, it may also be that the resistance value and B value of NTC are inaccurate, and the selection or production deviation of Rp, Rc, Rs is not ruled out. Then there are errors in subsequent tests D, A, and B. In any case, the modification can be done through Rp, Rc, Rs instead of changing NTC.

ChangeRp, Rc, Rs, make the Excel parameters meet the last actual measured value; record the Rp, Rc, Rs at this time, and find the difference from the first time; according to this difference, re-correct Rp, Rc, Rs, and again Physical changes. For example, the first time Rc=1.9325, the measured A=0.025 is unsatisfactory, and when Rc=2.04 is later modified, A=0.025, Rc increases by 0.1075, indicating that Rc is actually reduced by 0.1075.
Physically modify Rc, reduce by 0.1075 Euro, and increase Rs by 0.1075 Euro to complete the modification and compensation.

Update the compensation table and change the temperature drift of copper resistance. Originally calculated according to 4250ppm/K at 0 degrees, it is now 3900ppm/K at 23 degrees.

Compensation example: The second compensation of Wekomm RS9010A

is still the Wekomm resistance, but the NTC is changed to compensate for different parameters. Last time NTC chose Shibaura 231k resistor, this time NTC was changed to MF58, the resistance value increased to 1M, B=3950, which is very common.
The compensation process is the same as last time, omitted. An Excel file is attached. Let's just look at the result.



Rp=35.5M, which is 3775 times weaker, can be obtained by connecting resistors like RN55 with 10M+10M+10M+5M+500k in series.
Rc=1.985, Rs=0.6301, you need to do it yourself, and the weakening factor is more than 5000 times.
NTC is weakened by more than 130,000 times and will not have any impact on the long-term stability of the final resistance.

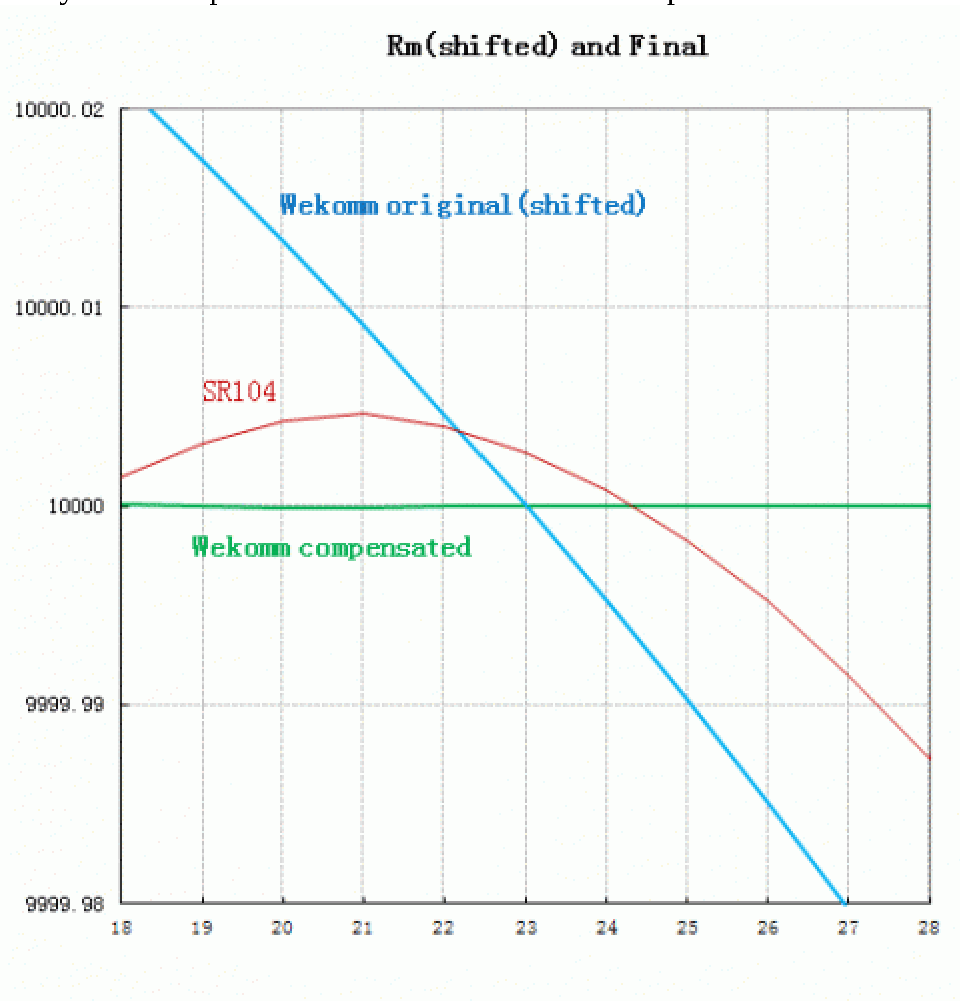
Take a look at the result table in the upper right part of the Excel spreadsheet:

Result After Compensation

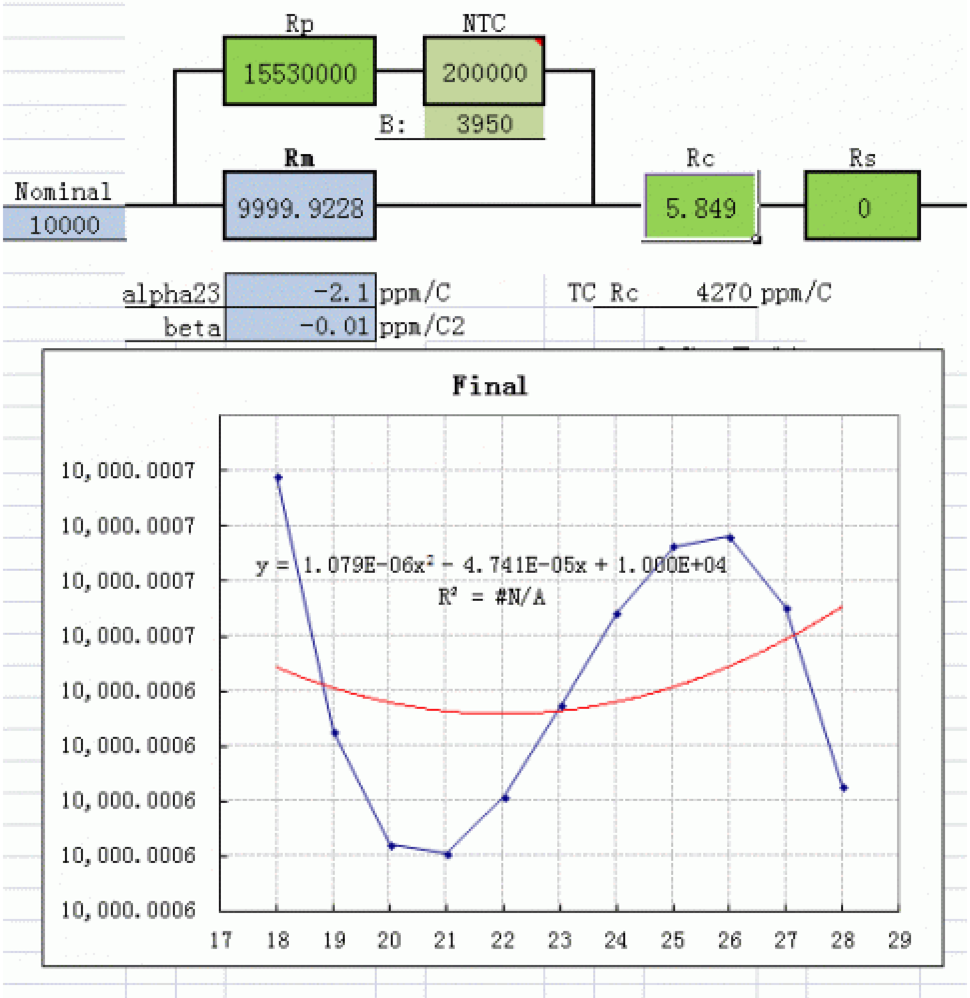
Value	10000	@23 deg C
Deviation	0.000	ppm @23C
Box variation	0.010	ppm 18C-23C
Alpha23	0.003	ppm/C @23C
Box TC	0.001	ppm/C

Box variation=0.01ppm, which means that under the temperature change from 18°C to 28°C, the resistance value only changes 0.01ppm, and the equivalent window temperature coefficient is

0.001ppm/K.
Then look directly at the temperature curve before and after compensation:



The blue line is before compensation, and the translation has been done, otherwise the effect will be worse. The green line is compensated, which is ideal.
This example can also show that this compensation method is more adaptable to NTC. For the occasion where the resistance value is different by more than 4 times and the B value is also changed, perfect compensation can still be obtained by adjusting Rp.
In fact, the compensation parameters here are better than the first time, because the weakening factor of each resistance is larger, and the resistance value of Rs is smaller.
Additional compensation: 10k metal foil resistance, A=-2 larger
Rm=9999.9228 is still the above Wekomm, B=-0.01 typical metal foil, A=-2 is a relatively extreme metal foil.

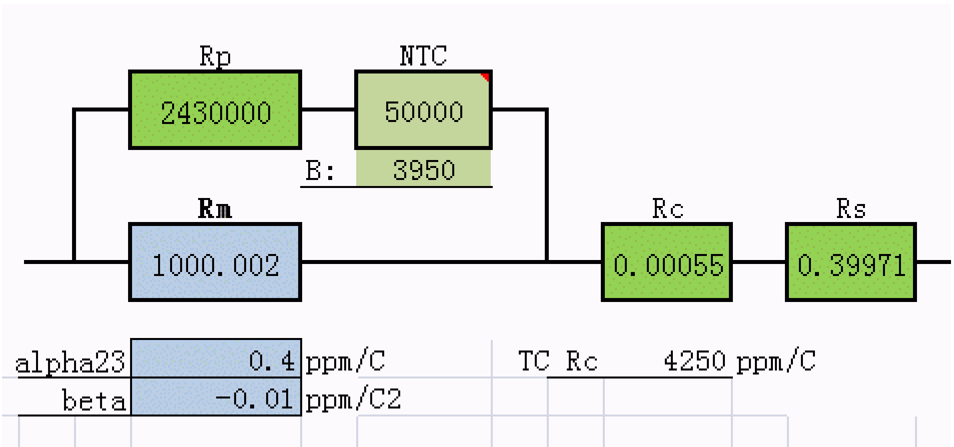


At this time, since the negative of A is relatively large, a larger Rc is needed, so a smaller NTC and Rp are needed in parallel.

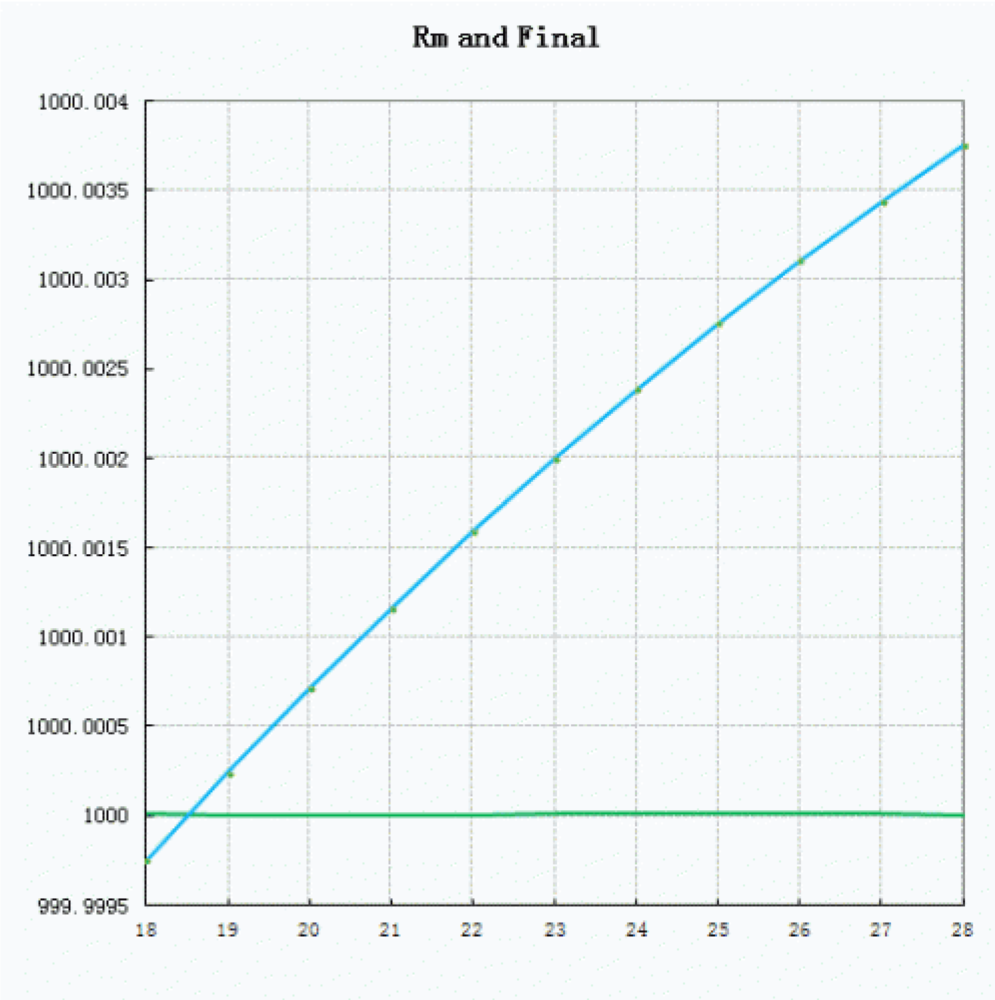
The actual NTC is 200k with B=3950, Rp=15.53M is in a supercritical state (that is, Rp=15.62M is an ideal compensation, and a small value is deliberately selected to slightly overcompensate), so that Rc=5.849 ohms will just compensate for A, Rs=0.

Additional compensation: 1k metal foil resistance

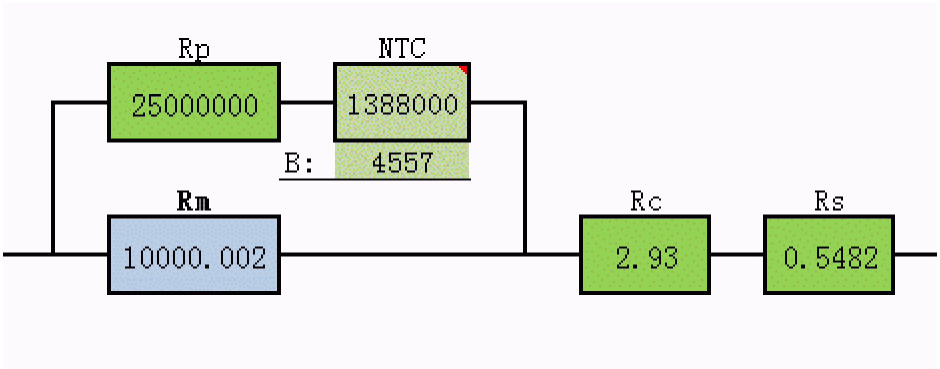
1000.02 ohms, A=0.4, B=-0.01, compensation parameters:



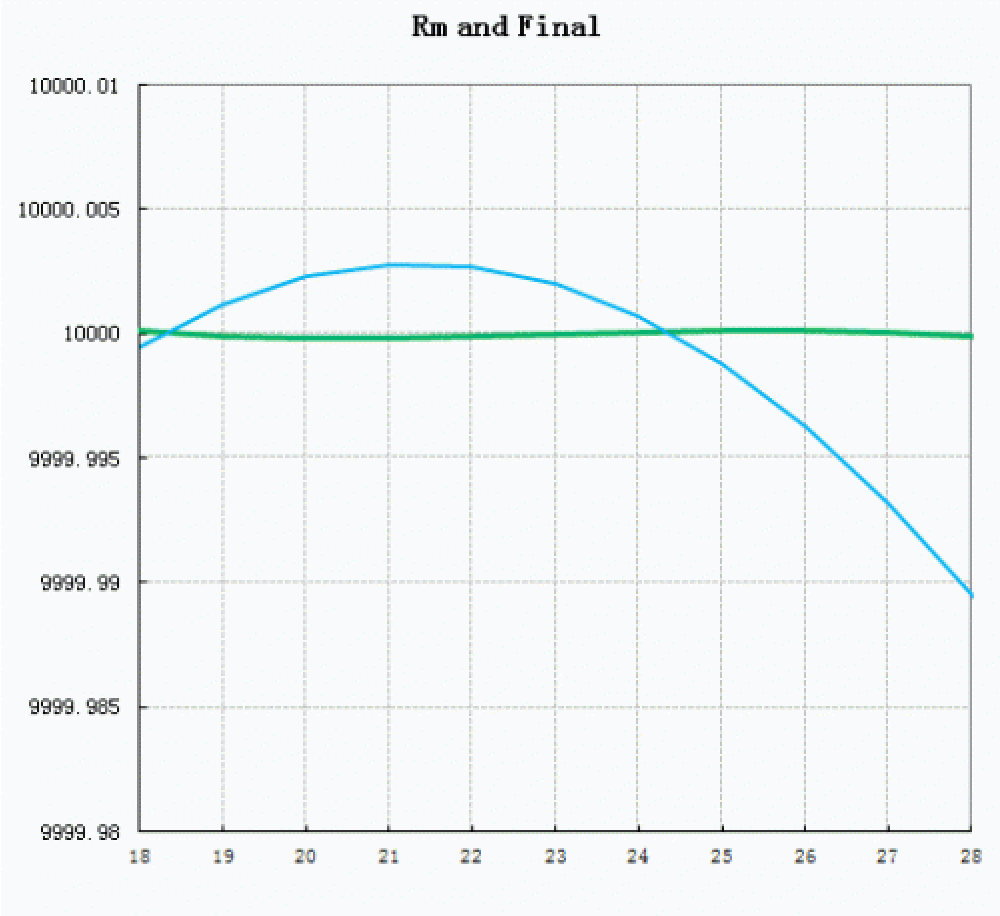
NTC=50k uses MF58, Rp=2.43M can use wire-wound + metal film mixed series connection. Compensation effect:



Compensation example: Before SR104 compensation, A=-0.1, B=-0.03, which belongs to the poorer SR104. Compensation method is similar. Excel file is attached. Compensation diagram:

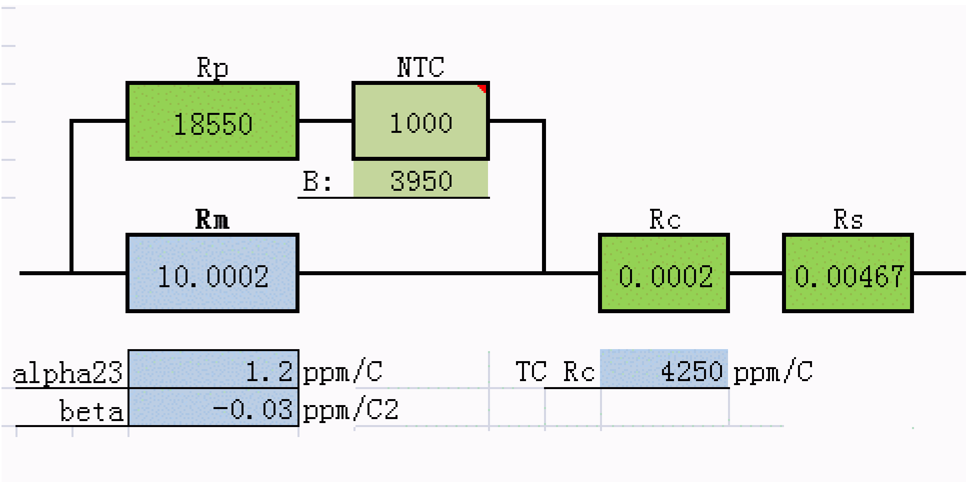


Compensation result: The window temperature coefficient is changed from 1.33 to 0.037, which is 1/36, and the A coefficient is reduced from 0.1 to 0.01, which is 1/10. The blue line in the figure below is before compensation, and the green line is after compensation.



The resistance used:
NTC is Japan Shibaura PMN-342-H1Z, 1.388M at 25 degrees, B=4557, weakening factor 50,000 times.
Rp is 25M, the weakening factor is 2788 times
Rc=2.93 ohms, the weakening factor is 3400 times
Rs=0.5482 ohms, and the weakening factor is 18,000 times.

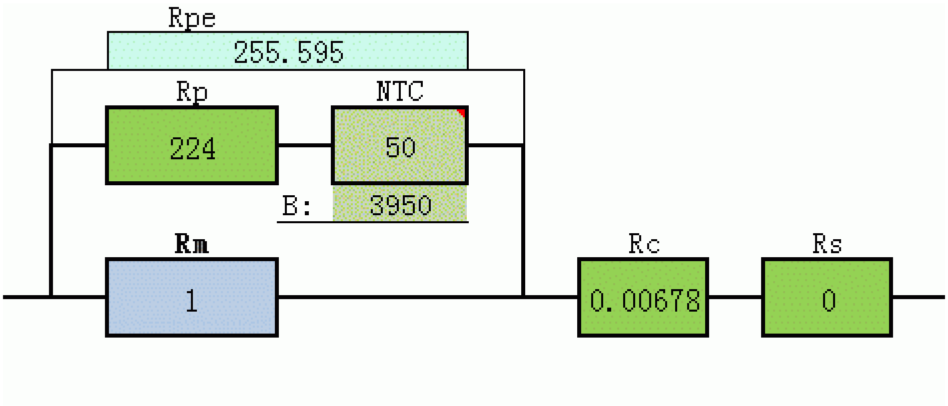
This example is only used to illustrate the compensation for a typical Evanohm resistor, in fact, it will not be compensated. , That would ruin the SR104.
But for SR104 compensation, it is of reference significance for similar Evanohm gold-sealed wire wound resistors. **Example of additional compensation: The resistance value is 10 ohms.** In this example, the original resistance of 10.0002 ohms is used, A=1.2, B=-0.03, a typical Evanohm:



NTC uses 1k MF58, Rp=18.55k, Rc and Rs are very small.
The compensation effect of each index is more than 100 times, which is better than that of SR104.

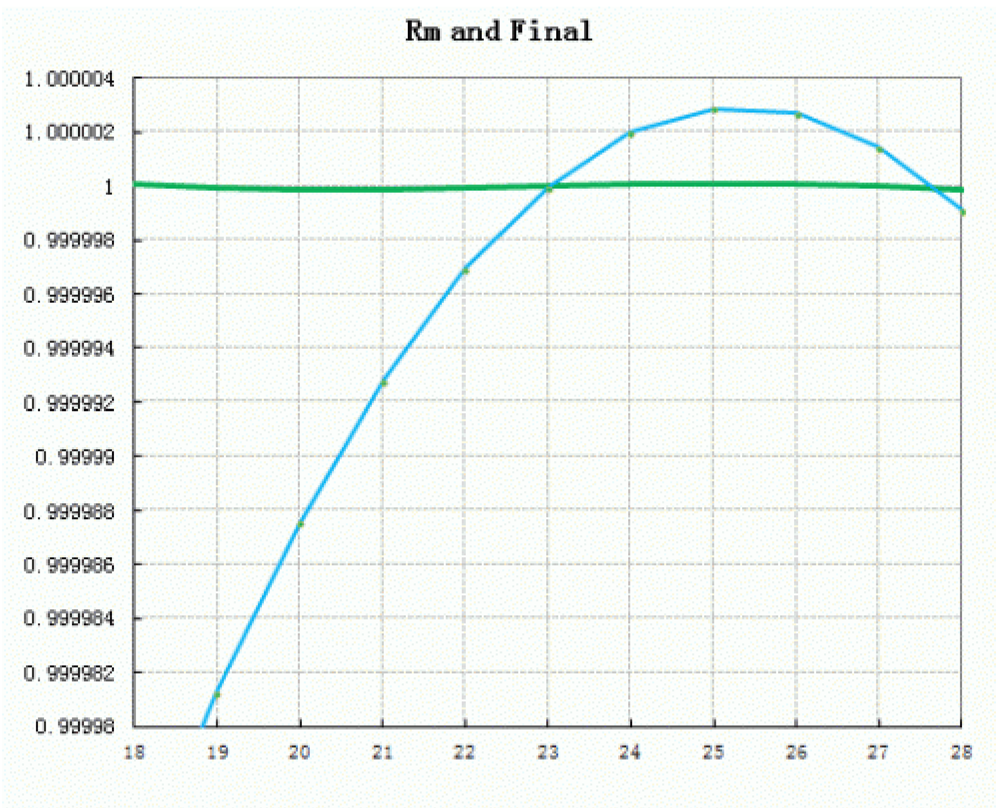
Compensation example: Thomas 1 ohm resistor.

This is a very extreme situation: the resistance is very small and the temperature drift is very large.
Compensation diagram:



NTC can only use 50 ohms, weakened 1500 times
Rp=224 ohms, weakened 340 times, not big
Rc=0.00678 ohms, weakened 147 times
Rs=0, because the above resistance makes the total value more than 1 ohm, so it needs to be connected in parallel instead of series
Rpe =255.595 Euro, weakened 258 times

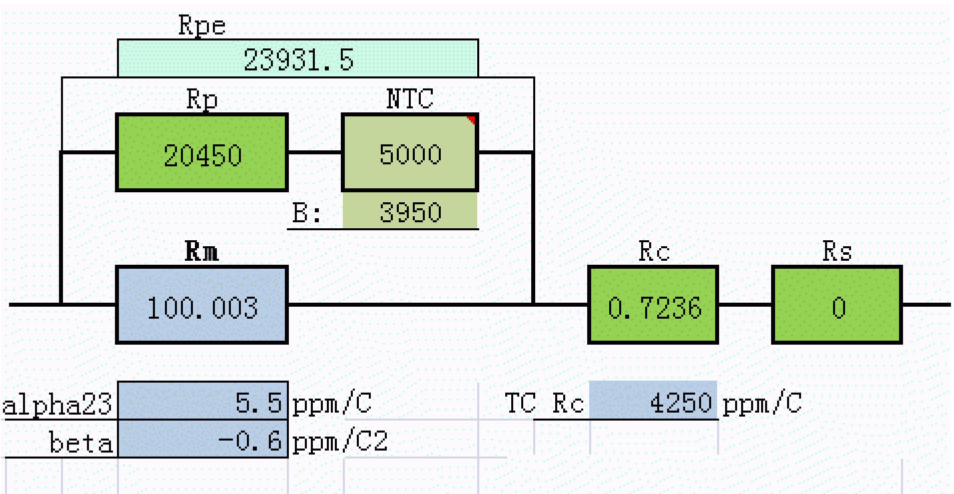
Compensation effect comparison:



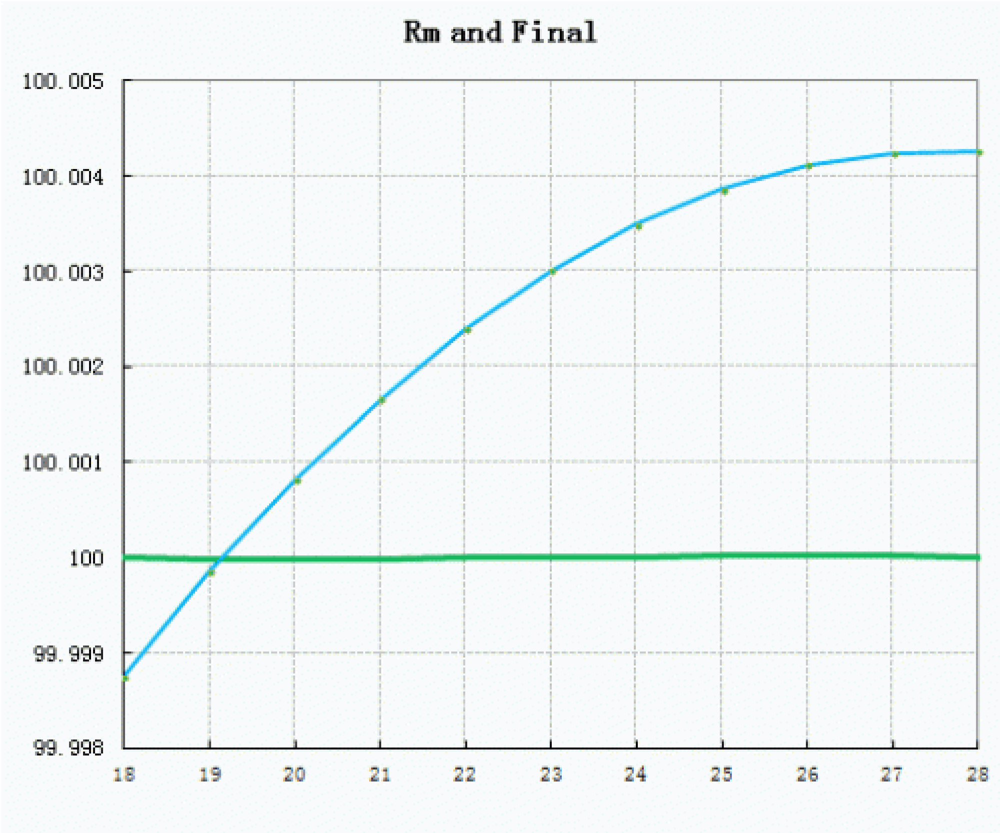
This example is only used to illustrate that even in such extreme situations, compensation can be carried out, and the effect of compensating errors can be obtained.

Of course, due to the poor temperature characteristics of the resistor being compensated, the compensation resistor can only be used relatively hard, resulting in poor sensitivity analysis results. In other words, the compensation resistor is too sensitive, and its long-term stability will have a serious impact on the final result. Therefore, this example should not be implemented in practice. **Additional compensation example: BZ3 100 ohms** . This is an actual domestic standard resistor

Compensation parameters:

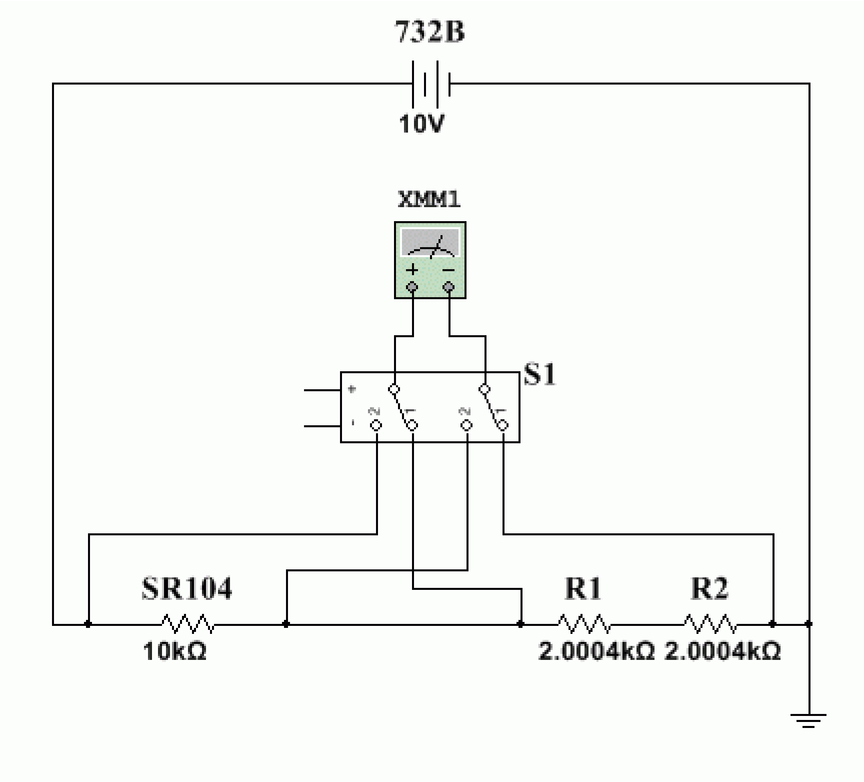


Comparison before and after compensation:

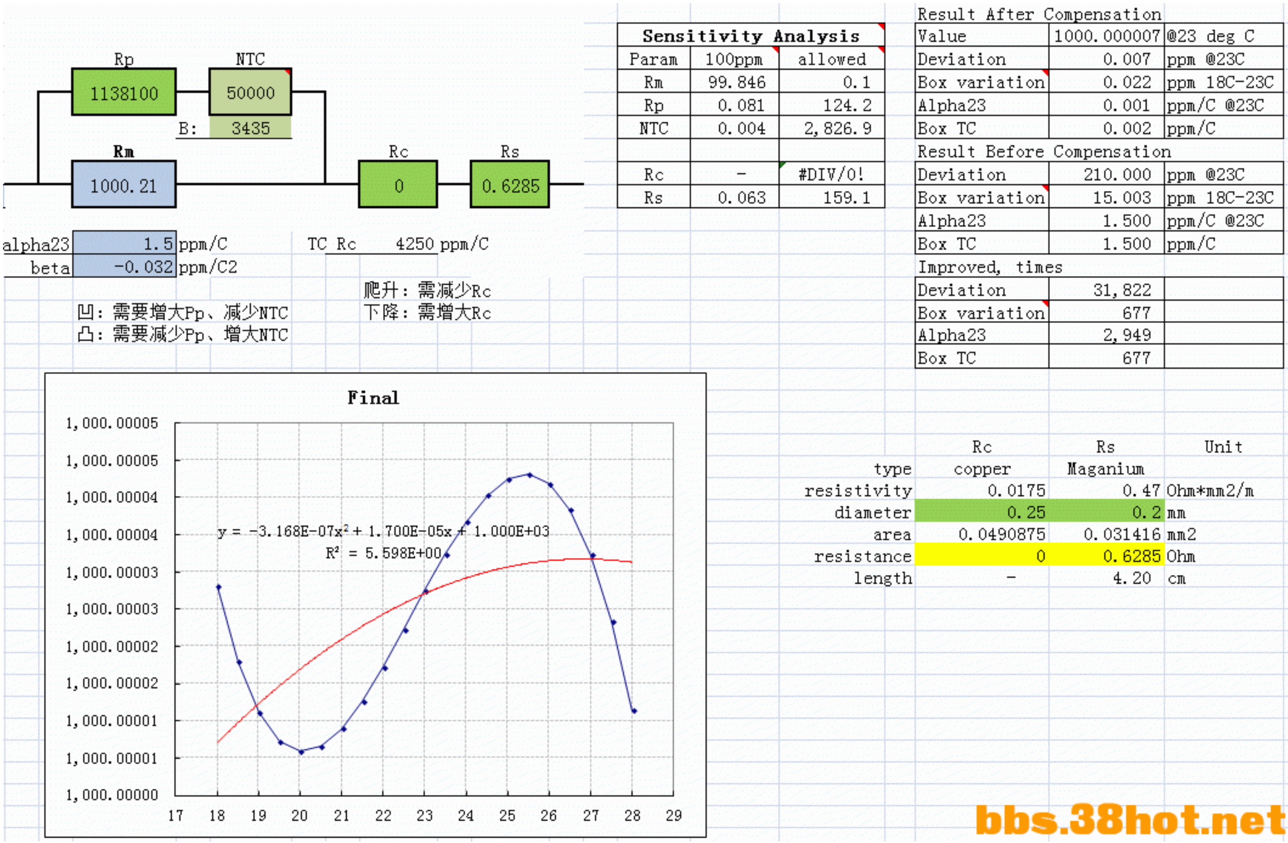


The fourth part: Beta temperature coefficient compensation example. This part needs to DIY at least two standard resistors to actually implement temperature drift compensation, including B parameter compensation. One is to use Fluke gold sealing wire to make a 1k (or 100k, in short, not 10k) to verify the compensation of the Evanohm resistance. Theother is to use a single Vishay VHP101 to make a 10k standard resistor to achieve a more ideal compensationexample: Use Fluke 2.0004k gold sealing wire to wind 2 pieces in parallel to make 1k standard resistance1. Choose two 2.0004k gold sealing wire windings that are very poor in the conventional sense

This kind of resistance was removed from the Fluke 731B voltage reference. The reason why it is said to be poor is because the resistance value is not exactly 2k, the temperature drift is 1.75 and the other 1.25 is relatively large, and it is positive, so it is not easy to compensate with copper resistance. If the NTC compensation of parameter B here is not used, it cannot be used as a standard resistor. 2. The parameter measurement circuit after testing two resistors in parallel is like this:



Two 2.0004k resistors are connected in series to test the temperature coefficient. Here to explain: two resistors with the same resistance, whether in series or in parallel, the temperature coefficient is the same. Because it is convenient to make 4k multiple measurements in series, there is no need for parallel testing, let alone separate testing.
After the 4k resistor is connected in series with my own 10k standard, it is connected to a stable 10V, and a 2×2 automatic switch is used to test the voltage on the two resistors respectively, set as V10 and V4, then the 4k resistor can be calculated as:
set SR104 to measure The voltage obtained is V10, the voltage measured on the two resistors is divided into V4, the resistance value of SR104 is R10, then the measured resistance=R10*V4/V10
According to the variable temperature test, the temperature-resistance curve is obtained: (After the parallel connection is obtained, R23 =1000.21, A23=1.5, B=-0.032) 3. Perform Excel compensation

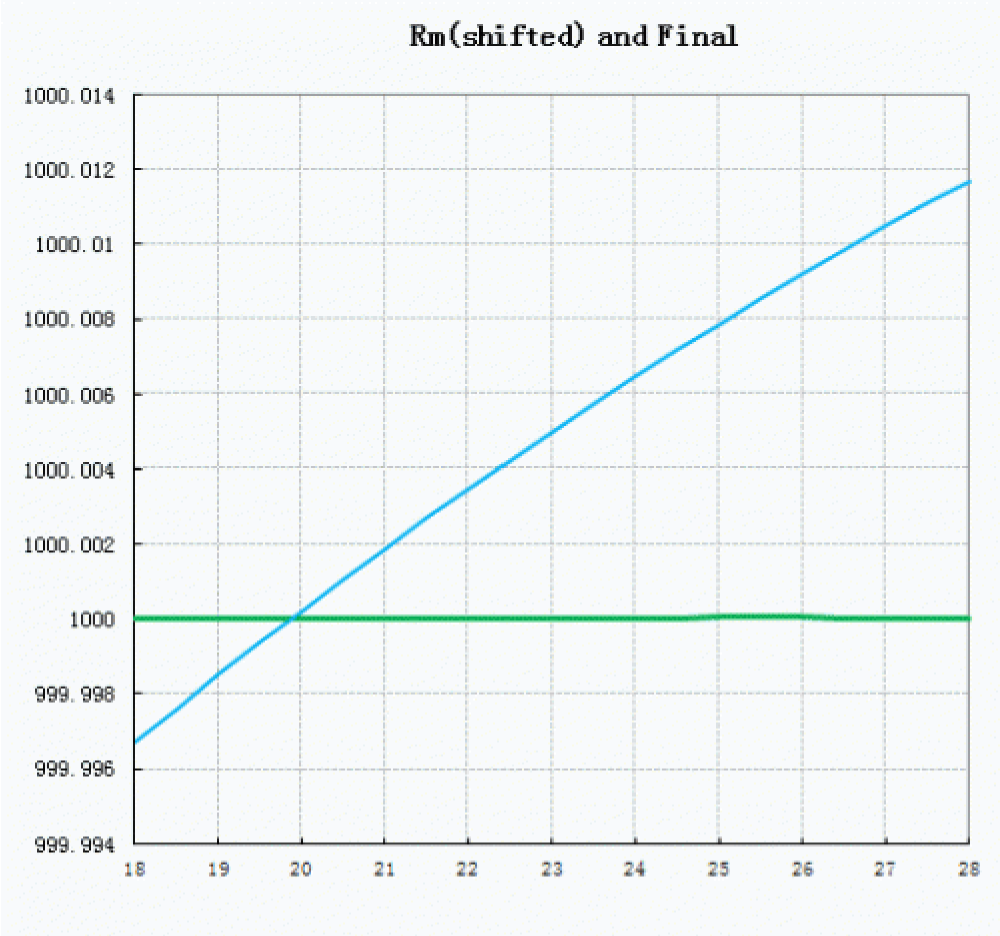


Sensitivity Analysis		
Param	100ppm	allowed
Rm	99.846	0.1
Rp	0.081	124.2
NTC	0.004	2,826.9
Rc	-	#DIV/0!
Rs	0.063	159.1

Result After Compensation		
Value	1000.000007	@23 deg C
Deviation	0.007	ppm @23C
Box variation	0.022	ppm 18C-23C
Alpha23	0.001	ppm/C @23C
Box TC	0.002	ppm/C
Result Before Compensation		
Deviation	210.000	ppm @23C
Box variation	15.003	ppm 18C-23C
Alpha23	1.500	ppm/C @23C
Box TC	1.500	ppm/C
Improved, times		
Deviation	31,822	
Box variation	677	
Alpha23	2,949	
Box TC	677	

	Rc	Rs	Unit
type	copper	Maganium	
resistivity	0.0175	0.47	Ohm*mm2/m
diameter	0.25	0.2	mm
area	0.0490875	0.031416	mm2
resistance	0	0.6285	Ohm
length	-	4.20	cm

NTC uses 50k with a B value of 3435, weakened 28,000 times
Rp to 11381k, weakened 1236 times, adopts 1M wire wound, 120k 0.1%, 18k 0.1% series connection
Rc=0, this compensation is just at the critical value.
Rs=0.6285 Euro is made of 0.2mm manganese copper wire 4.2cm.
After Excel compensation, the window temperature drift is only 0.022ppm (18 degrees to 28 degrees), and the window temperature coefficient is only 0.0022ppm/K.
Intuitive effect comparison, which is before compensation and which is after compensation, needless to say:



4. Actual assembly 5. Test 6. Re-correction 7. Final test

Part 6: Summary
As you have seen above, it can be well compensated for the three types of manganese copper, Evanohm, and metal foil resistors.

As you can see from the above, it can be well compensated for 1 ohm, 10 ohm, 100 ohm, 1k and 10k.

Of course, this kind of compensation also has certain limitations. For example
1. B is positive and cannot be compensated
2. The absolute value of B is very small, and A is positive and large. The combination of these two will make the compensation invalid. Because the absolute value of B is small, the amount of compensation required is small. After NTC parallel compensation, the temperature drift becomes less negative, and the larger positive A cannot be offset. Therefore, the overall temperature drift is still positive and cannot be compensated by Rc.
3. The absolute value of B is small, A is negative and large, and the positive deviation of the resistance value is large. The combination of these three will make the compensation troublesome. Due to the small amount of compensation, after Rp and NTC are connected in parallel to the main resistance, the resistance value becomes limited; at the same time, negative A requires a larger series Rc compensation, so the overall resistance value exceeds the nominal value, which has to be in the main resistance A resistor is connected in parallel, and the resistance and requirements of this resistor are relatively high.