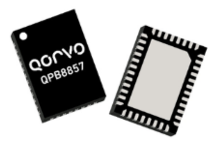
APPLICATION NOTE

Thermistor Gain Compensation for CATV Amplifiers

Addressing gain drift over temperature for QPA4425, QPB8857, and QPL8832

Introduction



This document provides application information for using thermistors to compensate for gain variation over temperature for Qorvo® QPA4425, QPB8857, and QPL8832 CATV MMIC amplifiers. A MMIC amplifier's gain will vary proportionally with the operating temperature of the IC and it is desirable to compensate for this effect. For broadband amplifiers with external feedback networks, it is possible to employ thermistors in the feedback path that will adjust the total feedback resistance and reduce the effect of gain variation over temperature. This document will describe a procedure for evaluating and selecting compensation methods for examples with different topologies.

Referenced Documents

The reference documents below take precedence over the contents of this application note and should always be consulted for the latest information.

QPA4425 Data Sheet
QPB8857 Data Sheet
QPL8832 Data Sheet
KOA Global LP73 Thermal Sensor Datasheet
Vishay TFPT Nickel Thin Film Linear Resistors

Gain Drift Over Temperature

An amplifier with no internal temperature compensation will typically show decreasing gain as the operating temperature of the IC increases and vice versa. The change in gain can be due to internal conditions such as changing bias current and due to external components such as the baluns on push-pull amplifiers. To limit this effect, we would first test the MMIC amplifier versus the expected temperature limits, then adjust the feedback network to find the values required to reduce the effects of gain drift to acceptable limits. Then it is possible to select thermistors to match the resistance changes needed to have the same effect in the final application.

Below in Figure 2.0 is an example of the gain drift over temperature that can be expected in a QPA4425 device.

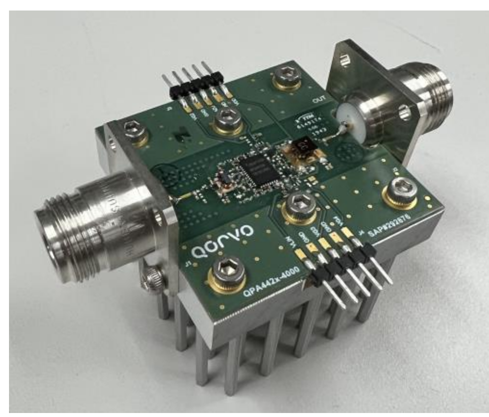
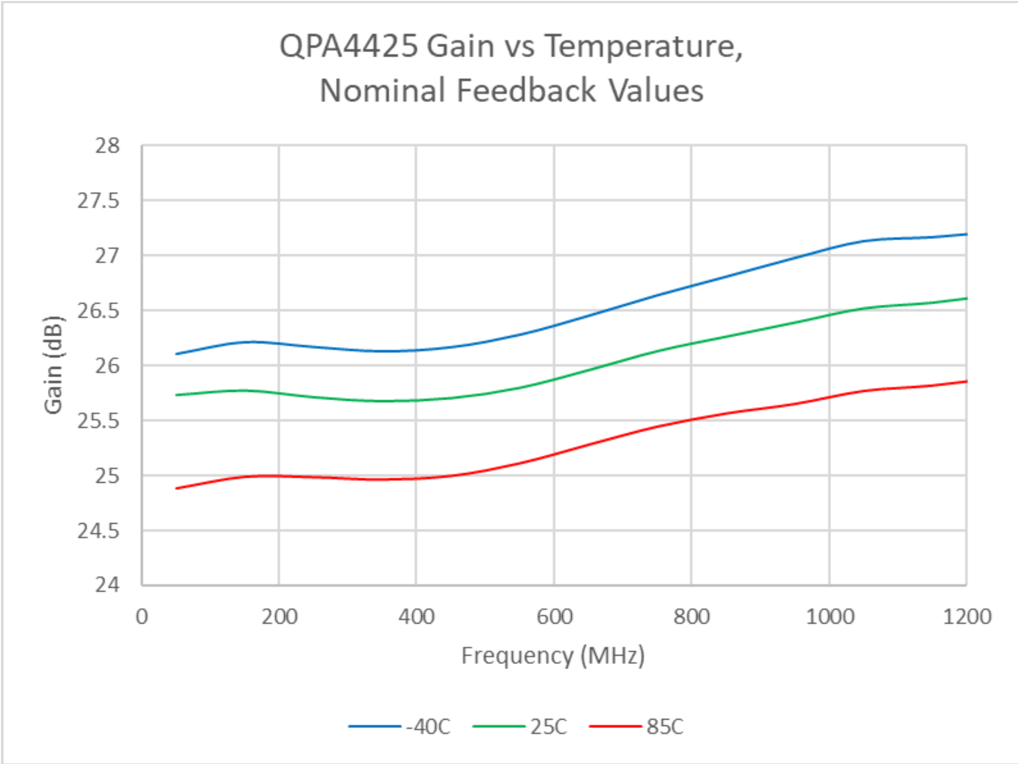


Figure 1.0. QPA4425 EVB

Figure 2.0, QPA4425 Gain vs Temperature



Amplifier Topologies

The first example presented is the QPL8832, which is a single stage push pull amplifier with 19dB of gain nominally (refer to Figure 3.0 below, QPL8832 Application Schematic). External feedback is applied from each output to each input with a DC blocking cap and the resistance is used to set the nominal gain. Two resistors are used in each path; the ratio of the resistors can be adjusted to manipulate the gain slope of the amplifier. The feedback network is composed of components R3+R5+C11 and R4+R6+C12. C11 and C12 are blocking capacitors, while R3+R5 and R4+R6 comprise the total feedback resistance. If the feedback value is increased, the gain will increase. If the feedback value is decreased, the gain will decrease.

Referring to Figure 2.0, at higher temperatures, the gain decreases and at lower temperatures the gain increases. To compensate for this tendency, the total feedback resistance needs to increase at higher temperature to maintain the gain as close to the nominal 25°C level as possible. As temperature decreases, the feedback resistance needs to decrease to reduce the overall gain to nominal levels. This behavior dictates the need for a positive temperature coefficient (PTC) thermistor such as the KOA LP73 series or the Vishay TPFT series, which are described in more detail in the sections to follow. Negative Temperature Coefficient (NTC) thermistors have an opposite temperature response and would be useful in other applications.

A QPL8832 evaluation board was tested at -40°C in a thermal chamber to determine the reduced amount of feedback resistance necessary to maintain nominal gain levels. By substituting smaller values of resistance for R3 and R4, the gain was reduced to be reasonably close to the measured baseline gain at 25°C. Conversely, larger values of feedback resistance were tested at +85°C to increase the gain towards the 25°C nominal gain. When the resistance values for -40 and +85°C are known, several thermistors can be selected for evaluation in place of R3 and R4, with R5 and R6 fixed resistor values selected to maintain a total nominal resistance of 560 ohms at 25°C for each path. Testing the QPL8832 in this manner showed that replacing R3 and R4 with 390 ohms at -40°C and 470 ohms at +85°C were good initial values to target for compensation.

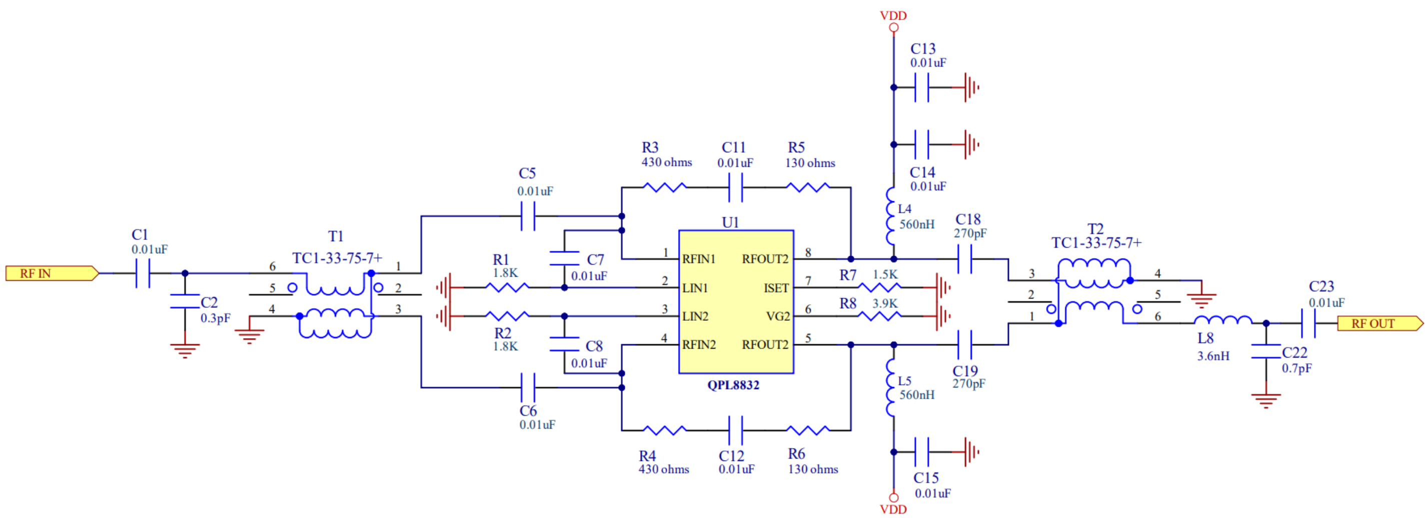


Figure 3.0., QPL8832 Application Schematic.

The next example is the QPA4425 which is a 24V high output push pull with two internal stages and featuring 25dB of gain nominally. Referring to Figure 4.0, QPA4425 Application Schematic, R33+R2+C2 and R34+R+C1 form the feedback network for the driver stage. The remaining passives in the RF paths are used for bias, gain shaping, and matching. Some effect on gain can be found by adjusting the interstage networks that feature R8 and R7, but the best impact comes from adjusting the combination of R2+R33 and R1+R34 to adjust the gain of the driver stage. By testing QPA4425 in the same manner as QPL8832, R1 and R2 were set to 120ohms at -40°C and 180ohms at +85°C to maintain the gain close to the same value measured at 25°C with R1 and R2 set to 160ohms.

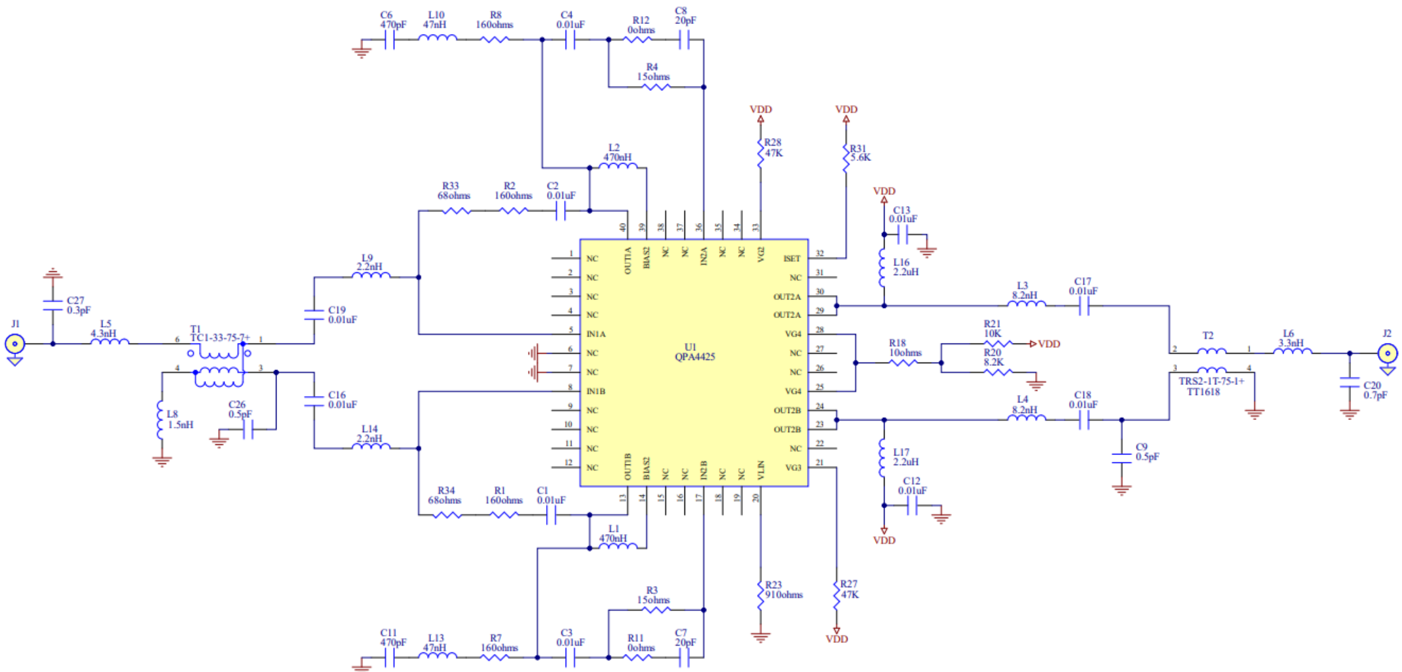


Figure 4.0, QPA4425 Application Schematic

Our final example is the QPB8857, a 24V power doubler. Like the QPA4425, the QPB8857 is a two-stage amplifier with 28dB nominal gain and features a similar topology internally. The behavior of the QPB8857 is similar to the QPA4425 in that the feedback network of interest will be on the input driver stage. Referring to Figure 5.0, QPB8857 Application Schematic, this network is comprised of R33+ R2+C2 and R34+R1+C1. Testing the QPB8857 showed R1 and R2 only needed to be adjusted to 5ohms at -40°C and 50ohms at +85°C.

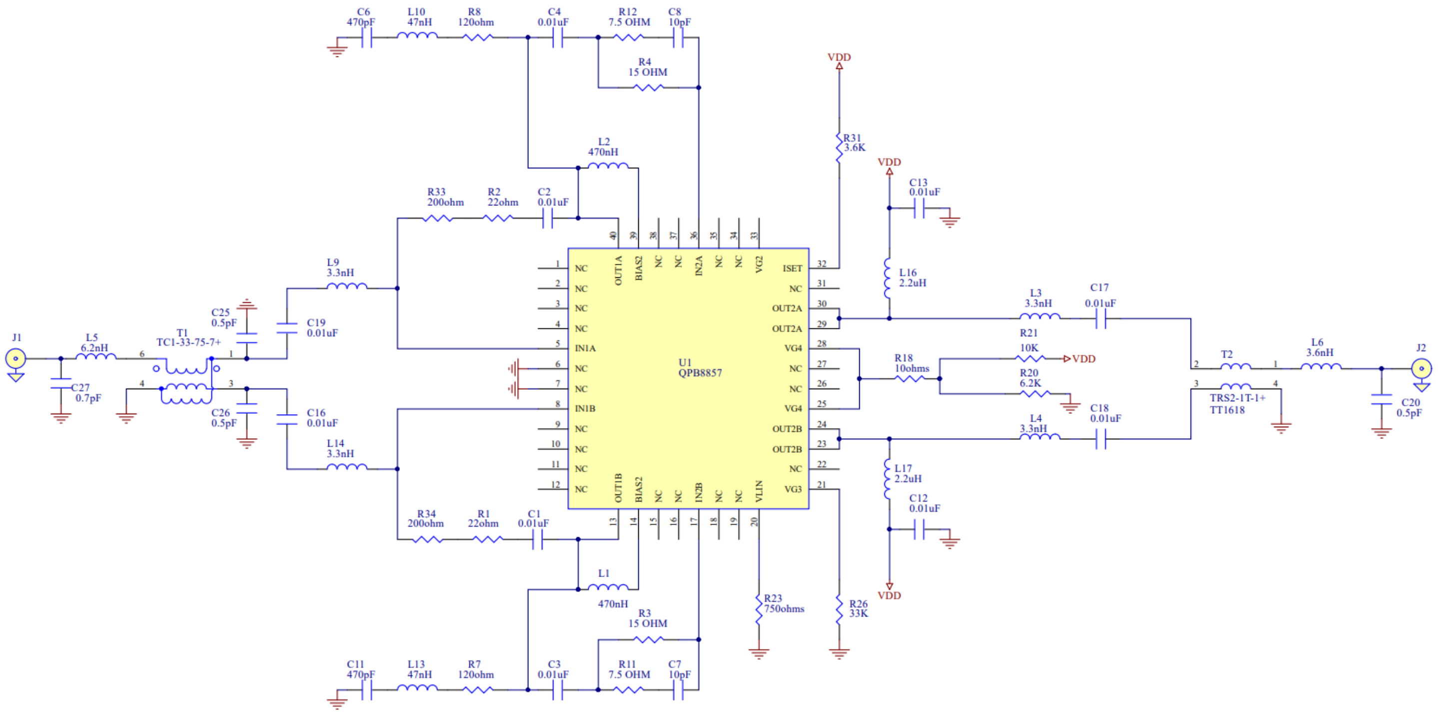


Figure 5.0, QPB8857 Application Schematic

Thermistor selection

The following section covers how to analyze and select a thermistor to best cover the resistance ranges determined from thermal testing of the amplifiers. To conveniently analyze a given thermistor, the datasheet for the KOA LP73 series gives an expression for the resistance vs temperature of

$R(T) = R_{25}(C_0 + C_1T + C_2T^2)$

where:

$R(T)$ is the resistance at a given temperature

R_{25} is the nominal resistance at 25°C

T is the temperature being evaluated

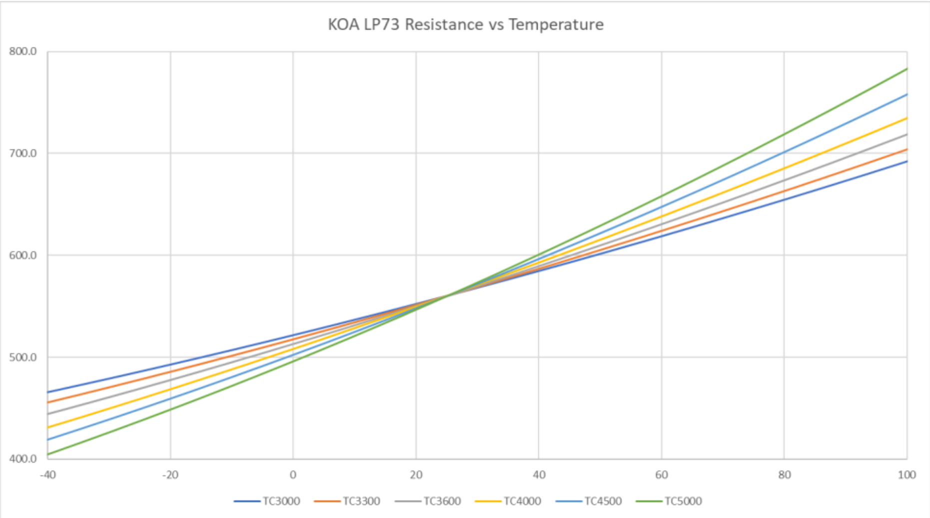
C_0, C_1, and C_2 are constants for a selected temperature coefficient given in the datasheet and shown in Table 1.0 below.

Table 1.0, Temperature Coefficients for KOA LP73 PTC Thermistors

Temperature Coefficient (10^{-6}/K)	C_0	C_1	C_2
3000	0.931258	0.00265213	3.90112×10^{-6}
3300	0.924355	0.00292569	4.00515×10^{-6}
3600	0.916356	0.00323714	4.34428×10^{-6}
4000	0.907039	0.00361006	4.33457×10^{-6}
4500	0.897412	0.00395222	6.05201×10^{-6}
5000	0.886014	0.00437224	7.48809×10^{-6}

Using the given equation and coefficients, the resistance vs temperature of an initial value can be calculated at the temperatures of interest. A device can also be plotted versus temperature and compared to several other devices or with combinations of series and parallel resistors to “trim” the total feedback to fit the design goals. In cases where the compensation is not completely accurate at both temperature extremes, a designer may choose to place an emphasis on one temperature extreme versus another. For example, it may be more important to compensate for the hotter temperatures than cold.

Figure 6.0, KOA LP73 Resistance vs Temperature, 560ohm Nominal



The Vishay TFPT series can be calculated by the same method. Vishay's TFPT series has a temperature coefficient of 4110 ppm/K and the equation from the Vishay datasheet given as:

$R(T) = R_{25} \times (C_0 + C_1 \times T + C_2 \times T^2 + C_3 \times T^3)$

where:

$R(T)$ is the resistance at a given temperature

R_{25} is the nominal resistance at 25°C

T is the temperature being evaluated

C_0, C_1, C_2, and C_3 are constants for a selected temperature coefficient given in the datasheet and shown in Table 1.1 below.

Table 1.1, Temperature Coefficients for Vishay TFPT PTC Thermistors

Temperature Coefficient (10^{-6}/K)	C_0	C_1	C_2	C_3
4110	9.0014×10^{-1}	3.87235×10^{-3}	4.86825×10^{-6}	1.37559×10^{-6}

Consult the datasheet for the respective vendors for available nominal values.

After determining the difference in total feedback resistance needed to compensate the change in gain at a given temperature, a thermistor that changes its resistance equal to that change can be selected. These thermistors can replace one or both resistors in the feedback. It's a good plan to select multiple candidates for testing, as the effect on gain within the feedback loop is not always quite as predicted. If the amount of compensation is high, or if other external factors are contributing such as baluns, there may need to be further iterative work to refine a selection, and the designer may also wish to compensate more for one temperature extreme than the other. As will be illustrated in the following sections, the selections chosen may have an influence on gain slope which would need to be refined with further testing.

For QPL8832, testing as described above showed that total feedback resistance of 520 ohms at -40°C and 600 ohms at +85°C were good initial values to evaluate vs the 560ohms nominal at +25°C. Three thermistors were evaluated for QPL8832 based on these initial values, the Vishay TFPT0603L3900JV (390ohms), KOA LP731JTBK561J3300 (560ohms) and KOA LP731JTBK561J3600 (560ohms). The expected resistances versus temperature for the three devices are shown in Table 2.0 below.

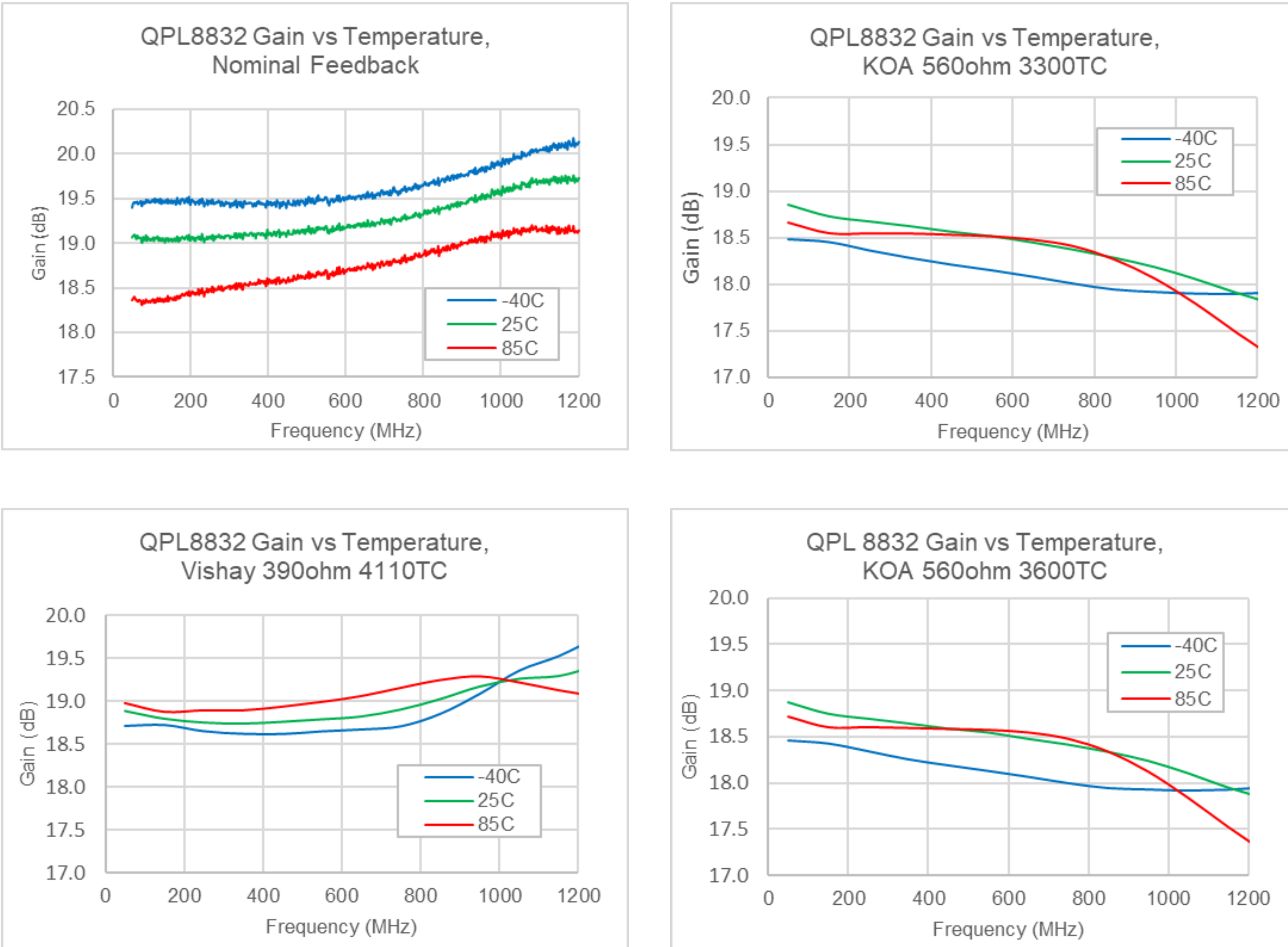
Table 2.0, Calculated Thermistor Values for QPL8832 Example

	-40°C	+85°C
KOA 560ohm 3300 T.C. + 0ohm series	455.7	673.1
KOA 560ohm 3600 T.C. + 0ohms series	444.5	684.8
Vishay 390ohm 4110 T.C. + 170ohms series	463.6	663.5

The three devices are shown in series combination to provide the 560ohms total feedback resistance needed for QPL8832 (R3 + R5, and R4 +R6. Refer to Figure 3.0). After selecting test candidates, temperature test the new devices to evaluate gain. The designer will also want to evaluate the impact to return loss and broadband stability to ensure no additional issues are incurred.

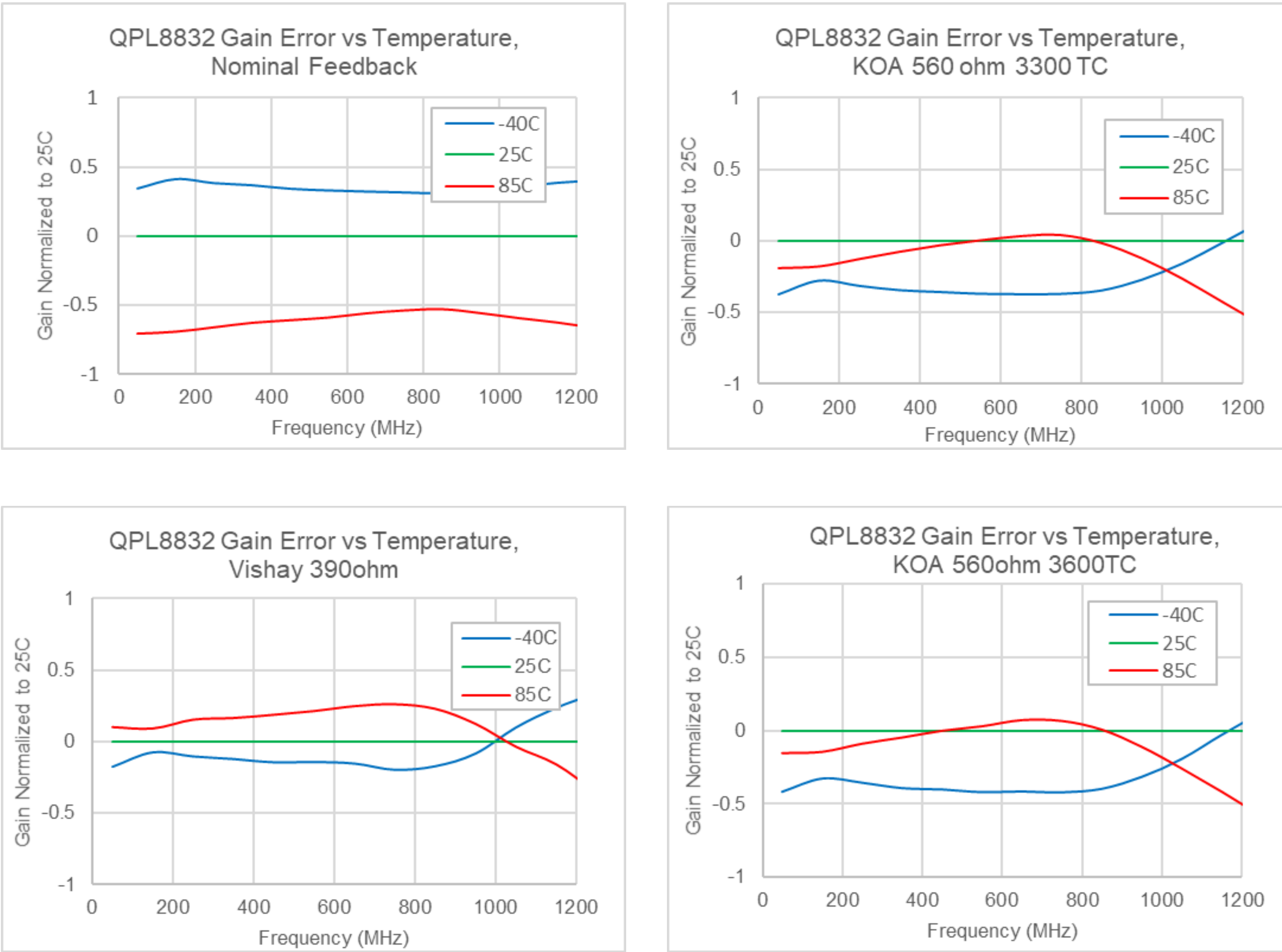
Below in Figure 7.0 are plots of QPL8832 gain with thermistors added to the feedback path. The first plot is the amplifier with no changes to the feedback. The values selected for the thermistors also show the effect of the ratios of R3 to R5 and R4 to R6. In this case, the 560ohm KOA devices with 0ohms in series have shown reasonably good temperature compensation at high temperatures, while simplifying the feedback, but there is now a downslope in the response. The Vishay 390ohm device in series with 170ohms maintains decent gain slope and temperature compensation. Additional testing could also be done with KOA devices using lower nominal resistance and a higher Temperature Constant (TC) of 4000, 4500, or 5000 to achieve similar results. For example, if a designer wanted to try to induce more upslope, one could use a KOA 300ohm device with TC of 5000 in series with 260ohms and still have a total feedback change of 477 ohms at -40°C and 653 ohms at +85°C.

Figure 7.0 QPL8832 Gain vs Temperature Plots



Another way of analyzing the effective application of gain compensation would be to look at the gain error vs nominal. In the plots in Figure 7.1, we normalize vs the gain taken at 25°C and look at the gain at -40°C and +85°C as an “error” by a simple subtraction of the gain at 25°C from each temperature plot. The effect is to directly see how much drift the thermistor is removing from the circuit (or introducing by means of added gain slope). In each of the plots below, the designer can see how closely optimized the end temperatures are to the 25°C baseline and determine which solution would be the most desirable for the end application. In the case of the KOA resistors, 85°C error is more tightly maintained, while a bit more balance is shown with the Vishay device. Similar performance with less gain slope could be achieved with the KOA devices by choosing a lower nominal value and a higher temperature coefficient in series with a fixed resistor to maintain the desired gain slope.

Figure 7.1, QPL8832 Gain Error vs Temperature



Returning to the QPA4425 example, three devices selected are listed below in Table 3.0. All three are similar in characteristics and are placed with a series resistor to maintain 228 ohms of total feedback resistance. In Figures 8.0 and 8.1 below, the temperature performance of the three configurations are compared. The plots indicate that a 120ohm KOA or a 100ohm Vishay would work well in this configuration. If a designer wished to further tighten gain performance at higher temperatures, higher nominal resistance thermistors could be used at the expense of a bit of overcompensation at low temperatures.

Table 3.0, Calculated Thermistor Values for QPA4425 Example

	-40°C	+85°C
KOA 100ohm 3000 T.C. + 128ohm series	211.4	246.5
KOA 120ohm 3300 T.C. + 108ohms series	205.6	252.2
Vishay 100ohm 4110 T.C. + 128ohms series	203.3	254.5

Figure 8.0, QPA4425 Gain vs Temperature Plots

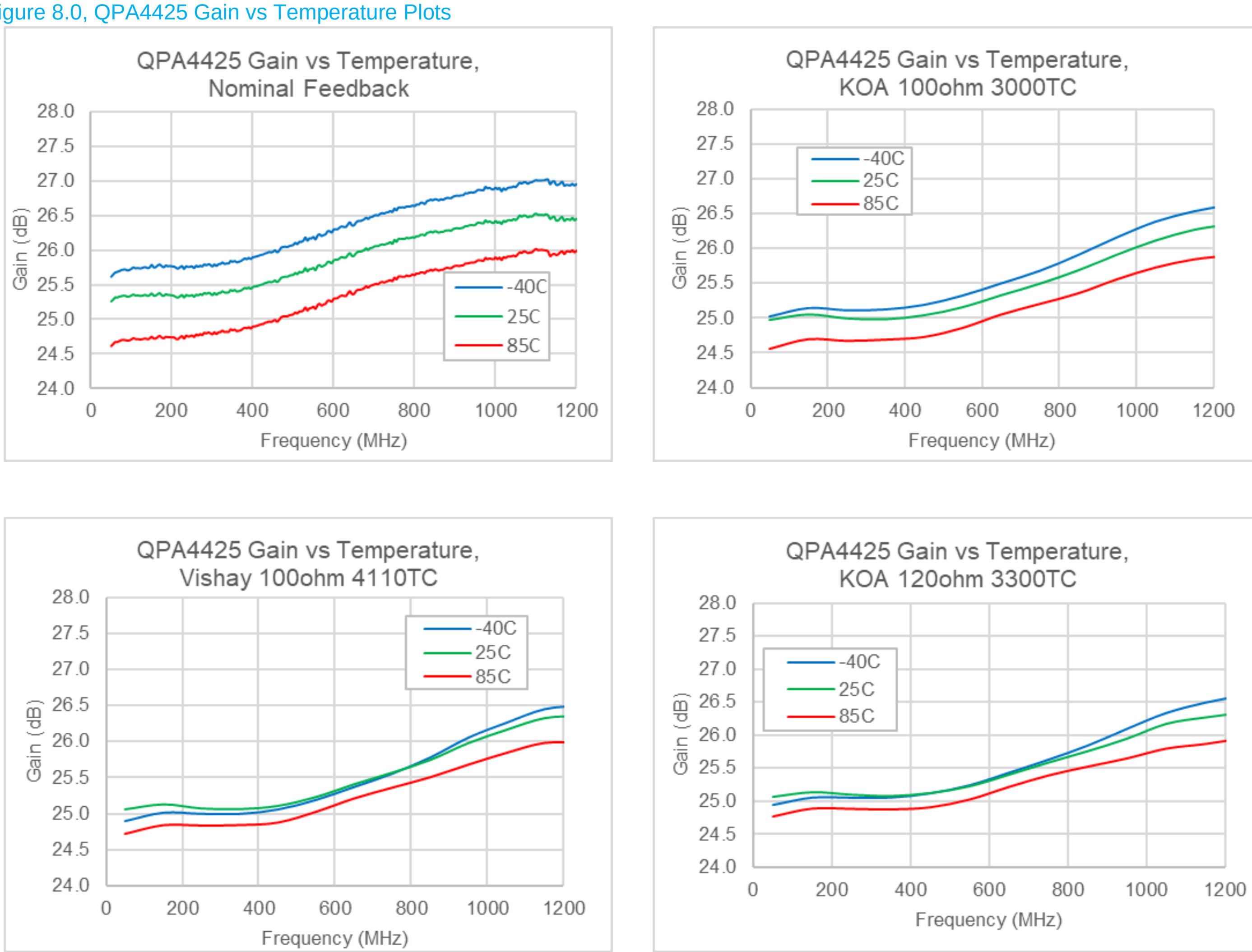
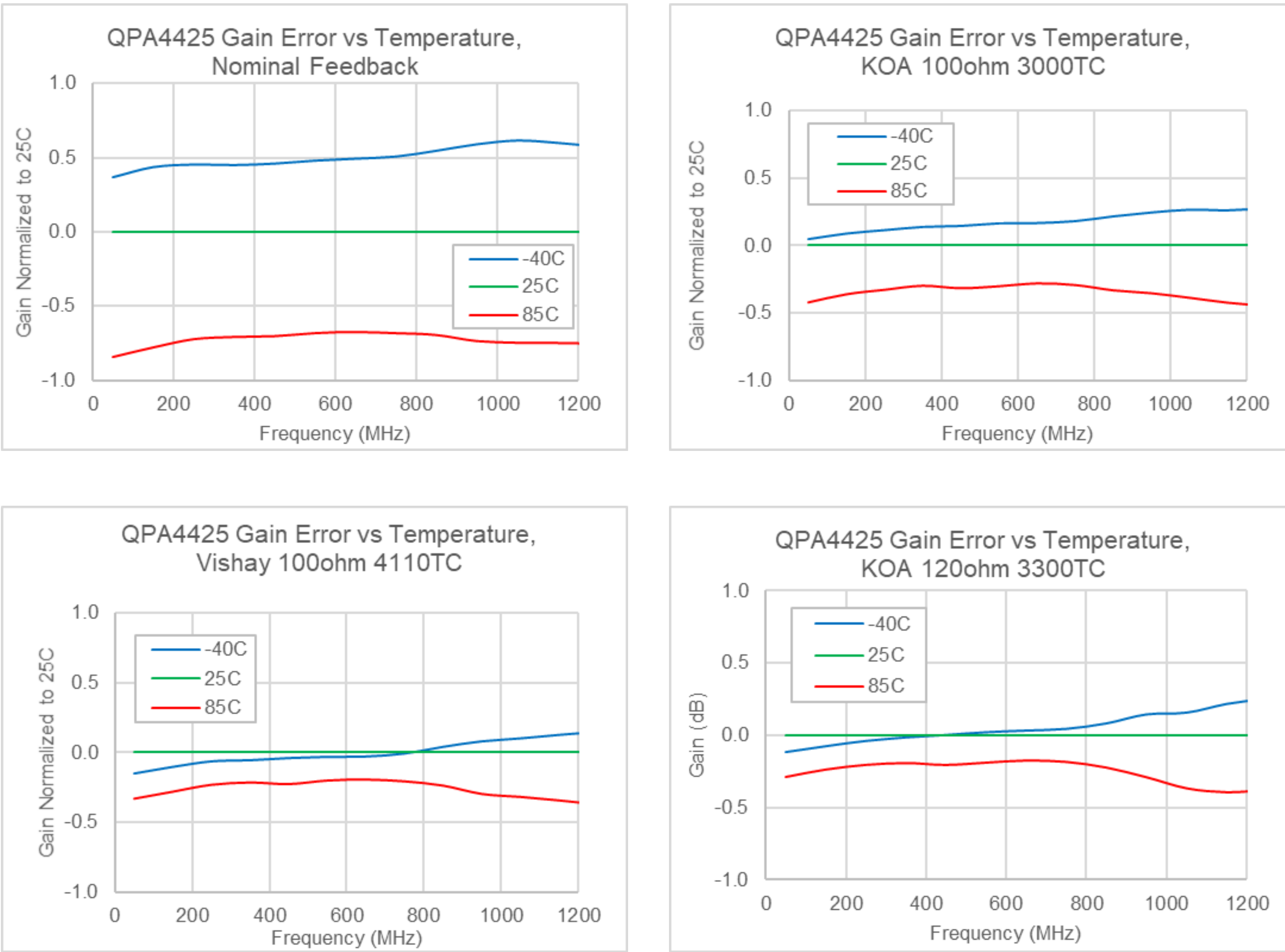


Figure 8.1 QPA4425 Gain Error vs Temperature

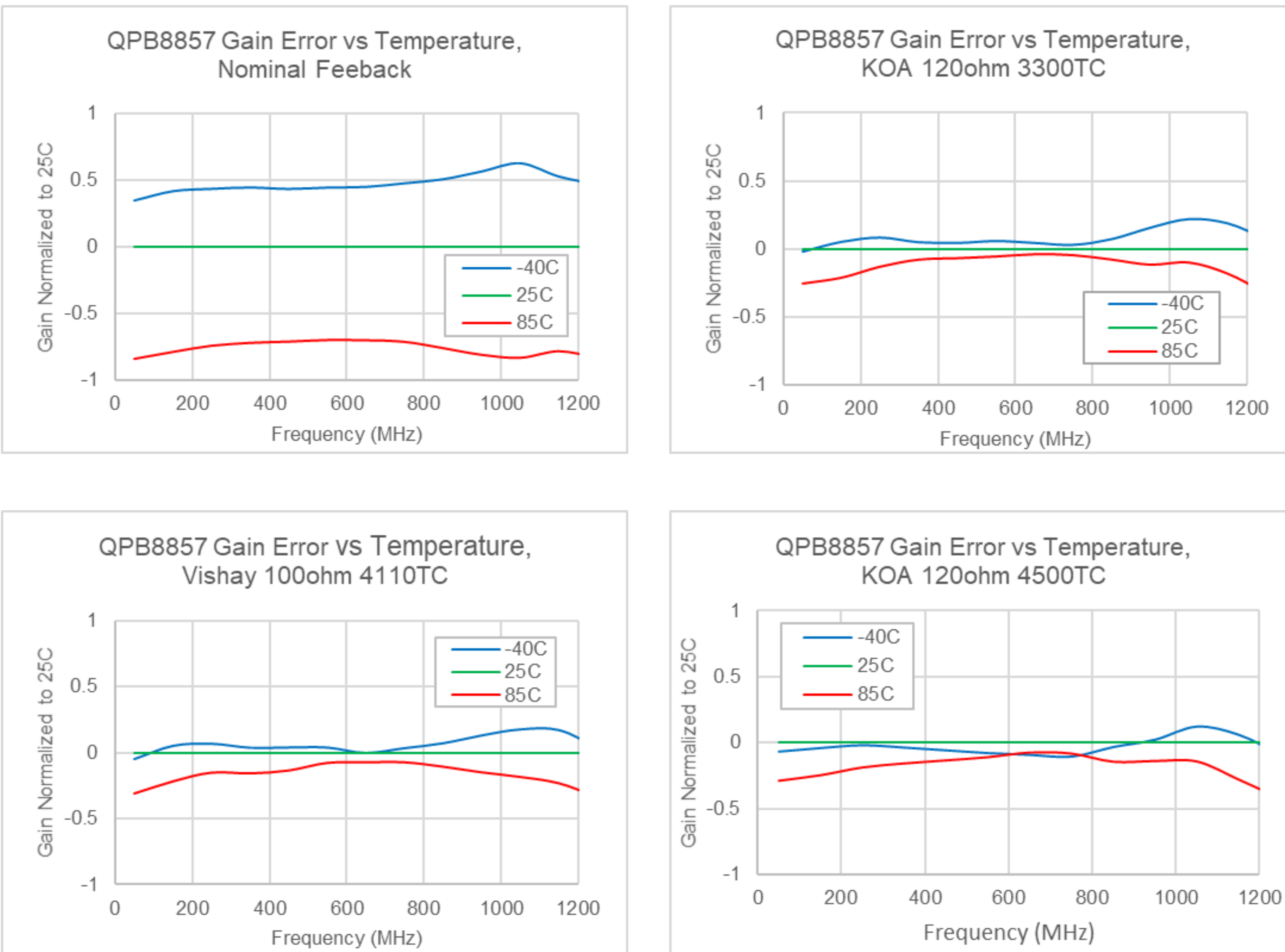


Our final example is the QPB8857, and again, three devices were selected for testing as shown in Table 4.0 along with the series resistors needed to maintain the total feedback resistance. If we look at the gain error plots for the devices shown in Figure 9.0, We see that all three selections were effective, with the KOA 120 ohm 3330TC and the Vishay 100ohm 4110TC providing the best balanced compensation with a bit of a nod to the KOA 120ohm device.

Table 4.0, Calculated Thermistor Values for QPB8857 Example

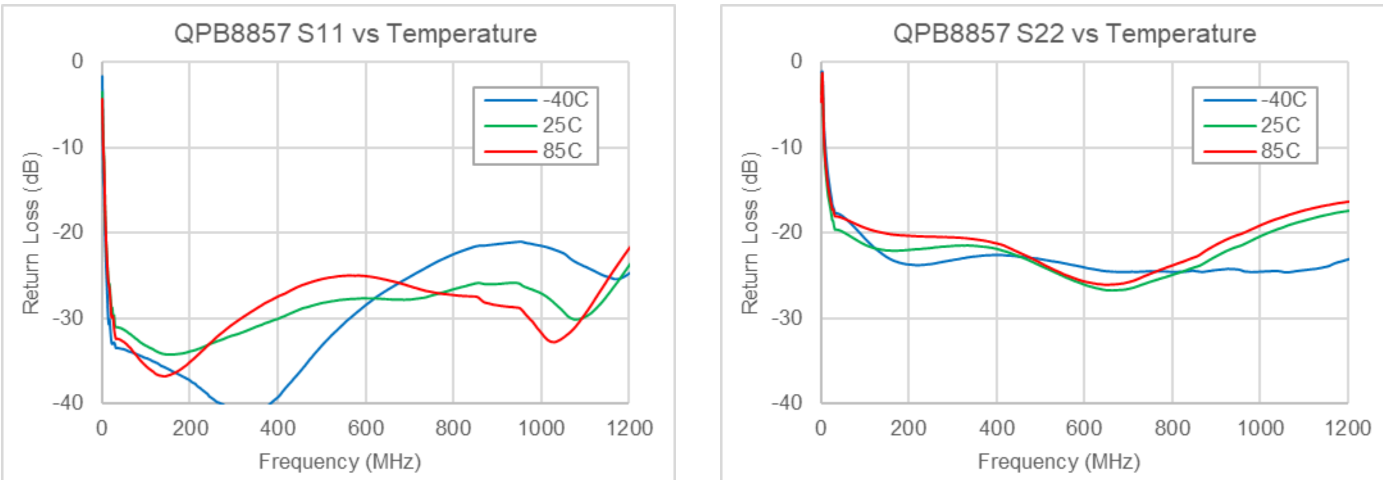
	-40°C	+85°C
KOA 120ohm 3300 T.C. + 102ohm series	199.6	246.2
KOA 120ohm 4500 T.C. + 102ohms series	191.9	255.2
Vishay 100ohm 4110 T.C. + 122ohms series	197.3	248.5

Figure 9.0 QPB8857 Gain Error vs Temperature



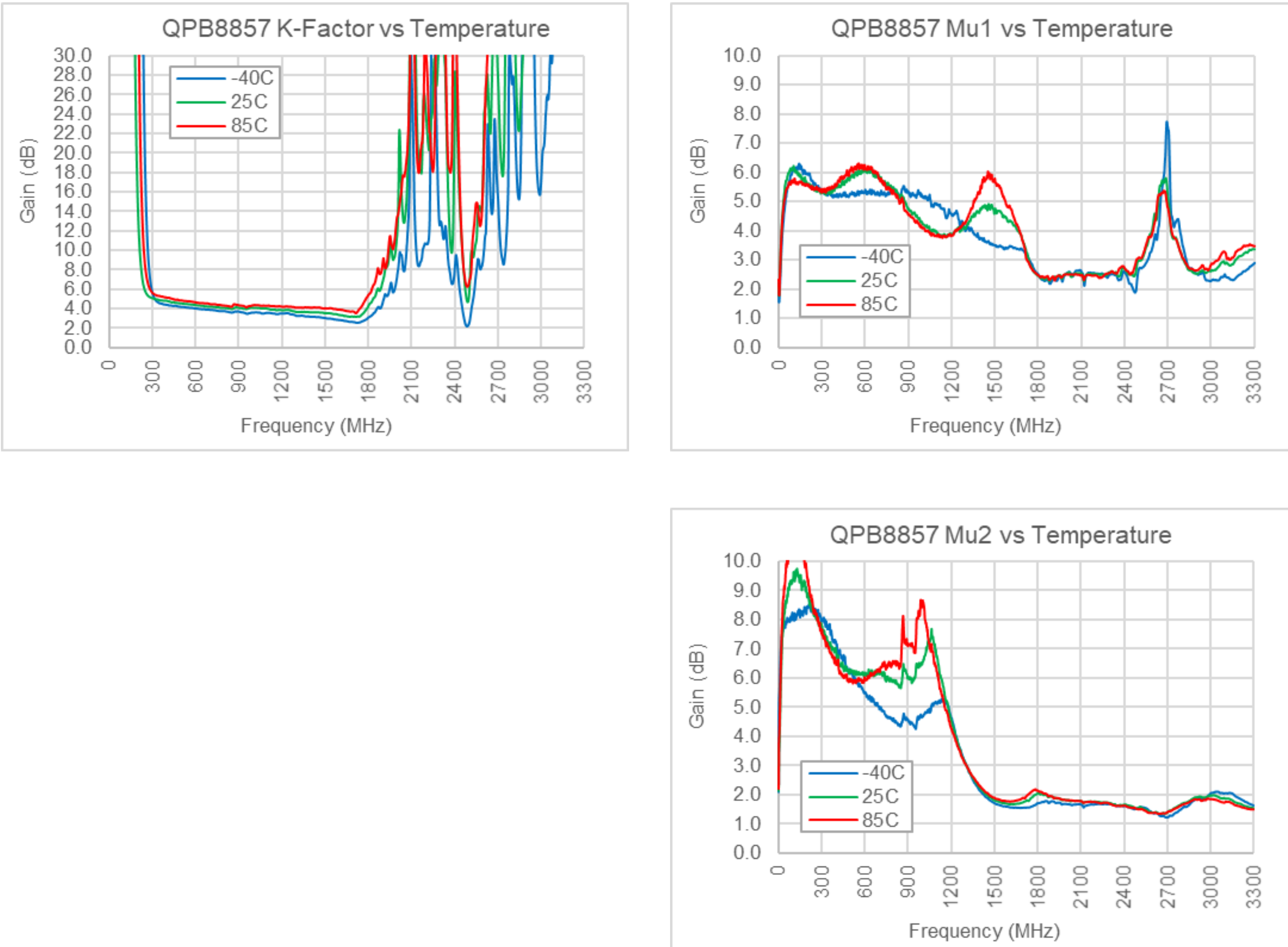
Our final analysis is to check the effect on return loss and stability. Continuing with QPB8857 and using the S-parameters from the KOA 120ohm 3300TC example, it's good practice to look analyze the impact to return loss and wideband stability to ensure no unforeseen issues may arise from manipulating the feedback. In each of the examples given, the gain is not being adjusted by a large magnitude relative to the total feedback which would indicate a lowered risk factor, but it is good practice to prove it out when possible. In Figure 10.0, Return Loss vs Temperature for QPB8857 with the KOA 120ohm 3300TC device is shown. S-parameters are well behaved over the operating range of interest.

Figure 10.0 QPB8857 Return Loss vs Temperature



When the phase information in the s-parameter data stored along with the magnitude, K-factors and Mu factors can also be computed to analyze stability. Many current Vector Network Analyzers (VNA) include stability analysis. It also possible to employ S-parameter plotting utilities or simulation tools that can import S2P Touchstone format file from a VNA. For MMIC amplifiers, it is desirable to analyze stability to frequencies beyond the usable operating range as many devices have usable gain to several gigaherz depending on the size of the transistors being used. In this case, we have swept out to 3.3GHz and as shown in Figure 10.1, the K-factor, Mu1, and Mu2 plots are above 1 for all temperatures. For an amplifier where the feedback is being adjusted by a much larger amount, the impact on stability may end up being more noticeable.

Figure 10.1 QPB8857 Stability vs Temperature



Conclusion

The total resistance in the external feedback path of MMIC amplifiers determines the gain of the amplifier. Changing the total resistance in the feedback path as the temperature changes will allow the designer to compensate for the gain drift caused by temperature changes. Through testing the gain characteristics of a given amplifier and selecting an appropriate thermistor, the gain change can be reduced to a sufficient level for the application. In the final configuration, the designer can verify gain compensation and performance parameters over temperature such as return loss and stability. It is also possible using the methods described above to temperature stabilize other performance parameters such as linearity and current drift if external resistive adjustments are available on the target device.

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