Understanding Open Loop Output Impedance of the PGA900 DAC Gain Amplifier

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ABSTRACT

The open-loop output impedance (Z_O) of an operational amplifier is one of the most important specifications. Proper understanding of Z_O over frequency is crucial for the understanding of loop gain, bandwidth, and stability analysis.

This application note provides an in-depth understanding of the PGA900 Z_O magnitude over frequency. The effects of temperature, power supply voltage, and semiconductor process variation on the Z_O curve were observed. The variation over these parameters was used to develop a worst-case model that can be used to create robust designs.

Contents

List of Figures

List of Tables

1 PGA900 Z_O

Figure 1 shows the typical frequency behavior of the PGA900 Z_O magnitude, $|Z_O(s)|$. The PGA900 Z_O phase ($\varphi(s)$) is shown in Figure 2.

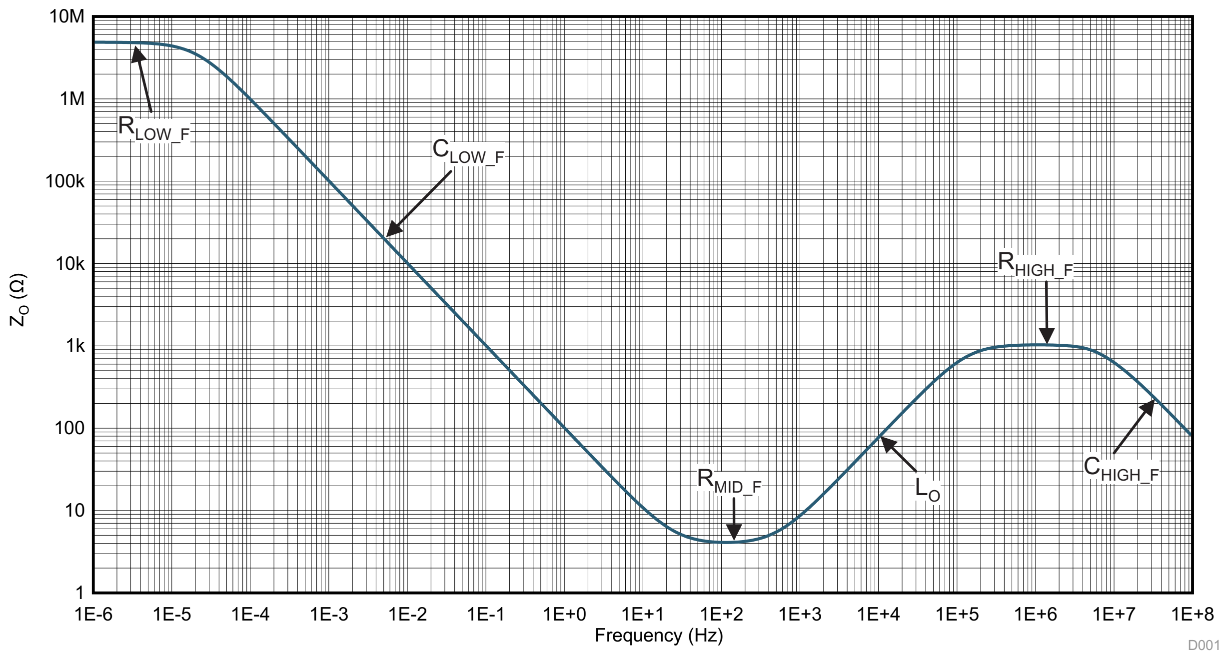

Figure 1. PGA900 Typical Magnitude of the Open-Loop Output Impedance Z_O

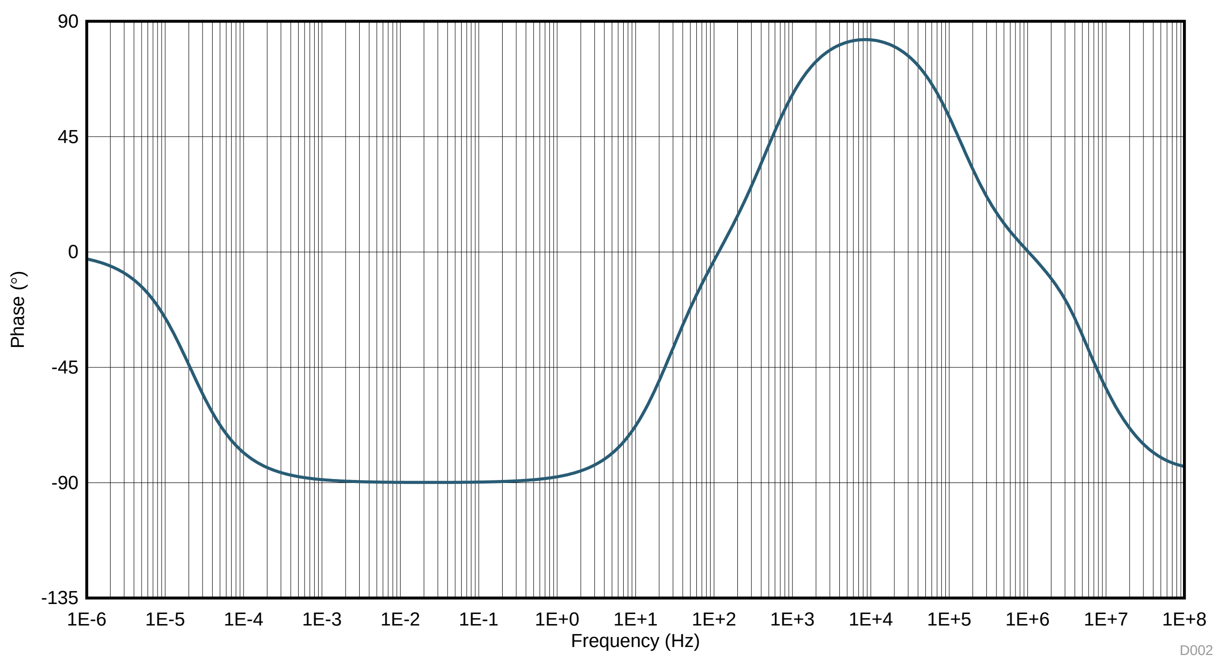

Figure 2. PGA900 Typical Phase of the Open-Loop Output Impedance Z_O

The PGA900 operational amplifier features a three-stage output stage architecture which results in the three distinct Z_O regions that can be seen in the Z_O magnitude. At low frequencies the Z_O curve is defined by a low frequency resistance value, R_{LOW_F}. As frequency increases Z_O becomes capacitive and Z_O in that region is defined by a low frequency capacitance value, C_{LOW_F}. At mid-frequencies, the Z_O becomes resistive again and is defined by a mid-frequency resistance value, R_{MID_F}. Z_O then becomes inductive and will be defined by an open-loop inductance value, L_O. This inductive region is the most important for stability analysis because capacitive loading on the output can interact with the inductance resulting in stability issues that are difficult to compensate. The inductive region turns resistive again at higher frequencies and can be defined by a high frequency resistance value, R_{HIGH_F}. Finally, at the high frequencies near the end of the region of interest Z_O turns capacitive again and can be defined by a capacitance, C_{HIGH_F}.

Nominal values for the PGA900 operational amplifier Z_O are listed below:

- R_{LOW_F} = 4.87 MΩ
- C_{LOW_F} = 1.57 mF
- R_{MID_F} = 4.09 Ω
- L_O = 1.23 mH
- R_{HIGH_F} = 1.03 kΩ
- C_{HIGH_F} = 20.14 pF

To create a robust design, it is important to understand how $|Z_O(s)|$ changes as the system operating conditions change. System operating conditions that affect the performance of the $|Z_O(s)|$ curve includes: temperature, power supply voltage, common-mode voltage and process variation.

2 Temperature Effects on PGA900 Z_o

The PGA900 is specified over an extended operating temperature range of –40ºC to 150ºC. The operating temperature affects the frequency behavior of the PGA900 $Z_O(s)$ over the full range of the curve as shown in Figure 3.

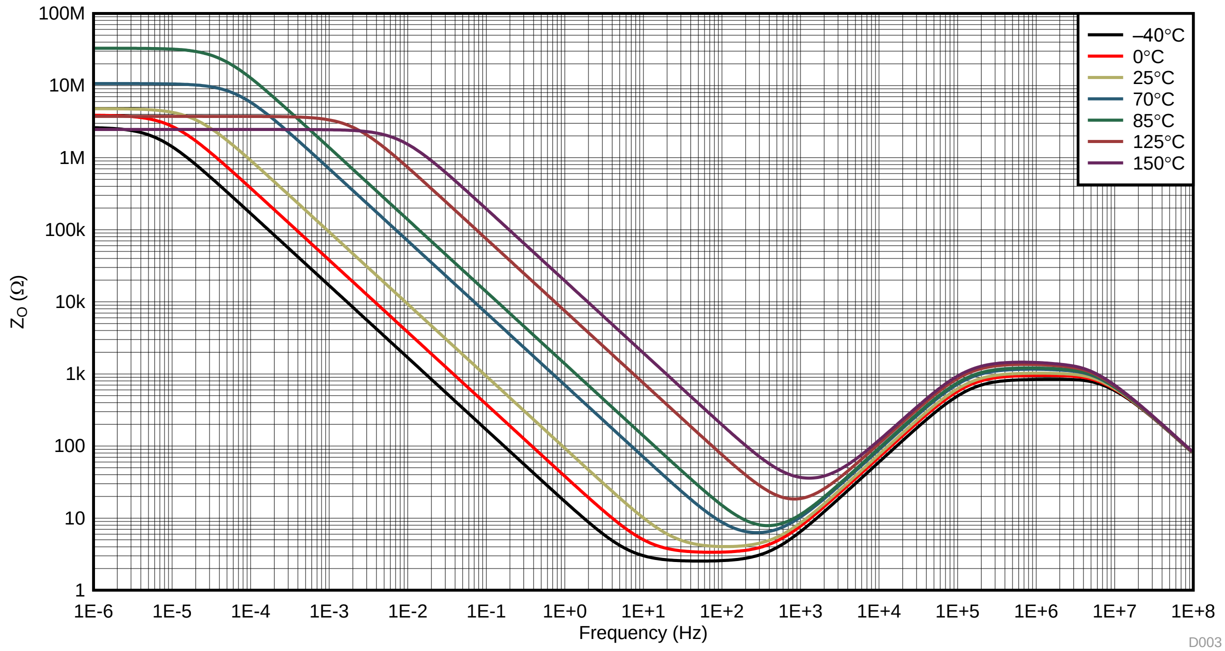

Figure 3. PGA900 $Z_O(s)$ vs Temperature

The Z_O parameter variations due to temperature are listed below:

- R_{LOW_F} = 2.46 − 32.88 MΩ
- C_{LOW_F} = 0.82 − 9.46 mF
- R_{MID_F} = 2.54 − 35.89 Ω
- L_O = 0.96 − 1.86 mH
- R_{HIGH_F} = 0.84 − 1.46 kΩ
- C_{HIGH_F} = 19.49 − 20.20 pF

3 Power Supply Effects on the PGA900 Z_o

The PGA900 can operate over a wide range of the power supply voltages from 3.3 to 30 V. The power supply voltage has minimal impact on $Z_O(s)$ as shown in Figure 4.

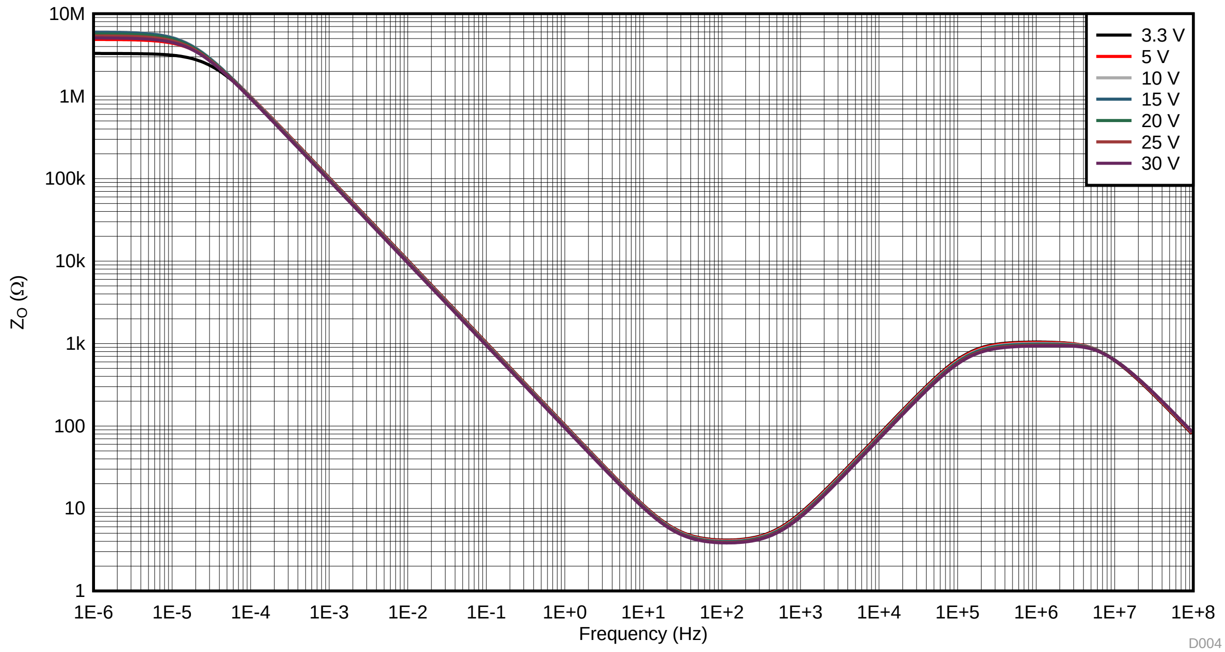

Figure 4. PGA900 $Z_O(s)$ vs Power Supply Voltage

The Z_O parameter variations due to power supply voltage are listed below:

- R_{LOW_F} = 3.3 − 6.02 MΩ
- C_{LOW_F} = 1.55 − 1.68 mF
- R_{MID_F} = 3.83 − 4.14 Ω
- L_O = 1.11 − 1.25 mH
- R_{HIGH_F} = 0.94 − 1.04 kΩ
- C_{HIGH_F} = 19.32 − 20.52 pF

4 Common-Mode Voltage Effects on PGA900

The common-mode voltage of the PGA900 has some minimal effects on the Z_O(s) as shown in Figure 5.

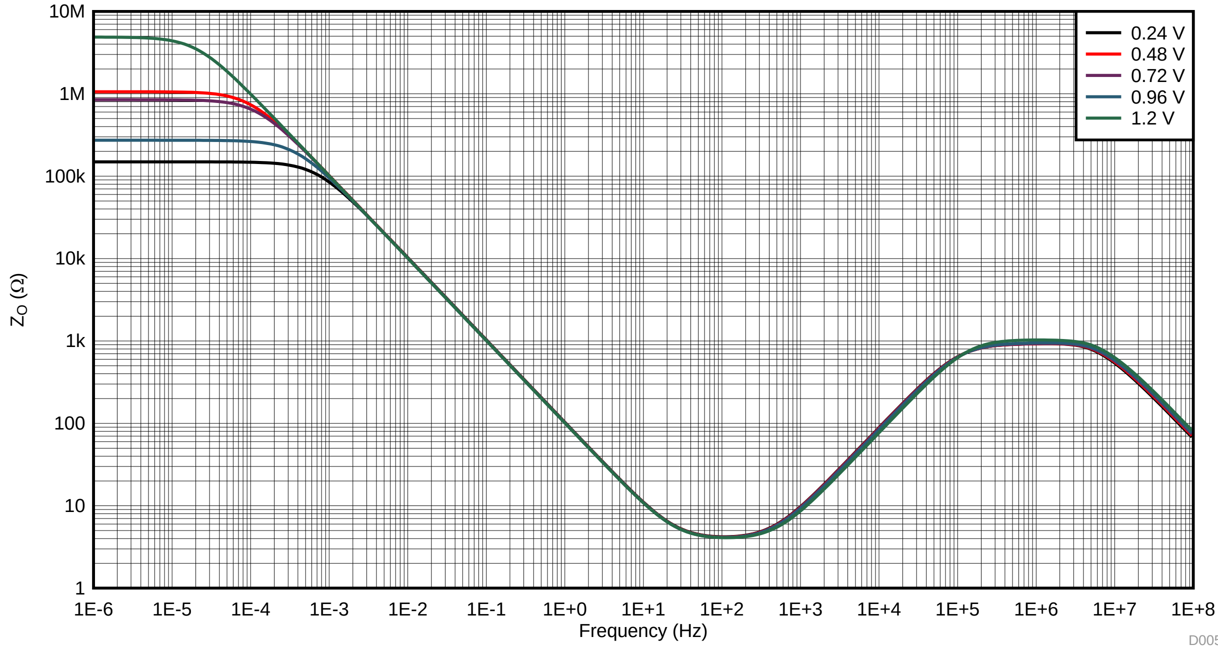

Figure 5. PGA900 Z_O(s) vs Common-Mode Voltage

The Z_O parameter variations due to common-mode voltage are listed below:

- R_{LOW_F} = 0.15 − 4.87 MΩ
- C_{LOW_F} = 1.56 − 1.88 mF
- R_{MID_F} = 4.09 − 4.20 Ω
- L_O = 1.23 − 1.40 mH
- R_{HIGH_F} = 0.93 − 1.03 kΩ
- C_{HIGH_F} = 20.14 − 24.31 pF

5 Process Variation Effects on PGA900 Z_o

During manufacturing, semiconductor process parameters are subjected to variations that result in performance differences in the final integrated circuits. Process corners represent the worst-case variations of these semiconductor parameters. The effects of the manufacturing process corners on the PGA900 Z_O(s) are displayed in Figure 6.

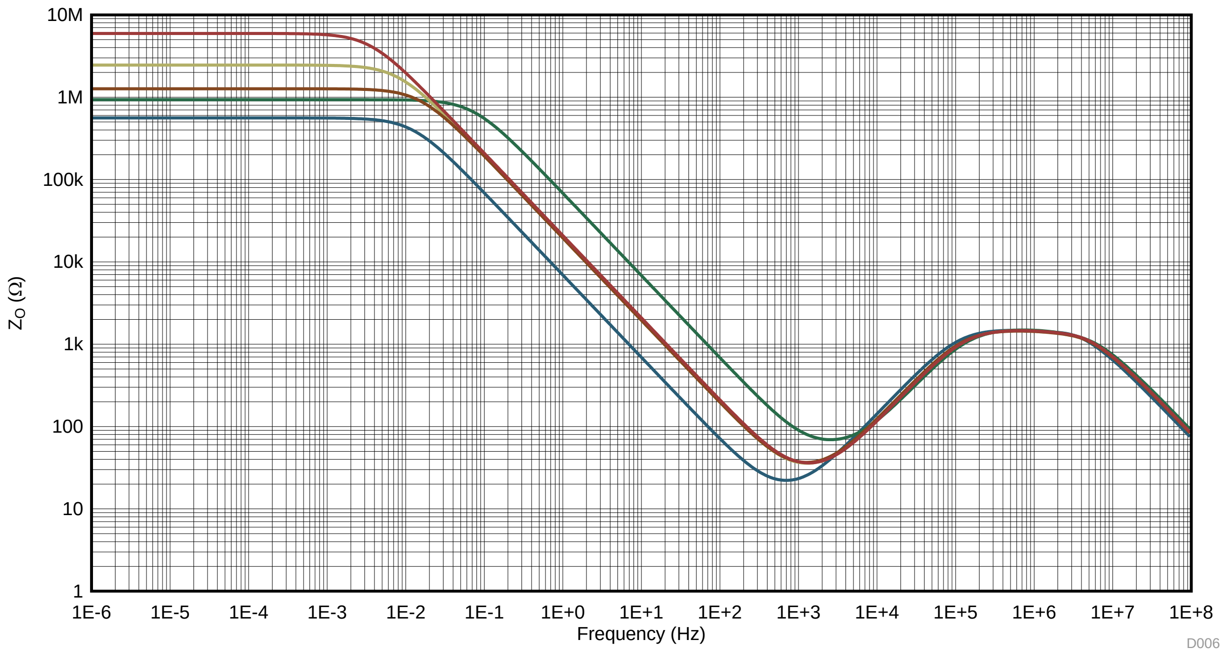

Figure 6. PGA900 Z_O(s) vs Process Variation

The Z_O parameter variations due to process variation are listed below:

- R_{LOW_F} = 0.35 − 5.95 MΩ
- C_{LOW_F} = 0.66 − 3.02 mF
- R_{MID_F} = 3.07 − 5.64 Ω
- L_O = 1.1 − 1.26 mH
- R_{HIGH_F} = 1.01 − 1.07 kΩ
- C_{HIGH_F} = 8.23 − 22.79 pF

6 Worst Case

The variations in the PGA900 $Z_O(s)$ due to temperature and process variations can be combined together to understand the worst-case variations that may occur in an application. The operating temperature results in the largest variations of $Z_O(s)$, while the power-supply voltage results in the smallest variations. The worst-case PGA900 $Z_O(s)$ can be observed in Figure 7.

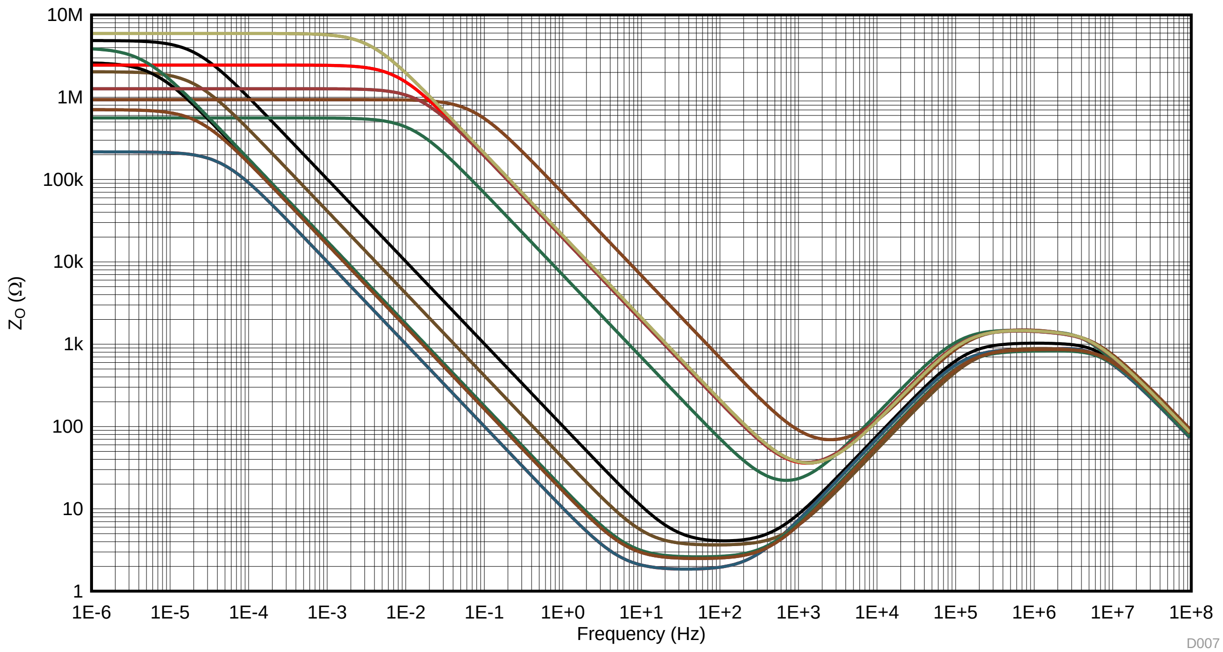

Figure 7. PGA900 Worst-Case $Z_O(s)$ vs Frequency

Taking the envelope of the minimum and maximum $Z_O(s)$ worst case results shows the possible variation of $Z_O(s)$ over several common application factors. The results are displayed in Figure 8.

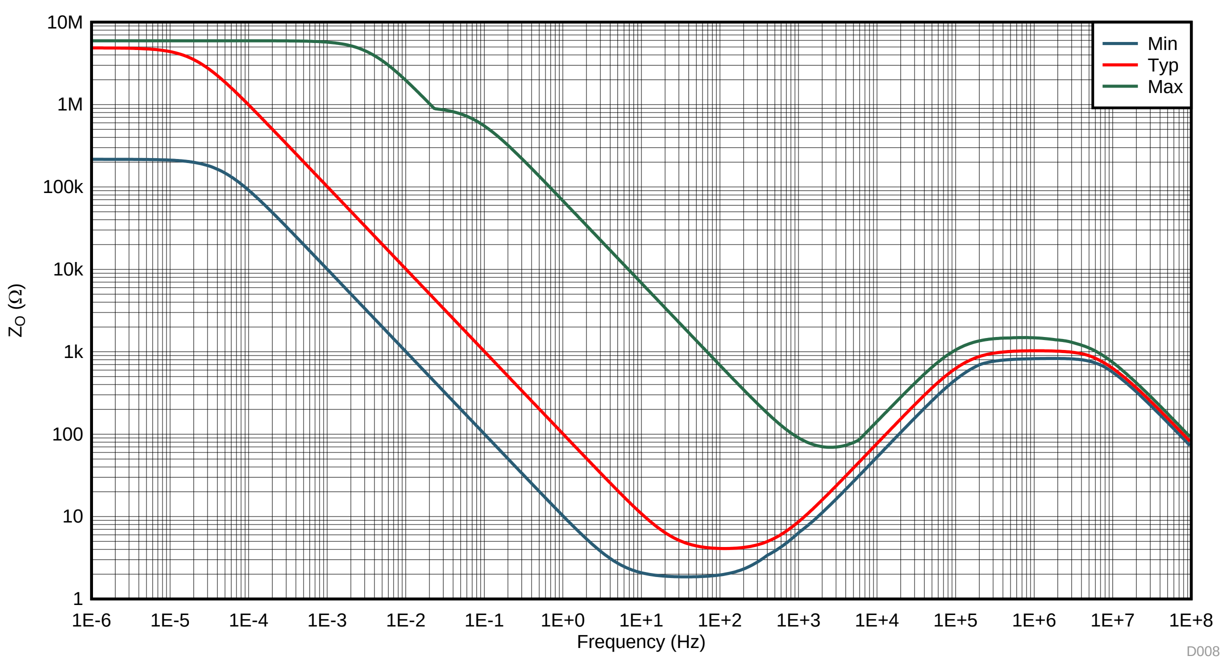

Figure 8. PGA900 Minimum and Maximum $Z_O(s)$ from Worst-Case Results

The Z_O parameter variations due to worst case are listed below:

- R_{LOW_F} = 0.22 − 5.95 MΩ
- C_{LOW_F} = 0.002 − 15.81 mF
- R_{MID_F} = 1.86 − 69.28 Ω
- L_O = 0.84 − 2.17 mH
- R_{HIGH_F} = 0.83 − 1.49 kΩ
- C_{HIGH_F} = 17.76 − 22.69 pF

7 Conclusion

The PGA900 Z_O curve is shaped by three resistive regions, two capacitive regions and one inductive region. The complete PGA900 Z_O curve is shown in Figure 1 and Figure 2.

The Z_O curve changes due to variations in the system operating temperature, power-supply voltage, common-mode voltage, and semiconductor processing. The changes in Z_O due to these varying application factors were presented in this article over the full operating range of the PGA900. The results from the individual parameters were used to determine the worst-case changes that may occur in a harsh industrial application. The results of the individual application factors along with the worst-case analysis are listed in Table 1. System designers can use this information to create a robust design over the expected application operating conditions.

Table 1. Summary of PGA900 Z_O

Application Factor	Conditions	R_{LOW_F}	C_{LOW_F}	R_{MID_F}	L_O	R_{HIGH_F}	C_{HIGH_F}
Temperature	–45 to 150°C	–49/+575%	–48/+503%	–38/+778%	–22/+51%	–18/+42%	–3/+0%
Power supply	3.3 to 30 V	–32/+24%	–1/+7%	–6/+1%	–10/+2%	–9/+1%	–4/+2%
Common-mode voltage	0.24 to 1.2 V	–97/+22%	–1/+20%	–0/+3%	–0/+14%	–10/+0%	–0/+21%
Process variation	Weak-strong	–93/+22%	–58/+92%	–25/+38%	–11/+2%	–2/+4%	–9/13%
Worst case	Temperature, Process	–95/+22%	–100/+907%	–55/+1594%	–32/+76%	–19/+45%	–12/+13%

8 References

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Revision History

Changes from Original (May 2015) to A Revision **Page**