Ultra-Low-Noise Amplifiers

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This white paper describes the performance and characteristics of three new ultra-low-noise amplifiers (LNAs) from Skyworks. Topics include techniques used in biasing and matching these devices. A circuit description, including information on thermal considerations, is also addressed.

The SKY67183-396LF, SKY67181-396LF, and SKY67189-396LF are designed to cover a wide bandwidth with the use of two separate devices with their design and performance analyzed from 400 MHz to 6.0 GHz. Package pinouts for each device are identical, with the only differences in the applications schematic and frequency band of interest for each device. The remainder of the paper will primarily focus on the SKY67183-396LF but will also be applicable, unless otherwise noted, for the SKY67181-396LF and SKY67189-396LF.

A primary function of the LNA is to minimize the cascaded noise figure (NF) of the receiver. As described by the Friis equation, the LNA gain minimizes the cascaded NF impact of subsequent stages, and its low NF minimizes its own NF contribution. This resulting low cascaded NF results in optimal receiver sensitivity in low signal level conditions and thus the LNA is a common receiver element in most receiver architectures. In addition to its gain and NF characteristics, the LNA linearity should also be high enough so that this stage does not limit the cascaded input third order intercept point (IIP3) and input 1 dB compression point (IP1 dB) of the receiver.

The family of products presented here are ultra-high-performance, low-noise, single-stage amplifiers designed for wireless applications in the 400 MHz to 6.0 GHz band of interest. Targeted applications are any systems requiring ultra-low-noise figures, very good linearity, and extended temperature performance to +115 °C ambient.

These single-stage, high-linearity, high-gain, low-noise amplifiers are housed in a low thermal resistance 8-pin 2 x 2 mm package. Thermal performance is also improved by the use of a low-resistance, high-conductivity thermal epoxy that is used to attach the amplifier die to the package lead frame. This attachment method - as well as rugged on-die structures, gives the devices the ability to operate safely up to the +115 °C maximum ambient temperature. The LNA’s active bias circuitry internally provides stable performance over temperature and process variations. Supply current is also controlled by adjusting one external resistor and can be varied over a very wide range independently from the device VDD. This feature allows the device efficiency to be optimized according to the linearity requirements of a particular application.

Any additional technical information required can be made available by Skyworks. If a new application from a customer requires a specialized tuning, requests may be forwarded as well.

Design and Configuration

Figure 1 shows the active biasing and matching circuits required for the device to operate properly. The operating current will be set through the external resistor component designated as R1.

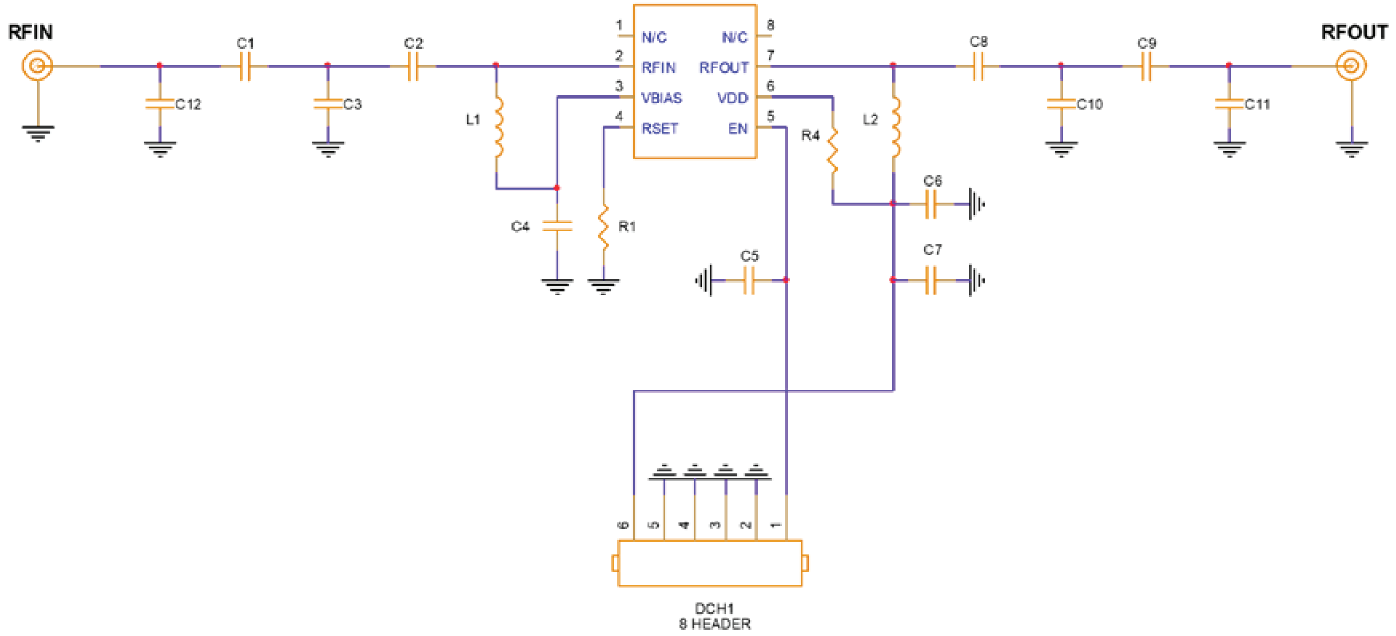


Figure 1. LNA Functional Schematic

A typical set of bias current vs. external resistor values R1 is shown in Figure 2. The recommended range of bias current for operating the modules is from 20 mA to 100 mA (IDQ), with operating voltages that can range from 3.3 V to 5.25 V. Operating the devices anywhere within these ranges of bias conditions will result in excellent performance. Generally speaking, higher device quiescent current will result in higher IP3 while higher VDD will result in higher P1dB. However, due to the constant current mirror integrated into these SKY67181-396LF, SKY67183-396LF, and SKY67189-396LF LNAs, Gain S(2,1), NF, and IP3 are relatively insensitive to device IDQ, VDD, and temperature variation. P1dB is also relatively insensitive to the IDQ while higher VDD results in higher P1dB.

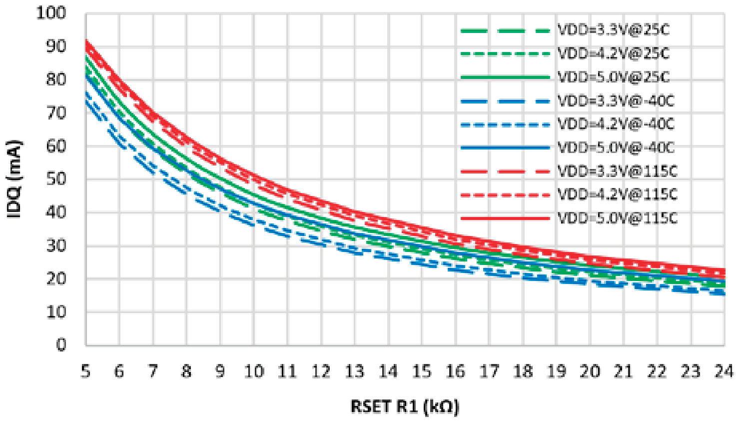


Figure 2. Bias Currents vs External Resistance

Referring to Figure 1, components C12, C1, C2, C3 and L1 are used for matching Input Return Loss S(1,1) as well as NF. L1 also acts as a high-impedance bias supply for the gate of the input FET, with C4 acting as an RF short circuit at the frequency of operation. C4 can also be used to match S(2,2) as well, but to a lesser degree than Inductor L1. For optimal NF, all the input matching components should have high Q with wire-wound inductors offering an excellent combination of price and performance.

Component L2 acts as a high impedance bias feed for the drain of the output FET as well as part of the matching for output return loss S(2,2). Capacitor C7 is also part of the bias structure and acts as a short circuit to ground at the RF frequency of interest. It can also be used to match S(2,2) as well, but to a lesser degree than Inductor L2. Capacitor C 6 is used for RF bypassing and should be placed closely to C7.

Components C8, C9, C10 and C11 are all for output matching and are used mostly for the tuning of S(2,2), IP3 and P1 dB. High frequency stability is also improved with the addition of resistor C11 with very minor degradations in performance. All devices on the output side of the amplifier can be standard Q components with no significant performance impact.

Both the SKY67183-396LF, the SKY67181-396LF have an enable or power down feature which is present on pin 5. The enable feature is active on a low signal input, <0.63 V and in this condition the amplifier is in the “ON” state. Levels above 1.17 V up to a maximum of 2.4 V will turn the amplifier to the “OFF” state and current consumption will be in microampere range. Note that when in the “OFF” conditions RF signal levels of -5 dBm or more will begin to re-bias the gate of the input transistor and the device will begin to turn back on to some degree. For applications in which the device must remain off under high input power levels, it is recommended that the VDD be switched low to prevent this self-biasing from occurring.

Figure 3 shows the evaluation board (EVB) used to test and tune the LNA in its different tuning states. As Figure 4, the board is comprised of a four-layer stack with the top layer being Rogers 4350B, 0.254 mm or 10 mils thick. Transmission Line Construction is coplanar with a ground plane spacing of 0.375 mm and via diameters are all 0.2 mm. Careful attention to the layout must be employed as to reduce the risk of stray capacitance or inductance which may result in decreased performance or instabilities in the device at especially high frequencies. Ground vias under the device must also be as detailed in Figure 5. An insufficient amount of ground via or those with increased inductance will increase the thermal resistance of the device, lowering its maximum operating temperature, as well as potentially induce high frequency instabilities in the amplifier from increased source inductance.

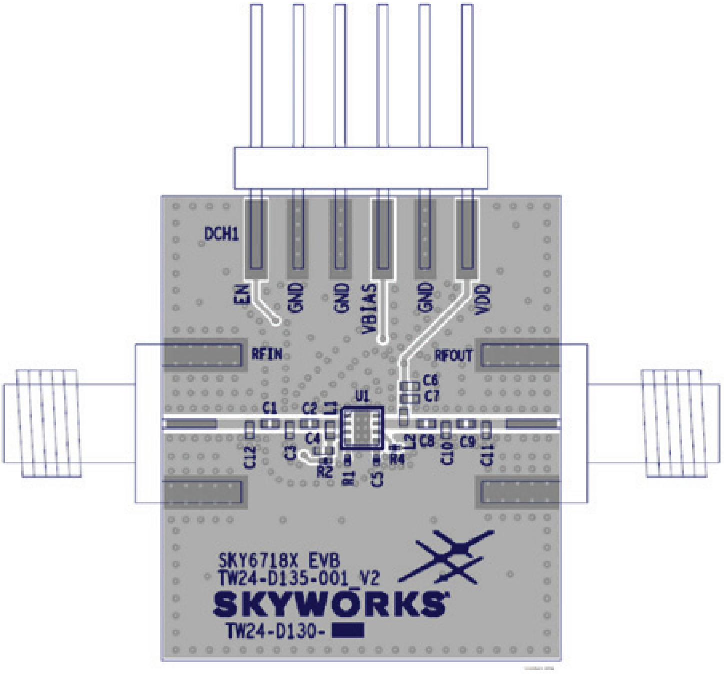
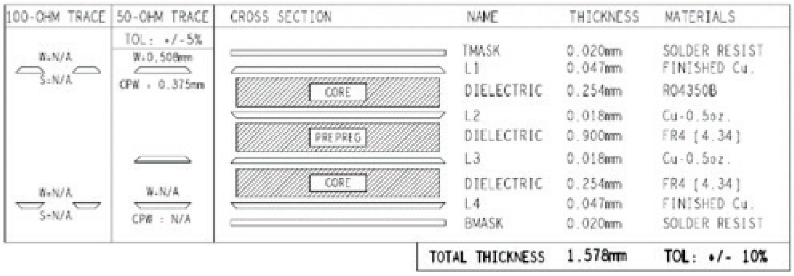


Figure 3. Applications Circuit



NAME	THICKNESS	MATERIALS
TMASK	0.020mm	SOLDER RESIST
L1	0.047mm	FINISHED Cu.
DIELECTRIC	0.254mm	RO4350B
L2	0.018mm	Cu-0.5oz.
DIELECTRIC	0.900mm	FR4 [4.34]
L3	0.018mm	Cu-0.5oz.
DIELECTRIC	0.254mm	FR4 [4.34]
L4	0.047mm	FINISHED Cu.
BMASK	0.020mm	SOLDER RESIST
TOTAL THICKNESS	1.578mm	TOL: +/- 10%

Figure 4. EVB Layer Details

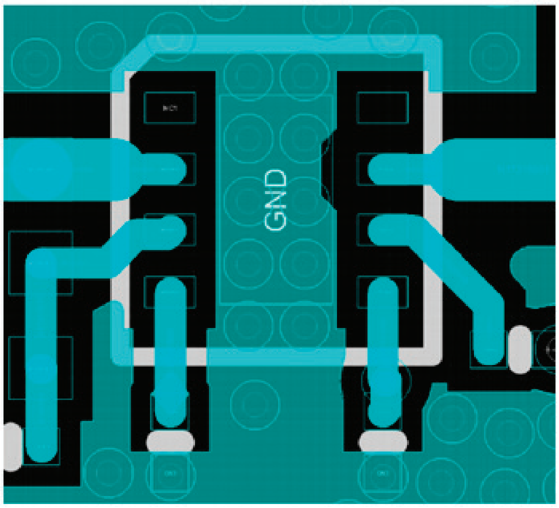


Figure 5. Ground Via Land Pattern

Typical Performance Data

There are a variety of matching structures which can be employed to cover as an example the performance of the SKY67183-396LF from 400 MHz to 6000 MHz. For this example, consider the tuning from 3300 MHz to 3800 MHz. Figures 6 through 14 highlight the typical small signal performance at 5 V and 52 mA when R1 sets 8.2kΩ. The device has been tuned for lowest NF in this example, while still maintaining a reasonable S(1,1) of -13 dB. The measured noise figure of the complete evaluation board with this particular set of matching components was found to be0.43 dB at 3600 MHz. This extremely low noise figure challenges the accuracy of the measurement equipment which has on its own uncertainty factor for the measurement. The device can also be tuned if required for best S(1,1) at the expense of slightly degraded noise figure. As an example, with an S(1,1) of approximately -18 dB or less, the measured NF would degrade to 0.5 to 0.55 dB. Gain S(2,1) for the device under these conditions was 19.1 dB and S(2,2) was measured to be -16.4 dB. Note also that the even with this excellent output match and high gain the output IP3 was +28.9 dBm or equivalently +10.4 dBm input IP3 Output compression point was also measured to be +20.1dBm (OP1 dB), +1.3 dBm (IP1 dB). So not only is the SKY67183-396LF an ultra-low noise amplifier which was primarily designed as an input or stage-one amplifier, it also could be a stage- two device because of its excellent linearity characteristics. The device also yields very good reverse isolation S(1,2), -32.4 dB, making it very insensitive to load matching while trying to match the input for lowest noise or best S(1,1).Stability vs. frequency and temperature is shown in Figures 11 and 12. Stability factors vs. bias voltage and current stay quite uniform and controlled. It is important that the applications circuit grounding of the device paddle be adhered to (Figure 5). This will ensure a good thermal contact as well as provide a low inductance path to ground for terminating RF currents.

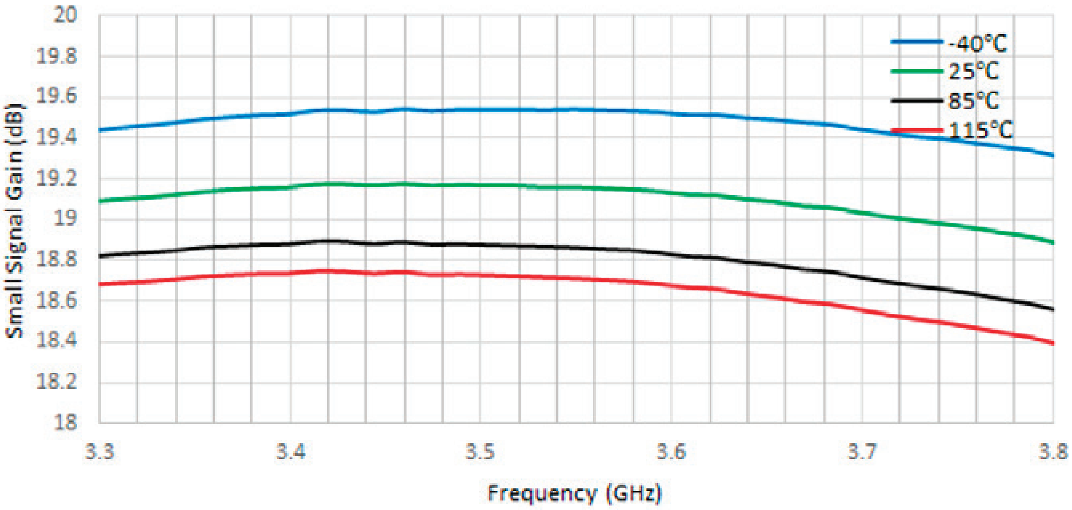


Figure 6. Small Signal Gain

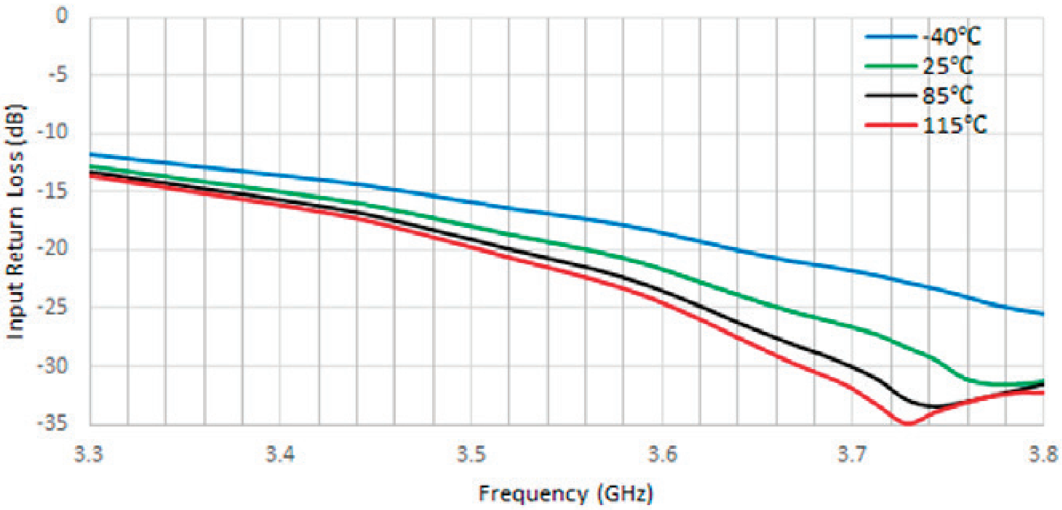


Figure 7. Input Return Loss

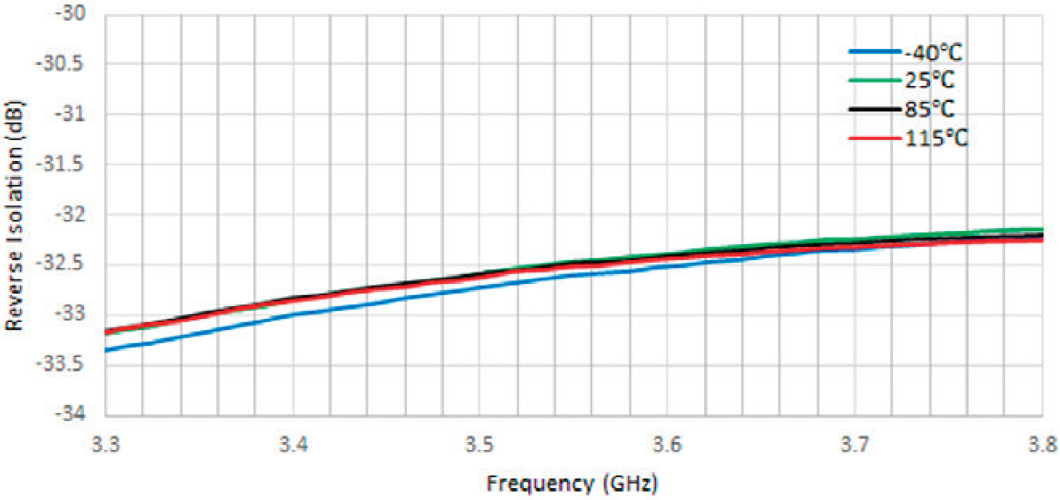


Figure 8. Reverse Isolation

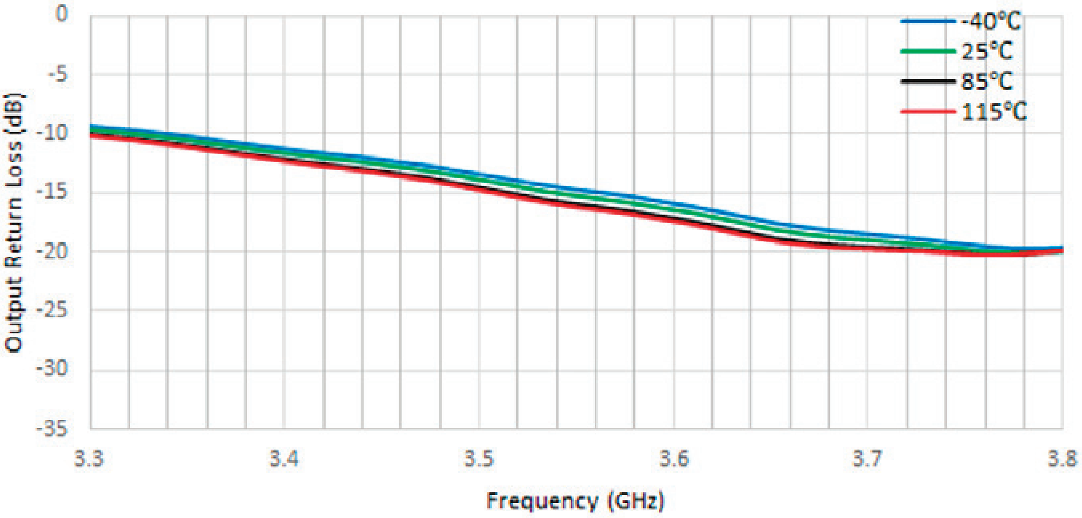


Figure 9. Output Return Loss

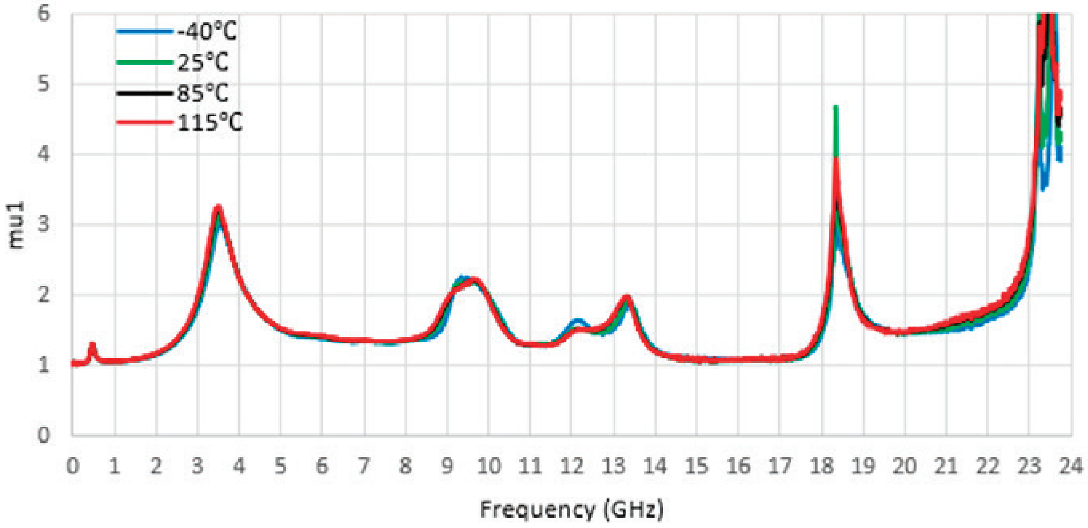


Figure 10. Stability Factor (µ1)

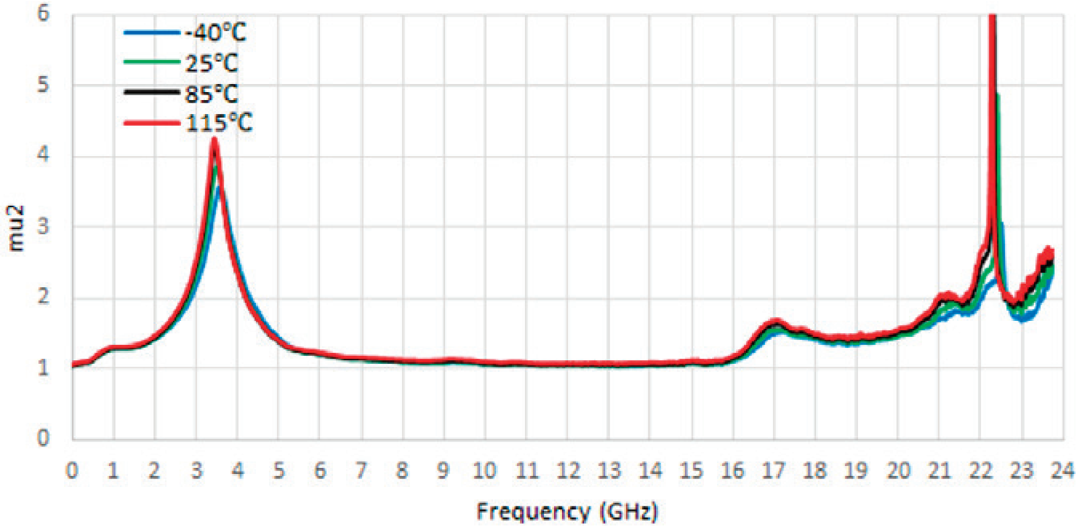


Figure 11. Stability Factor (µ2)

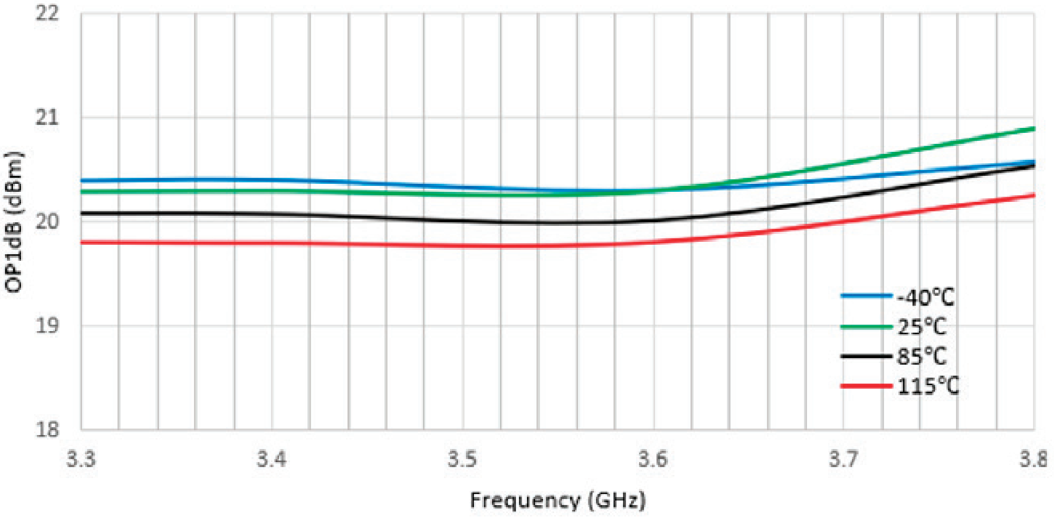


Figure 12. Output P1dB

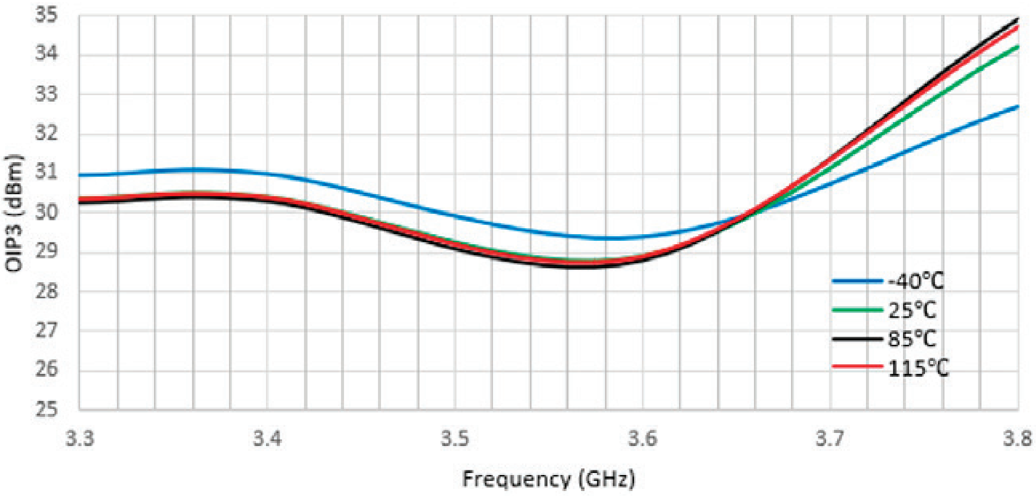


Figure 13. Output IP3

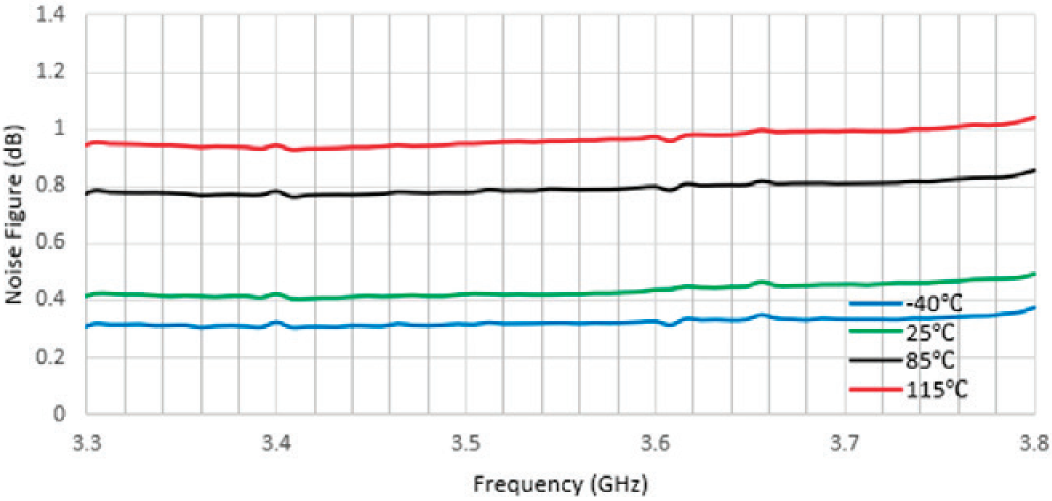


Figure 14. Noise Figure

Typical Performance Data Due to the Supply Current IDD and Supply Voltage VDD Variation

The internal active bias circuitry provides stable performance over temperature and process variation that integrated PTAT (proportional to absolute temperature) generates constant current through the current mirror. Specifically, output current remains proportional to input bias current at its high impedance output node of the current mirror, and as a result, output current remains consistent with input current regardless of temperature. Gain is defined by the ratio of input and output current, which remains stable due to the current mirror. Thus, gain is independent from VDD and remains stable over IDD.

Noise depends on current, temperature, and other factors, and as current remains stable, the noise figures also stay consistent across VDD and IDD. Finally, IP3 is only characteristic of current and thus remains similar across different VDD. Other factors regarding the input power level and current mirror circuitry keep IP3 relatively consistent across IDD as well. P1dB, however, remains dependent on VDD as a metric of power, and thus P1dB increases along with VDD. Consequently, the gain, noise figure, IP3, and P1dB performances show stable characteristics over IDD currents and VDD voltages, and P1dB depends on the VDD.

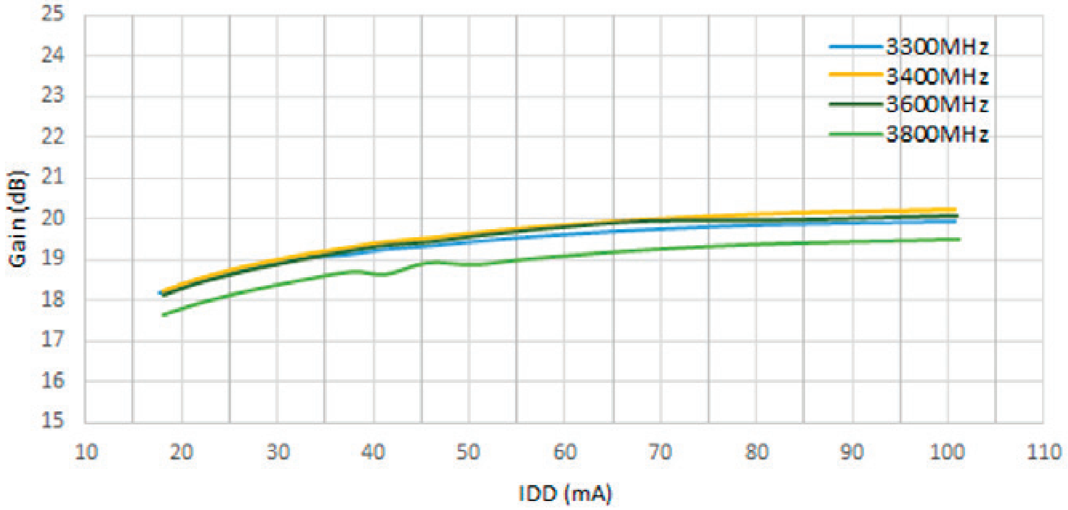


Figure 15. Gain (dB) vs IDD (mA) at VDD = 3.3V

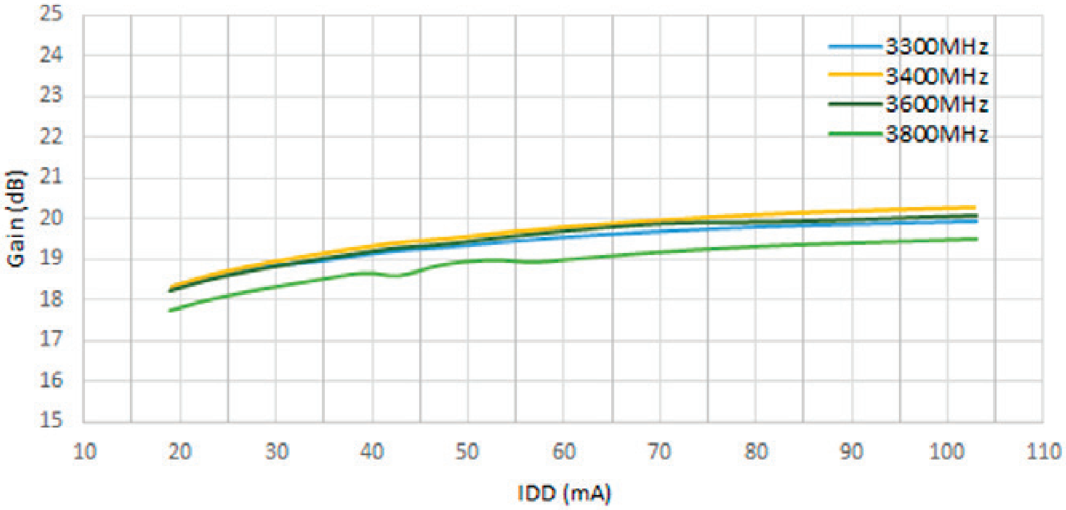


Figure 16. Gain (dB) vs IDD (mA) at VDD = 4.2V

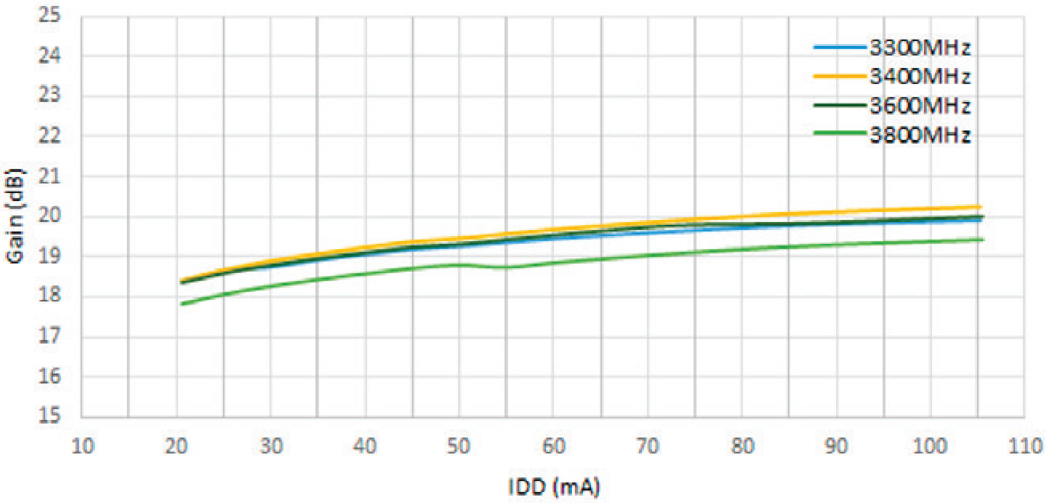


Figure 17. Gain (dB) vs IDD (mA) at VDD = 5.0V

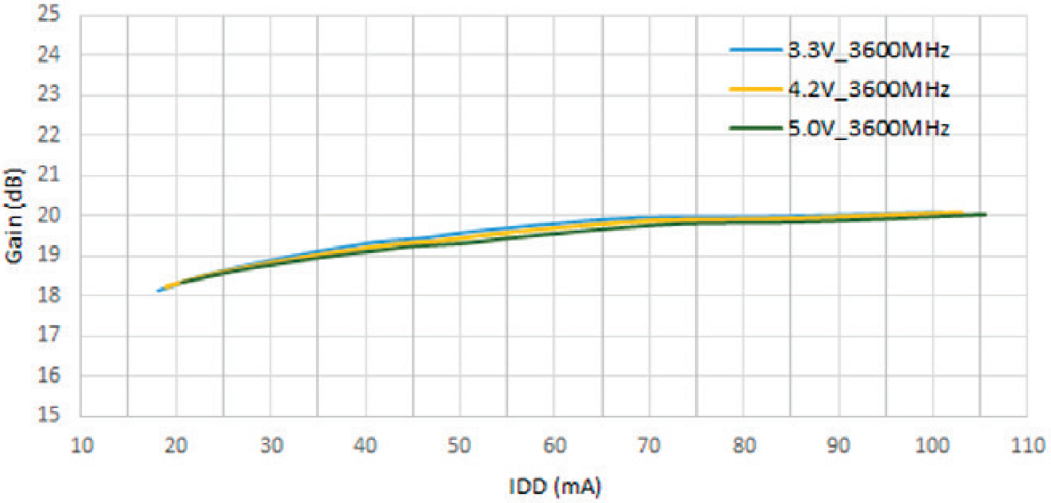


Figure 18. Gain (dB) vs IDD (mA) at VDD = 3.3V,4.2V,5.0V

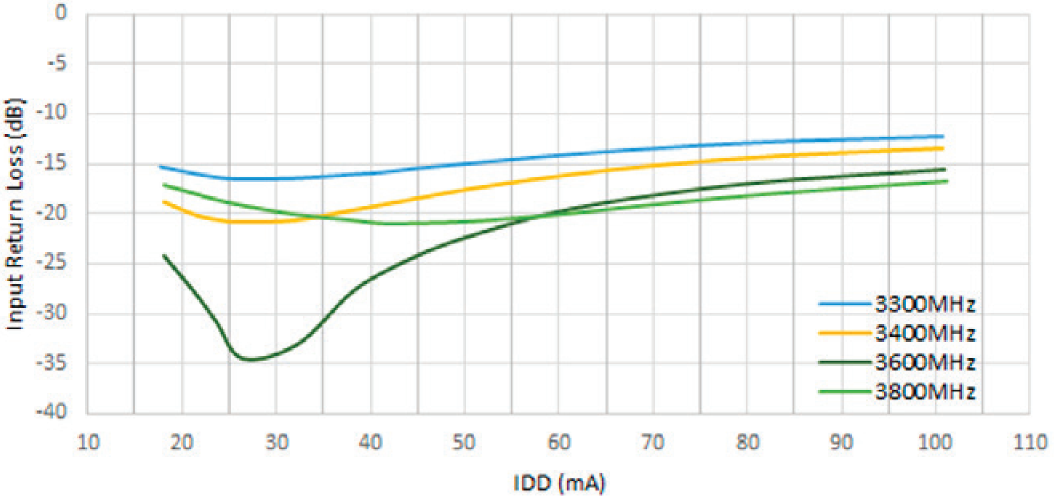


Figure 19. Input Return Loss (dB) vs IDD (mA) at VDD = 3.3V

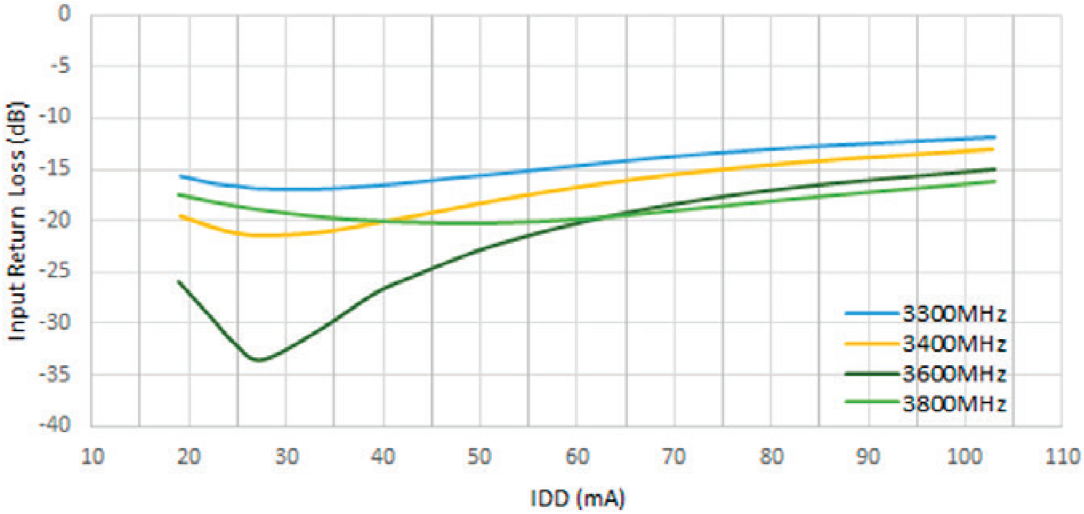


Figure 20. Input Return Loss (dB) vs IDD (mA) at VDD = 4.2V

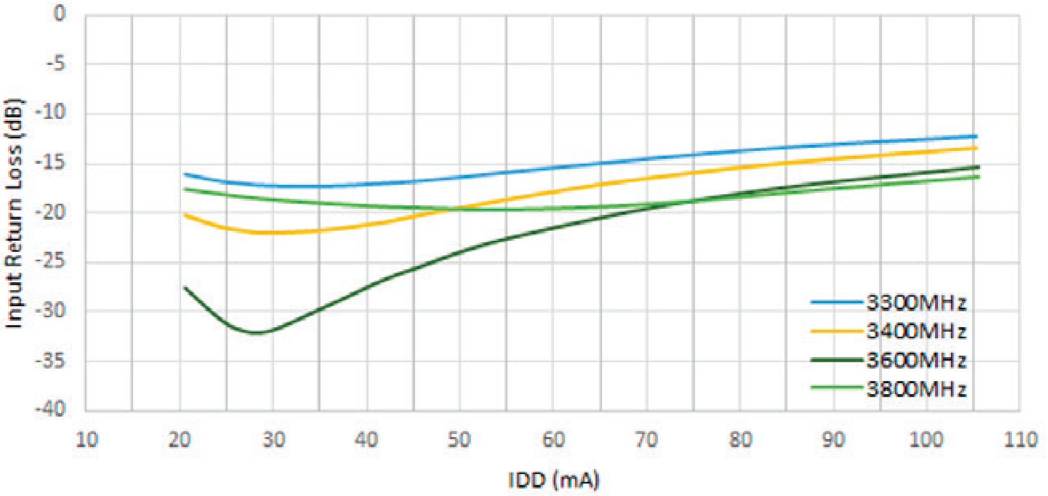


Figure 21. Input Return Loss (dB) vs IDD (mA) at VDD = 5.0V

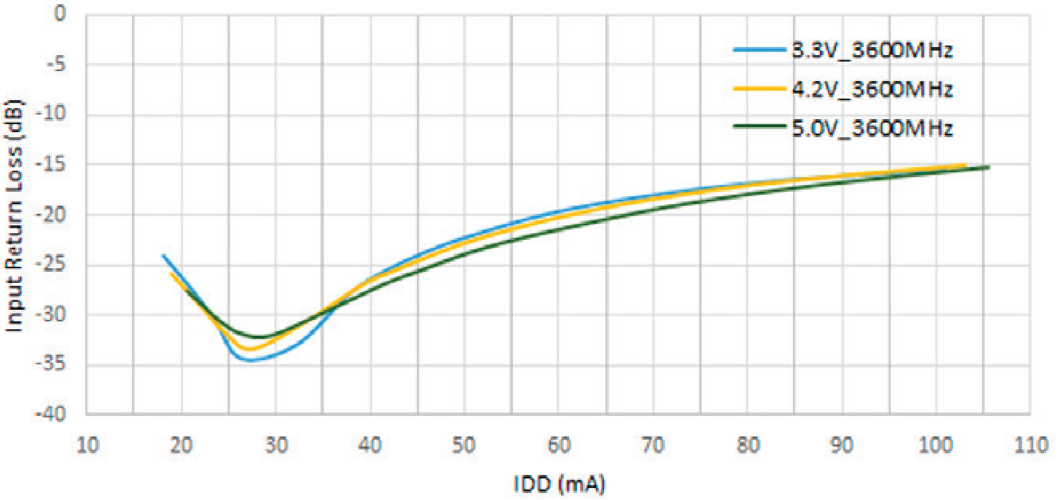


Figure 22. Input Return Loss (dB) vs IDD (mA) at VDD = 3.3V,4.2V,5.0V

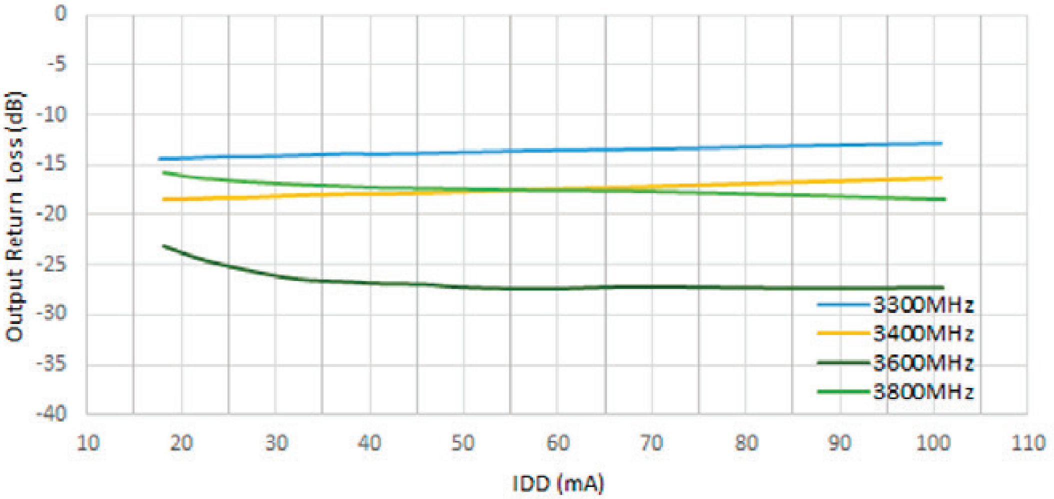


Figure 23. Output Return Loss (dB) vs IDD (mA) at VDD = 3.3V

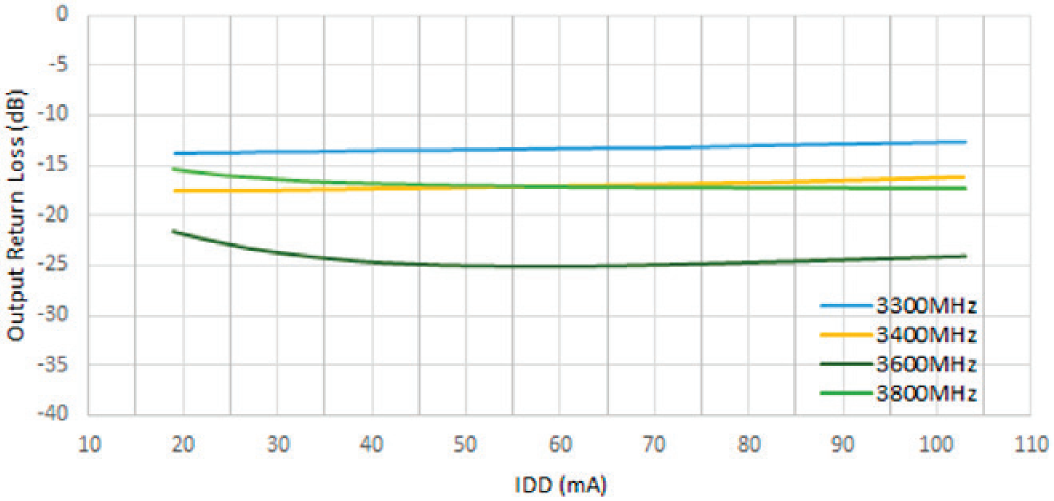


Figure 24. Output Return Loss (dB) vs IDD (mA) at VDD = 4.2V

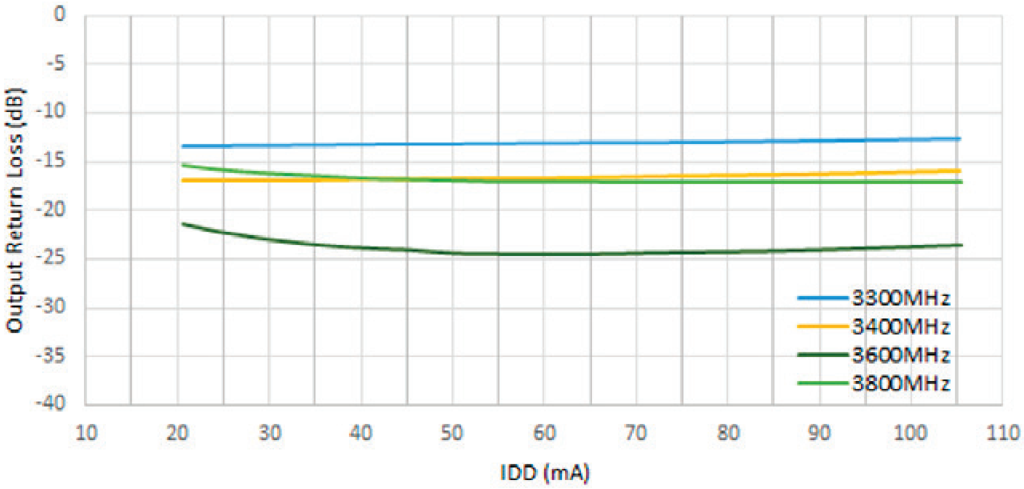


Figure 25. Output Return Loss (dB) vs IDD (mA) at VDD = 5.0V

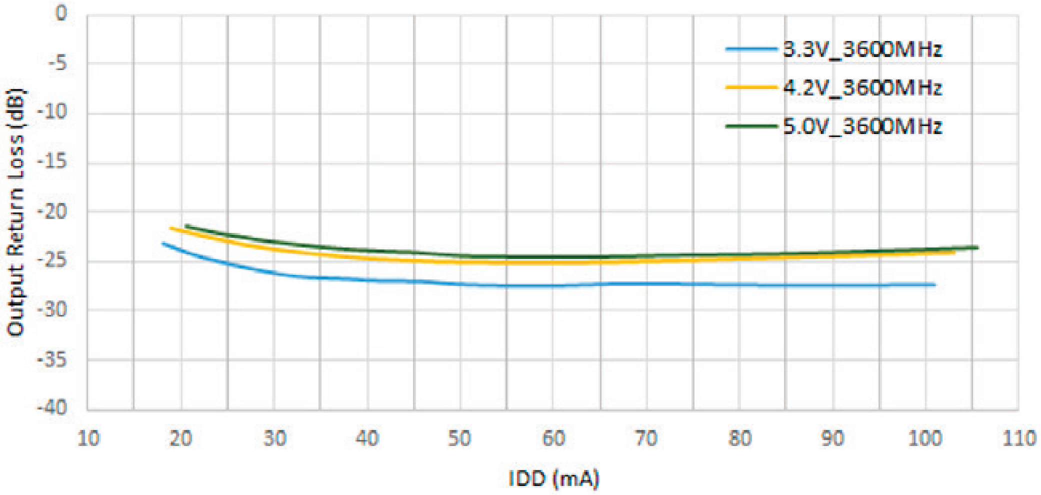


Figure 26. Output Return Loss (dB) vs IDD (mA) at VDD = 3.3V,4.2V,5.0V

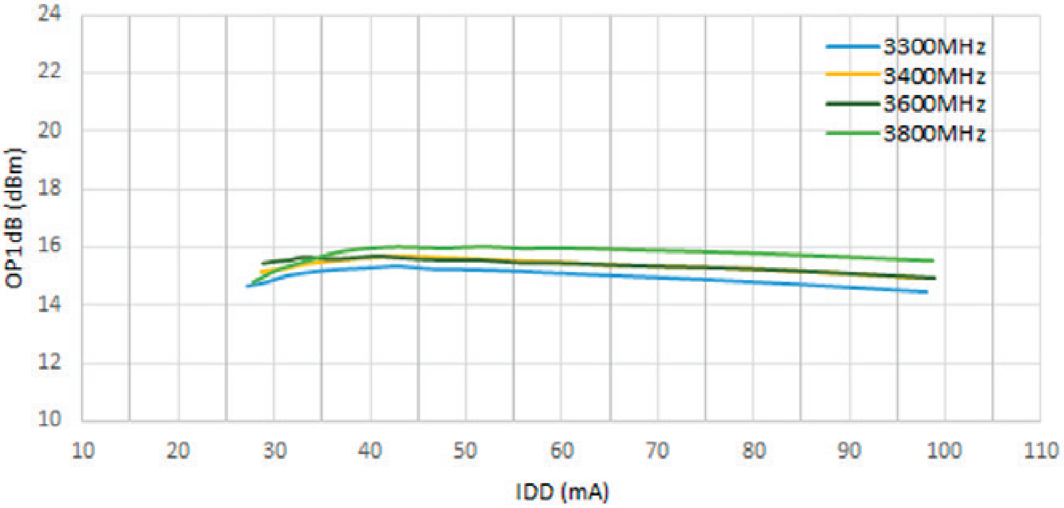


Figure 27. OP1dB (dBm) vs IDD (mA) at VDD = 3.3V

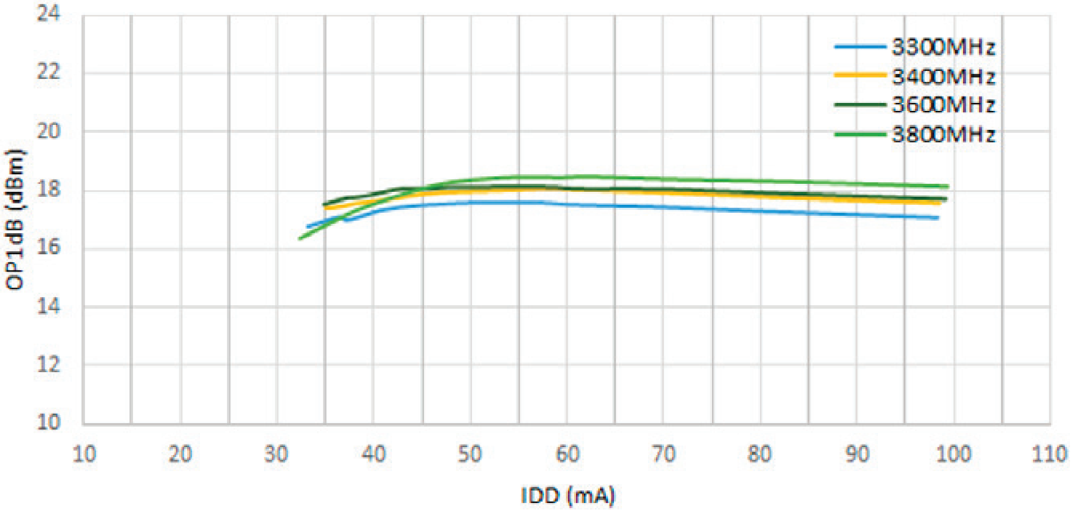


Figure 28. OP1dB (dBm) vs IDD (mA) at VDD = 4.2V

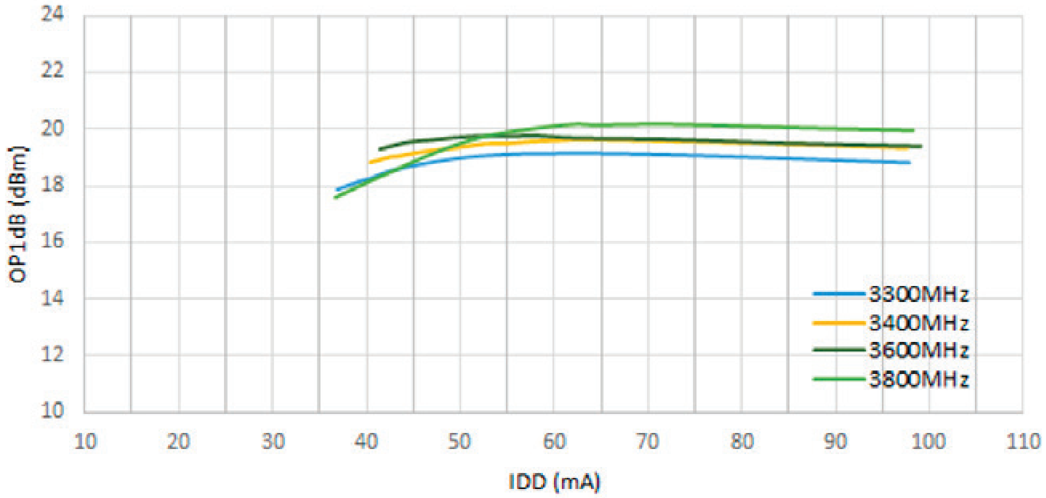


Figure 29. OP1dB (dBm) vs IDD (mA) at VDD = 5.0V

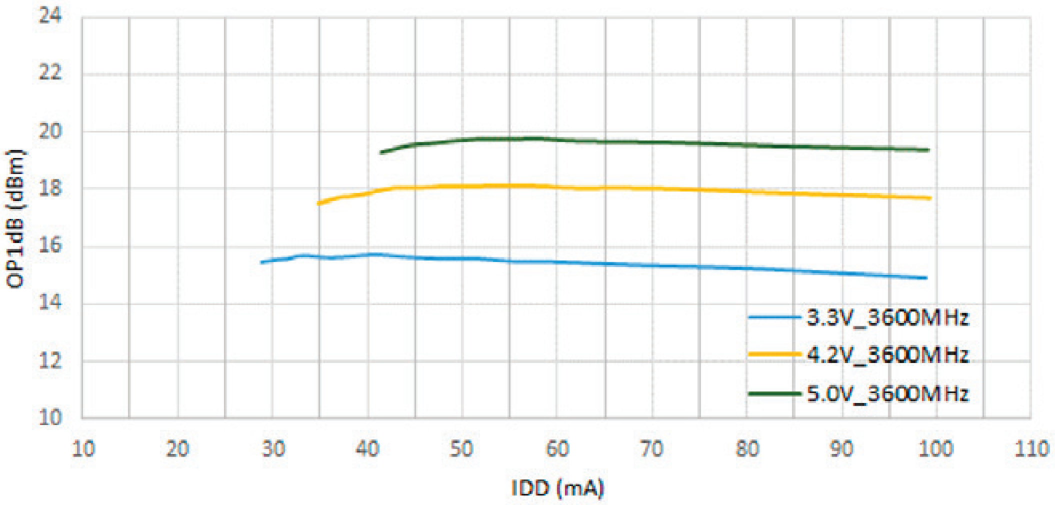


Figure 30. OP1dB (dBm) vs IDD (mA) at VDD = 3.3V,4.2V,5.0V

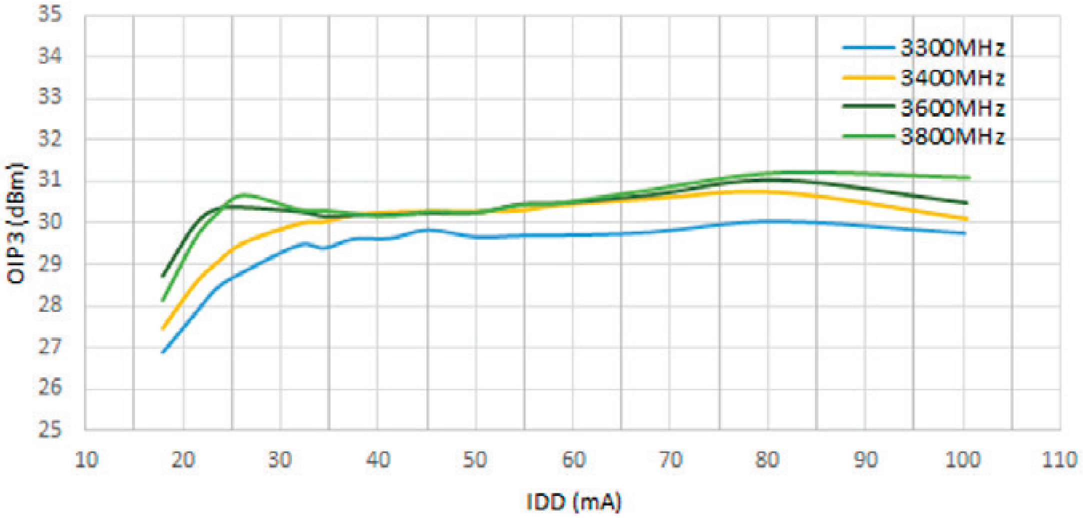


Figure 31. OIP3 (dBm) vs IDD (mA) at VDD = 3.3V

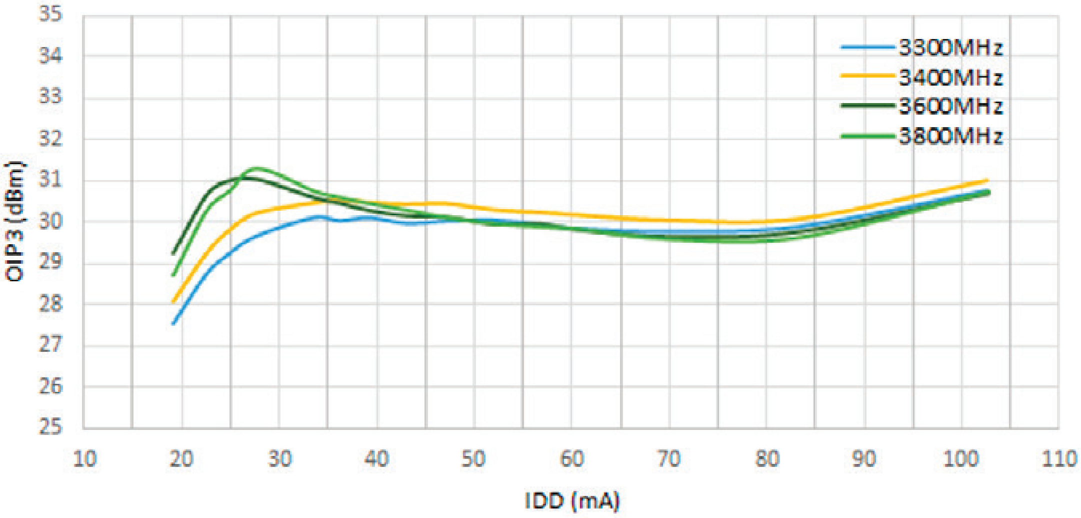


Figure 32. OIP3 (dBm) vs IDD (mA) at VDD = 4.2V

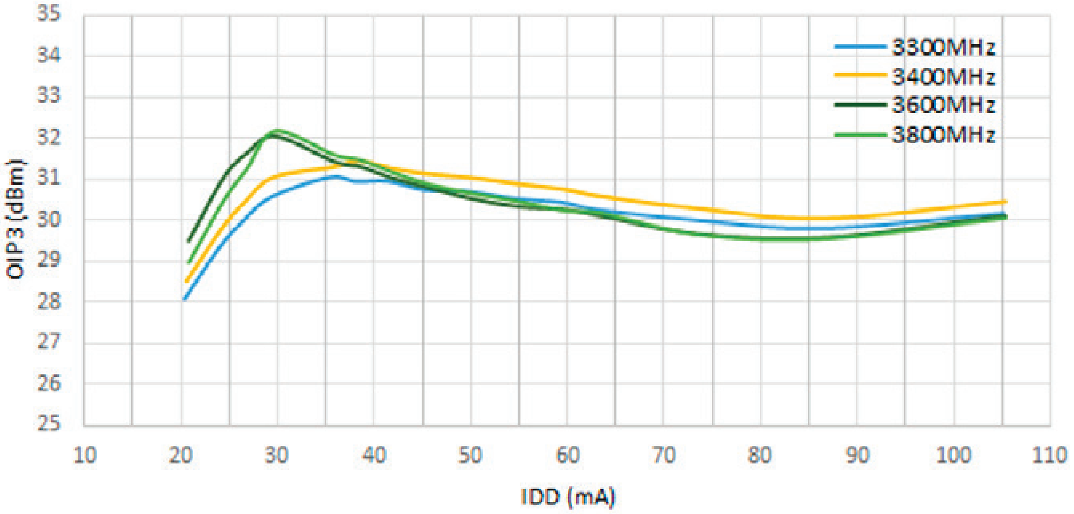


Figure 33. OIP3 (dBm) vs IDD (mA) at VDD = 5.0V

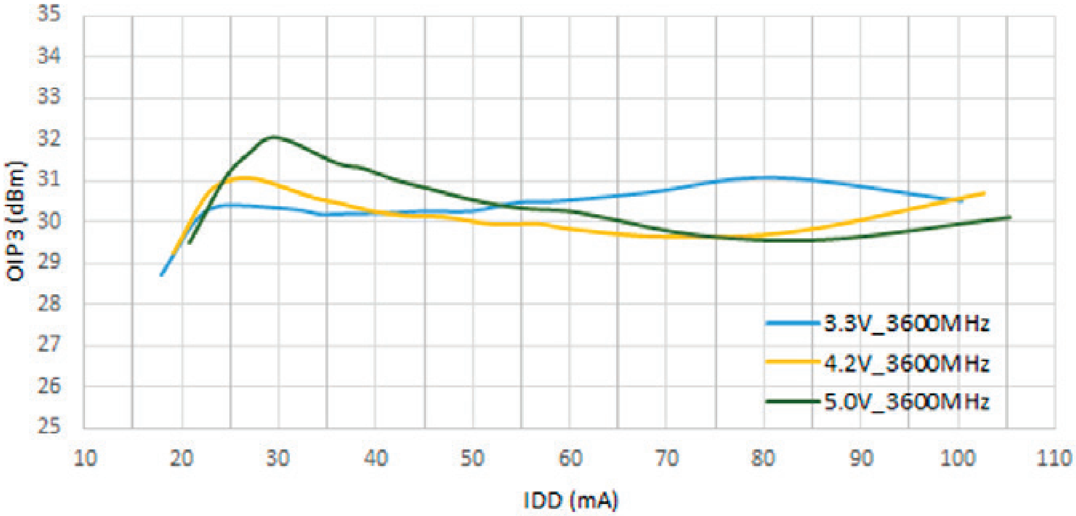


Figure 34. OIP3 (dBm) vs IDD (mA) at VDD = 3.3V,4.2V,5.0V

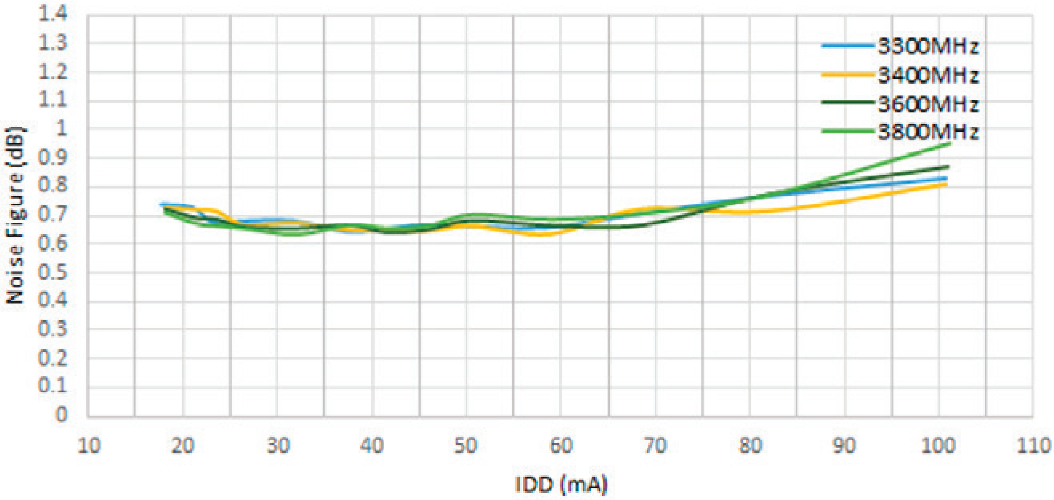


Figure 35. NF (dB) vs IDD (mA) at VDD = 3.3V

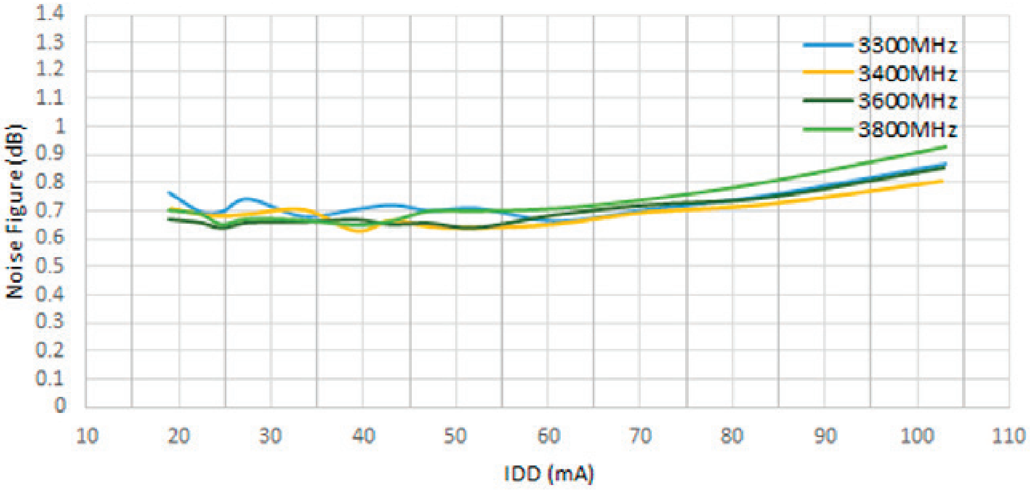


Figure 36. NF (dB) vs IDD (mA) at VDD = 4.2V

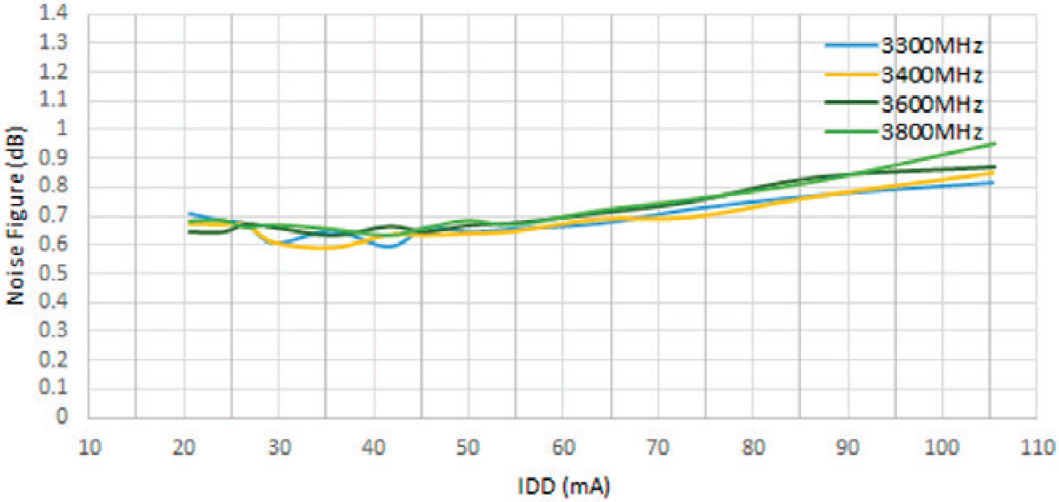


Figure 37. NF (dB) vs IDD (mA) at VDD = 5.0V

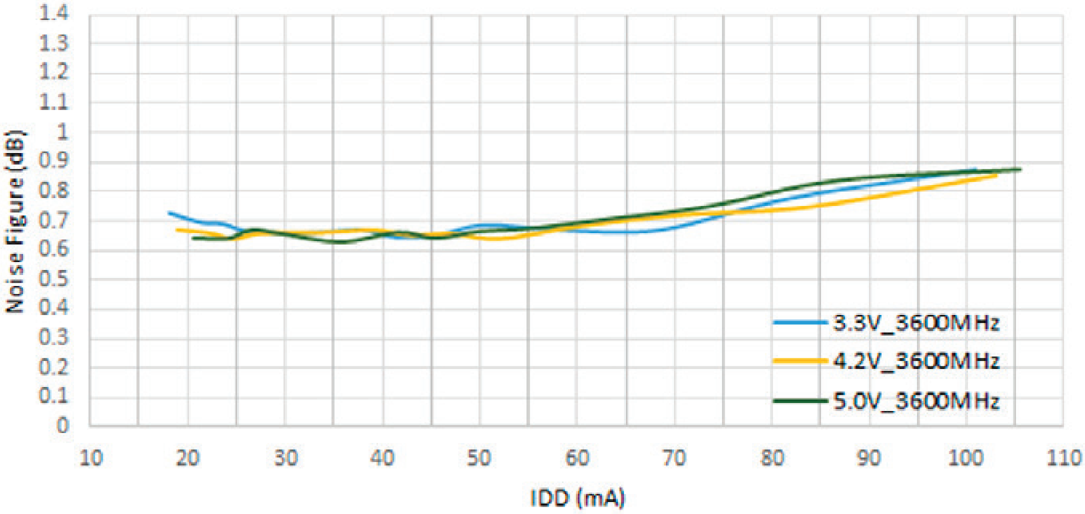
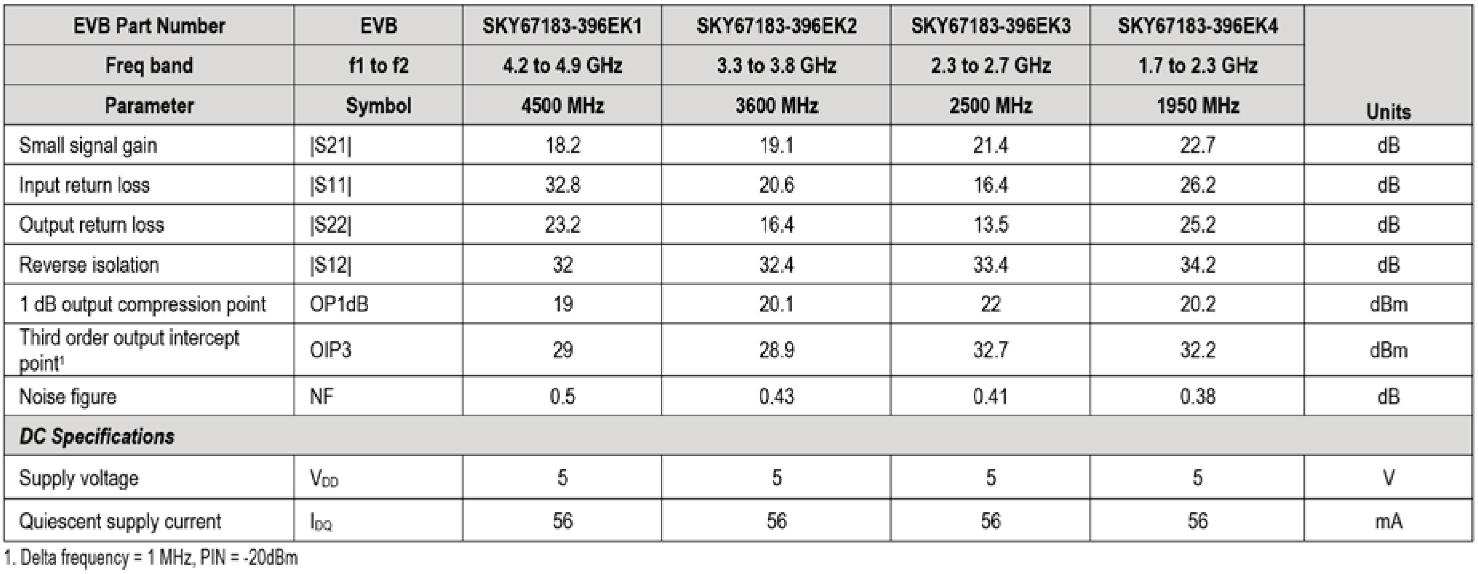


Figure 38. NF (dB) vs IDD (mA) at VDD = 3.3V,4.2V,5.0V

SKY67183-396LF, SKY67181-396LF, and SKY67189-396LF Frequency Response Data

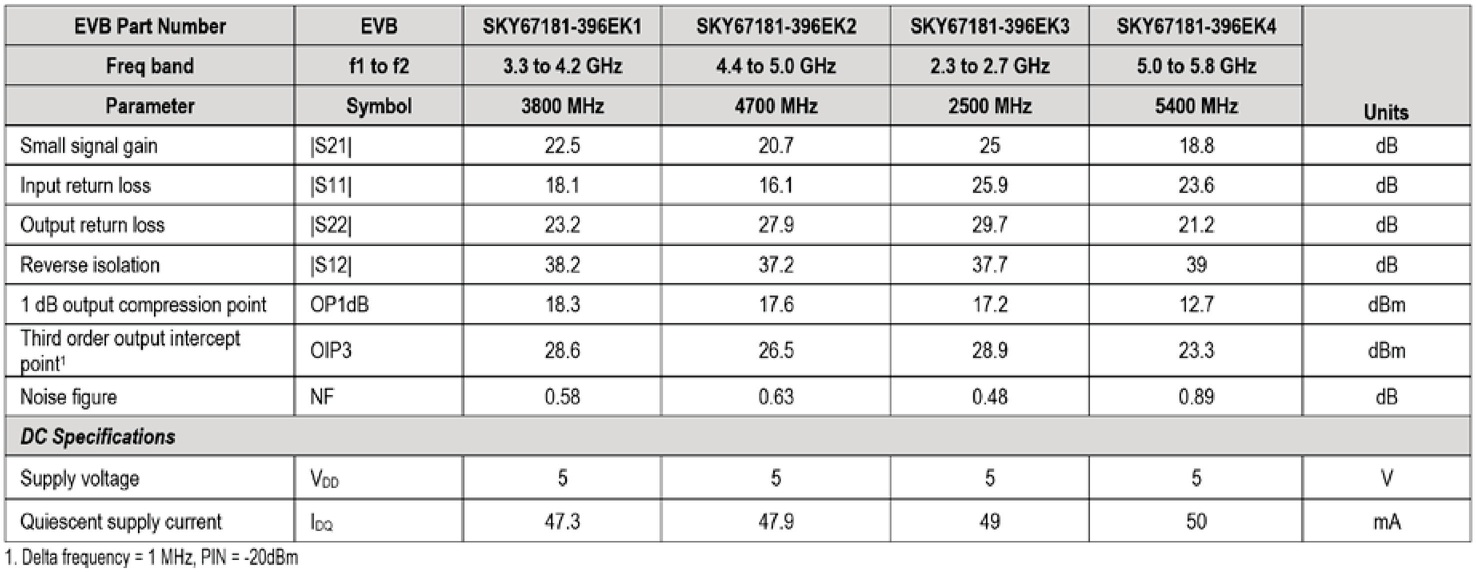
Table 1 shows the frequency banded performance of the SKY67183-396LFand Table2 and Table 3 highlight the frequency banded performances of the SKY67181-396LF and SKY67189-396LF.



EVB Part Number	EVB	SKY67183-396EK1	SKY67183-396EK2	SKY67183-396EK3	SKY67183-396EK4	
Freq band	f1 to f2	4.2 to 4.9 GHz	3.3 to 3.8 GHz	2.3 to 2.7 GHz	1.7 to 2.3 GHz	
Parameter	Symbol	4500 MHz	3600 MHz	2500 MHz	1950 MHz	Units
Small signal gain	|S21|	18.2	19.1	21.4	22.7	dB
Input return loss	|S11|	32.8	20.6	16.4	26.2	dB
Output return loss	|S22|	23.2	16.4	13.5	25.2	dB
Reverse isolation	|S12|	32	32.4	33.4	34.2	dB
1 dB output compression point	OP1dB	19	20.1	22	20.2	dBm
Third order output intercept point[1]	OIP3	29	28.9	32.7	32.2	dBm
Noise figure	NF	0.5	0.43	0.41	0.38	dB
DC Specifications						
Supply voltage	V_{DD}	5	5	5	5	V
Quiescent supply current	I_{DQ}	56	56	56	56	mA

1. Delta frequency = 1 MHz, PIN = -20dBm

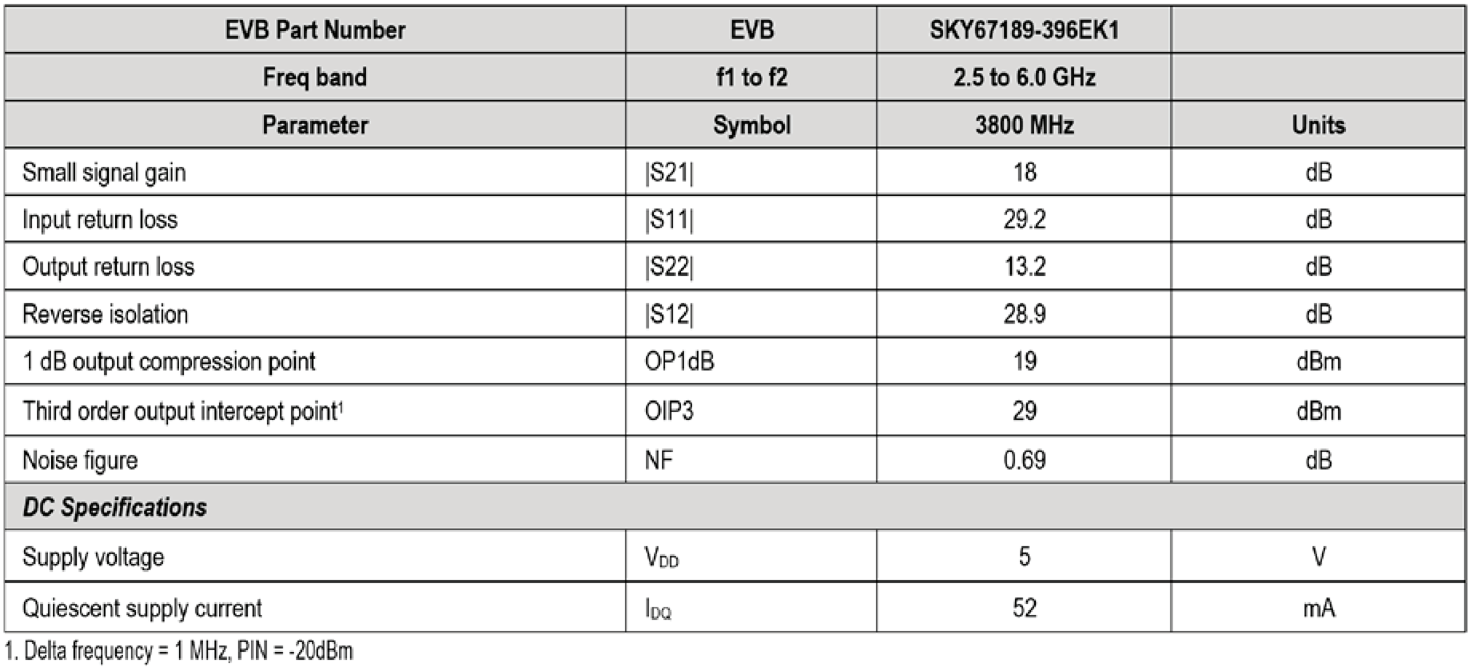
Table 1. SKY67183-396LF LNA Typical RF Performance vs Band



EVB Part Number	EVB	SKY67181-396EK1	SKY67181-396EK2	SKY67181-396EK3	SKY67181-396EK4	
Freq band	f1 to f2	3.3 to 4.2 GHz	4.4 to 5.0 GHz	2.3 to 2.7 GHz	5.0 to 5.8 GHz	
Parameter	Symbol	3800 MHz	4700 MHz	2500 MHz	5400 MHz	Units
Small signal gain	|S21|	22.5	20.7	25	18.8	dB
Input return loss	|S11|	18.1	16.1	25.9	23.6	dB
Output return loss	|S22|	23.2	27.9	29.7	21.2	dB
Reverse isolation	|S12|	38.2	37.2	37.7	39	dB
1 dB output compression point	OP1dB	18.3	17.6	17.2	12.7	dBm
Third order output intercept point[1]	OIP3	28.6	26.5	28.9	23.3	dBm
Noise figure	NF	0.58	0.63	0.48	0.89	dB
DC Specifications						
Supply voltage	V_{DD}	5	5	5	5	V
Quiescent supply current	I_{DQ}	47.3	47.9	49	50	mA

1. Delta frequency = 1 MHz, PIN = -20dBm

Table 2. SKY67181-396LF LNA Typical RF Performance vs Band



EVB Part Number	EVB	SKY67189-396EK1	
Freq band	f1 to f2	2.5 to 6.0 GHz	
Parameter	Symbol	3800 MHz	Units
Small signal gain	|S21|	18	dB
Input return loss	|S11|	29.2	dB
Output return loss	|S22|	13.2	dB
Reverse isolation	|S12|	28.9	dB
1 dB output compression point	OP1dB	19	dBm
Third order output intercept point[1]	OIP3	29	dBm
Noise figure	NF	0.69	dB
DC Specifications			
Supply voltage	V_{DD}	5	V
Quiescent supply current	I_{DQ}	52	mA

1. Delta frequency = 1 MHz, PIN = -20dBm

Table 3. SKY67189-396LF LNA Typical RF Performance vs Band

Three new ultra-low noise LNAs in 2 x 2 mm 8-pin packages have been presented. These devices achieve extremely low noise figure, excellent stability, high linearity, and gain using simple external matching circuits that allow these devices to cover a frequency range of 400 MHz to 6.0 GHz and beyond. Their excellent linearity characteristics allow these devices to be used as both first stage and second stage LNAs, and they can provide outstanding solutions for linear driver transmit applications as well. The various device application schematics offer solutions over the full application frequency range with unconditional stability over the full operating temperature range of -40 °C to +115 °C.

Further, we have shown that these devices can also be operated over a wide range of current and voltages thus allowing optimal efficiency given the linearity requirements of a particular application. Their outstanding performance at low voltages and currents makes these device ideals for high efficiency, high performance battery powered applications. Finally, the thermal characteristics of these parts allow them to achieve high long-term reliability and excellent performance up to an ambient temperature of +115 °C making the devices ideal for applications having demanded environmental conditions such as military, automotive, and cellular infrastructure.

For additional information on each of these devices please refer to the data sheets which are located at: www.skyworksinc.com.

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