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Design Solution for Achieving the Lowest Possible Receiver Noise Figure

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Skyworks' new SKY67151-396LF e-mode pHEMT low noise amplifier (LNA) sets a new standard for low noise figure (NF) for frequencies from 700 - 3800 MHz, while also delivering the gain and linearity necessary to achieve the highest possible cascaded receiver performance. From power sensitive applications requiring low current and voltage to performance driven infrastructure applications operating at ambient temperatures up to +105C, the SKY67151-396LF will allow designers to create receivers with low cascaded NF values that approach the measurement limitations of their test equipment.

Fabricated in Skyworks' latest e-mode pHEMT technology, the device consists of a common source input stage driving a common gate output stage. With internal, active bias, the two stages partition the supply voltage and share a common bias current in what is commonly known as a cascode configuration. This pHEMT cascode architecture delivers super-low NF, high linearity, excellent bandwidth and unconditional stability all from positive voltage supplies with no negative voltage requirement using a thermally efficient, 2 x 2 mm, 8-pin, plastic DFN package.

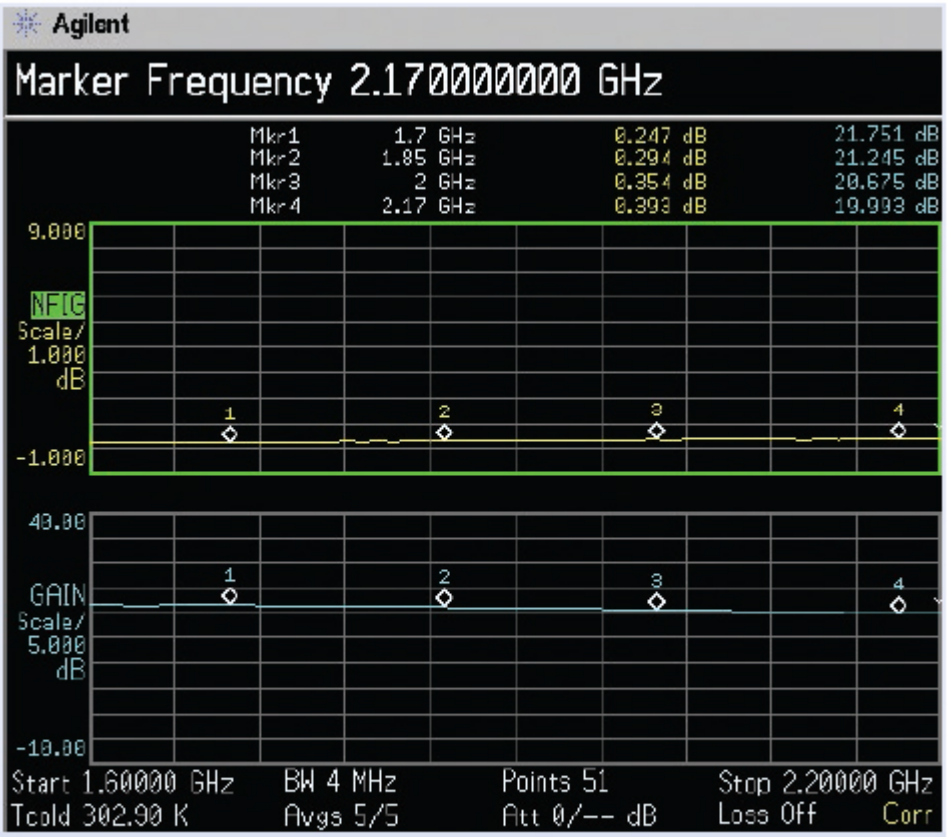

Figure 1: SKY67151-396LF Evaluation Board NF and Gain; Bias: 5 volts and 60 mA.

The SKY67151-396LF can be used with a wide range of supply voltages and quiescent currents which give the part a high degree of flexibility. Combined with its broad tuning capability, this bias flexibility allows the device to achieve optimal efficiency for a wide variety of applications with varying linearity requirements. The device uses a common layout to cover a frequency range of 700 - 3800 MHz with individual tunes achieving outstanding performance over typical percent bandwidths of 30 percent.

NF and Gain Performance

Figure 1 is included to provide the reader with an understanding of the test method used for the NF and gain data contained in this document. This screenshot shows an average of five traces for the standard evaluation board using the 1600 - 2200 MHz tune at an ambient temperature of roughly +25C. The NF measurement system consisted of an Agilent N8974A noise figure analyzer and an Agilent N4000A noise source.

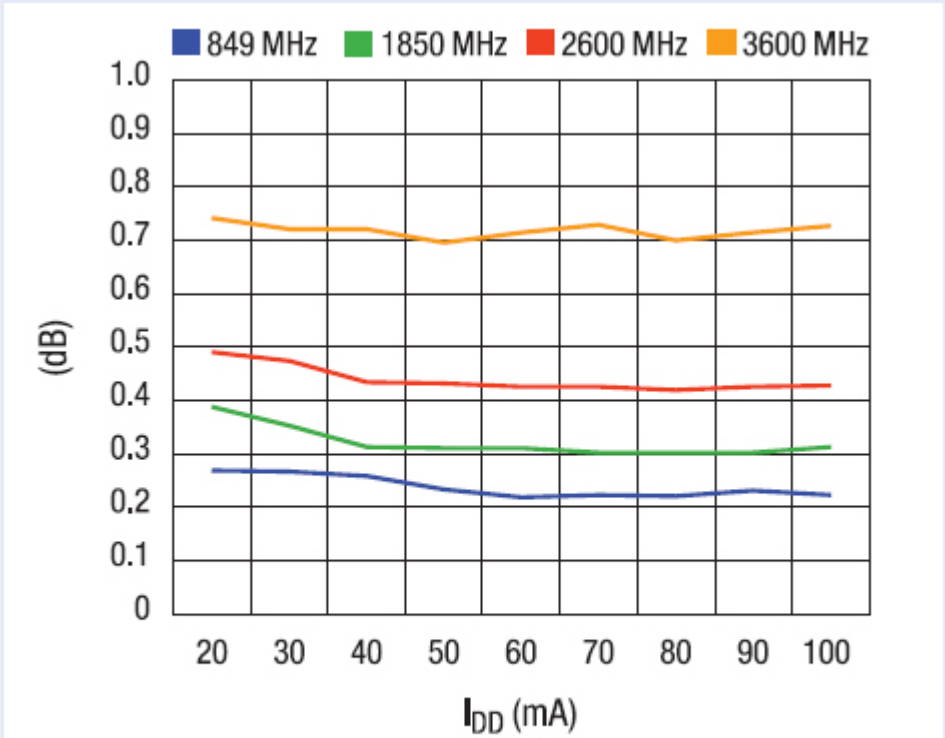

Figure 2: SKY67151-396LF Evaluation Board NF versus Quiescent Current; Bias: 5 volts

Note the excellent gain and gain flatness over this wide band to go along with the industry leading NF performance. Since the evaluation board losses have not been de-embedded from this data, this NF and gain is representative of the performance the device can achieve on an actual customer system board using an efficient layout.

As is typical for LNA devices, the SKY67151-396LF NF response is somewhat dependent on the device current. **Figure 2** shows the superior NF capability of the device for its four primary tunes which cover 700 - 1000 MHz, 1600 - 2200 MHz, 2300 - 2700 MHz and 3300 - 3800 MHz. These plots also show that the SKY67151 NF is relatively insensitive to current above 45 mA but the NF does begin to slowly rise for lower currents. Still, the device achieves superior NF values with Iddq values as low as 20 mA. The data is only shown for Vdd at 5.0 volts because NF and gain for this device are essentially independent of Vdd over the usual bias supply ranges of 3 to 5.5 volts.

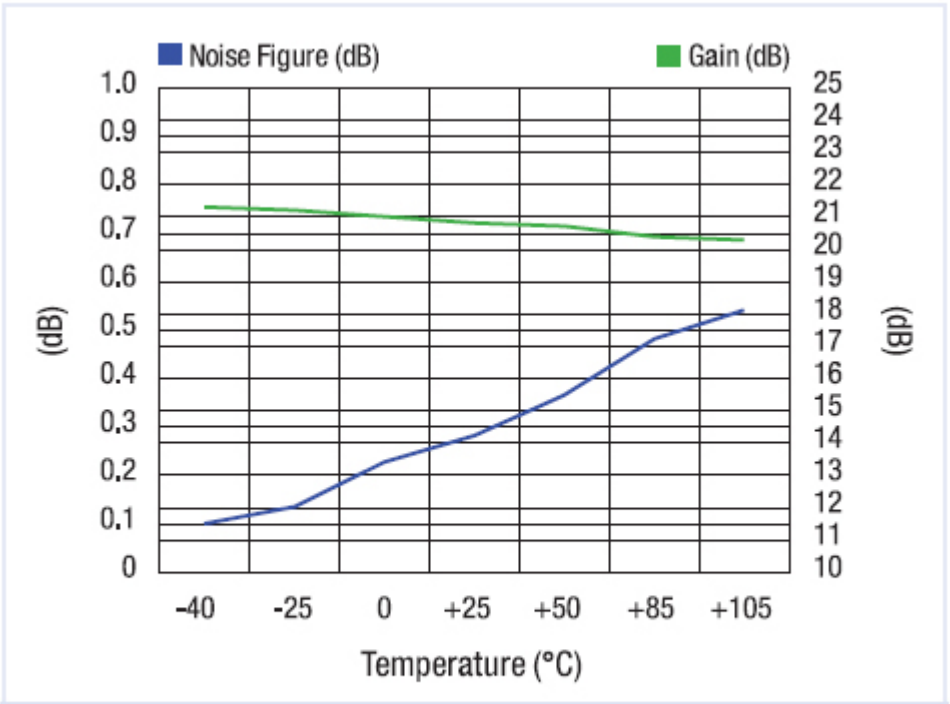

Figure 3: Gain and Noise Figure vs. Temperature @ 1.85 GHz V_{DD} = 5 V, I_{DDQ} = 70 mA

With its low thermal resistance of 45 degrees C/W and stable bias current over temperature, the SKY67151-396LF has been engineered to operate with high reliability and excellent performance at device heat sink temperatures up to +105C. **Figure 3** shows gain and NF over a range of temperatures from -40 to +105C at a reference frequency of 1850 MHz. Notice that the measured NF values at low temperatures are well into the measurement uncertainty of the test system. At the extreme temperature of +105C, the evaluation board NF at 1850 MHz is still less than 0.6 dB and the gain remains above 20 dB.

Linearity

Beyond NF and Gain, the linearity of an LNA is another key consideration. For a given application, the linearity of the first stage LNA should be high enough so that this stage does not limit the overall cascaded linearity of the receiver. Generally speaking for pHEMT LNA of this type, the compression point (P1dB) will be dominated by the Vdd level and the third-order intercept point (IP3) will be influenced more by the device quiescent current (Iddq). Typical OP1dB numbers for the SKY67151-396LF are shown in the performance summary **table 1** near the end of this article and **figure 4** below shows the IP3 versus Iddq performance.

Table 1: Typical Evaluation Board Performance at +25°C

Parameter	Low Band Tune	Mid Band Tune	High Band Tune	Extended High Band
Tune Bandwidth (MHz)	700-1000	1600-2200	2300-2700	3300-3800
Evaluation Board Noise Figure (dB)	0.25	0.35	0.50	0.70
Gain (dB)	26.0	21.0	19.0	16.5
Output P1dB (dBm)	+21.5	+20	+19.5	+18.0
Output IP3 (dBm)	+35	+36	+36	+35
Input Return Loss (dB)	12	11	12	12
Output Return Loss (dB)	23	23	18	18
Stability (10 MHz to 24 GHz)	Unconditional	Unconditional	Unconditional	Unconditional
Reference Test Condition	5V; 80 mA 849 MHz	5V; 70 mA 1850 MHz	5V; 70 mA 2600 MHz	5V; 80 mA 3600 MHz
General Features (all tunes)				
Gain Slope vs. Temp (dB/deg. C)	-0.007			
Iddq Slope vs. Temp (mA/deg. C)	-0.076			
Adjustable Current/ Power Down	Yes			
Vdd Range (volts)	3.0 - 5.5			
Typical Iddq Range (mA)	20 - 90			
Typical I_bias (uA)	450			
Max RF Input Power (dBm) into 50 ohms	+23 dBm			
Thermal Resistance (deg. C/W)	45			
Operating Temp Range (deg. C)	-40 to +105			
ESD Rating (Human Body Model)	Class 1A			

Figure 4 shows the dependence of OIP3 on the device Iddq. Note that for the mid and high band tunes, there is a sweet spot for IP3 around 60 mA but, for the lower band, the OIP3 gets progressively better as Iddq increases. These linearity characteristics, along with the NF versus Iddq plots from **Figure 2**, provide a practical illustration of the benefits of the bias flexibility of the SKY67151-396LF.

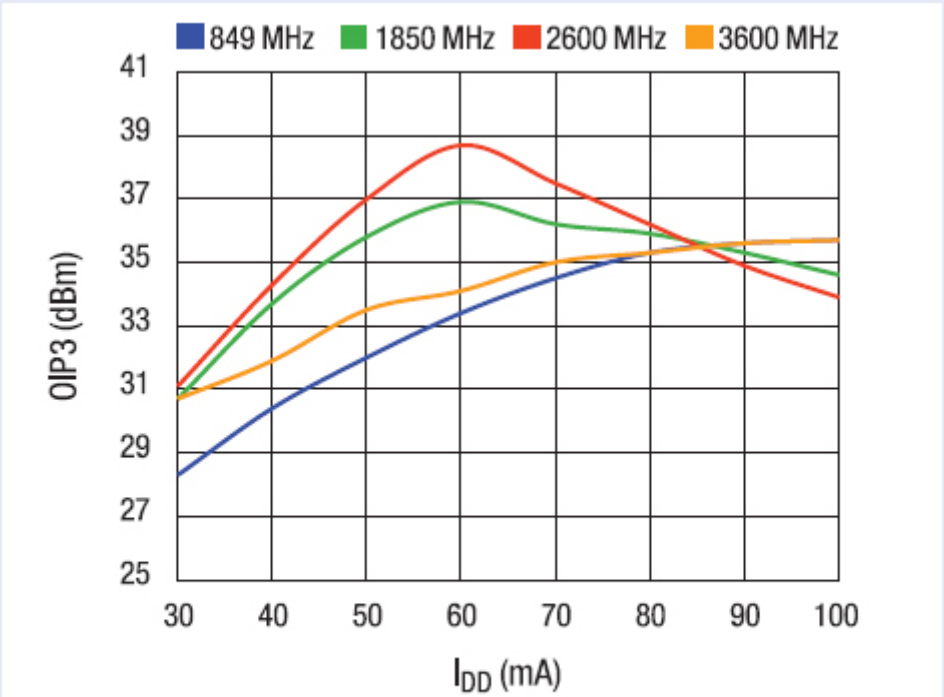

Figure 4: SKY67151-396LF OIP3 vs. Quiescent Current

Stability

With high gain devices such as the SKY67151-396LF, stability is an important concern. Using the standard mid-band tune as a reference, **Figure 5** below shows the Mu factor stability indices for the evaluation board under the worst case operating condition of -40C.

These Mu factors are >= 1.0 from 10 MHz up to the 20 GHz limit of our measurement capability, thus indicating unconditional stability. Similar results are obtained with the tunes optimized for other bands of operation. In some cases, a small amount of resistive loading is useful in correcting potential stability issues for high gain, low noise devices such as this. The recommended application schematic provides locations in the output match for this resistive loading as needed.

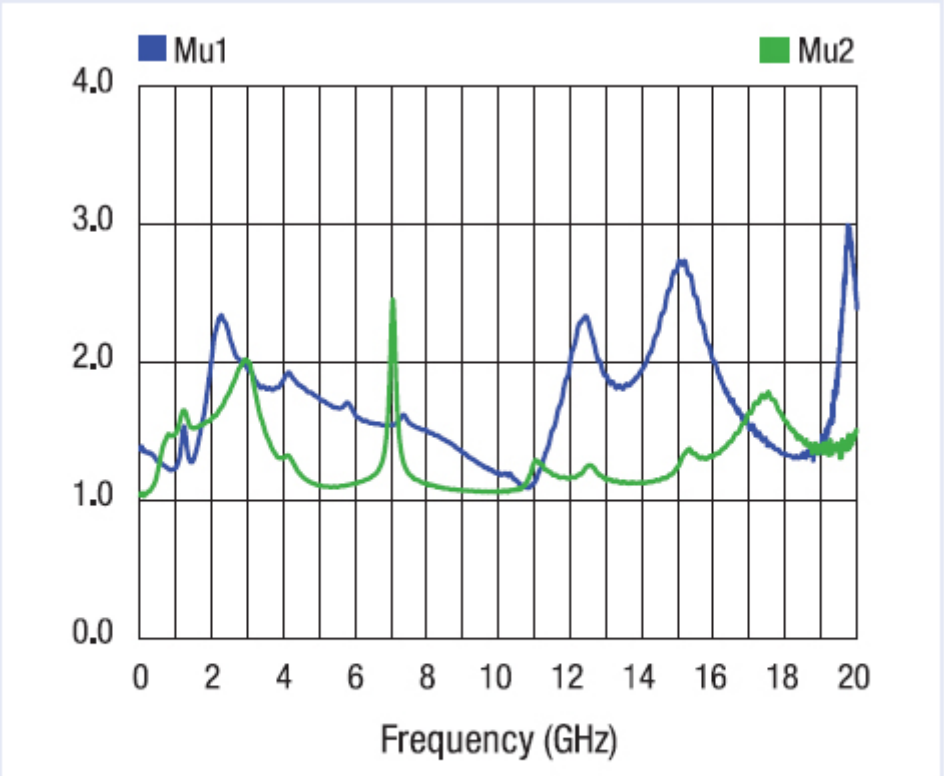

Figure 5: SKY67151-396LF Mu Stability Factors 1600-2200 MHz Tune at -40°C

Matching

In order to show the broad band tuning capability of the device, the four standard tunes are optimized over fairly large bandwidths of around 30 percent where this bandwidth is defined as the center frequency in MHz divided by the useable bandwidth in MHz. Optimizing any of these tunes over a narrower bandwidth of 5 to 10 percent is likely to yield slightly improved performance in terms of one or more key parameters such as linearity, gain flatness, return loss, etc. Most of the applications work with this device has centered on the 700 - 3800 MHz band, but the device has shown excellent gain and NF at frequencies as low as 500 MHz. The standard tunes have good input return losses and nearly conjugate output matches with output return losses typically greater than 18 dB. The key point here is that the device is achieving its outstanding NF and good input return loss simultaneously along with good linearity, stability and excellent output return loss. All tunes use a common evaluation board layout with only component value changes to differentiate the bands.

A note about input return loss: The NF and gain values shown in this article were all achieved with input return losses of approximately 11 - 12 dB. For those applications requiring very high input return loss, the device can be easily matched to input return losses of 20 dB or more with 0.05 to 0.1 dB degradation in NF.

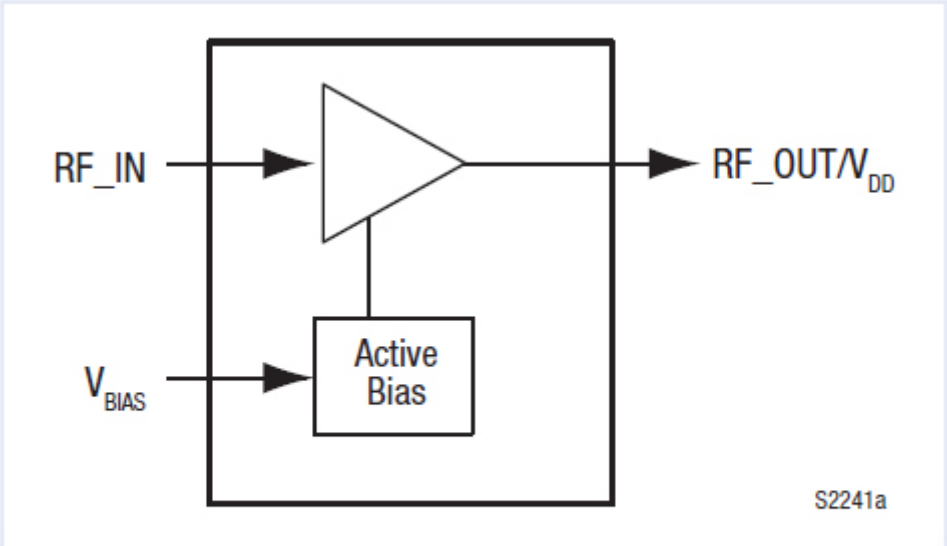

Figure 6: Simplified Block Diagram of the SKY67151-396LF Device

Biasing

As **Figure 6** shows, the signal connections to the device are RF_In, RF_Out/Vdd and Vbias. Vbias is important since it is this pin which serves a dual role as a low current, power down pin and as the control pin for the device quiescent current or Iddq. V_bias is typically applied to the device through an external resistor in series with the desired control voltage. For a given control voltage, the value of this resistor will set the Iddq level, and taking the control voltage below 0.2 volts will place the device in a low current, power down state. This V_bias control scheme is important since it allows a customer to set Iddq independently from the drain supply voltage (Vdd). For a given V_bias setting, the Iddq is relatively insensitive to the Vdd level.

Its fully integrated bias circuitry allows the part to be used over a wide range of supply voltages from 3 to 5.5 volts with excellent bias current stability over temperature. Quiescent currents (Iddq), typically ranging from 20 to 90 mA, can be set independently from the Vdd thus allowing the most efficient operating condition for a given linearity requirement.

Conclusion

The SKY67151-396LF is the first device in a new family of ultra low noise LNAs which will enable the design of receivers with lower cascaded NF than ever before. With its high gain and industry leading NF, this part allows a designer to create a receiver with superior NF performance in even the most demanding thermal environments. Its flexible biasing capability allows the device to be used with a range of common supply voltages and quiescent currents for optimal efficiency. Easily matched, the device achieves excellent return losses and unconditional stability with bandwidths up to 30 percent from a single tune. This new part joins a series of fully integrated low noise amplifiers requiring zero external matching components which have also just been released, and are based on Skyworks' industry leading pHEMT and multi-chip module technology.

Skyworks' applications engineering regularly provides custom solutions which are tailored to specific application requirements and we will be happy to optimize any of our devices to your specification. The SKY67151-396LF is scheduled for production release in March 2013 with samples and custom tuned evaluation boards available now.

Skyworks Solutions, Inc.

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