High Dynamic Range GaAs HBT LNA/Mixers for PCS Systems

Abstract

A family of fully monolithic GaAs Heterojunction Bipolar Transistor (HBT) LNA/Mixer products have been developed to address spread-spectrum Personal Communication System (PCS) applications in the North American 1930MHz to 1990MHz frequency band. Three products have been developed to provide low-cost solutions for high-performance RF products. The RF9936 family of products include monolithic LNAs that provide a typical gain of 13.5dB and an associated 50Ω noise figure of 1.4dB. Cascaded LNA/Mixer (including a 3.5dB loss image filter) gain is 26dB to 28dB, single-side band noise figure is typically 2.5dB, and input third-order intercept point (IIP3) ranges from -11dBm to -14dBm (product dependent). All three products are available in low-cost plastic packages to support commercial/ consumer wireless applications.

PCS Spread Spectrum Systems

Unlike the 900MHz U.S. cellular frequency band, devices designed for 1900MHz Personal Communication Systems (PCS) will predominantly utilize some form of spread-spectrum multiple access method. Code Division Multiple Access (CDMA) and Time Division Multiple Access (TDMA) are two such competing spread spectrum technologies approved for use in the 1900MHz PCS frequency band. Both access methods offer advantages over analog Frequency Division Multiple Access (FDMA) systems. The performance advantages of these next generation spread spectrum systems include increased channel capacity (more users per MHz), reduced susceptibility to multipath fading, intrinsic communication link security due to digital coding, and extended operating time in battery operated products. While many of the performance advantages of these spread-spectrum techniques are realized through digital modulation and digital signal processing techniques, high performance RF components must be applied in these systems to realize the theoretical benefits in real world applications. Increased system channel capacity is one spread spectrum performance advantage that can be limited by the performance of the receiver's RF front-end. Maximizing the dynamic range of the spread-spectrum receiver at 1900MHz requires selection of a robust technology for active devices that simultaneously achieve low noise and high levels of linearity. In portable wireless products, it is particularly important to achieve low noise, highly linear active device performance at DC bias levels that can be supported in battery powered products.

Receiver Dynamic Range Issues

Optimizing the dynamic range of any receiver requires careful management of the intercept point and noise figure of the various components used in the receiver design. In most applications, the LNA/Mixer generally limits the useful dynamic range of the receiver. The spurious-free dynamic range (SFDR) is a useful quantity for receiver designers because it provides a figure-of-merit indicative of the receiver's ability to receive signals near or at the minimum detectable level in the presence of interference (usually from adjacent channels). The SFDR of a receiver is defined as the difference in dB between the receiver noise floor (usually the noise power in the detection bandwidth) and the level of two equal signals that produce an intermodulation product equal to the noise power in the detection bandwidth. The SFDR can be related mathematically to the n-order input intercept point, thermal noise in the detection bandwidth, and receiver noise figure. The two-tone third order intercept point relation is used most often because third order distortion products are generally most likely to fall inside the receiver detection bandwidth. It can be derived that the SFDR of a receiver is related to the two-tone third order input intercept point (IIP_3) by the following equation:

$$SFDR = 2/3[IIP_3 + 174 - NF - 10\log(BW)]\ dB$$

IIP_3 = Two-tone third order intercept point referred to the receiver input

NF = Receiver Noise Figure

BW = Detection BW

Since the receiver detection bandwidth (BW) is primarily dictated by issues unrelated to LNA/Mixer performance (usually modulation type and frequency tolerances), LNA/Mixers that simultaneously minimize noise figure and maximize intercept point optimize the useful dynamic range of receivers.

Receiver Linearity Issues

A block diagram of the RF portion of a typical CDMA spread spectrum handset is shown in Figure 1. CDMA handsets operate full duplex. Therefore, a duplexer is used to avoid receiver interference from the transmitter.

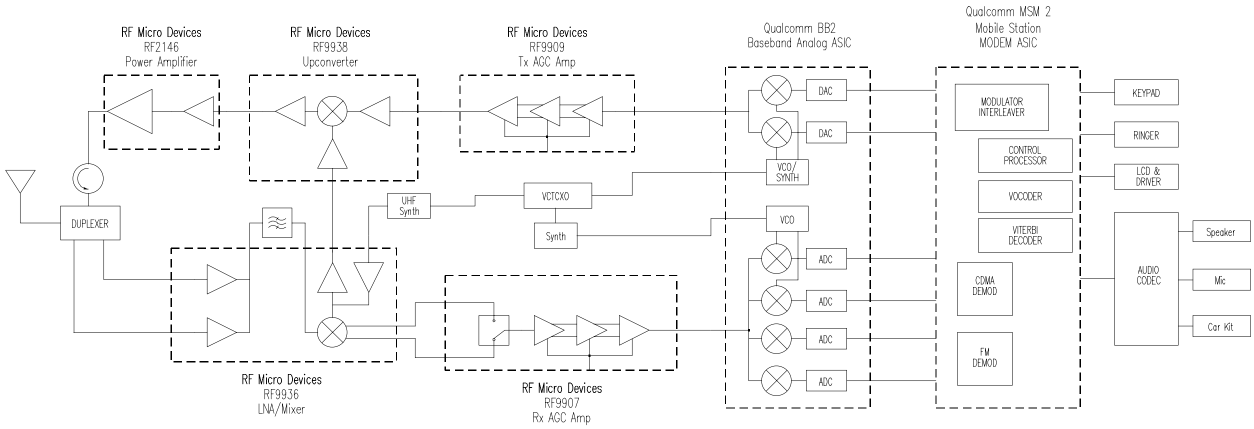


Figure 1. Typical CDMA Handset block diagram

Since the duplexer can not completely filter the transmitted signal, the receiver's LNA may see relatively high out-of-band power levels at its input from the transmitter. Depending on the rejection of the duplexer and the distance of the user from the base station, the power level that leaks into the receiver input can be many dB higher than the received input signal. This operating condition drives the linearity (IP3) requirements of the LNA. If the LNA is not sufficiently linear, the potential exists for receiver desense and/or cross modulation distortion from the transmitter on the received signal. A full-band image filter follows the LNA in the receiver cascade. Since many dB more of additional attenuation of the transmit band signal is provided by the image filter, the linearity requirements of the mixer are driven primarily by adjacent channel interference considerations rather than transmit band interference.

In spread spectrum systems, the total power at the receiver input is spread over the entire channel bandwidth. Although the average channel power transmitted per user per hertz is lower than narrowband systems, the total channel power in either system is equivalent. Since more users are intended to occupy adjacent channels, the potential for adjacent channel interference may actually be higher in spread spectrum receivers as compared to narrowband systems. Figure 2 presents this classical adjacent channel interference scenario for a 1.25MHz CDMA channel allocation. The third-order intermodulation distortion product of two adjacent channels (1960, 1958.75MHz) falls directly in the channel bandwidth of the third channel (1962.5MHz). Since the RF front-end passes the entire receive band, the total adjacent power from all users must be used to determine the linearity requirements of the RF front-end. If the RF front-end is not sufficiently linear, the systems channel capacity will be degraded. The potential for third-order intermodulation distortion can be reduced in the IF electronics if the adjacent channel is rejected sufficiently by the channelizing filter that follows the RF mixer.

Receiver Noise Figure Issues

PCS spread spectrum receiver noise figure considerations are no different than those of any other receiver. Lower RF front-end noise figure in the handset allows the receiver to operate reliably at increased distances from the base station. The RF front-end must also have sufficient gain to establish the overall noise figure of the receiver. As was mentioned in the previous section, channelizing filters are often used at the RF mixer output. Due to the relatively high IF, SAW filters are the technology of choice in CDMA hand-sets. While SAW filters do an excellent job establishing the receiver's operating channel, high out-of-band rejection performance requirements often produce multi-resonator designs that have insertion loss that exceed 10dB. This places additional pressure on the gain and noise figure that must be achieved in the RF front-end.

Active RF Component Technology Selection

At RF Micro Devices, we utilize Optimum Technology Matching™ to select the appropriate IC technology to satisfy the technical requirements of our products at the lowest cost. Optimum Technology Matching™ means that we consider all IC technologies at our disposal (GaAs HBT, GaAs MESFET, Silicon Bipolar) on an application-by-application basis. For our PCS LNA/Mixer products, the technology selected for these products is GaAs HBT. GaAs HBT was selected over GaAs MESFET and Silicon Bipolar in these products primarily for the due to the superior spurious-free dynamic

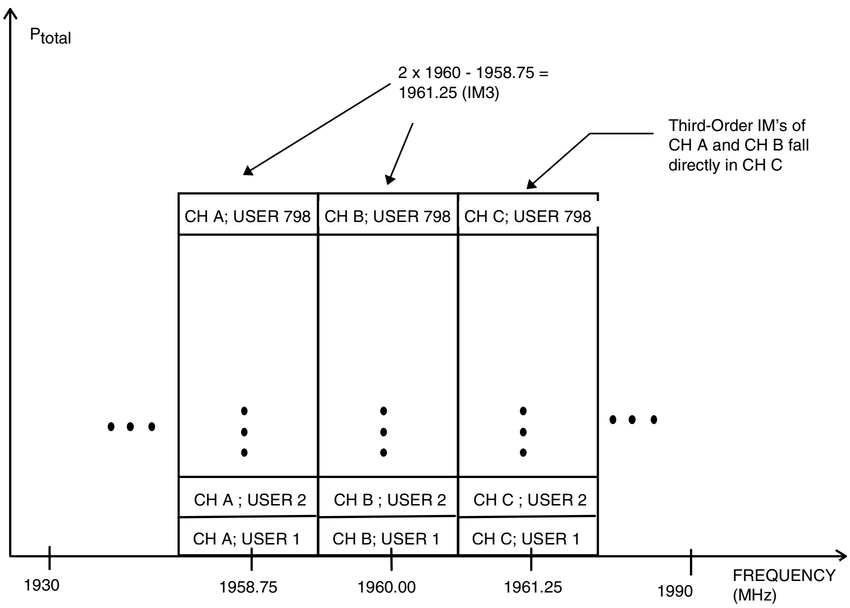


Figure 2. Third-order intermodulation distortion products can produce interference in LNA/Mixers that lack adequate linearity.

range that can be achieved in LNA/Mixers operating at the 1900MHz PCS frequency band under the same DC bias conditions. In comparison, GaAs MESFET's are more non-linear than GaAs HBT's due primarily to the inherently non-linear output conductance of the MESFET. Source degeneration in the MESFET can be used to linearize these devices, but due to the lower transconductance of the MESFET, both the gain and noise figure suffer in these high performance applications. On the other hand, silicon bipolar devices have similar transconductance characteristics to GaAs HBT's, but exhibit additional distortion characteristics primarily due to non-linear base collector capacitance [1]. Another major difference between the GaAs Heterojunction bipolar and the Silicon homojunction bipolar is that the base of the HBT can be much more heavily doped than the emitter. The effect of the additional base doping is a reduction in the base sheet resistance by as much as two orders of magnitude [2]. Since the base resistance is a major contributor to bipolar device noise, the result is an inherently lower noise device.

PCS LNA/Mixer Products

Over the past two years, a family of PCS LNA/Mixer products have been developed to support development of PCS CDMA handsets by Qualcomm, Inc. of San Diego, CA. Part pinout block diagrams for the RF9936, RF9976, and RF9986 are shown in Figure 3.

The RF9936 was the first PCS LNA/Mixer developed at RFMD. The RF9936 includes two selectable LNAs that share a common output, an variable gain low noise amplifier, an active balanced mixer, a LO isolation buffer, and a switchable LO buffer. The RF9936 was architected with two LNAs to interface to two half-band duplexers. The LNAs provide 13.5dB of gain with an associated 50Ω noise figure of 1.4dB typically without source tuning. Due primarily to the linearity of the GaAs HBT device, the LNA/Mixers achieve an OIP3 of +16dBm and consume a modest 5mA @ 3.6V. The spectrum for a two-tone third-order intercept point characterization of the LNA is as shown in Figure 4.

Another feature provided by the RF9936 is a low noise variable RF gain amplifier. Using an analog control input voltage, the power gain of the part can be adjusted more than 10dB. This is accomplished by a monolithic PIN diode network (positioned prior to the active mixer) in conjunction with IP3 optimized DC current steering. The measured two-tone, third-order input intercept point (IIP3) of the part as a function of cascade power gain is shown in Figure 5A. As can be seen in the figure, the cascaded IP3 referred to the input of the part (IIP3) can be increased with a corresponding reduction in gain. Also plotted in Figure 5B is the cascaded noise figure as a function of gain control. Both the measured IIP3 and noise figure shown in Figure 5A & 5B include the effect of an interstage

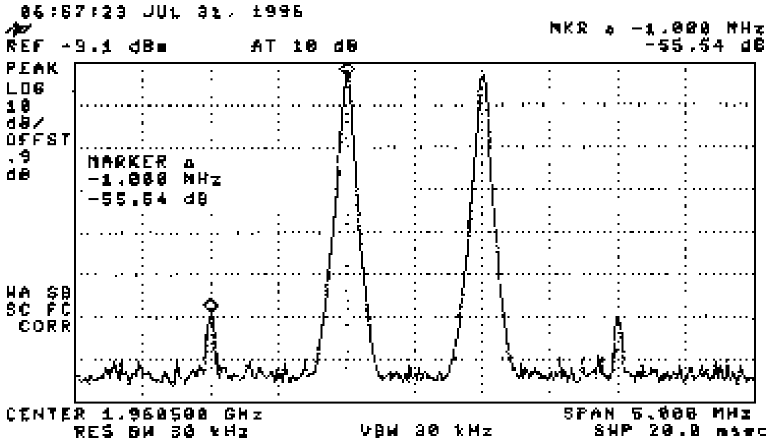


Figure 4. The LNA's Measured OIP_3

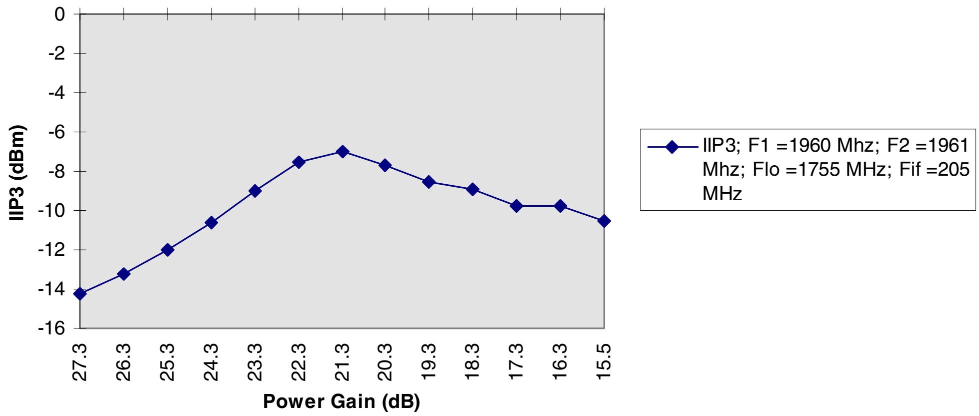


Figure 5a. Measured IIP_3 versus Power Gain for the RF9936

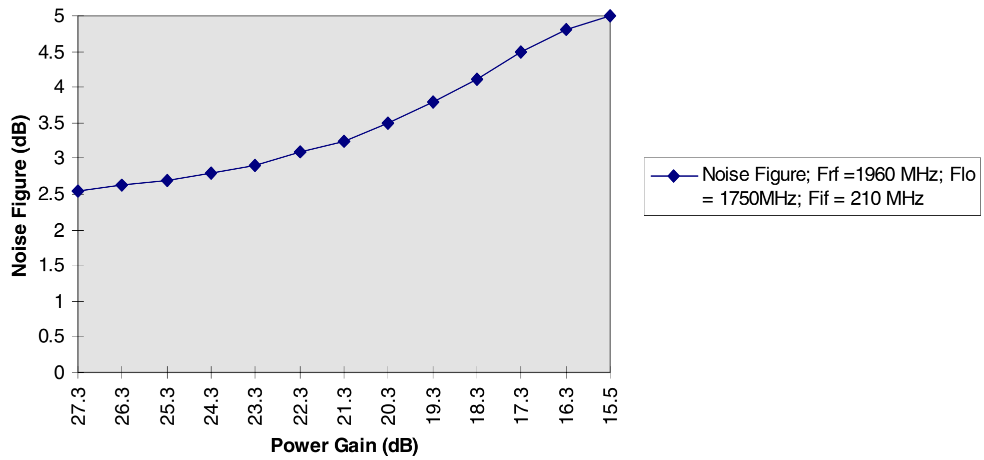
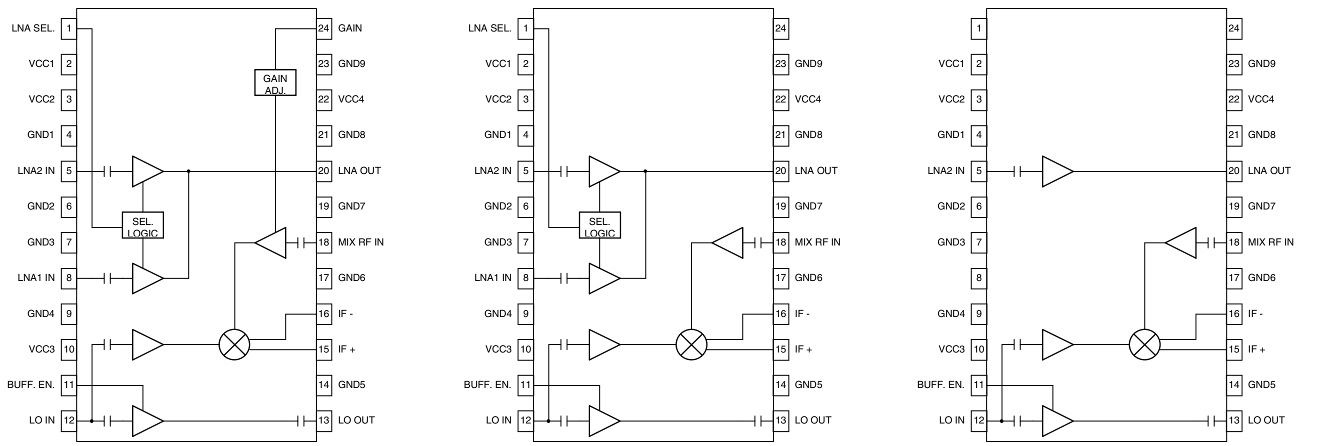


Figure 5b. Measured Noise Figure versus Power Gain for the RF9936

SAW image filter that passes the 1930MHz to 1990MHz PCS receive band. In order to minimize the number of external components, on-chip DC blocking capacitors are included on all RF I/Ohs except for the LNA output. The RF9936 provides a balanced IF output impedance of 1KΩ to interface to a balanced SAW or high impedance filter. IF chokes are required at the output of the part to supply bias to the mixer. Two monolithic LO buffer amplifiers are provided on the RF9936 as well. One buffer is used to provide additional isolation between the LO port of the mixer and the RF input port. The second buffer is switchable and is used to buffer the LO into the transmitter's upconverter, or the PLL prescaler.

The RF9976 differs from the RF9936 in that the OIP3 of the part is 2dB higher and is typically +15dBm. The RF/IF conversion gain is also 1dB higher than the RF9936. No gain control is provided in the RF9976. Other AC performance parameters and functionality are equivalent to the RF9936. The additional 2dB of OIP3 comes with an additional 8mA of DC current consumption. A complete performance summary for the RF9976 is provided in Table 1.

RF9936 RF9976 RF9986



-No Gain Control

IP3I: ~1 dB Higher than RF9936

-No Gain Control

-Single LNA

IP3I: ~3 dB Higher than RF9936

Figure 3. The RF9936, RF9976, and RF9986 PCS LNA/Mixers provide feature and performance options in low-cost, pin-for-pin compatible packages.

Parameter	**RF9936**	**RF9976**	**RF9986**
LNA Gain	13.5 dB	13.5 dB	13.5 dB
LNA Noise Figure	1.4 dB	1.4 dB	1.4 dB
LNA IIP3	+5.5 dBm	+5.5 dBm	+5.5 dBm
LNA/Mixer Gain*	27 dB	28 dB	26 dB
LNA/Mixer Noise Figure*	2.5 dB	2.5 dB	2.5 dB
LNA/Mixer IIP3*	-14 dBm	- 13 dBm	-11 dBm
Gain Control Range	12 dB	N/A	N/A
DC Power	42 mA @ 3.6V	50 mA @ 3.6 V	50 mA @ 3.6V
Package	QSOP-24	QSOP-24	QSOP-24

* Cascaded Gain/NF/ IP3 performance parameters include a 3.5 dB insertion loss image filter between the LNA and mixer.

Table 1. The RF9936, RF9976, RF9986 provide three design options for PCS LNA/Mixers

The third LNA/Mixer in the trilogy is the RF9986. The RF 9986 is a single LNA/Mixer without gain control. The gain of the RF9986 is 1dB lower than the RF9936 with an equivalent cascaded noise figure. The OIP3 is equivalent to the RF9976's +15dBm. The RF9986 provides the highest IIP3 of the three parts. The typical IIP3 for the RF9986 is -11dBm. Like the RF9976, no gain control is provided in this part. A complete performance summary of the RF9986 is provide in Table 1.

Conclusion

For 1900Mhz PCS applications, three unique HBT LNA/Mixer products have been developed that achieve wide dynamic range for high performance commercial applications. These products were developed for CDMA handsets, but offer designer's using other multiple access techniques the opportunity to achieve peak performance in their wireless products. The RF9936, RF9976, and RF9986 are supplied low cost, QSOP-24 plastic packages in production quantities.

References

1. William J. Pratt, "High Linearity HBT Amplifier Targets Multicarrier Systems", RF Design, March 1996, pp. 47-54.

2. J.A. Higgins, "GaAs Heterojunction Bipolar Transistors: A Second Generation Microwave Power Amplifier Transistor", Microwave Journal, May 1991, pp. 176-194.