



Active GaAs FET Mixers Using the ATF-10136, ATF-13736, and ATF-13484

Application Note G005

NOTE: The ATF-13484 has been obsoleted. However, the design techniques used with the ATF-13484 active mixer can be applied to the ATF-13736 as well.

Introduction

This application note documents the results of using the ATF-10136 as an active mixer at S band and the ATF-13736 and ATF-13484 at Ku band.

The ATF-10136 is a 500 μm gate periphery MESFET device that typically provides a 0.6 dB noise figure in LNA applications at S band. As an active mixer the ATF-10136 is capable of SSB noise figures as low as 4.5 dB with several dB of conversion gain. Both the ATF-13736 and the ATF-13484 are 250 μm MESFETs that typically produce LNA noise figures of about 2 dB at 12 GHz. As active mixers, these MESFETs are capable of SSB noise figures of 5.0 dB with associated conversion gains from unity to nearly 5 dB depending on bandwidth requirements.

The typical microwave communications system uses mixers for frequency up- or down-

conversion. Passive double-balanced mixers (DBMs) are commonly used for both applications. DBMs offer reasonable impedance matches and good port-to-port isolation but do require at least +7 dBm of LO drive and always have conversion loss of 6 to 8 dB which adds directly to the IF amplifier noise figure. An alternative solution is the use of a MESFET as an active mixer. By making use of the non-linear properties of a MESFET when it is biased near cut-off, the active FET mixers described in this note provide low noise figures, reasonable conversion gain and good port-to-port isolation with a minimum of matching network circuitry.

Although downconverters are described, the same design concepts can be applied to the

design of an upconverter. The active mixer is not a reciprocal device as is the typical diode balance mixer. In a typical double-balanced mixer, each port is designed to cover a particular frequency range. The RF port typically covers the higher frequencies whereas the IF port is generally matched at the lower frequencies. Therefore when used as a down-converter, the RF port is the input port and the IF port is the output port. When upconverting, the IF port becomes the input port and the RF port the output port. The situation for an active mixer is different due to the non-bidirectional properties of the active device. Whether designed as a down-converter or an up-converter, the gate-source junction of the MESFET is matched at the frequency that

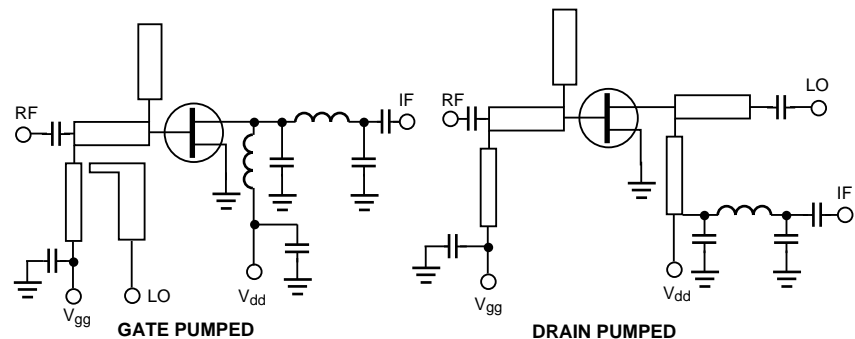


Figure 1. Gate and drain pumped active mixers

needs to be converted and is designated as the input port. The drain-source junction of the MESFET is then matched at the desired converted frequency and is designated as the output port.

Mixer Topologies

An active mixer can take on any of three basic circuit topologies. The difference in each topology is determined by how local oscillator power is injected.

The most common form of active GaAs FET mixer is the gate-pumped configuration shown in Figure 1. In this configuration, the FET source leads are normally placed at RF ground potential and the LO is injected into the FET gate. The LO is normally injected through a 10 to 13 dB coupler. This allows the RF signal to be injected into the gate through the low loss path of the coupler, thereby minimizing its contribution to noise figure. A microstripline coupler is typically used at the microwave frequencies where size is small. At the lower frequencies the coupler could actually be manufactured using discrete component/toroidal transformer techniques. The IF is then extracted from the drain through an impedance matching network.

Alternative active mixer designs include injecting the LO into either the drain or the source of the FET. The advantage of the drain-pumped mixer, is the inherently lower noise figure with a reduction in noise figure on the order of 1 dB. A typical drain-pumped mixer circuit is also shown in Figure 1. With the LO being injected into the drain, there is no need for the input coupler that is required with the gate

pumped mixer – thereby minimizing losses that contribute to noise figure.

The source-pumped mixer is somewhat harder to implement. Raising the source above RF ground may introduce some stability problems that are more difficult to solve than with other mixer types.

The mixer designs presented in this bulletin are the drain-pumped variety. It is relatively easy to take a stable amplifier circuit and adapt it for active mixer use. The RF input port of the amplifier is also used as the RF input port of the drain pumped mixer with the RF output port of the amplifier serving as the LO input port. The existing bias decoupling network in the drain circuit can be used with slight modification for extracting the IF signal. Additional information on active mixers can be referenced. ^{1,2,3}

Mixer Design

Although the active mixer is a non-linear application, it is still possible to use a linear analysis circuit design program to aid in the initial design. The sections to follow describe the basic steps that went into designing the mixers, including the use of the computer to optimize impedance match and stability. The techniques described in this note give the designer a method from which to begin, and with some benchwork an active mixer can be designed and duplicated.

This design philosophy centers around the drain pumped mixer with the source at RF ground. The references suggest that it is not necessary to match the input of the FET for minimum noise figure

to achieve a low noise active mixer. Simply matching S_{11} , the input reflection coefficient of the device, for lowest input VSWR at the RF frequency should provide the lowest noise performance. (Circuits presented in this note were originally designed for a low noise match to be used as an LNA.) With the addition of a small amount of source inductance, however, a noise match provides a reasonable input match. Low noise amplifier design principles are covered in application notes AN-G004 and AN-G001.^{4,5}

A good start for the output matching network is to merely match the device output reflection coefficient, S_{22} , at the LO frequency. With the help of the computer, the input network is optimized for low low noise or best input match while the output network is designed to provide a good match at the LO frequency. The optimum LO match and LO power can then be found empirically during bench tests. Providing a good impedance match at the LO frequency reduces the LO requirement. Generally 0 to +3 dBm is optimum for lowest noise operation while higher LO power raises conversion gain and power output at the risk of increased noise figure.

The bias decoupling circuit design should follow similar guidelines to those used when designing a typical small signal amplifier. A $\lambda/4$ high impedance microstripline followed by an open circuited low impedance $\lambda/4$ microstripline provides adequate decoupling of the DC bias current from the input matching network. One of the most important circuit parameters to monitor during optimization is stability. The computer analysis program can be best used to

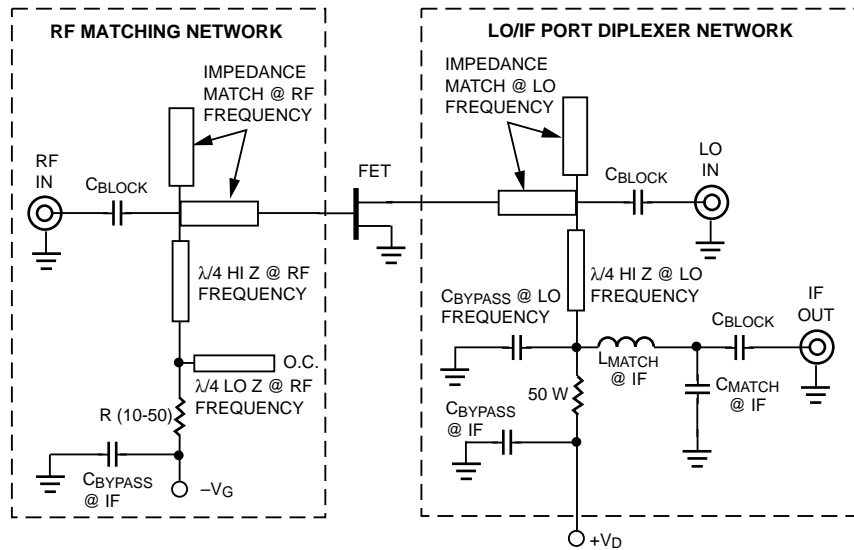


Figure 2. Drain pumped active mixer using DC grounded source leads

ensure virtually unconditional stability. Although the FET is driven into its non-linear region where the S parameters are somewhat different, the small signal analysis is still useful in determining any potential problem areas. Since the bias decoupling network is low-pass by design, it also provides a convenient means of extracting the IF signal. The IF can be coupled out through a blocking capacitor or an additional low pass matching network can be used to improve the IF match and conversion gain. RF to IF and LO to IF isolation also improves with the addition of the low pass matching network at the IF port.

For maximum mixer efficiency, the following additional guidelines should be followed. In the case of a downconverting drain-pumped active mixer, the circuitry attached to the drain of the FET should provide a short or a low impedance at the RF frequency. This helps to recirculate the RF currents, preventing loss of RF signal out of the LO port which could effect conversion gain. For a drain-

pumped mixer this becomes difficult if the RF and LO frequencies are near each other. This would occur for an IF that is in the VHF frequency range, i.e., up to several hundred MHz.

For a drain pumped mixer, it is best to present a diplexer circuit at the drain. One port provides the LO match with rejection at the IF frequency. The second port of the diplexer provides the IF match with a high impedance at both the RF and LO frequencies. This can be accomplished with the simple circuitry shown in Figure 2. Choosing a LO port blocking capacitor with a very small value provides some rejection at the IF frequency where the IF is less than $0.1 f_{LO}$. The use of a series $\lambda/4$ bias decoupling line (at the LO frequency) off the drain port provides rejection at the LO frequency while simultaneously passing DC and the IF. The IF can then be matched to improve conversion gain if desired. A properly designed diplexer minimizes LO drive requirements while simultaneously directing the IF signal to the IF port.

A low impedance at the IF frequency should also be placed at the gate of the FET. This prevents loss of IF signal out of the RF port. The bias decoupling network consisting of a $\lambda/4$ transmission line (at the RF frequency) followed by a low frequency resistive termination can be used. Although the guidelines suggest that a “short” be provided, a quick analysis on the computer generally shows an instability. It is best to provide as low an impedance as possible without creating any potential stability problems. A good compromise is to place a 10 to 50 Ω resistor in series with the bias decoupling line. The use of an open circuited $\lambda/4$ microstripline in parallel with the resistive termination provides a good low impedance at the RF frequency, thereby minimizing the effect of the resistive termination on mixer noise figure. Stability is always the goal.

2.3 GHz Active Mixer

The 2.3 GHz active mixer is a slight variation of the low noise amplifier described in Agilent application note AN-G0044. Figure 3 shows the required modifications to the LNA for mixer operation. The input matching network, which was designed for optimum noise figure, was left intact. The output matching network was used “as is” to feed the LO signal into the mixer. A lowpass network consisting of a series inductor and a shunt capacitor was added to the output bias decoupling network to improve the IF match. The mixer was tested with an RF signal of 2300 MHz and an LO frequency of 2150 MHz. The resultant IF was 150 MHz.

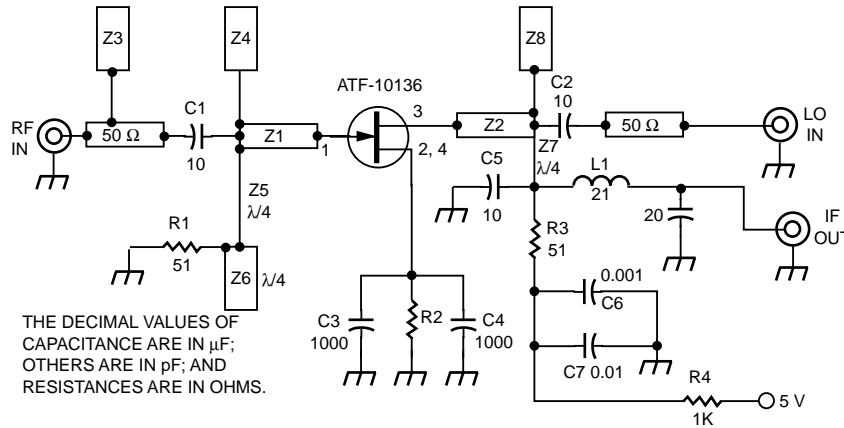


Figure 3. Schematic diagram of the 2.3 GHz active mixer using the ATF-10136, Z1 through Z8 are etched microstripline circuitry discussed in Application Note AN-G004. Change R2 to 215 ohms and add inductor L1 = 7 turns #30 wire, 0.050 inch ID

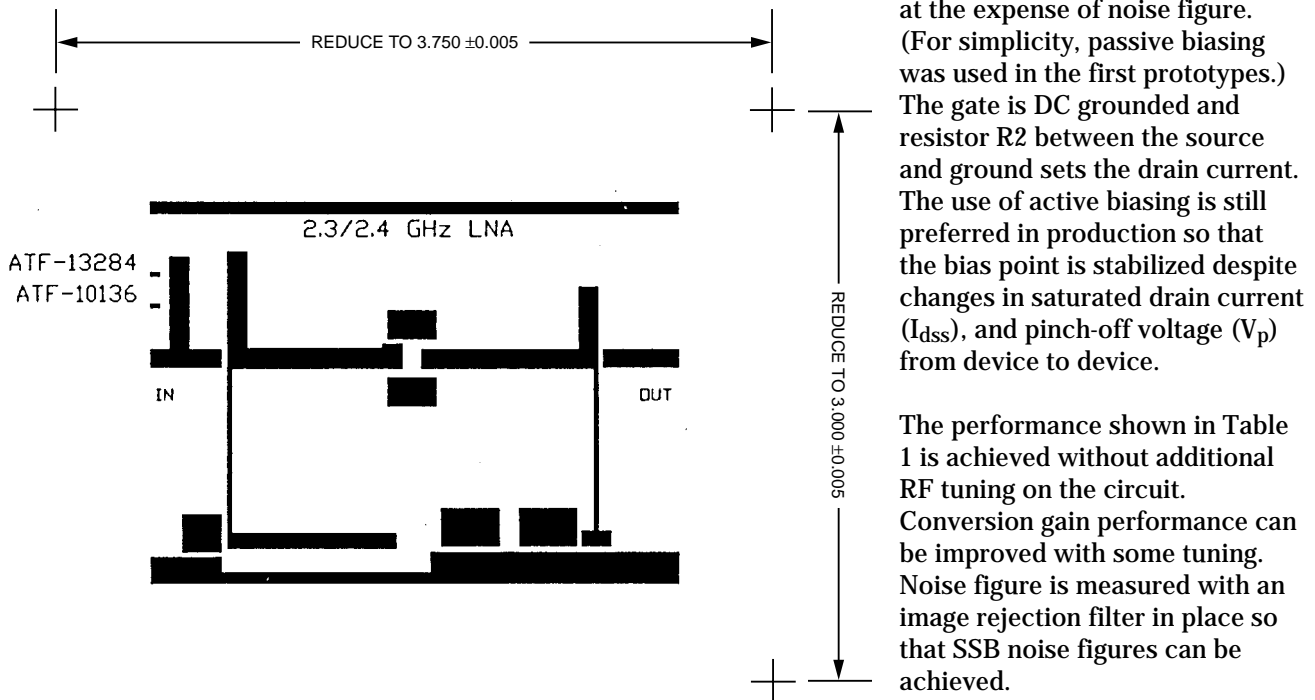


Figure 4. 1X artwork for the 2.3 GHz active mixer etched on 0.031 inch material with dielectric constant of 2.2

Table 1. 2.3 GHz ATF-10136 Mixer Performance ($V_{ds} = 0.5 \text{ V}$, $I_d = 3.7 \text{ mA}$)

LO Power	Conversion Gain	SSB NF
1.20 mW	2.65 dB	4.45 dB
1.35 mW	3.00 dB	4.93 dB
1.50 mW	3.40 dB	5.23 dB

Both the LO drive level and the DC operating point of the FET are varied for optimum performance. Table 1 describes typical performance.

Higher conversion gain is achieved with increased LO drive. Generally, lower noise performance is achieved at lower LO drive levels.

The optimum drain-to-source voltage was found empirically to be 0.5 V at a drain current of 3.7 mA when LO is applied. Increasing the drain-to-source voltage increases conversion gain at the expense of noise figure. (For simplicity, passive biasing was used in the first prototypes.) The gate is DC grounded and resistor R2 between the source and ground sets the drain current. The use of active biasing is still preferred in production so that the bias point is stabilized despite changes in saturated drain current (I_{dss}), and pinch-off voltage (V_p) from device to device.

The performance shown in Table 1 is achieved without additional RF tuning on the circuit. Conversion gain performance can be improved with some tuning. Noise figure is measured with an image rejection filter in place so that SSB noise figures can be achieved.

12 GHz Active Mixer

The ATF-13736 and the ATF-13484 are analyzed as 12 GHz mixers for DBS service. The ATF-13736 is in the micro-x package and is typically used as a third stage in a typical three-stage DBS LNA. The noise figure of the device used in a mixer application is not as critical as it would normally be for a first stage of an LNA.

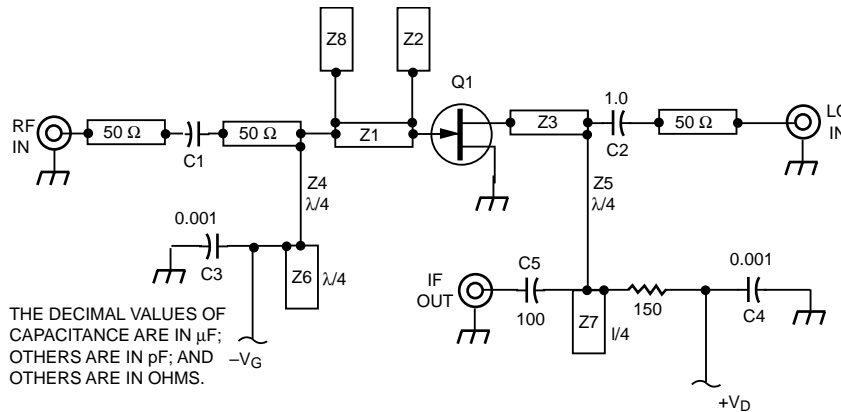


Figure 5. Schematic diagram of the 12 GHz active mixer using either the ATF-13736 or the ATF-13484. Z1 through Z8 are etched microstripline circuitry

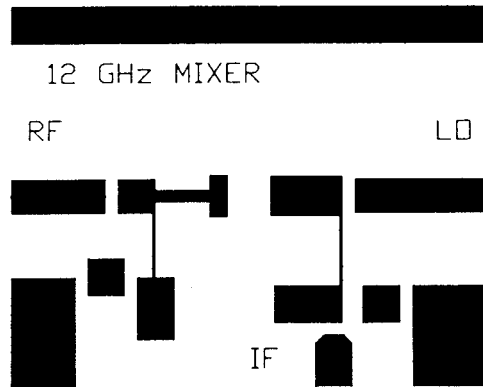


Figure 6. 2X artwork for the 12 GHz active mixer etched on 0.031 inch material with dielectric constant of 2.2

The schematic diagram of the 12 GHz mixer is shown in Figure 5. The artwork shown in Figure 6 can be adapted easily for either device. The input matching network's design provides a reasonable impedance match to 50 Ω and a good noise figure from 11.7 to 12.2 GHz. Table 2 shows the microstrip parameters and component parameters required for each of the devices. The output matching network provides a good match at the LO frequency of 10.75 GHz for both devices. The IF is simply tapped off of the bias decoupling network with a capacitor to provide DC isolation.

Mixer 1 was tuned specifically for maximum gain in the middle of the 11.7 to 12.2 GHz frequency range while mixer 2 was tuned for a flatter broadband response. Tuning is accomplished by adjustment of the input matching network elements. The conversion gain and SSB noise figure performance for both mixers is shown in Tables 3 and 4.

Table 2. Circuit Parameters for Ku band Mixers

Mixer	Q1	C1	Z1 Width	Z8 Length
1	ATF-13736	2.7 pF	0.035 in.	0.120 in.
2	ATF-13484	1.0 pF	0.024 in.	0.0 in.

Both Ku band mixers required +10 dBm of LO for best overall gain and noise figure performance. This could possibly be reduced to +7 dBm by providing a better impedance match at the LO port. The ATF-13736 mixer was purposely optimized for maximum conversion gain at mid-band while the ATF-13484 mixer was designed for flatter conversion gain. Both mixers exhibit acceptable gain and noise figure performance over a bandwidth of about 1 GHz.

For best performance and repeatability at Ku band frequencies it is suggested that active biasing be used. Direct grounding of the FET source leads prevents undesirable bypass capacitor parasitics from having an effect on mixer stability.

Port-to-port isolation was very good considering the simple matching circuitry involved. The ATF-13736 mixer exhibited a LO to IF isolation of 22 dB and an LO to RF isolation of 18 dB. The ATF-13484 mixer exhibited LO to IF isolation of 24 dB and an LO to RF isolation of 13 dB. With a drain-pumped mixer, the S_{12} of the FET is the major factor in determining the LO to RF isolation. LO to IF isolation is determined primarily by the simple $\lambda/4$ bias decoupling network.



Table 3. 12 GHz ATF-13736 Mixer, $V_{ds} = 1.5$ V, $I_d = 2.6$ mA

RF Frequency (GHz)	IF Frequency (MHz)	Conversion Gain (dB)	SSB Noise Figure (dB)
10.9	150	-1.4	8.8
11.1	350	1.0	7.0
11.2	450	-1.5	7.6
11.3	550	-1.7	7.6
11.4	650	-0.5	7.6
11.5	750	0.3	7.7
11.6	850	1.2	6.0
11.7	950	1.5	5.6
11.75	1000	1.3	4.8
11.8	1050	3.0	5.1
11.85	1100	5.0	5.2
11.9	1150	3.6	5.0
12.0	1250	2.8	5.9
12.1	1350	2.6	5.8
12.2	1450	0.5	6.9

Ku band. Design techniques for converting a simple LNA design into an active mixer are also included.

In a typical Ku band downconverter, the substitution of an active mixer for the standard diode mixer can produce an improvement in overall noise figure of nearly 0.1 dB with an associated improvement in conversion gain of 7 to 9 dB.

References

1. R.A. Pucel, D. Masse, R. Bera, "Performance of GaAs MESFET Mixers at X Band", *IEEE Trans. Microwave Theory and Techniques*, MTT-24, PP. 351-360, June 1976
2. S. Maas, "Analysis and Design of GaAs MESFET Mixers", *1984 IEEE MTT-S Digest*, pp. 432-433
3. P. Bura, R. Dikshit, "FET Mixers for Communications and Satellite Transponders", *IEEE MTT-S Int. Microwave Symp Digest*, 1976, pp. 90-92.
4. Agilent application note *AN-G004: S-Band Low Noise Amplifiers - ATF- 10136 and ATF-13484*
5. Agilent application note *AN-G001: ATF-13136 Demonstration Amplifier*

Table 4. ATF-13484 Mixer, $V_{ds} = 1.1$ V, $I_d = 2.6$ mA

RF Frequency (GHz)	IF Frequency (MHz)	Conversion Gain (dB)	SSB Noise Figure (dB)
11.0	250	-2.6	13.0
11.1	350	-1.8	12.0
11.2	450	0.3	8.1
11.3	550	0.3	7.0
11.4	650	-0.1	7.6
11.5	750	-0.4	8.2
11.6	850	0.9	6.7
11.7	950	2.1	5.2
11.8	1050	1.3	5.4
11.9	1150	1.6	5.4
12.0	1250	1.8	5.3
12.1	1350	0.2	6.7
12.2	1450	0.3	8.9

Conclusion

This application note presents the results of using GaAs FET devices as active mixers in the 2.3 GHz and 12 GHz frequency ranges.

Active mixers are capable of producing SSB noise figures of less than 5 dB with associated conversion gains of up to 5 dB at