microstrip patch exhibiting $RL < -12$ dB over 15% frequency bandwidth. Figure 2(b) shows the E-plane pattern and the H-plane pattern along with the photograph of the U-slot rectangular microstrip patch, which is shown as an inset in Figure 2(b).

Using the theoretical formulation discussed in previous section, the normalized amplitude and progressive phase shifts synthesized for the linear microstrip antenna array are \{0.4038, 0.567, 1, and 0.725\} and \{0°, 14°, 0°, and −36°\}, respectively. Theoretical cosec²-shaped beam pattern peaked at 5° and obtained using these values has shown a good agreement with the desired pattern having coverage beyond 30° with an antenna array gain ($G$) better than 10 dB and SLL less than −13.5 dB, as shown in Figure 1.

A (1:4) way air-dielectric stripline feed network has been designed for realizing the array excitations using CST MW Studio and ADS 2004 softwares. The basic power splitter element used for realizing the power division is a five-port hybrid ring, which has been chosen for good isolation and input/output port-matching properties. The power divider has been tested with amplitude and phase accuracies of 0.3 dB and 2°, respectively over 15% BW [1]. The photograph of the power divider is shown as an inset in Figure 3.

The measured radiation pattern of the microstrip antenna array assembled with the designed power divider is shown in Figure 3 and exhibits a good agreement with the desired pattern in terms of coverage beyond 30°, with $G > 10$ dB and SLL $< -13.5$ dB. The photograph of the practically realized array is shown as an inset in Figure 3.

4. CONCLUSIONS
This letter has presented new design architecture of a four-element linear microstrip antenna array with a wide coverage cosec² radiation pattern using Orchard Elliott’s technique and genetic algorithm method. The array antenna having a wide coverage beyond 30° with fairly low sidelobe levels and a good gain has been realized. This work has a direct usage in the surveillance radar antenna applications.

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DESIGN OF A 3–5-GHz ULTRAWIDEBAND BIFET MIXER USING 0.35-µM SiGe BICMOS TECHNOLOGY

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ABSTRACT: A fully integrated ultrawideband (UWB) bipolar cascode with metal oxide semiconductor field effect transistor (BiFET) mixer using standard commercial 0.35-µm silicon germanium bipolar complementary metal oxide semiconductor technology was first proposed and fabricated in this study. This presented BiFET mixer using bipolar junc-
tion transistor as the transconductor stage and metal oxide semiconductor field effect transistor as the switch stage to achieve noise power and linearity trade-off. This 3–5-GHz UWB mixer achieves a conversion gain of $4.5 \pm 0.5$ dB at the designed band. The mixer core draws a current of 2.5 mA from a supply voltage of 3 V, while consumes chip area of $0.9 \times 0.9 \text{ mm}^2$. © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 965–968, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22305

Key words: bipolar cascade with metal oxide semiconductor field effect transistor (BiFET); bipolar complementary metal oxide semiconductor (BiCMOS); mixer; ultrawideband (UWB)

1. INTRODUCTION

Since the Federal Communications Commission (FCC) allocated the 7.5 GHz (3.1–10.6 GHz) spectrum for ultrawideband (UWB) radio application in February 2002, the UWB system has been experiencing a rapid progress these years owing to its low complexity, low cost, low power consumption, and high data rate wireless connectivity among devices within or entering the personal operating space [1]. As a short-range wireless connectivity technology, it has the potential to provide very high connectivity among consumer products in the home, such as video conferencing, audio distribution systems, new home entertainment appliances, and position location and navigation applications [2]. To avoid the conflict with current existing wireless system, the UWB system was divided into low frequency (3.1–5 GHz) and high frequency (6–10.6 GHz) bands. The lower 3.1–5 GHz frequency band is allocated to the first generation UWB system [3]. According to FCC spectrum mask demands of UWB system, the maximum allowed RF power is $-41.3 \text{ dBm/MHz}$. Because of this extremely low power spectra density and excessive signal bandwidth, potentially yields increased susceptibility to noise and interference in the UWB receiver [4].

The Gilbert type mixers have been the most popular mixer structure in radio frequency integrated circuits (RFIC) and monolithic microwave integrated circuit (MMIC) application, since it was developed by Barrie Gilbert 40 years ago [5]. The traditional Gilbert type mixer is normally realized by pure bipolar junction transistor (BJT) or metal oxide semiconductor field effect transistor (MOSFET) [6–8]. However, with the development of modern integrated circuit fabrication technology, designer can now use high performance BJTs and MOSFETs at the same time. Ma et al. have reported a bipolar cascade with metal oxide semiconductor field effect transistor (BiFET) LNA using bipolar complementary metal oxide semiconductor (BiCMOS) process [9], the designed LNA combines a very low noise bipolar first stage with a linear cascaded MOSFET (BiFET) to improve the trade-off among power consumption, noise, gain, and linearity relative to the more traditional configurations.

As a nonlinear block of a UWB system, mixer must have the ability to covert all the in-band signal to the desired IF band, import as little noise as possible, consume a very low power, and keep a relatively good linearity at the same time. However, the bipolar mixer has very good noise and gain performance, but relatively poor linearity. The MOSFET version can achieve the best linearity but very poor noise and gain capability.

In this letter, we report and fabricate a 3–5-GHz UWB BiFET mixer for the first time. The BiFET mixer circuit is based on a Gilbert type topology, with BJT used as transconductor stage and active current source load, while using MOSFETs as switch stage. With this new topology, the designed mixer can achieve trade-off among noise, power, and linearity. This BiFET mixer is intended for use in an UWB frequency translation block, in which noise and power consumption is more concerned than linearity. The wideband input matching of RF and LO port is realized by LC ladder matching networks. On-chip common drain buffers are adopted at the IF output ports for output matching and testing considerations.

2. DESIGN METHODOLOGY

According to the report of Rudell et al. [10], for multiplier-based mixers, like Gilbert type mixer, there are four noise sources. They are from transconductance stage, switch stage, load resistance, and finally the noise generated by an active current source load. Rudell et al. plot the equivalent input noise resistance versus LO overdrives, which shows with the increase of LO overdrives the noise contribution from transconductance stage and the noise generated by active current source load will be the main noise source of a Gilbert mixer. That is mean when provided with enough LO overdrive to the switch stage the noise performance of a Gilbert mixer will be determined mainly by the noise from transductance stage and active current source. BJT always has much better noise performance and transconductance than MOSFET with same current consumption. So BJT mixer always has much better noise performance than pure MOSFET mixer.

However, when talking about linearity performance, mixer that is made up of MOSFETs can always show much better linearity capability than a BJT one. Because MOSFET is square device and idea switches with little current leakage at cut-off state when driven by sufficient LO signals.

As mentioned in the first part, the maximum RF power of a UWB system is very low, and very susceptible to the affect of noise, so this system has much more stringent demands on noise and power consumption than linearity. When used as a frequency conversion block in UWB system, the selected mixer topology should show a very low noise and power but only reasonable linearity performance.

For BiCMOS process, the designer could use high performance BJT and MOSFET at the same time. So it will be very helpful to get a very good noise, power, and linearity trade-off of a mixer while using BJT as transconductor stage and MOSFET as switch stage at the same time, especially when the LO amplitude is high enough and the cut-off frequency of the switch stage’s active devices are not much higher than the mixer operating frequency.

![Figure 1 Schematic of a MOSFET Gilbert mixer](image-url)
Figure 1 shows the simplified BiFET mixer circuit topology. With this proposed structure, the noise and power performance of a mixer will perform much better than a pure MOSFET counterpart, but only with a little poorer linearity, which will not be a very important index for UWB application. When compared with a fully BJT mixer, the linearity performance of the designed mixer will be improved for using a much idea switch at switch stage. Although this will sacrifice some 1/f noise at lower frequency band, it will not be a big problem for wideband application.

To improve the working bandwidth of mixer, it is necessary to adopt wideband impedance matching techniques to reduce input RF and LO signal reflection loss. Of all the wideband matching techniques, the LC ladder matching networks, shown in Figure 2, which are generally used in distributed circuits, are adopted in this design to implement the wideband input impedance matching of the RF and LO input ports. This wideband matching network is loaded by the BJT base to emitter capacitance. \( C_{\text{par}} \) and \( R_{\text{par}} \) are parasitic capacitance and resistance of the input PAD respectively, which should be considered during the design of this wideband matching networks. All the passive elements of this matching network, including resistors, capacitors, and inductors, are integrated on chip.

The whole circuit schematic of the designed broadband direct conversion mixer is shown in Figure 3. The input and output of the mixer are both matched to 50 \( \Omega \). For test consideration, this BiFET mixer does not adopt a traditional differential RF and LO input signal. The RF signal is inputted to the base of Q1 through the wideband matching network, while the base of Q2 was connected to the ground through a DC block capacitor. For the input of LO signal, this structure was also adopted. By this means, the test of the mixer could be greatly simplified. Without using PCB board and bonding wire, the parasitic inductors and capacitors could be avoided. The values of the resistance load \( R_i \) are selected according to noise, voltage headroom, and conversion gain consideration. Common drain buffer is adopted at the output of IF port for 50 \( \Omega \) output matching and testing consideration. When designed as a fully integrated UWB system, this buffer will not be an indispensable part.

3. MEASUREMENT RESULT AND DISCUSSION

The designed mixer was fabricated using a standard 0.35-\( \mu \)m SiGe BiCMOS process; the minimum emitter width of the SiGe HBT is 0.3-\( \mu \)m, featuring a \( f_T \) of 46 GHz. The chip photograph of the designed wideband mixer is shown in Figure 4. The size of the whole chip is about 0.9 mm \( \times \) 0.9 mm. The fabricated mixer chips were measured using on-wafer GSG probes on RF and LO input ports. IF output port was connected to a spectrum analyzer through a DC probe and isolated by a dc-blocking capacitors. The measured conversion gain versus RF frequency...
and RF/LO ports input matching are shown in Figure 5, with both RF and LO ports swept in frequency up to 6 GHz. The output IF frequency is fixed to 10 MHz, with LO input power of 5 dBm. The conversion gain of this mixer is 5.1 dB at 3 GHz. The S11 of both ports are better than $-15$ dB at the designed band. The measured LO to RF and RF to LO isolation was shown in Figure 6. With RF and LO power of $-20$ dBm and 5 dBm, the measured LO to RF and RF to LO ports isolation are both better than 28 dB within the operating band. The measured IF output power versus swept RF input power shows a 1 dB compression point of $-13$ dBm at 4.0 GHz (see Fig. 7), which is 6 dBm better than a bipolar mixer when biased at the same current. The simulated result shows that the noise figure of the designed BiFET mixer is 8 dB, which is 3 dB lower than the pure MOSFET mixer with same current dissipation. The supply voltage of the designed circuits is 3.0 V and the mixer core draws a current of only 2.5 mA from supply. The total power consumption of this mixer including buffer and bias networks is 29 mW.

4. CONCLUSION

An active Gilbert type ultrawideband BiFET mixer in commercial 0.35-μm SiGe BiCMOS technology was presented. The presented BiFET mixer, with BJT as the transconductor stage and MOSFET as the switch stage, achieves a very good noise and linearity trade-off, while consume a very low power. The broadband input impedance matching network for the LO and RF input ports are both achieved by a LC ladder matching networks. The maximum conversion gain of the mixer is 5.1 dB at RF input frequency of 3 GHz. The mixer core is operated from a supply voltage of 3.0 V and draws a current of only 2.5 mA.

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COMPACT ULTRAWIDEBAND WIDE-SLOT ANTENNA

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ABSTRACT: A printed wide-slot antenna for portable ultrawideband application is presented in this article. It consists of a staircase-shape patch and an arc-shape slot etched on different sides of a thin microwave substrate. By using a microstrip feedline with matching stubs to excite the patch and placing a thin conductor-backed ab-