Maejo Int. J. Sci. Technol. **2011**, *5*(03), 350-357

Maejo International Journal of Science and Technology

ISSN 1905-7873
Available online at www.mijst.mju.ac.th

Communication

A good conversion loss and a very high LO-to-RF isolation of 24-GHz single balanced mixer for RF front-end receiver

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Received: 29 November 2010 / Accepted: 14 October 2011 / Published: 17 October 2011

Abstract: This work describes the design, analysis and fabrication of a 24-GHz microwave single balanced down-conversion mixer based on Schottky diode, hybrid ring coupler and a wide and deep stopband low-pass filter (LPF). The LPF is composed of three uniform defected ground structures along with a compensated microstrip line. The selected frequencies are 24.125 GHz for RF signal and 24 GHz for LO signal. When the LO and RF signals are injected as 10 dBm and 0 dBm respectively, a conversion loss of 12.85 dB with an LO-to-RF isolation greater than 38 dB is obtained. The measured results agree well with the simulated results and the reported design.

Keywords: Schottky diode, low pass filter, signal balanced mixer

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INTRODUCTION

One of the important blocks in the radio frequency (RF) front-end receiver is the down-conversion mixer which forms a critical part of the system. The down-conversion mixer converts an RF signal at the input to an intermediate frequency (IF) at the output through the use of a local oscillator (LO) signal. Single balanced diode mixers have a benefit of low-level of LO signal to produce a high RF/IF isolation. A Schottky diode can be used to produce an output spectrum consisting of sum and difference frequencies of two input signals. It has received considerable attention from the researchers due to its simplicity and efficiency of application in mixing signals. Mixer circuits have been much

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presented in the literature [1-8]. However, only Roselli et al. [6] have designed a hybrid mixer at 24 GHz but have not investigated all its characteristics.

This paper presents and proposes a reasonably good conversion loss (CL) and a very high LO-to-RF isolation of a hybrid single balanced down-conversion mixer (SBDCM) with and without DC power supply. The designed, optimised and tested SBDCM, with two silicon Schottky diodes [9], five-port hybrid coupler and an low-pass filter (LPF), is intended to be implemented in a radar receiver front-end system. The novelty of the proposed down-conversion mixer is the use of an LPF with a wide and deep stopband microstrip with and without DC power supply. The LPF is composed of three defected ground structures (DGS) etched on the backside metallic ground plane under a microstrip line [10], and a compensated microstrip line to reject the unwanted harmonics of the designed 24-GHz SBDCM. The relative permittivity and thickness of the substrate are 3.63 and 0.25 mm respectively for all designs. The complete circuit was designed and analysed using an Agilent's advanced design system (ADS) circuit simulator, then prototyped and verified by measurements. The input signal frequencies of the RF and the LO are 24.125 GHz and 24 GHz respectively. The design goals are: (i) conversion loss of less than 15 dB and (ii) isolation of greater than 25 dB.

CIRCUIT DESIGN, THEORETICAL ANALYSIS AND FABRICATION

A down-conversion mixer operates on a theoretical basis of trigonometric identities where the input signal (called RF signal, $V_{RF}(t)$) coming from the receiver antenna is filtered, amplified and multiplied at the mixer by another signal (called LO signal, $V_{LO}(t)$) generated by a local oscillator to be down converted to the intermediate frequency (called IF signal, $V_{IF}(t)$). However, this conversion process causes a set of difficulties which affect the overall mixer performances such as gain, noise, power consumption, linearity, isolation and cost. In practice, the mixing operation is performed using non-linear components. Besides, although mathematically simple, the multiplication operation is virtually impossible to be achieved.

In a non-linear system, a response may be in the form [11]:

$$v_{out}(t) = av_{in}(t) + bv_{in}^{2}(t) + cv_{in}^{3}(t) + \ldots \tag{1}$$

where a, b and c are constant and v_{in} is the co-sinusoidal signals of the combined excitation input of the form:

$$v_{in}(t) = V_{RF}\cos(w_{RF}t) + V_{LO}\cos(w_{LO}t) \tag{2}$$

where V_{RF} and w_{RF} are the voltage and angular frequency of the RF signal respectively, and V_{LO} and w_{LO} are the voltage and angular frequency of the LO signal respectively.

It has been shown that the generated frequency is given as follows [11]:

$$f_{mn} = |mf_{RF} \pm nf_{LO}| \tag{3}$$

where $m, n = \ldots, -3, -2, -1, 0, 1, 2, 3, \ldots$. The term f_{mn} is called a mixing frequency and f_{RF} and f_{LO} are the RF signal and LO signal frequencies respectively.

The MA4E2502 silicon Schottky diodes (SSD) is selected for its extremely low parasitic capacitance and inductance, mountable surface in microwave circuits and lower susceptibility to electrostatic discharge (ESD) damage. Its spice model is given as [9]: I_S = 5E-1 nA, C_{JO} = 1E-02 pF,

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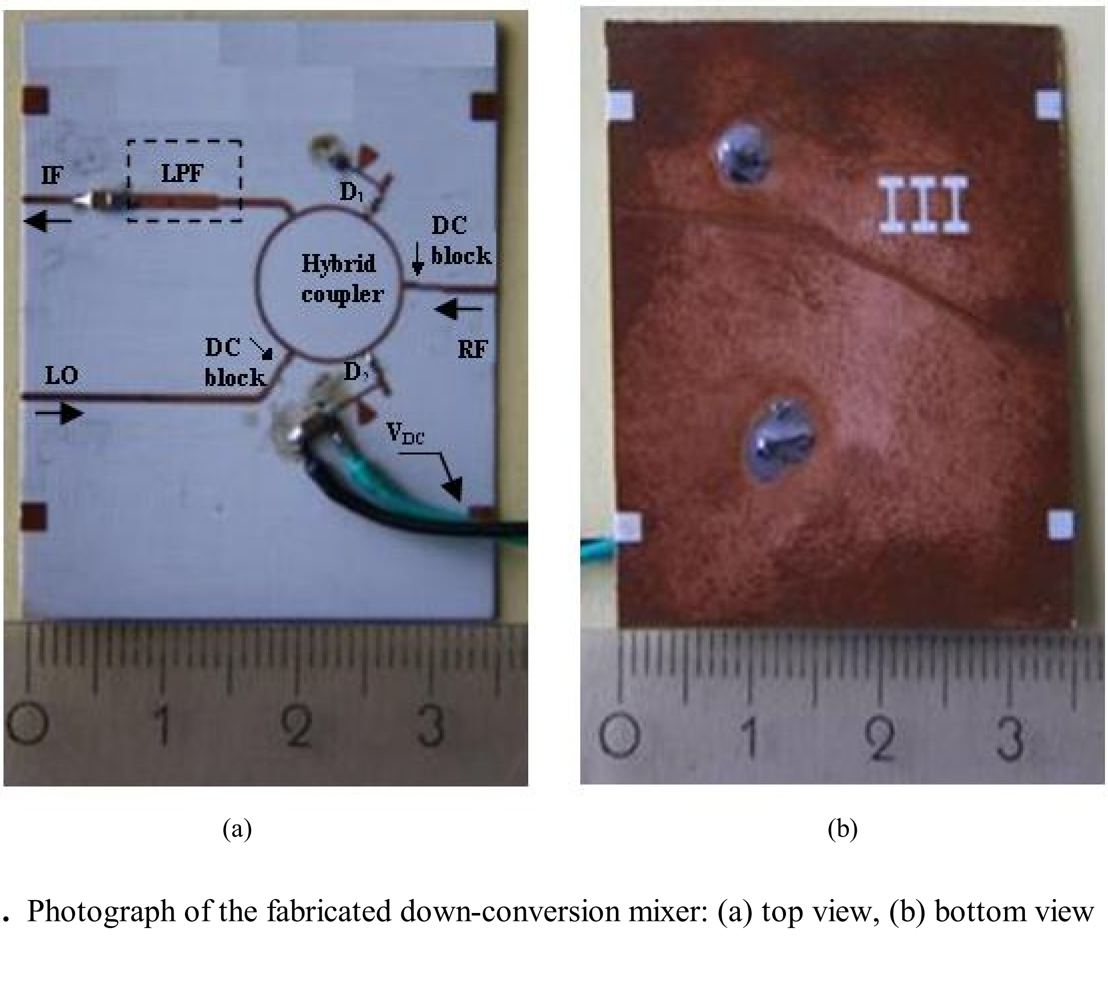
V_J= 8E-2 V, BV=5 V, IBV= 1E-2 mA, N=1.2, RS= 9.6 Ω, M=0.5, Ik=10 mA, C_{jpar}= 9E-2 pF, FC=0.5, and it is implemented in our circuit simulator.

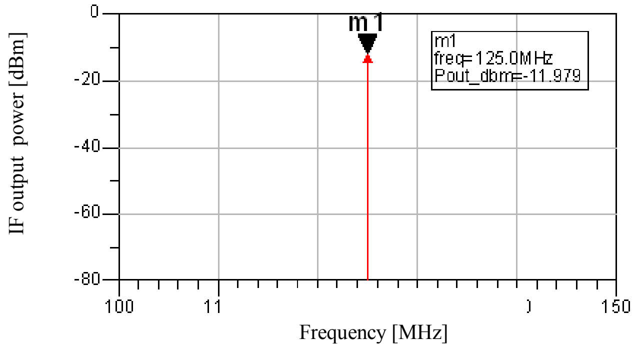
To suppress the spurious responses present at the IF output mixer, several researchers have demonstrated that with the use of low-pass filter based on DGS, the obtained performance considerably improves with wider and deeper stopband characteristics than the conventional LPF [12-22]. To reject the undesirable harmonics and take only the IF signal, a unit cell of well-known dumb-bell shaped DGS with 50-Ω microstrip line is used [10, 12]. In this paper, the designed LPF is based on three DGS units of dumb-bell shaped DGS integrated to the mixer circuit. In the mixer, both RF and LO signals are mixed in the two diodes to generate signals which are combined through the ring and taken out through a DGS-LPF. A photograph of the fabricated 24-GHz SBDCM is shown in Figure 1. It consists of a hybrid coupler, two DC blocks, two Schottky diodes (D_1 and D_2) and an LPF. In order to increase the output power and decrease the losses, the designed mixer is also biased with low DC voltage (V_{DC}) as shown in Figure 1.

Figure 2 shows simulation results of the output power in a spectral domain at the IF port with RF power of 0 dBm at 24.125 GHz and LO power of 10 dBm at 24 GHz (input power at the mixer RF and LO ports is -11.75 dBm and -6.78 dBm respectively). When the diodes are biased, the biased current (I_d) is equal to 2 mA from a 0.2 V power supply. Figures 3 and 4 show the measured output power with and without bias respectively.

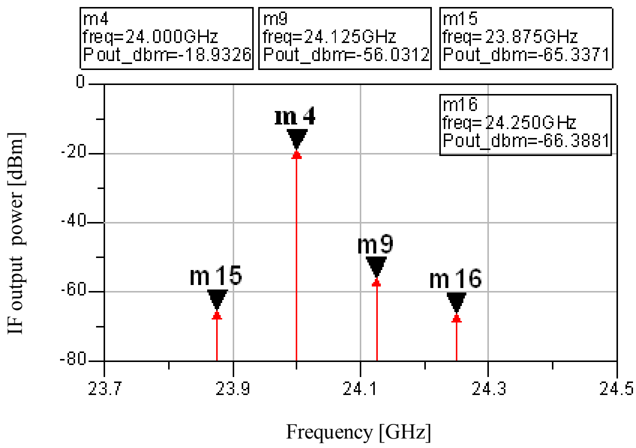


(a) (b)

Figure 1. Photograph of the fabricated down-conversion mixer: (a) top view, (b) bottom view



(a)



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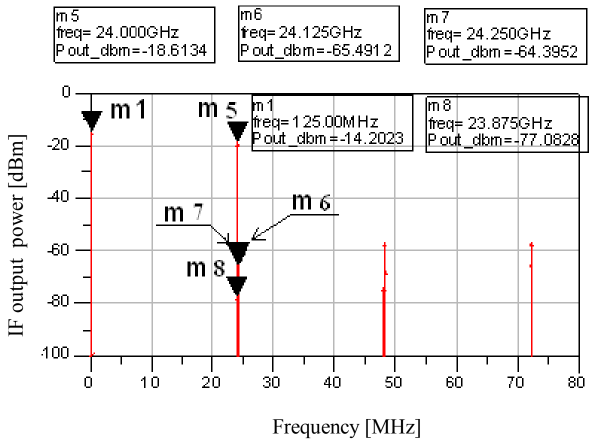
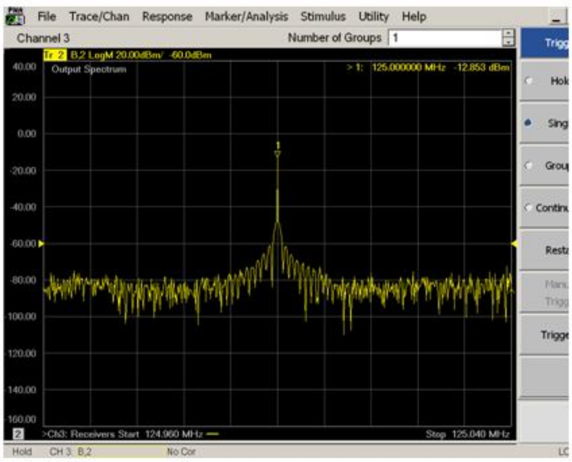
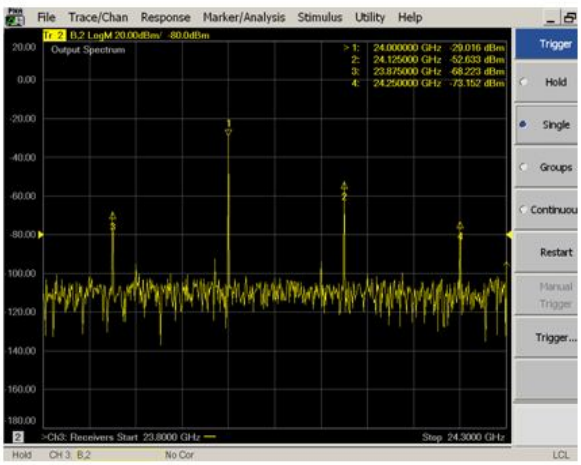


(c)

Figure 2. Simulated IF output spectrum: (a) f_{IF} = 125 MHz (I_d = 2 mA), (b) other harmonics (I_d = 2 mA), (c) f_{IF} = 125 MHz along with other harmonics (without bias)



(a)



(b)

Figure 3. Measured IF output spectrum (in dBm) versus frequency (I_d =2 mA): (a) f_{IF} =125 MHz, (b) other harmonics

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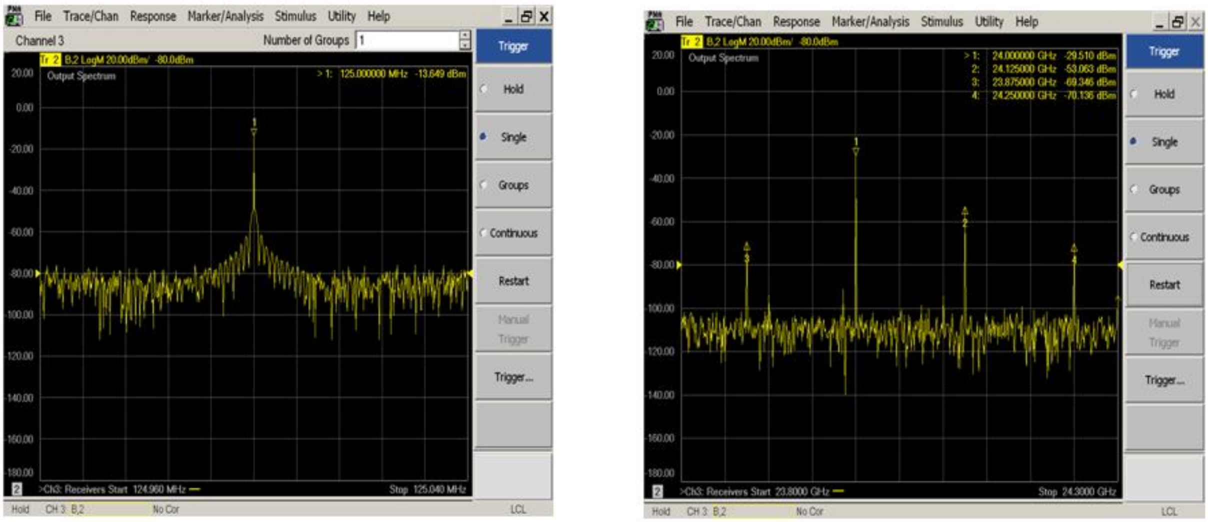


(a) (b)

Figure 4. Measured IF output spectrum (in dBm) versus frequency (without bias): (a) f_{IF} =125 MHz, (b) other harmonics

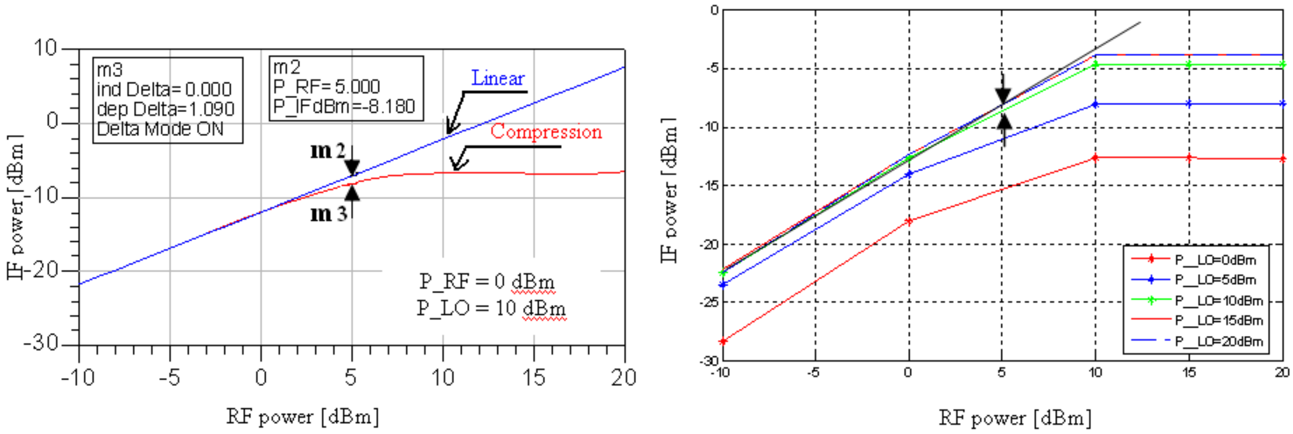
As shown in Figures 3-4, the mixer demonstrates a good down-conversion of f_{RF} and f_{LO} to f_{IF}. It can be seen that a good agreement is achieved between the simulated and measured data results. Furthermore, by adding a DC bias to the mixer, it is observed that the output power is increased: the measured IF power is equal to -13.64 dBm (before bias) and then equal to -12.85 dBm (after bias).

Figure 5 shows the simulation and the measurement of 1-dB compression point, which is approximately equal to 5 dBm.

The simulated and measured CL are shown in Figures 6(a) and 6(b) respectively. From the measured results, the maximum CL of a mixer is equal to 12.85 dBm with a 2-mA diode biased current. It can be seen that it is constant below 0 dBm (power at RF port) and then decreases due to the non-linearity of the mixer. Therefore, the CL decreases from 13.64 to 12.85 dBm when the mixer is biased.

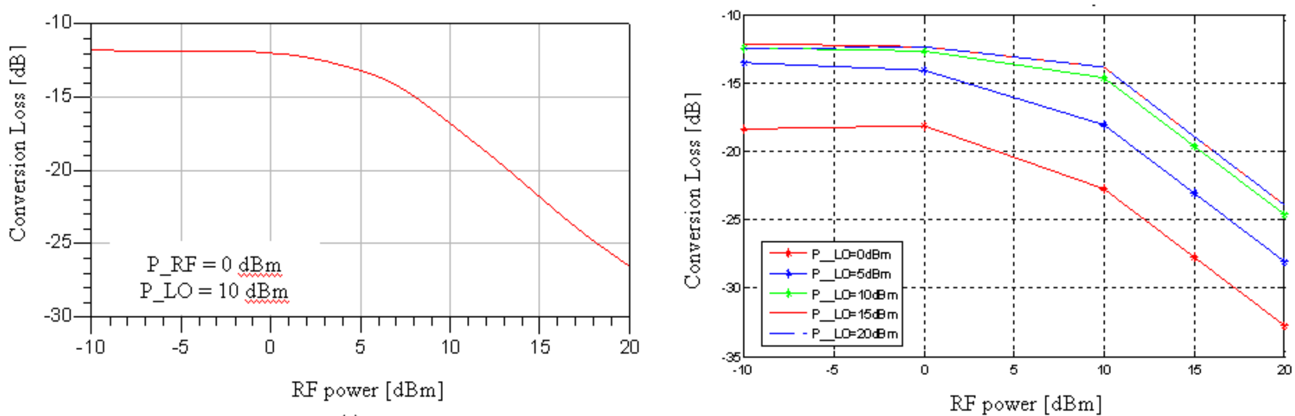
In order to determine the isolations between different ports, the power at RF port was also measured and is shown in Figure 7. From Figure 5 and Figure 7, the LO-to-IF, LO-to-RF and RF-to-IF isolations are 39.01 dB, 38.38 dB and 52.63 dB respectively.

The 24-GHz SBDCM presented here was compared with another circuit in terms of performance and the results are summarised in Table 1, which shows a good agreement in CL. The literature result shows that when a DC bias is added to the mixer, the CL decreases from 15 dBm to 12 dBm, whereas in our circuit it decreases from 13.64 dBm to 12.85 dBm under a 2-mA diode biased current.



(a) (b)

Figure 5. 1-dB Compression point: (a) simulated, (b) measured for different values of P_LO



(a) (b)

Figure 6. Conversion loss: (a) simulated, (b) measured for different values of P_LO

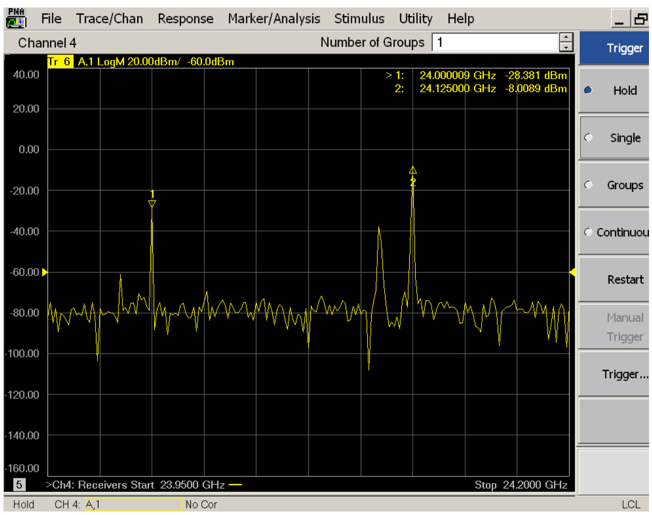


Figure 7. Measured power (in dBm) at RF port versus frequency

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Table 1. Comparison of reported designs

Ref.	f_{RF} [GHz]	f_{LO} [GHz]	f_{IF} [MHz]	P_RF [dBm]	P_LO [dBm]		V_{DC} [V]	I_{DC} [mA]	CL [dB]	1-dB [dBm]	Isol. [dB]
Roselli et al. [6]	–	24.15	0.18	- 30	- 3		–	2.5	12	–	–
							Without bias		15	–	–
This work	24.125	24	125	- 11.75	- 6.78	Simul.	0.2	2	11.97	5	> 38
						Simul.	Without bias		14.2	–	–
						Meas.	0.2	2	12.85	~ 5	> 38
						Meas.	Without bias		13.64	–	–

CONCLUSIONS

A 24-GHz single balanced diode mixer has been designed, analysed and fabricated. It shows good optimised performance in terms of DC power supply, conversion loss (CL) and isolation. We obtained a CL of 12.85 dB, a 1-dB compression point of 5 dBm and isolations greater than 38 dB. It was demonstrated that when a DC bias is added, the mixer performance is affected positively. Measured results agreed well with the simulated data.

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