Design of a Broadband Single Balanced Diode Mixer Using Vertical Coupling and Defected Ground Structure (DGS) Low Pass Filter

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Abstract

A broadband single balanced diode mixer using Defected Ground Structure (DGS) is proposed. This mixer consists of 180° hybrid rat-race and DGS low pass filter with broadband and harmonic suppressed characteristics. RF and LO signals to select IF of 140 MHz have the bandwidth of 730~1500 MHz and 490~1360 MHz, respectively.

Keywords : Mixer, DGS, Broadband, Low pass filter, Rat-race

1. Introduction

The field of RF (Radio Frequency) and microwave is rapidly growing due to its use in wireless communication systems including cellular, PDA, 3G wireless phone, satellite, ultra-wide band (UWB), ubiquitous, and optical network. Also, communication technologies give growing trends toward higher frequencies, wide bandwidth, and higher data rates. For these purposes, it is desirable to operate the broadband frequency range of microwave system components [1]. In wireless communication systems, a mixer is one of the most important system components and it has been developed for broadband performance using hybrid circuit such as branch-line, balun, and rat-race hybrid. However, hybrid circuit can hardly be realized for broadband performance in conventional microstrip line [2, 3]. The conventional 180° hybrid rat-race has inherently a narrow bandwidth. Previous works have attributed this bandwidth limitation to the narrow-band $\lambda/2$ phase inverter within the $3\lambda/4$ line section. Consequently, S. March replaced the $3\lambda/4$ section by $\lambda/4$ short coupled lines [4]. Although the bandwidth increases considerably, the even-mode impedance required for the coupled section would be too large to be realized with microstrip circuits. Therefore, in this paper, the wideband rat-race is suggested such that $\lambda/4$ short parallel coupled line section is replaced by $\lambda/4$ short vertical coupled line section to overcome the limitation of implementation of microstrip circuits. Also, a single balanced diode mixer using harmonic-suppressed DGS low-pass filter with dumb-bell shape is presented.

2. Broadband Single Balanced Diode Mixer with DGS LPF

DGS is suitable for planar transmission lines such as microstrip and coplanar waveguide. It is realized by etching off defected patterns from the ground plane. The basic shape of DGS is Dumb-bell. That is composed of two large defected areas and narrow connecting slot as shown in Fig 1. The parallel capacitance in a lumped low-pass filter can be realized by using the parallel open stub on both sides, and the open stubs are realized with cross-junction structure [6].

For conventional parallel coupled line, a coupling coefficient (k) consists of mutual capacitance (C_m) and self capacitance (C_a) which is given by [8].

$$k = \frac{C_m}{C_m + C_a} \tag{1}$$

Also, for a parallel plate, capacitance (*C*) is well known as [9]

$$C = \varepsilon \frac{w \cdot l}{h} \tag{2}$$

where ε is a dielectric constant for the substrate, *w* is width of coupled line, *l* is length of coupled line, and *h* is the distance between the plates, and *C* corresponds to C_m in Eq. (1). From this equation, gap size of the conventional parallel coupled line can be determined. A design for realizing very high even-mode impedance in $\lambda/4$ short coupled line is proposed using vertical coupling between the top microstrip and bottom signal line, which is connected to each other with via-hole as shown in Fig. 1

A 180° rat-race mixer consists of two individual mixers connected to two mutually isolated rat-race with the other ports used for the LO and RF inputs [5]. These ports are also mutually isolated, so the LO to RF isolation of the mixer is usually about as good as that of the rat-race itself, even through the individual mixer's input VSWRs are relatively poor. If LO is applied to one of the ports of the rat-race, the LO voltage has 180° phase difference at two diodes as shown Fig. 1.

Because the polarities of the diodes to be connected are reversed, the waveforms of junction conductance for the two diodes are in phase. The RF and LO are applied to a pair of mutually isolated ports. Thus, both the LO and RF signals appear at the remaining two ports, to which the diodes are connected. Either port can be used for the RF or LO, but the port should be chosen for the spurious response rejection. Depending on the choice of a port, RF or LO signal is split with 180° phase difference, and the other is in phase at the diodes. The resulting IF voltages are in-phase in the diodes, which are simply connected in parallel at the IF [7]. RF band for the mixer is selected for 730 MHz ~ 1500 MHz, the LO band is from 590 MHz to 1360 MHz, and IF frequency range is consequently determined to be 140 MHz. Two HSMS-2822 Schottky diodes from Agilent are used for the nonlinear devices. The AWR ver. 2011 is used for the simulation tool.
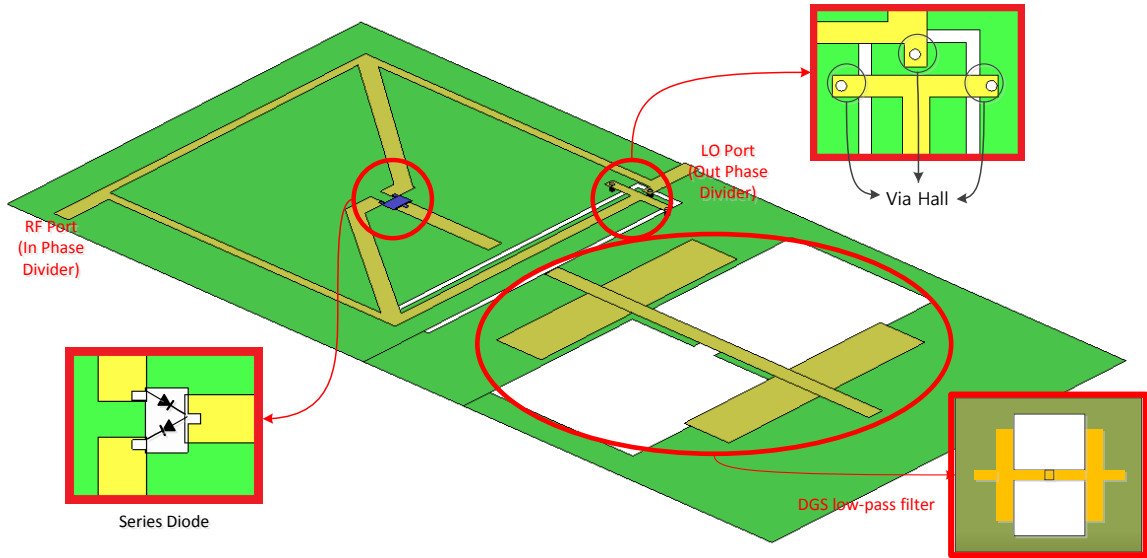

Fig 1: Single Balanced Diode Mixer 3D Layout

3. Experiments for the Single Balanced Diode Mixer

Fig 2(a) shows the measurement results for the conversion loss versus frequency band of 0.7 GHz to 1.6 GHz with variable LO power. The best and worst conversion losses are about 5.08

dB and 10.05 dB, respectively and the average conversion loss is 8 dB. Increase in conversion loss is caused by the magnitude and phase difference within the broadband rat-race hybrid.

Fig 2(b) shows the measurement results for the conversion loss versus LO power with variable RF power. One of the important characteristics for the mixer is the LO saturation power level, which is defined when conversion loss is at LO saturation point. The LO and RF frequencies are 1 GHz and 0.86 GHz, respectively. The RF and LO powers are varied from -40 dBm to -25 dBm and from -4 dBm to 14 dBm, respectively. The conversion loss becomes saturated at approximately -6 dB with an LO power of greater than 6 dBm.

Fig 3(a) shows the LO to RF isolation versus frequency with variable RF power. From the measurement results, the LO to RF isolation is good enough with broadband frequency range of 0.7 GHz ~ 1.6 GHz with variable RF power. Also, the LO to IF isolation is good enough with broadband frequency range of 0.7 GHz ~ 1.6 GHz with several LO power levels as shown in Fig.3(b).

Fig. 4(a) shows the spectrum at the IF port. From the result, the conversion loss of the mixer is measured to be 5.6 dBm for the RF power of -25 dBm at 1 GHz and the LO power of 4 dBm at 0.86 GHz, and Fig 4(b) shows the photograph of the broadband single balanced mixer which is fabricated with broadband rat-race and low pass filter.
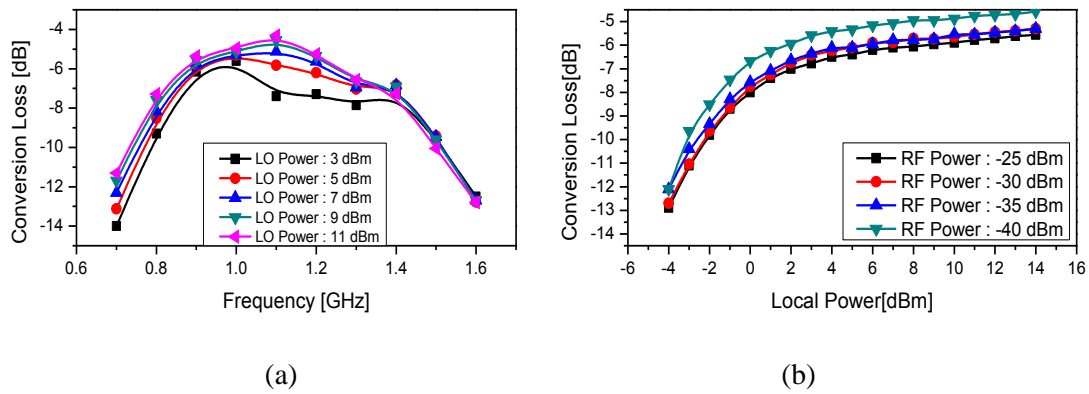

(a)   (b)

Fig 2:   (a) Conversion loss vs. operating RF & LO frequency for incident LO power level
(b) LO saturation power levels for variable RF power level
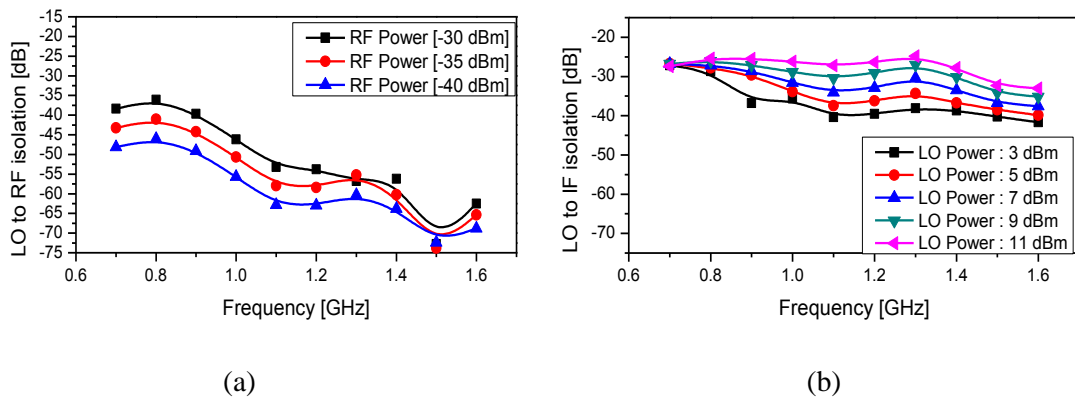

(a)   (b)

Fig 3: (a) LO to RF isolation vs. frequency for incident RF power levels
(b)LO to IF isolation vs. frequency for incident LO power levels
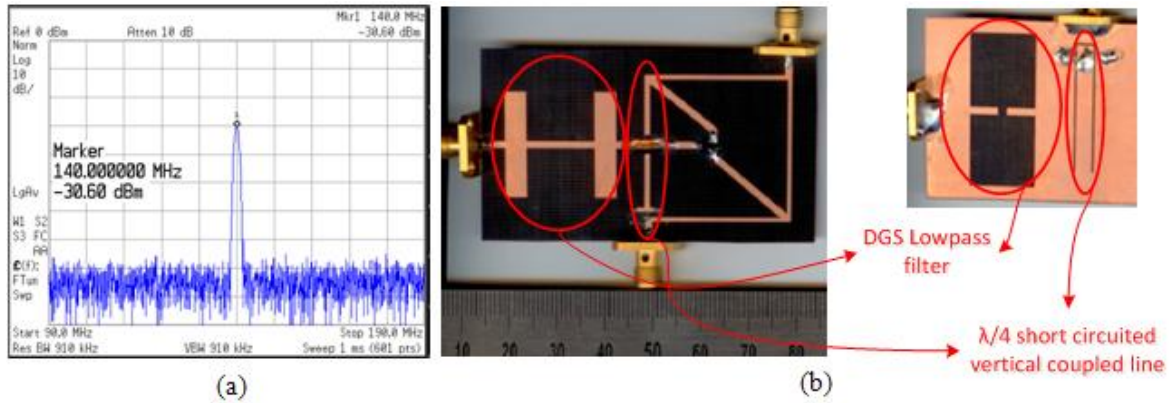
Fig 4: (a) A spectrum of the IF signal
(b) Photograph of the broadband single balanced mixer

4. Conclusion

The broadband single balanced mixer has been successfully implemented on the conventional microstip structure and demonstrated its superior characteristics. From the results, the RF-to-LO isolation is better than 35 dB and LO-to-IF average isolation is 25 dB. The measured average conversion loss is about 8 dB at the 69 % RF bandwidth (730 MHz ~ 1500 MHz), which is mainly resulted from the magnitude and phase difference of the broadband rat-race. The broadband single balanced mixer provides the possibility of usage in broadband wireless communication system.

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