48/24 GHz and 20/10 GHz Regenerative Frequency Dividers

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Abstract

Low power regenerative frequency dividers have been designed and experimentally evaluated. The dividers consist of a resistive FET (HEMT) mixer, bandpass filters and an amplifier. Experimental verification of the dividers at 48/24 GHz and 20/10 GHz shows that stable division in a bandwidth of 3-5 % can easily be obtained. This is, to our knowledge, the highest frequency of operation of such type of dividers.

Introduction

Frequency division is an important operation, crucial for miniaturization of microwave and millimeter wave systems. The reported working frequency of frequency dividers is limited to lower millimeter frequencies [1-7].

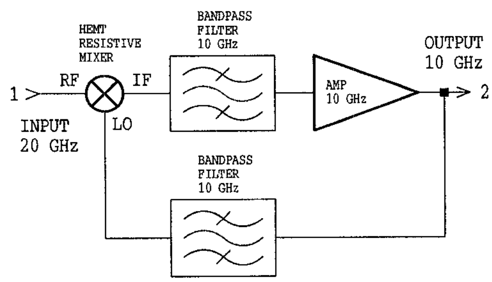

Fig. 1: Block diagram of the regenerative frequency divider

It is essential for a millimeter wave frequency divider, that the circuits are compatible with technologies used to produce MMIC if the dividers are intended for quantity production. One such configuration suitable for use at high frequencies is the classical Miller divider [1] (fig. 1).

In order to make the regenerative process working it is necessary to satisfy the magnitude and phase conditions defined in [1-3]. A critical subcircuit in the Miller divider is the mixer. We have previously proposed the use of a MESFET (HEMT) resistive mixer in a regenerative divider and experimentally investigated such a divider working at 10 GHz [8]. This divider type has several advantages: i. The circuit is compatible with MMIC processing technology since MESFETs or HEMTs are both used for the mixer and the amplifier. ii. The mixer is always electrically stable regardless of the source and load impedance's since the FET is operated in a passive mode (the drain-to-source bias-voltage is zero), iii. the conversion loss of the resistive mixer can be reasonably low even at a very low pumping power and as a consequence, the divider will start to divide at a fairly low input power level, iv. the power consumption can be very low since the mixer is passive, and v. the isolation between the LO-port (gate) and the RF/IF port (drain) is of the order of 10 to 15 dB intrinsically and determined mainly by the feedback-capacitance. We have previously investigated different types of resistive HEMT-mixers up to 120 GHz. The operation of this divider type should be possible to extend well above 100 GHz with the present HEMT technology.

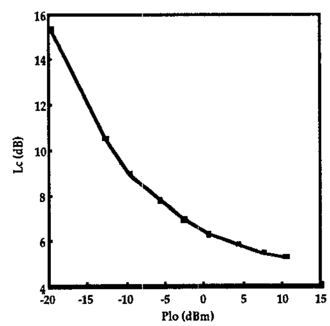

Fig. 2: Experimental conversion loss of a resistive mixer vs. LO power at Q-band (33-50 GHz).

The experimental conversion loss is of the order of 5 dB for the fundamentally pumped mixer at Q-band (33-50 GHz) and 9 dB at F-band (120 GHz) [9]. As an example, the measured conversion loss versus LO-power of our Q-band mixer is shown in Fig. 2. If the gain of the amplifier is higher than the conversion loss of the mixer, the system will operate as a divider in the frequency region in which the phase condition is satisfied. When the input signal is below a certain limit, the conversion loss of the resistive mixer will increase significantly. The division process is consequently stopped and there is no output from the divider.

Circuit design and experimental results

Dividers based on the block diagram in figure 1 were designed for 20/10 GHz and 48/24 GHz. The layouts of dividers are shown in figure 3. A coupled microstrip line bandpass filter was selected for the 20/10 GHz divider. A $\lambda/4$ (at 20 GHz) open stub filter was added to the amplifier input, since the filter did not provide enough attenuation at the input frequency. A modified hairpin filter was used for the 48/24 GHz divider. This type of filter is more compact, combine

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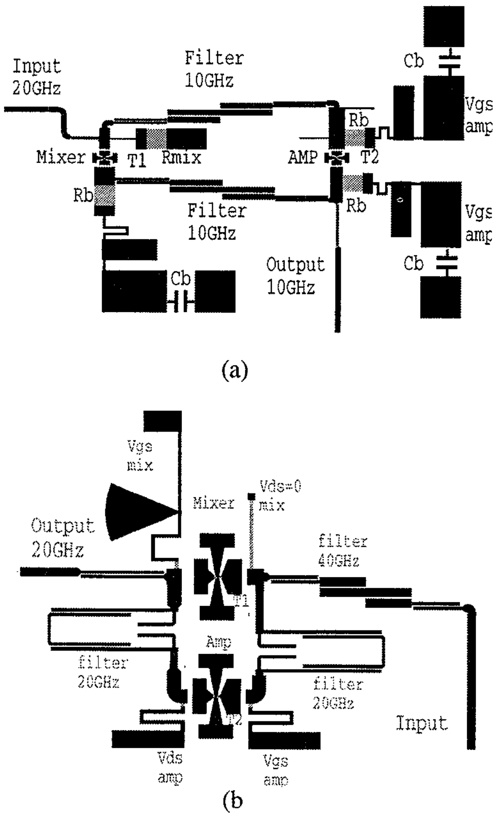


Fig. 3: Layout of the dividers (20/10 GHz (a) and 48/24 GHz divider (b)).

low losses in the pass band and high attenuation at the input frequency and they are better suited for future implementation in MMICs. The calculated bandpass characteristics are shown in figures 4 a and b. MDS from Hewlett Packard and Microwave Harmonica from Compact Software were used in the simulations.

The bandwidth of the divider is determined by the bandwidth of the filter and amplifier, and the phase condition [3] for the total loop:

$$(-\pi/2+2\pi K) \leq \phi(\omega) \leq (\pi/2+2\pi K)$$

where K is an integer. This means that if the gain in the loop is high enough to compensate the losses and the phase relations are satisfied, multiple stable and unstable regions will be observed. The goal in this design was to minimize these multiple division regions. The total length in the feedback loop was hence kept to a minimum, but still fulfilling the phase requirements and providing enough filtering.
The gain of the amplifier under compression G must compensate the conversion losses of the mixer L_c and loses in the filters L_f i.e. $G > L_c + L_f$. The amplified power from mixer IF output will be enough to pump the same mixer and the regenerative process will start.

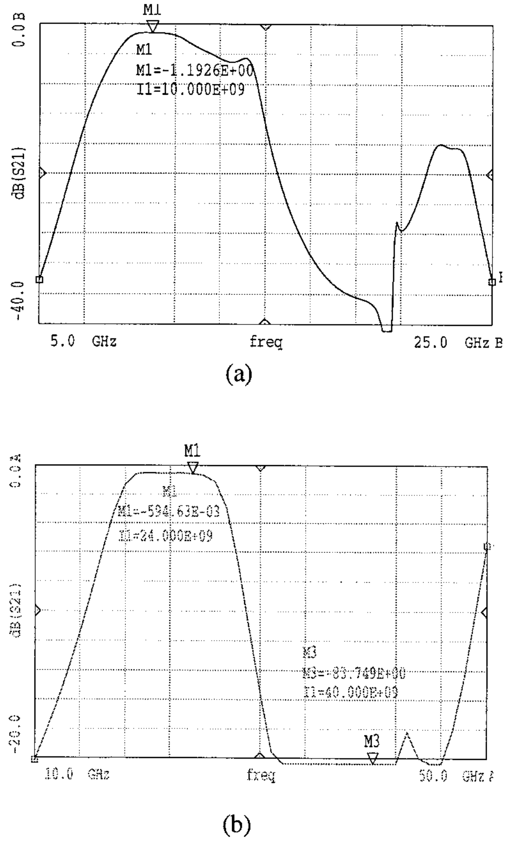
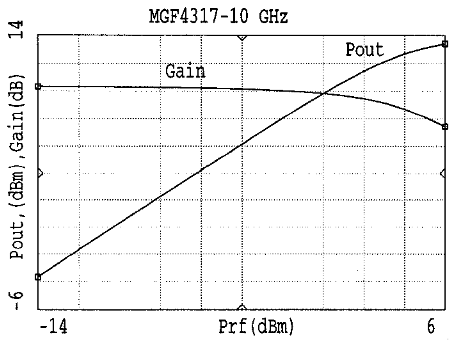


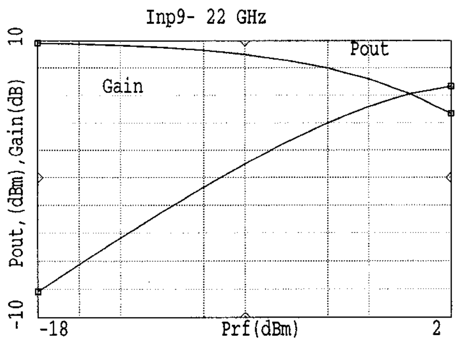
Fig. 4: Calculated response of the bandpass filter used in the divider (20/10 GHz (a) and 48/24 GHz divider (b)).

The simulated amplifier response, i.e. the gain and output power vs. input power is shown in figure 5 for both dividers. In the simulation of the large-signal response, we have used a non-linear model described previously [10, 11]. For the low frequency divider packaged HEMT transistors, MGF4317D from Mitsubishi, were used in the resistive mixer and the amplifier. For the high frequency divider 100 μm x 0.15 μm 'in house' InP HEMTs with an f_{max}>300 GHz, were used. The amplifiers, were stabilized by loading the input and output with 50 ohm resistors, connected via λ/4 lines to the bias. We used a 250 μm thick Duroid substrate for the 20 GHz divider and a 125 μm alumina substrate for the 48 GHz divider.

Figure 6 shows the measured characteristics of the divider i.e. the output power as a function of frequency and input power. The bandwidth is increased with increasing input power. If the input power is removed the division process is stopped. A stable frequency division is obtained within a bandwidth of 3- 5 %. No spurious responses were observed. The output spectrum of the divider in the stable region was clean. The unwanted harmonics were 20 dB below the output signal. Outside the stable region many mixing products and even chaotic behavior can be observed.

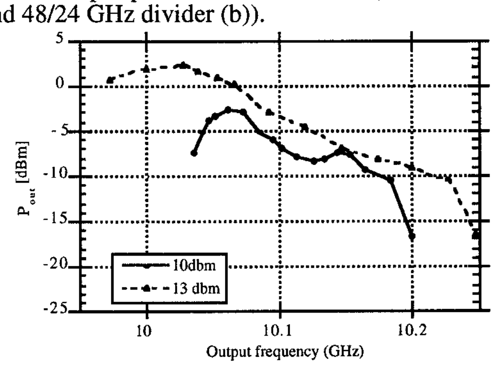


(a)

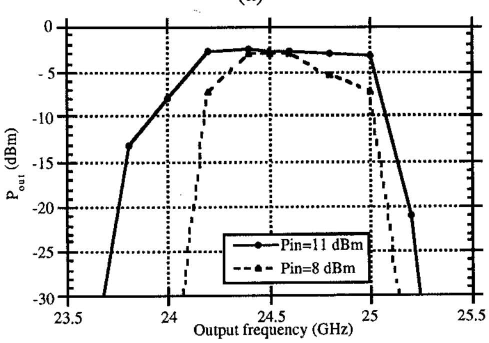


(b)

Fig. 5: Simulated output power and gain of the amplifiers vs. input power for the dividers (20/10 GHz (a) and 48/24 GHz divider (b)).



(a)



(b)

Fig. 6: Output power P_{out} vs. output frequency $f_{out}=(f_{in}/2)$ of the regenerative dividers (20/10 GHz (a) and 48/24 GHz divider (b)).

The experimental dependencies for the output power vs. input power and the spectral characteristics of the 48/24 GHz divider are shown in figure 7 and 8. A HP 8526 Spectrum analyzer was used for the phase noise measurements. Spectral characteristics are approximately 6 dB better after the division using offset frequencies larger then 10 kHz from the carrier. Similar characteristics were obtained for the low frequency divider. The transition response of the divider to a pulse modulated RF was also investigated. There is no sign of degradation of the shape of the pulse within the capability of the measuring equipment used (5 ns rise and fall time), and it should, hence, be possible to use this divider in fast switching synthesizers.

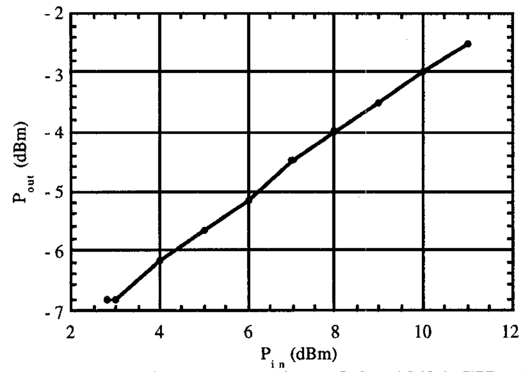


Fig. 7: P_{out} vs. input power P_{in} of the 48/24 GHz divider.

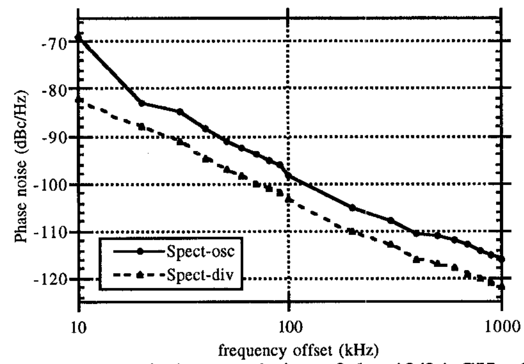


Fig. 8: Spectral characteristics of the 48/24 GHz divider

Conclusions

Regenerative frequency dividers using resistive FET mixer have been designed and experimentally verified at 20 and 48 GHz. This is, to our knowledge, the highest frequency of operation of such dividers. They can be used in fixed frequency synthesizers and in clock recovery circuits. The proposed divider should be capable to operate at millimeter wave frequencies well beyond 100 GHz using MMIC technology. This type of divider dissipates very low DC power (≈10-20 mW) compared to digital dividers which requires hundreds of milliwatts .

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