

PHEMT FREQUENCY DIVIDERS

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ABSTRACT

A novel active parametric frequency divider configuration using coupled microstrip transmission lines and two balanced pHEMTs is presented. The analysis of the divide-by-two divider presented applies the principles of subharmonic generation using a nonlinear reactance to an active semiconductor device such as a pHEMT. A 2GHz – 1GHz active analogue frequency divider is designed and measurements show a 20% bandwidth with 13.5 dB conversion gain and harmonic rejection levels of more than 22dBc. A maximum conversion gain of 18dB is also achieved. These higher conversion efficiencies and cascadability allow for higher order division ratios to be possible with the same topology.

Keywords: frequency dividers, parametric pHEMT dividers, nonlinear subharmonic generation, balanced coupled lines

I. INTRODUCTION

Frequency dividers find applications in many communications systems to military applications. They are also essential to a variety of microwave system needs. Among the classic examples are applications involving straight frequency counting, phase-locked loops (PLL) and phase noise reduction [1]. Frequency dividers also have bandwidth compression capabilities which opens up the possibility of transferring wide microwave bands, to the region where the power of digital logic can be used for processing [2].

So far, there have been a number of different microwave frequency divider concepts described in the literature. Digital dividers are capable of broadband performances up into the microwave frequency range (up to 40 GHz) but their power consumption increases with frequency (several watts DC power at millimetre wavelengths). Analogue dividers feature lower power consumption, simpler circuit designs and higher

operating frequencies, which makes them attractive for communications purposes.

Among the various analogue solutions [1], parametric frequency dividers [3-4], represent simpler circuit configuration and broader synchronisation bandwidth. Parametric division is a process in which a subharmonic oscillation is generated from a nonlinear reactive element. The most common element used is a varactor i.e. exploiting the asymmetrical voltage-dependent depletion layer capacitance of an abrupt junction diode. The basic theory of device operation is presented in [5] and [6]. Divider designs based on the empirical techniques are described in [7-9].

Because of circuit losses within the varactor diodes, amplifiers are generally required to recover the input signal level. For systems that require cascaded frequency dividers at least one amplifier is required for each frequency divider. The active parametric frequency divider design presented in this paper, eliminates the need for separate amplifiers. The design employs active pHEMT devices to perform parametric

frequency division and amplification simultaneously at microwave frequencies.

A working design has been developed and tested for an active parametric frequency divider with a large divide-by-two bandwidth and high conversion gain. The presented circuit design can also be fabricated in MMIC form on a single chip.

II. PARAMETRIC FREQUENCY DIVISION

The name parametric has become associated with a class of amplifying and frequency-converting devices which utilize the properties of nonlinear or time-varying *reactances*. Manley and Rowe [10] have derived a general set of equations relating power flowing into and out of an ideal nonlinear reactance with no particular nonlinearity specified. It uses the principle of energy conservation and can be used to show the possibility of frequency division [6]. These parametric oscillations are also dependent on variations of particular external parameters such as bias, drive and frequency.

Existing documentation describe two basic types of parametric dividers: filter-based dividers and balanced dividers. The primary performance discriminator between the two types of dividers is bandwidth-related [1].

The filter-based divider is limited in bandwidth because of the high-Q selective filters, but offers the best possibility of producing a minimum threshold design due to its narrow bandwidth and single varactor loss [9, 11]. On the other hand, the balanced design is more amenable to wide-band performance and has better transient response. The balanced divider, which requires dual varactors, has been analysed by Harrison [7]. He shows that the even/odd modality of the device lends itself to closed form solutions, and has documented, in conjunction with Kalivas [3, 12], several practical dividers and

design techniques, but all are passive designs which require high input powers with conversion loss.

The analysis presented here is similar to that of [3] but replaces the nonlinear varactor with an active semiconductor device such as a pHEMT. The input nonlinear junction capacitance of a pHEMT, functions as a varactor divider producing subharmonics and the device transconductance, g_m , simultaneously provides amplification.

Higher order 2^N division can also be obtained by cascading several dividers. The associated gain of the active device, compensates for most of the conversion losses and enables more frequency dividers to be cascaded without too much concern about signal degradation and power loss.

III. CIRCUIT STRUCTURE

The balanced circuit, as with other parametric divider designs, requires two basic resonant loops in the circuit, resonant at the fundamental frequency f_{in} , and the subharmonic output frequency $\frac{1}{2} f_{in}$. The circuit should be constructed in such a way as to minimize coupling of the input frequency f_{in} , to the output port. These requirements can be satisfied by a parametric microstrip resonant structure consisting of a pair of symmetrical coupled microstrip lines, in combination with two nonlinear reactive elements (i.e. nonlinear input capacitance of the active device, represented here in the form of $C(v)$). Figure 1 shows the basic balanced frequency divider circuit design.

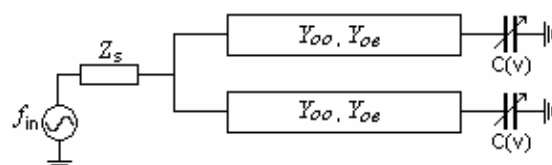


Figure 1 – Basic balanced coupled line frequency divider circuit.

An input signal at f_{in} entering the microstrip lines, divides equally between the two lines so they have potentials equal in magnitude and sign. This excites the nonlinear capacitances in phase and the propagation is determined by the even-mode admittance, Y_{oe} .

The coupled lines are designed to support oscillations at $\frac{1}{2} f_{in}$ frequency, where the resonant behaviour is determined by the odd-mode admittance, Y_{oo} , of the pair of coupled lines. Because of the nonlinear coupling mechanism between the even-mode and the odd-mode, energy is transferred from f_{in} to $\frac{1}{2} f_{in}$, via the nonlinear capacitances.

IV. DESIGN ANALYSIS

A simplified analysis of coupled transmission lines is given by [13] leading to an equivalent circuit as shown in Figure 2 for the pair of coupled lines.

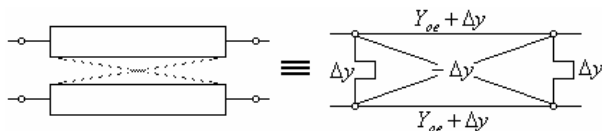


Figure 2 – Simplified equivalent circuit of a pair of coupled lines.

where $\Delta Y = \frac{Y_{oo} - Y_{oe}}{2}$, and Y_{oo} and Y_{oe} are the odd- and even-mode admittances of the coupled lines respectively. This method applied to the divider circuit of Figure 1, leads to the equivalent circuit of Figure 3. Each of the coupled lines are reactively loaded with the pHEMT, the average capacitance of which is C_0 at the input bias voltage V_{gs} .

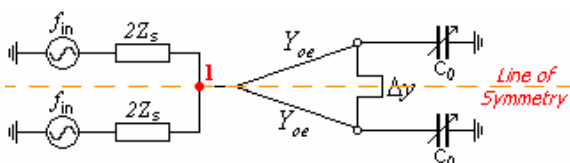


Figure 3 – Equivalent circuit of the balanced parametric divider.

The analysis is based on two separate modes of excitation for the circuit of Figure 3, even- and odd-mode, for which the line of symmetry is shown. Node 1 is the common input point to the coupled lines. In the even-mode, a finite voltage is presented at this node at f_{in} and an open circuit exists across the line of symmetry. The equivalent circuit is shown in Figure 4(a). The even-mode resonance condition at the fundamental frequency, $f_{in} = \omega_{in} / 2\pi$, is therefore

$$Z_{oe} \cot \theta_e \omega_{in} C_0 = -1$$

(1)

Similarly, in the odd-mode case, zero-voltage exists at node 1 with a short circuit across the line of symmetry. This reduces the equivalent circuit in the odd-mode to that shown in Figure 4(b). The condition for resonance at the subharmonic frequency, $\frac{1}{2} f_{in}$ is

$$j \frac{\omega_{in}}{2} C_0 = \frac{j Y_{oo}}{\tan \theta_o}$$

(2)

This gives

$$Z_{oo} \tan \theta_o \frac{\omega_{in}}{2} C_0 = 1$$

(3)

as the odd-mode resonance condition.

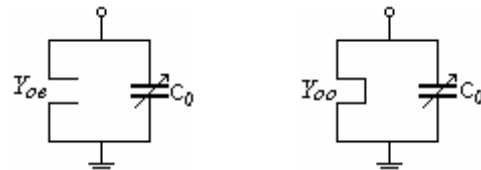


Figure 4 – (a) Even-mode and (b) Odd-mode equivalent resonance circuits.

From equations (1) and (3) we can obtain the ratio of the even- and odd-mode impedances as $Z_{oe} / Z_{oo} = -\tan \theta_e \tan \theta_o$. In order for the lines to be physically possible [14], the condition is

$$\frac{Z_{oe}}{Z_{oo}} > 1$$

(4)

Since the value of C_0 is known (i.e. can be extracted from measurements of the active devices), suitable values of θ_e and θ_o are chosen to satisfy condition (4). Given the frequency of operation and substrate parameters, physical dimensions of the coupled lines such as the width, length and the spacing can be derived from Z_{oe} , Z_{oo} and the electrical lengths. For maximum bandwidth, the resonator size should be minimised.

V. PRACTICAL EXAMPLE

A 2GHz – 1GHz divider is designed in microstrip, on Rogers RTDuroid 5880. The active device used in this work is the Filtronic FPD1500SOT89 pHEMT, which has a gate length of 0.25 μ m. The small-signal input capacitance of the pHEMT is initially measured and plotted against the input bias voltage, V_{gs} (Figure 5). From this, the average capacitance value, C_0 , is taken to be about 3pF.

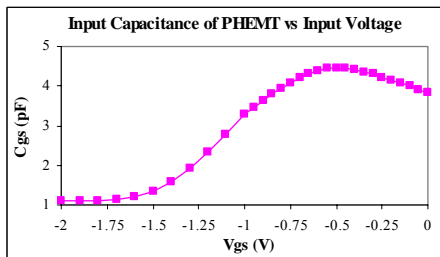


Figure 5 – Input Capacitance variation of the pHEMT with bias voltage, V_{gs} .

With substrate parameters of $\epsilon_r = 2.2$ and thickness of 0.787 mm, θ_e and θ_o are chosen to be 130° and 65° respectively. This gives $Z_{oe} = 31.6\Omega$ and $Z_{oo} = 24.7\Omega$. The coupled line dimensions are hence calculated to have width of 5.1 mm, length of 38.8 mm with a spacing of 0.38 mm between the two lines.

Figure 6 shows the fabricated pHEMT frequency divider. The input gate bias of the pHEMTs is applied via a bias-tee to the input of the circuit. The drain bias is applied on the output of the pHEMTs via two bent high impedance lines, each $\lambda/4$ at the 1GHz output frequency. The radial stubs produce broadband shorts at the junction of each high impedance line.

The nonlinear model TOM3 is used to simulate the biased active devices in Agilent's ADS software, to look at the output impedances. The pHEMT biased at gate voltage of $V_{gs} = -0.6V$ and drain bias of $V_{ds} = +3V$, showed an output impedance of 17.613+j8.44 Ω . This impedance is conjugately matched to the 50 Ω output to maximise the power delivered to the load at the output frequency of 1GHz. The matching network consists of a length of transmission line and an open circuit stub as shown in Figure 6. Two capacitors are also used as DC blocks on the output.

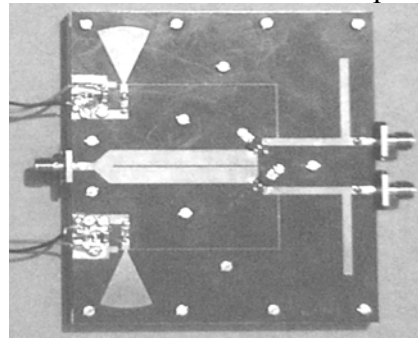


Figure 6 – Photograph of the balanced active divide-by-two circuit.

VI. MEASUREMENTS

A minimum level of input power P_{in} is required in order for frequency division to occur. For this 2GHz – 1GHz active parametric divider the threshold input level is about -14 dBm, at which frequency division commences abruptly. This is clearly shown in Figure 7 where the output power spectrum is plotted versus the input power, P_{in} . As P_{in} increases beyond this level, the bandwidth increases.

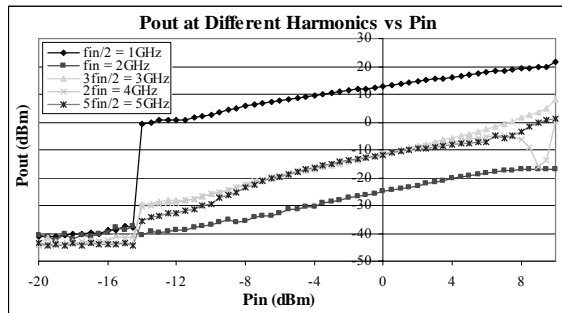


Figure 7 - Results for 2GHz-1GHz Frequency Divider Showing the output power spectrum versus the input power.

The divider is biased at $V_{gs} = -1V$ and $V_{ds} = +3.15V$ for optimised results. The output frequency response and working bandwidth of the divider tested at $P_{in} = 0$ dBm are shown in Figure 8. As shown a wide frequency bandwidth of about 20% is achieved with harmonic rejection levels of more than 22 dBc. The average gain produced by this active divider is about 13.5 dB at $f_{in} = 2$ GHz, with maximum gain of 18 dB with $P_{in} = 0$ dBm occurring at $f_{in} = 1.88$ GHz.

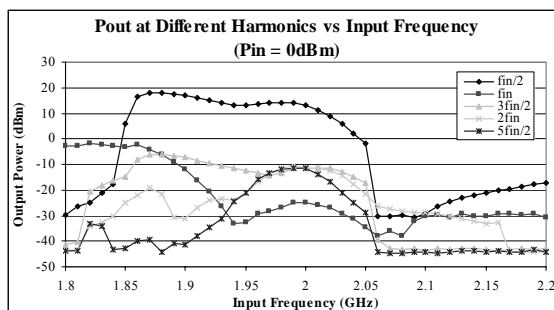


Figure 8 - Results of the divider showing the output power spectrum versus the input frequency.

VII. CONCLUSIONS AND FUTURE PLANS

A practical and efficient approach for the design of an active microwave frequency divider has been demonstrated. Using the balanced parametric division method, a 2GHz – 1GHz frequency divider was designed and built. A working bandwidth of 200 MHz with a maximum conversion gain of 18 dB, and harmonic rejection levels of more than 22 dBc have been

obtained.

In order to complete this design, the balanced output of the divider can be fed into a 180-degree hybrid coupler so to separate the subharmonic $\frac{1}{2}f_{in}$ frequency from the fundamental f_{in} and other harmonics. This is an efficient way of filtering out the required output signal without the use of extra filters, since it can also act as a balun circuit to convert the two balanced outputs of the divider, into a single unbalanced output.

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