PARAMETRIC FREQUENCY DIVIDERS IN SATELLITE COMMUNICATIONS

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ABSTRACT

The performance of two different parametric frequency dividers, using GaAs varactor diodes in a balanced circuit configuration implemented by planar (microstrip) or quasi-planar (finline, coupled finline) elements respectively, is presented. The almost phase noise free operation of these devices allows the construction of efficient miniature synthesizers or carrier recovering schemes, incorporated on the space segment of Ku- or Ka-band satellite communications systems.

I. INTRODUCTION

Rapidly expanding activities in satellite communications hardware developments have created an urgent need for frequency subharmonic generators immune to phase noise. Indeed, the realization of highly sophisticated TDMA or even CDMA systems, require very stable carrier recovery, symbol timing recovery and pseudo-noise sequence recovery circuits. During the past decade microwave frequency dividers have been succesfully used in many space applications below 20 GHz [1]. In these applications the most frequently used frequency divider is the microstrip parametric divider, well described in references [1] and [2] and being simulated in the time domain using the two-Dimensional Transmission Line Matrix (2D-TLM) method in reference [3]. However, parasitic radiation associated with planar microstrip waveguides make the use of microstrip-based frequency dividers problematic, especially for millimeter-wave applications (e.g. $f > 30$ GHz). Hence, a finline-based parametric frequency divider has been proposed in [4].

The operation of parametric frequency dividers is based on the concept of the non-linear reactance, usually achieved by means of the depletion capacitance in varactor diodes [5]. Generally speaking, this non-linear capacitance of a varactor can be used to convert power from one RF frequency to another. Two, three, four or more frequencies may interact in the varactor and of those some may be useful inputs or outputs. In the case of subharmonic generation (frequency division) the varactor is excited at an input frequency f_{in} and power is delivered to the load at an output frequency $f_{out} = f_{in}/\eta$ for some fixed integer η.

Furthermore, other interesting properties of the parametric frequency divider (mostly applicable in satellite communications) include:

- *Ability to function without a Local Oscillator (LO).*
- *Accurate frequency-division by two.*
- *Output that is phase-coherent with input.*
- *Excellent RF pulse-responce.*
- *Ability to cover octave bandwidths.*

To emphasize the difference between frequency subharmonic generation and frequency translation by mixing (downconvertion), Fig. 1a shows the results of a divider-by-two operation on a 2-4 GHz input band, while Fig. 1b shows the result of downconverting the same band using a 2 GHz LO frequency [1]. From this figure it is evident that the frequency divider has compressed the original 2 GHz wide octave band into a 1 GHz wide octave band and that a subsequent stage could further compress it down to a 0.5 GHz width. The mixing approach, on the other hand, offers no such bandwidth compression. On the contrary, the fractional bandwidth $\Delta f/f$ is actually increased. Hence, potential satellite application of the parametric frequency divider could be [1]:

- *Frequency translation of microwave signals for digital frequency-memory systems.*
- *Generation of high quality microwave signals for space communications.*
- *Carrier recovery in phase- shift-keyed systems.*
- *Enhancement of effective modulation index of a phase-locked loop.*
- *Down convertion in onboard frequency synthesizers.*

However, the primary reason for using a parametric frequency divider in a given digital satellite application, is to improve the overall system phase noise performance. Indeed, when a signal with a certain phase noise level is divided by a parametric frequency divider, the signal's phase noise is reduced, due to the resulting bandwidth compression, by a factor of **20 log(η)** dB. In addition, parametric frequency dividers, using advanced GaAs beam lead varactors, introduce very low levels of additive noise. Therefore, the overall system noise will be significantly reduced.

This paper deals with the performance of parametric frequency dividers circuits implemented using two GaAs beam lead varactor diodes, mounted on planar microstrip structures for $f_{in}<$ 20 GHz, or on quasi-planar finline structures for $f_{in}>$ 30 GHz.

II. THE BASIC CIRCUIT CONFIGURATION

The idealized circuit model, usually used to design parametric frequency dividers [5], is shown in Fig. 2. This structure is a transmission line driven at its center point by a pump voltage $v(t)$ at frequency f_{in}. A varactor diode is connected at each end of the line. This composite resonator has a small-signal resonance at frequency f_{out} at which the diodes are excited 180^0 out of phase. However, at the input frequency f_{in} the diodes are energized in phase. If we set $f_{out}=f_{in}/2$ then, under certain conditions, the two modes are coupled via the nonlinear capacitances of the varactors and a divide-by two circuit results

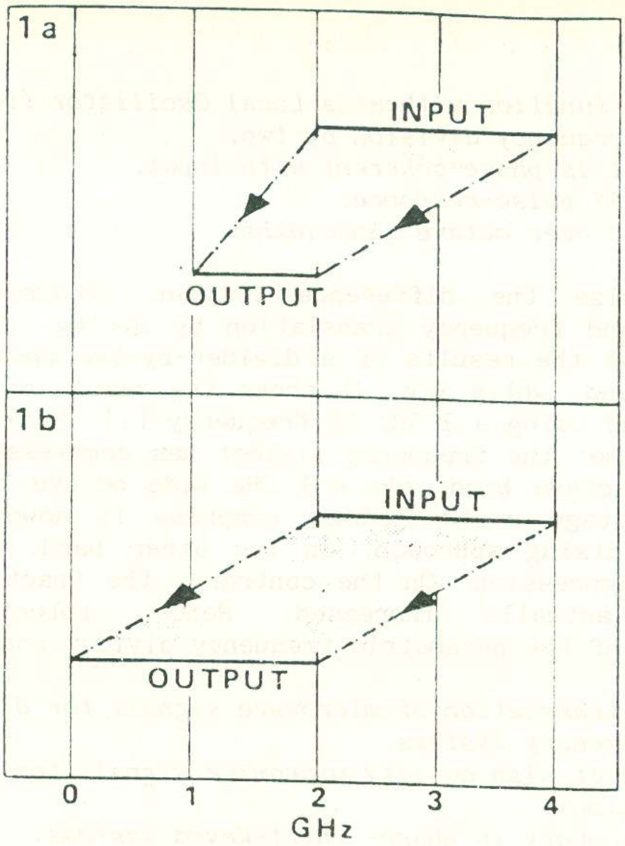

Fig. 1: Bandwidth compression a) of a subharmonic parametric frequency divider and b) a conventional downconverter.

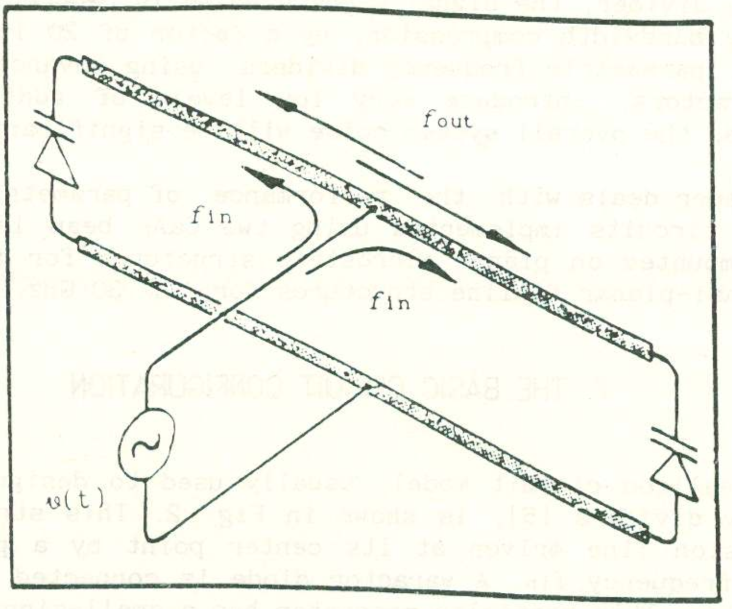

Fig. 2: Basic structure of an idealized frequency divider.

[1]. If $f_{in} \neq 2f_{out}$, the frequency division can persist over large bandwidths. Furthermore, the important impact of the balanced structure is that the generated subharmonic signal, which exists as the difference between the varactor voltages, is free of even and odd harmonics of f_{out}. Even the most important second harmonic is attenuated due to the existing isolation between the input and the output circuits. Of course, this isolation is achieved by the mode of the wave propagation; the diodes are excited at the even-mode and dividing at the odd-mode [5].

In the case of very small transmission lengths ($<< \lambda_g$), the transmission line can be approximated by a center-taped inductor [1]. Hence, an exact differential equation can be obtained under the assumption that the reversed biased varactors follow the hyperabrupt junction type of capacitance-voltage law [3]; i.e.:

$$C_j(\upsilon) = \frac{C_j(V_{bias})}{\left[1 - \frac{\upsilon(t)}{\phi_o - V_{bias}}\right]^{\gamma}} \qquad (1)$$

with

$$C_j(V_{bias}) = \frac{C_j(0)}{\left[1 - \frac{V_{bias}}{\phi_o}\right]^{\gamma}} \qquad (2)$$

and

$$\upsilon = V_{bias} + \upsilon(t) \qquad (3)$$

where

ϕ_o = the built-in potential ($\cong$ 1.2 Volt for GaAs),
γ = a constant depending on the type of the **pn**-junction ($\cong$ 1.0 for an hyperabrupt junction),
$C_j(0)$ = the varactor junction capacitance at zero bias.

For forward bias ($0 \leq V_{bias} \leq \phi_o$) the varactor difussion capacitance C_d, derived directly by the continuity equation for a forward biased **pn**-junction [5], is becoming important as well.

III. PERFORMANCE EVALUATION

a) The Microstrip Frequency Divider.

The most important part of this frequency divider is a planar microstrip resonator (see Fig.3). The purpose of this patch is firstly to split the input signal power between the two varactor diodes and secondly to block the subharmonic output signal from leaving through the input port. The two varactor diodes, symmetrically located around the middle axis of the resonator, are simultaneously excited at f_{in} by an even-mode propagating sinusoidal wave. Given the appropriate DC-bias (V_{bias}), the two nonlinearly operating diodes generate frequency components at

$f_{in}/2$, f_{in}, $3f_{in}/2$, $2f_{in}$,...These frequency components propagate in the odd-mode through the output port, usually realized by a 50 ohm coplanar waveguide balun [1] [6]. This balun is desighed such that attenuates all frequency components except the $f_{in}/2$ component.

Fig. 3 illustrates the output spectrum of this frequency divider by two, being printed on a 0.254mm RT/Duroid 5880 substrate and using two MA 46585 beam lead GaAs varactor diodes, when is excited at f_{in} = 12 GHz. These simulation results were obtained by means of the nonlinear version of the 2 Dimensional Transmission Line Matrix (2D-tlm) method, well described in references [3] and [7].

b) The Finline Frequency Divider.

For this millimeter-wave frequency divider the input frequency resonance is achieved by means of a quasi-planar T-junction integrated into a WR28 rectangular waveguide. Doing so, a 180° hybrid was used realized by a parallel-coupled finline coupler (see Fig.4) [4]. The two coupled slots form a coupled transmission-line arrangement, supporting two mormal modes of propagation. Indeed. the two GaAs beam lead varactor diodes located on the T-junction, are simultaneously excited at f_{in} (≅ 33 GHz) by an even-mode propagating wave. Hence, given the appropriate V_{bias}, the two nonlinear devices generate frequency components at $f_{in}/2$, f_{in}, $3f_{in}/2$, $2f_{in}$,.., propagating in the odd-mode through the output port (a 50 ohm microstip line or a suspended substrate LPF).

The designing of this frequency divider has been possible by the use of the spectral domain method, which as known is an efficient CAD tool for practical microwave and millimeter-wave applications [1] [4].

CONCLUSION

Parametric frequency dividers are low phase noise, low power devices that can be used in microwave and millimeter-wave satellitesystems to produce low noise frequency dividing chains (i.e. onboard frequency downconvertion by means of frequency synthesizers).

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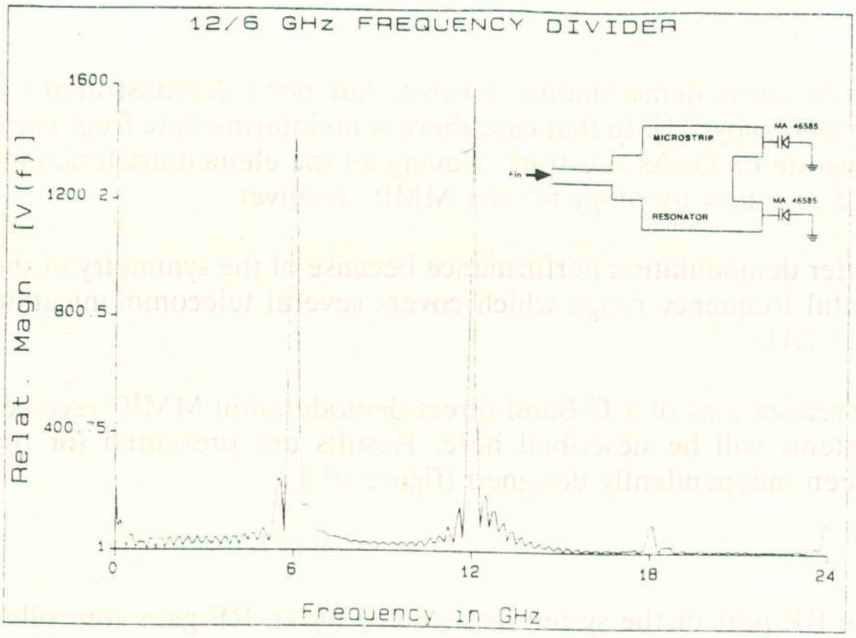

Fig. 3: Performance evaluation of a 12/6 GHz microstrip frequency divider.

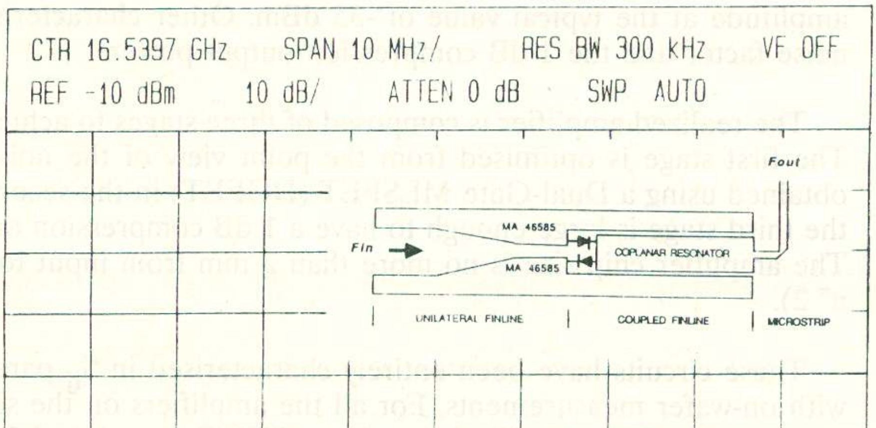

Fig. 4: Performance evaluation of a 33/16.5 GHz filine frequency divider [4].