BROADBAND FREQUENCY DIVIDERS USING MICROWAVE VARACTORS

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Abstract

A novel configuration using GaAs varactors in a balanced circuit incorporating both coplanar waveguide and microstrip elements has permitted the construction of frequency dividers which have near-octave divide-by-two bandwidth and excellent response to pulsed r.f. inputs. The design and performance of such a frequency divider for inputs in the 4 to 8 GHz range is discussed.

Introduction

Existing microwave frequency dividers either have good response to RF pulses but narrow bandwidth[1] or broad bandwidth but poor pulse response[2]. Previous investigations[3] showed that near-octave bandwidth with good pulse-response could be obtained at MHz frequencies using balanced varactor sub-harmonic resonators. This work shows that such performance can be obtained at GHz frequencies also. Frequency dividers of this type are potentially important in applications where RF pulses must be translated to lower frequencies for analog or digital processing or where microwave sources must be locked to low frequency references.

Structure

Figure 1 shows the basic layout. A microstrip resonator consists of a pair of coupled lines loaded by matched GaAs varactors. The combination forms a bridge

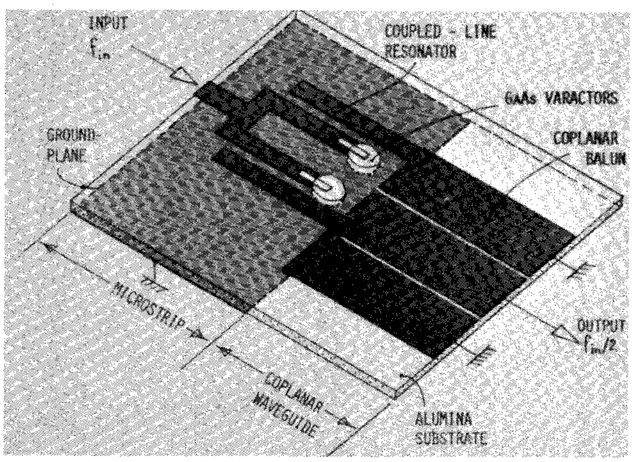

Figure 1-Basic layout of balanced varactor frequency divider.

circuit. An input f_{in} divides equally between the lines, the propagation being determined by the even-mode admittance Y_{oe}. The resonator supports oscillations at $\frac{1}{2}f_{in}$, energy being transferred from f_{in} to $\frac{1}{2}f_{in}$ via the nonlinear reactances of the varactors. At $\frac{1}{2}f_{in}$, resonance is determined by the odd-mode admittance Y_{oo}. An outer line-pair couples the balanced $\frac{1}{2}f_{in}$ signal to a coplanar balun[4] which converts it to an unbalanced output.

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Figure 2 shows the resonator schematically. Since the input point is a

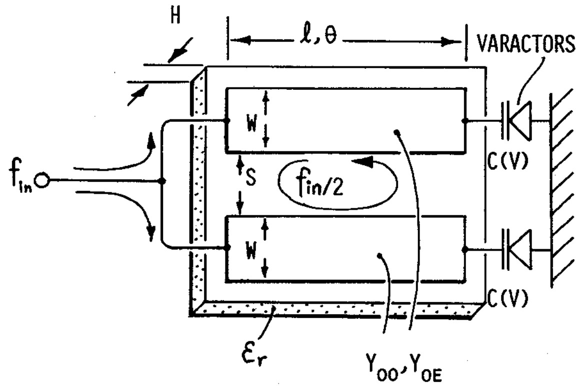

Figure 2-Microstrip/varactor coupled-line subharmonic resonator.

voltage null at $\frac{1}{2}f_{in}$, the open-wire equivalent circuit of Figure 3 can be derived[5].

Design of a Frequency Divider

From Figure 3, small-signal resonance at output frequency $f_o = \omega_o/2\pi$ occurs when $\frac{1}{2}Y_1 + Y_2 = 0$, i.e. when

$$\omega_o C_o = Y_{oo} \cot\theta \qquad (1)$$

where C_o is the total small-signal capacitance of one varactor at bias V_b. The line-length ℓ is found thus:

- Determine W/H and S/H as defined in Figure 2.
- Find the coupled-line admittances Y_{oo} and Y'_{oo} using the dielectric constant ε_r for

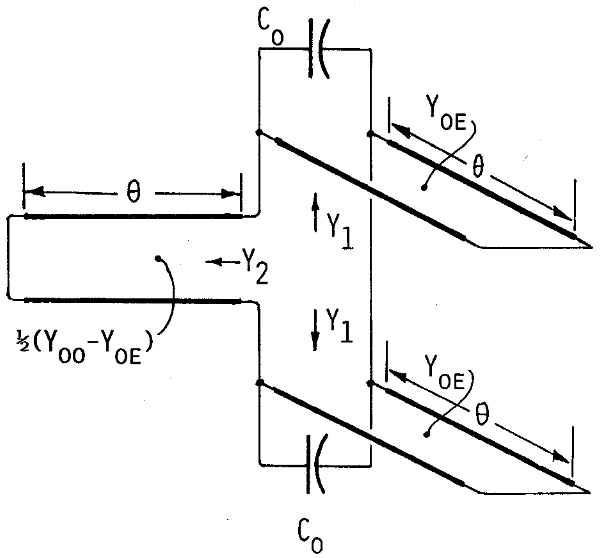

Figure 3-Open-wire equivalent circuit at $\frac{1}{2}f_{in}$.

the substrate material and vacuum respectively[6].

- Using $\theta = \omega_o \ell / v$ and since the velocity of propagation is $v = cY'_{oo}/Y_{oo}$, Eq. (1) gives

$$\ell = \frac{c}{\omega_o} \frac{Y'_{oo}}{Y_{oo}} \arctan\left(\frac{Y_{oo}}{\omega_o C_o}\right) . \qquad (2)$$

It is known[3] that the maximum obtainable value of the frequency-divided signal $\frac{1}{2}f_{in}$ will be near f_o. In the present example, the divider is to accommodate input frequencies f_{in} in the range 4 to 8 GHz, so f_o was made 4 GHz.

For maximum bandwidth, resonator size should be minimized. Because of the capacitive loading, ℓ can be $\leqslant \lambda/8$. W was made 0.13 mm; minimum S was fixed by the varactor package diameter at 0.83 mm. Using an alumina substrate with H = 0.635 mm, $\varepsilon_r \sim 9$, one finds Y_{oo} = 0.011 mho and Y'_{oo} = 0.0047 mho. For varactors with $C_j(0)$ = 0.375 pF, C_p = 0.138 pF, Eq. (2) gives ℓ = 3.56 mm. The outer lines were made 0.13 mm wide and were spaced 0.13 mm from the inner lines. Varactor cutoff frequency was $f_c(0) \sim 260$ GHz.

Figure 4 shows the complete divider. A DC blocking capacitor isolates the 50 ohm input line from the resonator. The four high-impedance lines are each $\lambda/4$ at the 6 GHz centre input frequency. The fan-shaped radial lines produce broadband shorts at the junction of each pair. Two bias circuits permit independent varactor biasing to optimize balance (separate chip capacitors would be used). Substrate dimensions are 28 x 14 mm. The carrier includes a cavity beneath the coplanar balun, which, according to the data of DeBrecht[4], has Z_{oo} = 55 ohms, Z_{oe} = 49 ohms. The balun length is $\lambda/4$ at the 3 GHz output centre frequency.

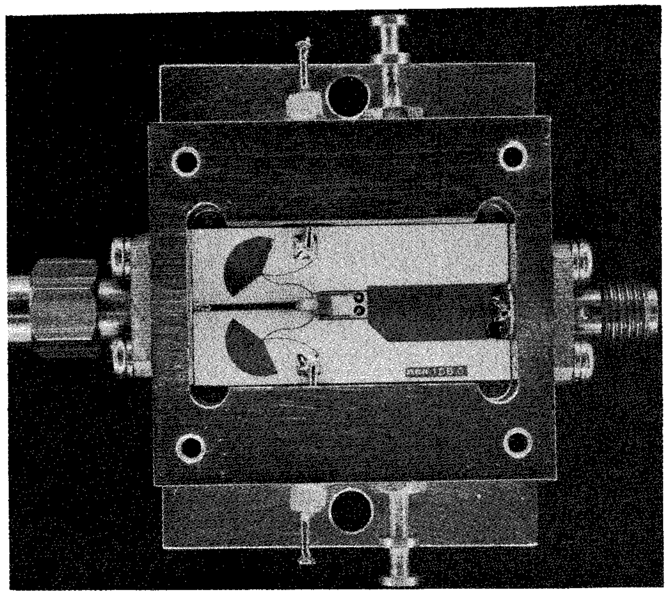

Figure 4-Broadband varactor frequency divider for 4-8 GHz input frequencies. Substrate is 28 x 14 mm.

Measured Results

Figure 5 indicates the region of frequency division. A minimum level of P_{in} is required for output at $\frac{1}{2}f_{in}$. Consider

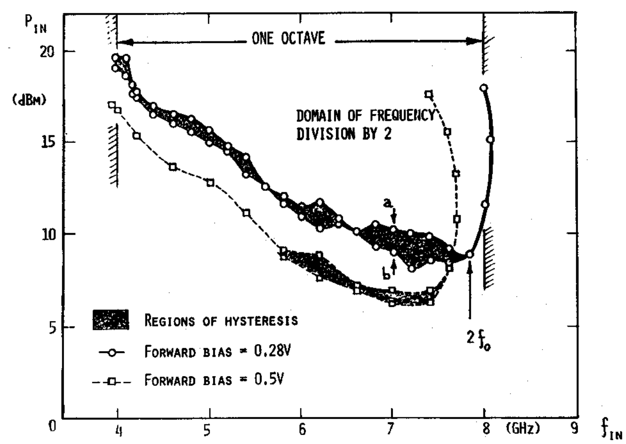

Figure 5-Domain of frequency division, shown for two different values of bias V_B.

the region for V_b = 0.28 V forward bias, which gives maximum bandwidth. Let f_{in} be 7 GHz. Then as P_{in} increases from zero, frequency division commences abruptly at point "a". If P_{in} is reduced, the $\frac{1}{2}f_{in}$ output persists down to point "b", where it suddenly drops to zero. This hysteresis region is shown shaded. Figure 5 also shows the effect of increasing V_b to 0.5 V. A reduction in threshold level is accompanied by a reduction in the maximum operating frequency.

Figure 6 depicts the frequency response for a fixed P_{in}. As Figure 5 indicates,

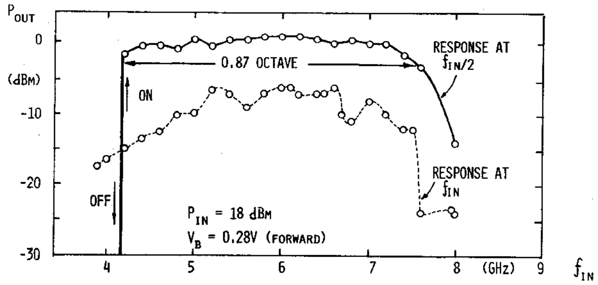

Figure 6-Frequency response at $\frac{1}{2}f_{in}$ for a fixed input level. The response at f_{in} is also shown.

bandwidth increases as P_{in} increases. A high P_{in} is chosen here to obtain near-octave division bandwidth. For narrower bandwidths, P_{in} can be reduced. Further reductions in P_{in} can be obtained by increasing the forward bias V_b*. At the lower band-edge amplitude hysteresis occurs, corresponding to the shaded region of Figure 5. Figure 6 also shows the f_{in} level at the output port. This signal is due both to feedthrough of the input and to resonator unbalance. Feedthrough at the high end of the band was suppressed using ferrite material in the cavity beneath the balun.

Figure 7 shows the frequency response of the divider with a 21 dB gain GaAs FET preamplifier. Here P_{in} is -6dBm; the maximum P_{out} is 0 dBm. Because of the reduced input level to the divider, turn-on occurs at 4.75 GHz, rather than the 4.18 GHz of Fig. 6.

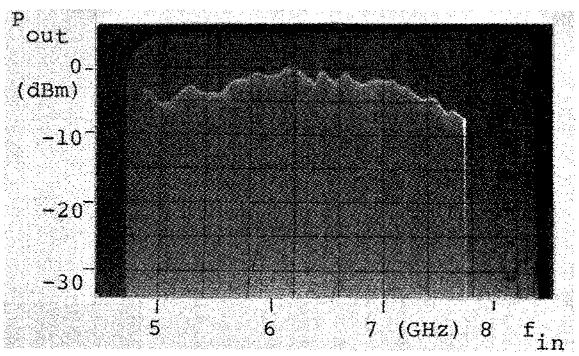

Figure 7- Frequency response of varactor divider with a 21 dB gain GaAs FET preamplifier. P_{in} is -6 dBm. The $\frac{1}{2}f_{in}$ spectral line is shown as f_{in} sweeps from 4 to 7.7 GHz.

*In another design, narrow-band operation was obtained at input levels as low as +2 dBm for f_{in} = 10 GHz.

Conclusion

A broadband microwave frequency divider using parametric subharmonic resonance has been demonstrated. A ±2 dB bandwidth of 0.87 octave has been obtained without circuit optimization.

Acknowledgements

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