A BROADBAND FREQUENCY DIVIDER IN WAVEGUIDE

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ABSTRACT

A new waveguide configuration permits the construction of a completely symmetrical balanced varactor frequency divider. The example described translates the full 12.4 to 18.0 GHz waveguide band down to the range 6.2 to 9.0 GHz.

Introduction

Microwave frequency dividers of several different types have appeared in the literature[1,2,3]. Recently[4], a configuration was described which employed a matched pair of varactors in a balanced microstrip/coplanar circuit to yield near-octave bandwidth for input frequencies up to 8.0 GHz. In that design the isolation between input and output frequencies was limited by a residual asymmetry.

The unit described here requires no substrate and is bilaterally symmetrical so that good isolation between input and output frequencies is obtainable. An experimental model of the new design has shown divide-by-two operation over the complete 12.4 to 18.0 GHz band of input freqenices. It appears that the basic structure should be applicable up to mm wavelengths.

Circuits of this type have important applications where RF-pulse of CW signals must be translated to a lower frequency domain, in extending the range of frequency counters, or where microwave sources must be locked to lower-frequency references. A further application is carrier-recovery in microwave PSK systems.

Unlike frequency-translation using mixers, these circuits frequency-divide the entire bandwidth of the input signal.

Structure

Figures 1(a) and 1(b) show the basic configuration. A signal at frequency f_{in} enters the reduced-height waveguide W_1 as indicated. The associated electric field vector is shown as $\underline{E}_1$. Dimension a_1 of guide W_1 is chosen so that the input signal will be propagated in the dominant TE_{01} mode over the desired bandwidth Δf. The height b_1 conforms to the height of the ceramic part of the matched pair of varactors V_1 and V_2. Guide W_1 is provided with an adjustable short-circuit. Between the varactors is an elongated coupling slot S in a thin iris I which forms a common wall between guide W_1 and a second, larger guide W_2. The dimension a_2 of guide W_2 is chosen so that the frequency-divided output signal $\frac{1}{2}f_{in}$ can be propagated over a bandwidth of $\frac{1}{2}\Delta f$. The output guide W_2 is oriented so that the electric field vector $\underline{E}_2$ therein is orthogonal both to the vector $\underline{E}_1$ and to the direction of propagation in the input guide W_1.

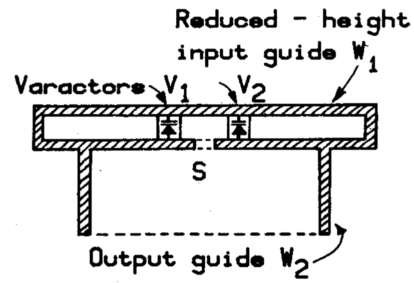

Figure 1(a): Cross-section of basic structure

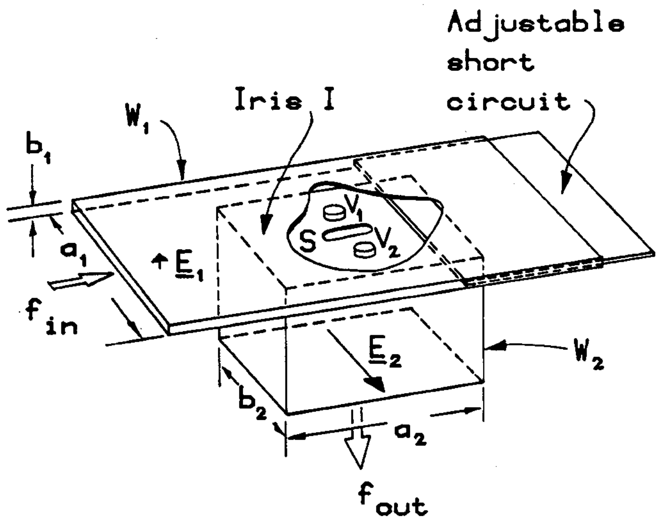

Figure 1(b): View of basic structure, showing relative orientation of vectors $\underline{E}_1$ & $\underline{E}_2$

A resonant loop is formed by the two varactors V_1 and V_2 (which are both oriented in the same polarity), the section of guide W_1 between them, and the reactance of the slot S. The resonant frequency will depend on the slot-width, the spacing between the varactors and also on the effective varactor capacitances, which are voltage dependent. The small-signal resonant frequency is chosen to be at or slightly above the upper end of the desired output frequency band.

When the varactor-pair is pumped at the input frequency f_{in} the devices are excited equally both in magnitude and phase. However, as described above, the resonant loop can support subharmonic oscillations at the division-frequency $\frac{1}{2}f_{in}$. At this frequency, the varactor potentials are equal and opposite. A corresponding potential difference is developed across the long edges of the slot S and gives rise to the electric field vector $\underline{E}_2$ which is coupled into the output waveguide W_2. Energy is transferred from f_{in} to $\frac{1}{2}f_{in}$ by means of the nonlinear reactance property of the varactors.

If the input power level is small, then frequency division will be obtained only over a relatively narrow bandwidth in the vicinity of the small-signal subharmonic resonance frequency. However, if the input power exceeds a certain threshold level, then the bandwidth of operation will expand considerably. The expansion will occur predominantly toward the lower frequencies of operation. To maximize the bandwidth, the following measures can be taken:

(1) The small-signal resonant frequency of the loop is set slightly higher than the maximum value of $\frac{1}{2}f_{in}$.

(2) The resonant loop is made as small as physically possible. This means using varactors with small packages and relatively large capacitances.

The behaviour of the device can be modified by applying dc bias to the varactors. Forward biasing the varactors has the following consequences:

(i) The threshold input power required for broadband operation is reduced.

(ii) The output power level decreases.

(iii) The small-signal subharmonic resonance frequency is reduced because of the increase in varactor capacitance.

To apply dc bias to the varactors, a high quality choke is required. The choke must provide high isolation between the interior of the guide W_1 and the external dc bias supply. It must also present a very low RF impedance to the signals inside the waveguide. This low impedance must be maintained across both the input and output bands of frequencies.

Coupling of the subharmonic signal into the output guide W_2 can be optimized by varying the size of the slot S.

Experimental Unit

Figure 2 shows a cross-sectional view of a practical frequency divider constructed according to the principles described above.

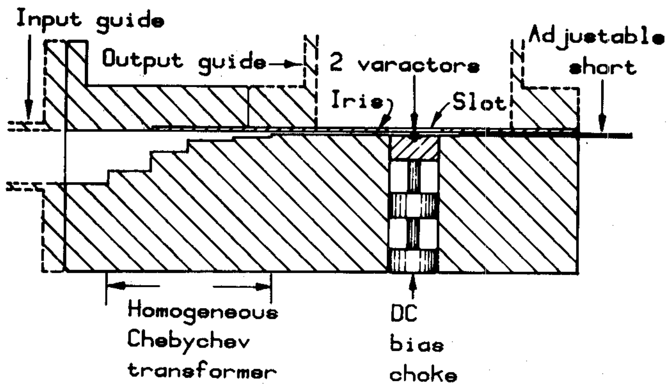

Figure 2: Cross-section of experimental waveguide frequency divider

A homogeneous four-step Chebyshev waveguide transformer was designed to provide a broadband match between the WR-62 input waveguide (a = .790 cm, b = 1.580 cm) and the reduced-height guide W_1 (a_1 = .790 cm, b_1 = .043 cm). The output waveguide size is WR-112 (a_2 = 2.850 cm, b_2 = 1.262 cm).

A matched pair of GaAs varactors is mounted at one end of the coaxial dc bias choke structure, the axis of which is mounted opposite the coupling slot in guide W_1. The large-signal varactor cutoff frequency $F_c(0)$ should be of the order of 100 times the maximum required output frequency[5], where

$$F_c(0) = f_c(0)[1 + V_B/\Psi]^n.$$

In this expression $f_c(0)$ is the small-signal

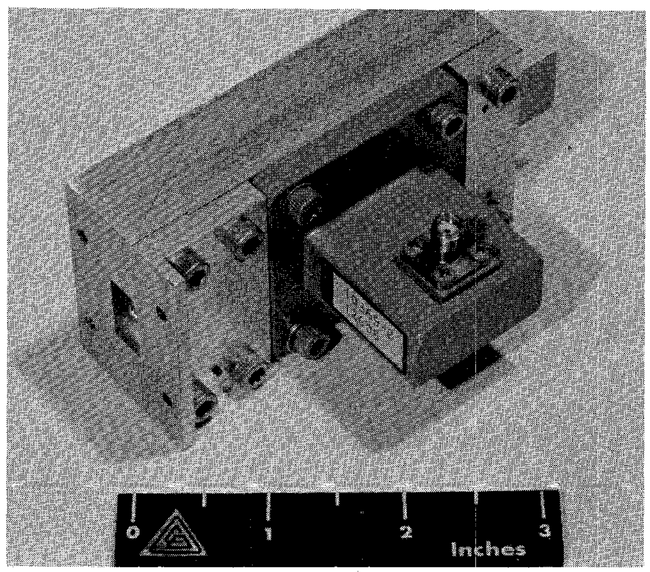

Figure 3: Assembled waveguide frequency divider

cut-off frequency, V_B is the breakdown voltage, $\Psi = 1.2V$ for GaAs and n is the exponent in the capacitance law $C_j(V) = C_j(0)(1 - V/\Psi)^{-n}$. For the varactors used here, $f_c(0) = 988$ GHz, $V_B = 26V$ and $n = 0.41$ so that $F_c(0) = 3552$ GHz, i.e., the devices should be operable with inputs up to about 70 GHz.

Figure 3 shows the assembled unit.

With the short circuit positioned approximately $\lambda/4$ away from the varactors, the domain of frequency division by two was as shown in Figure 4. This measurement shows

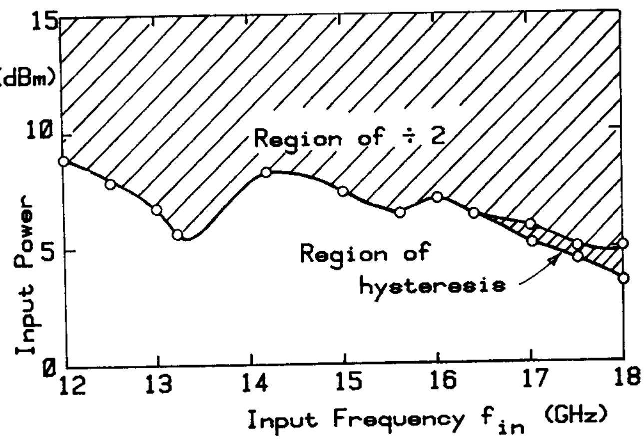

Figure 4: Domain of frequency division by two for experimental unit. Varactor bias is 0.85V forward.

that the unit is capable of operating over the full 12.4 to 18.0 GHz waveguide band.

A recording of the division response for a level input power is shown in Figure 5. The upper trace shows the input power at frequency f_{in}. The lower curve indicates that the response at $\frac{1}{2}f_{in}$ is flat to ±3.5 over the

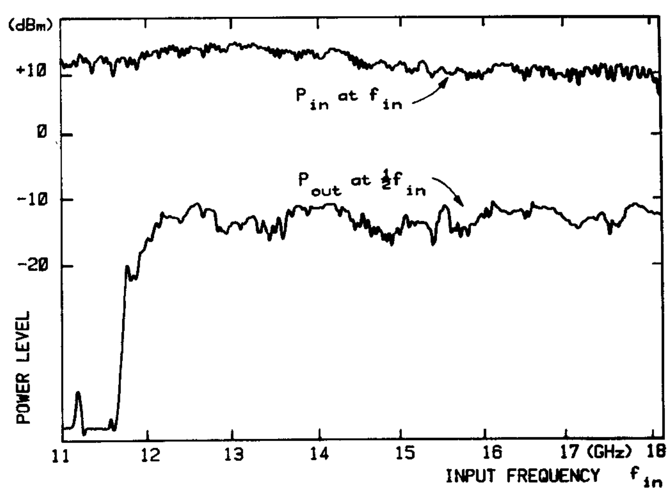

Figure 5: Division response of experimental unit

range 12.0 to 18.0 GHz. The actual transducer loss is less than Figure 5 suggests because the data have not been corrected for losses due to an input isolator and an output low-pass filter.

This wideband result was obtained without any optimization of the output coupling slot or other tuning. It is believed that even wider bandwidth, together with reduced threshold level and transducer loss, can be achieved through further circuit refinement.

Conclusion

A novel waveguide structure has been developed which permits the realization of an intrinsically wideband frequency divider of the type which utilizes subharmonic generation. An experimental unit has demonstrated divide-by-two operation over an input bandwidth of more than 12.4 to 18.0 GHz.

Acknowledgements

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