PLANAR BROADBAND MIC BALANCED FREQUENCY DOUBLERS

Rainer Bitzer

Wandel & Goltermann, Electronic Measurement Technology
WGR, PO-Box 1262, D-7412 Eningen u. A., Germany

Abstract

Broadband microwave frequency doublers employing beam-lead Schottky barrier diodes in a new planar balun configuration are presented. Measurement results for output frequencies up to the K-band show good agreement with analytical results. A minimal conversion loss of 8.4 dB and an output frequency ratio exceeding 1 : 3 were achieved. The low-cost, small-sized multipliers are useful to generate the wideband local oscillator signals required in broadband measuring instruments.

Introduction

Wideband receivers at extended frequencies in commercial measurement equipment have continually increasing dynamic range and spectral purity requirements. One method to convert the RF signal into a fixed frequency band for further processing is to employ a single wideband fundamental mixer with selectable stabilized local oscillator (LO) sources. If frequency stability, low cost and small size are further requirements, a multiplied LO technique can be employed. Excellent phase-noise performance can be achieved by multipliers driven by microwave synthesizers. This results in a demand for a wideband frequency multiplier that can accomodate the full LO bandwidth while providing adequate output power to drive an unbiased single-balanced mixer.

Beam-lead Schottky barrier diodes in a planar hybrid MIC (microwave integrated circuit) would allow low cost production and exhibit RF impedances that are compatible with broadband transmission-line structures, such as microstrip or coplanar-lines (CPW).

Operation Prinziple and Limits

Wideband frequency doubling with high conversion efficiency can be achieved by using diodes as full-wave rectifiers as shown in Fig. 1. The input signal is fed in antiphase to the diodes in order to switch on one diode path every half cycle. The rectified output signal is coupled to the load via a balanced-unbalanced circuit (balun). If the circuit is perfectly balanced, there will be no odd-order harmonics at the output port. The second harmonic dominates and is fed to the load via transmission-line circuits.

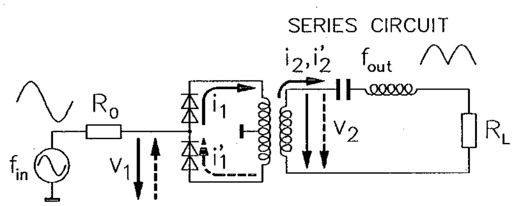

Fig. 1 Schematic circuit of the balanced frequency doubler

In theory the second harmonic is 7.4 dB and the fourth harmonic is 21.6 dB below the input signal level. [1,2] Practical conversion efficiency will be reduced by the forward drop of the rectifier diodes, by losses within the diode series resistor and the balun, and by imperfect matching.

The non-linear properties of the balanced doubler were analyzed with CAD tools using a simple diode model and approximate line impedances at midband frequency. "Spice" takes the dynamic behavior of the diodes in consideration using non-linear charge storage. The calculated conversion characteristic is shown in

Fig. 2 as a function of input power. At low input levels the diodes are not completely turned on, so the conversion loss is high. As input power increases, the conversion loss decreases until the diodes begin to experience current saturation. If current saturation would not occur, the conversion loss would remain constant once the diodes are fully turned on. The essential parameter affecting low conversion loss however is a low diode bulk resistance R_b. The zero bias capacitance largely affects the upper frequency limit and the characteristic at low input levels.

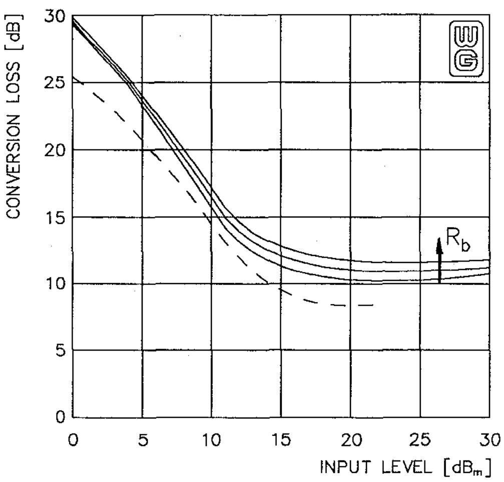

Fig. 2 Simulated and measured (dashed) characteristics of the balanced frequency doubler

Circuit Configuration

The planar MIC doublers are realized on both sides of a 15 mil thick aluminia substrate (Fig. 3). The balun consists of a combination of microstrip, coplanar and slotline. A beam-lead Schottky diode is attached at the crossing point of two orthogonal transmission lines, a CPW-line on the front side and a microstrip on the back side. The input signal is applied to the diode center terminal via the CPW-line, which is connected via a plated-through hole to the 50 Ω microstrip input on the back side. The CPW-line was designed for a 50 Ω even-mode impedance at the input frequency and a high odd-mode impedance at the output frequency. At the second harmonic the CPW-line operates in odd-mode. The back shorted CPW-line and the slotline represent two high-impedance quarter-wave stubs connected in parallel. A broad bandwidth in the desired frequency range was optimized by adjusting the balun length and width. In particular, by tuning the balun lengths, i. e. the CPW-line and the slotline, to values obtained by empirical methods performance was enhanced.

The realized frequency doubler employs a four-junction beam-lead Schottky diode as shown in Fig. 4. The use of a four-junction diode allows for increased power handling and compression characteristics that are necessary to obtain high output power.

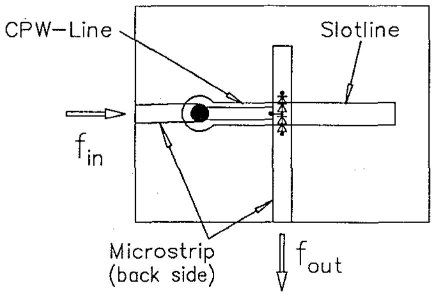

Fig. 3 Planar MIC doubler circuit layout

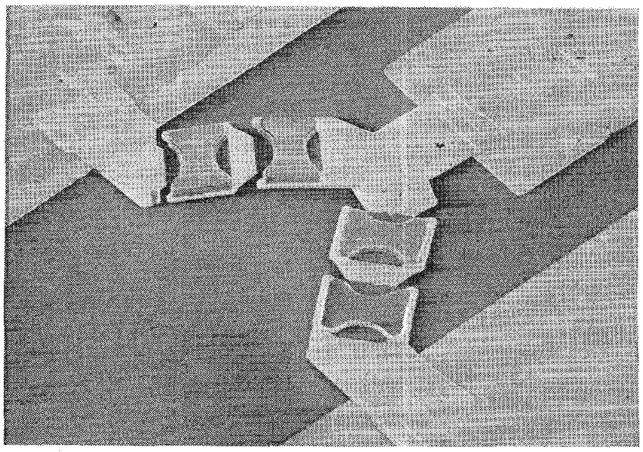

Fig. 4 Four-junction beam-lead diode in MIC doubler

Experiments and Measurements

The circuits can be scaled to different output frequencies, particularly to frequencies above 18 GHz where direct power generation is difficult. To demonstrate the scaling, two separate doublers for output frequencies in X-band and K-band were designed and measured in a test setup covering 2 to 26.5 GHz.

Conversion efficiency versus frequency at constant input power of 100 mW is shown in Fig. 5. The conversion loss is 9.5 dB ± 1 dB for output frequencies from 6 to 18 GHz, i. e. the output bandwidth where the multiplier produces sufficient power to drive unbiased single-balanced mixers exceeds 100 percent. The output spectrum was checked for fundamental and third harmonic components, showing that typically a 20 dB rejection ratio had been achieved.

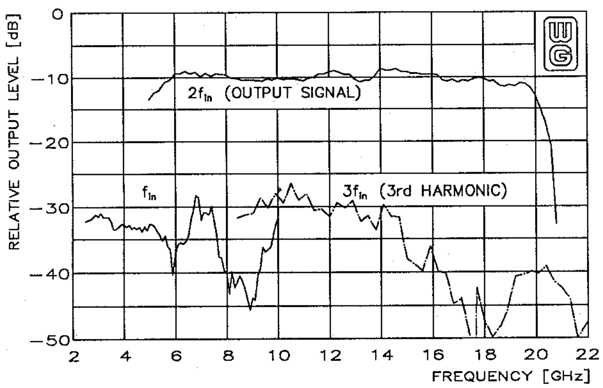

Fig. 5 Measured results of 6 - 18 GHz band frequency doubler at constant input power +20 dB_m

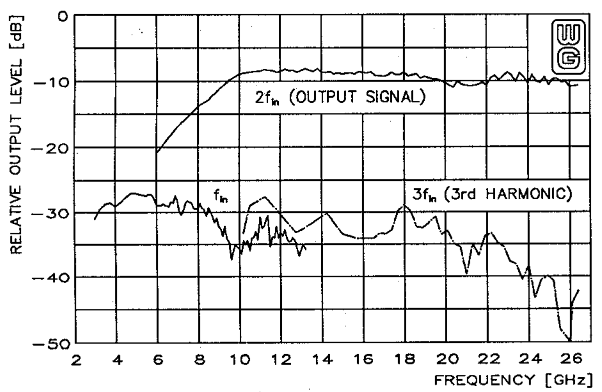

Fig. 6 Measured results of 10 - 27 GHz band frequency doubler at constant input power +20 dB_m

A further circuit was designed for output frequencies covering the 10 - 27 GHz band and the measured frequency response is shown in Fig. 6. A performance similar to the preceding results was achieved.

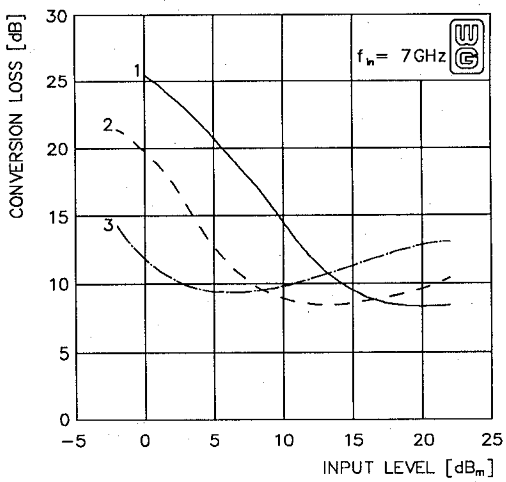

Fig. 7 Measured conversion loss vs. input level employing
1 four-junction beam-lead diode pair (DMJ 3181)
2 extra-high barrier diode pair (MSS 60)
3 low barrier diode pair (MSS 30)

The measured performance as a function of input power is shown in Fig. 7 for a fixed input frequency of 7 GHz. A minimal conversion loss of 8.4 dB at 100 mW input power has been achieved. The optimum input power range is between +15 dB_m and +25 dB_m when employing the presented four-junction diode. The multiplier can also be optimized for lower input levels when alternatively employing medium barrier or low barrier Schottky diodes. The optimum input power is +8 dB_m ... +20 dB_m for high barrier diodes and +3 dB_m ... +10 dB_m for low barrier diodes respectively.

Reverse Operation Mode

Feeding the input frequency via a microstrip to slotline transition to a Schottky diode pair enables a reverse operation mode (Fig. 8). The balun lengths have to be tuned to the input midband frequency. Therefore, the same circuit layout can be used at a double frequency band, avoiding unfavourable aspect ratios of the balun lines. The rectified output signal generated at the common-cathode diode terminal is coupled via the CPW-line and the plated-through hole to the microstrip output line. To close the DC-path a broadband low-loss DC-return has to be inserted at the output.

For high drive levels, typically exceeding +16 dB_m, a shorted DC-return gives the best performance.

Optimization of the conversion efficiency at lower input levels by adjusting a proper forward bias voltage has been reported [3]. This effect is demonstrated by applying a forward bias voltage of 0.65 ... 0.8 V to obtain the minimum conversion loss at lower input power as sketched in Fig. 9.

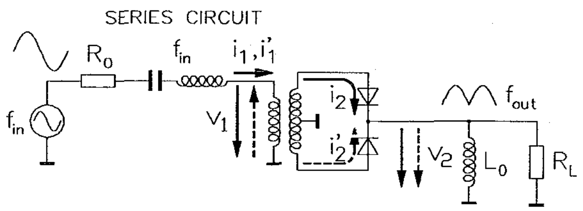

Fig. 8 Schematic circuit for reverse operation mode

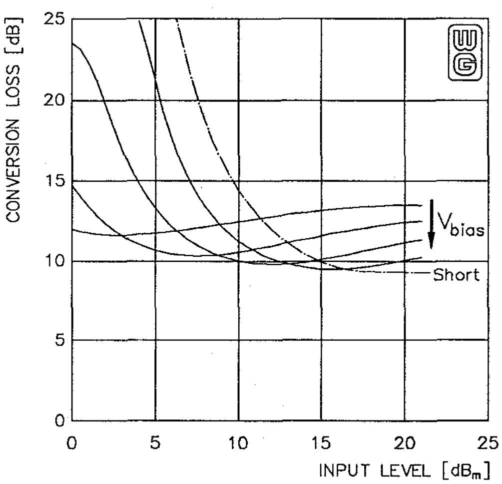

Fig. 9 Measured performance in reverse operation mode V_{bias} = 0.65 ... 0.8 V and shorted DC-return

Discussion and Conclusion

A new broadband microwave doubler employing beam-lead Schottky diodes in a planar MIC has been presented. The doubler circuits can be scaled to different frequency bands. Two circuits have been developed with a nominal output power of +11 dB_m covering the 6 - 18 GHz and 10 - 27 GHz bands respectively. This output power level is sufficient to provide local oscillator power for unbiased single-balanced mixers. Excellent performance was achieved, combined with a wide operating bandwidth and flat frequency response. Also the high fundamental frequency isolation is of special note here. Further a reverse operation mode has been presented, which allows to optimize the performance at low input power levels by forward biasing the diodes. Other advantages of the doubler are small size, little weight and low costs in production. Simple integration in complex hybrid microwave modules is guaranteed.

Acknowledgements

The author would like to thank Dr. H. Dollinger at WGR for many valuable ideas and helpful discussions.

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