AN EFFICIENT MICROSTRIP UPCONVERTER FOR K_a-BAND

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Abstract

A hybrid integrated upconverter from 1.8 GHz to 30 GHz is described. The converter, consisting of a microstrip circuit on a quartz substrate and a high-cutoff varactor diode, delivers 50 mW output with 6 dB conversion loss.

Introduction

A large-signal microstrip varactor upconverter, intended for use in a high-speed phase-modulation transmission system, has been designed, built and tested. The device described here converts an IF input at 1.8 GHz to an upper sideband (USB) output at 31.9 GHz. The circuit has the following novel features:

1. The converter is built in microstrip.
2. Low conversion loss from the LO input at 30.1 GHz to the USB output at 31.9 GHz is obtained by using a strong IF drive.
3. An output power of 50 mW at 6 dB conversion loss is achieved.

Circuit Description

The microstrip circuit is shown in Figure 1. The conductor pattern is deposited on a 14-mil-thick quartz substrate. In order to minimize radiation losses, the entire circuit is surrounded by a mettalic shield. A diffused junction varactor (Alpha DVE 6347-G, See Table I) makes contact with the ground end of a resonator nominally a quarter-wavelength long, which is used as an impedance step-up transformer. At the high-impedance (open) end of the transformer, half-wave sections tuned to the LO and USB frequencies are used to couple power into and out of the diode circuit. The d-c bias and IF are applied through a half-wave choke. The upconverter is connected to waveguide test equipment through probe-type waveguide-to-microstrip transitions not shown in the figure.

The values of circuit parameters which optimize the upconverter are based on elementary theoretical considerations outlined below.

Basic Theory

The primary goal in designing the upconverter is efficient conversion of LO power at 30.1 GHz to USB power at 31.9 GHz. Minimizing conversion loss requires that the capacitance variation of the varactor be driven mainly by the 1.8 GHz IF source. Thus the pump is not a C-W source, as is usually the case, but is the IF signal itself. The reduced upconversion gain associated with this design approach is acceptable because the IF amplifier can deliver all the drive power necessary. With strong IF pumping the LO and USB signals cause negligible capacitance modulation of the varactor. Under these conditions it can be shown that minimum conversion loss is achieved when the LO and USB ports are matched to generator and load resistances, R_g and R_L respectively, such that

$$\frac{R_g}{R_s} = \frac{R_L}{R_s} = \left[\frac{(mf_c)^2}{f_{USB}f_{LO}} + 1\right]^{1/2} \qquad (1)$$

where R_s is the effective series resistance due to losses in the diode and its resonator, f_c the dynamic cutoff frequency associated with R_s, m the pumping parameter or capacitance modulation coefficient[1], and f_{LO} and f_{USB} are respectively the LO and USB frequencies. For the circuit and diode considered here, $m \sim 0.2$. The dynamic cutoff frequency can be measured by reflection techniques[2] and if found to be 340 GHz. These values of m and f_c substituted into Eq. 1 yield

$$\frac{R_g}{R_s} = \frac{R_L}{R_s} = 2.4 \ . \qquad (2)$$

The minimized conversion loss, L_c, achieved when Eq. 1 is satisfied, is given by

$$L_c = 10 \log \left[\frac{f_{LO}}{f_{USB}} \cdot \frac{(R_g/R_s) + 1}{(R_g/R_s) - 1}\right] . \qquad (3)$$

Substituting from Eq. 2 we find a predicted conversion loss of 3.6 dB.

Upconverter Tuning

Adjustment of the upconverter for minimum conversion loss is most easily accomplished with the pump (IF) turned off. This decouples the LO and USB ports so they can be tuned separately. The resistance seen looking into either port is due to dissipation in the circuit, most of which occurs in the diode and its resonator. In order to satisfy Eq. 2, the coupling to the varactor circuit must

provide a loading resistance that equals 2.4 times the circuit loss resistance. Thus the unpumped upconverter must be adjusted to achieve a VSWR of 2.4 at the LO and USB ports. In practice the coupling gap nearer the diode resonator is set first to give adequate bandwidth, then the farther gap is set to obtain a 2.4 VSWR.

This systematic tune-up procedure allows near-optimum performance to be achieved quickly and easily. Typically, touch-up tuning of the operating (pumped) upconverter results in only ∿1/2 dB improvement in conversion loss.

Performance

The performance of the upconverter is summarized in Table II and Figure 2. The maximum USB power of 50 mW is limited by available klystron LO power, so the ultimate output capability of the upconverter is not known. The stated conversion loss (∿6 dB) includes ∿2 dB due to the half-wave resonators and waveguide-to-microstrip transitions. The remainder can be attributed to dissipation in the diode and diode resonator. This is consistent with the 3.6 dB conversion loss predicted earlier. The IF-to-USB bandwidth of the device, as shown in Figure 2, is about 500 MHz between the 1-dB points. At LO power levels below +15 dBm, the shape of the transfer characteristic is approximately constant. Above this level ripples become more noticeable.

Conclusions

It has been shown that good conversion efficiency and output power can be obtained from a hybrid integrated varactor upconverter at millimeter-wave frequencies. The circuit described can be readily scaled to higher frequencies. The fact that the large-signal conversion loss of 6.0 dB is only slightly greater than the small-signal value of 5.7 dB suggests that the upconverter has not yet been pushed to its maximum output power.

References

1. P. Penfield and R. P. Rafuse, Varactor Applications, Cambridge, Massachusetts: MIT Press, 1962.

2. C. B. Swan, "Design and Evaluation of a Microwave Varactor Tripler," Intl. Solid State Circuits Conf. Digest of Tech. Papers, 1965.

Table I

Properties of Alpha DVE 6347-G Diode

$C_j(0)$	0.34 pF
V_B	15-1/2 Volt
$f_c(0)$	250 GHz
$f_c(-6)$	507 GHz
Package Capacitance	∿0.1 pF
Package Inductance	∿0.1 nH

Table II

Upconverter Performance

P_{LO} (30.1 GHz) dBm	P_{IF}* (1.8 GHz) dBm	P_{USB} (31.9 GHz) dBm	Conversion Loss dB
-14.3	+14	-20.0	5.7
+14.9	+15	+ 9.0	5.9
+23.0	+19	+17.0	6.0

* P_{IF} is available power from 50-ohm IF source.

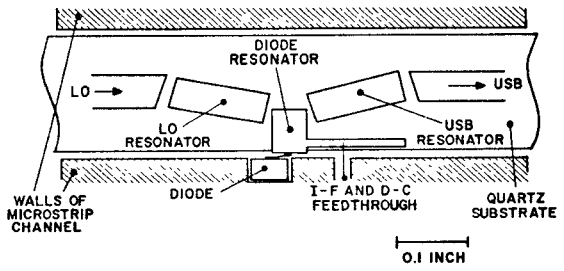

Fig. 1. The microstrip circuit for the upconverter.

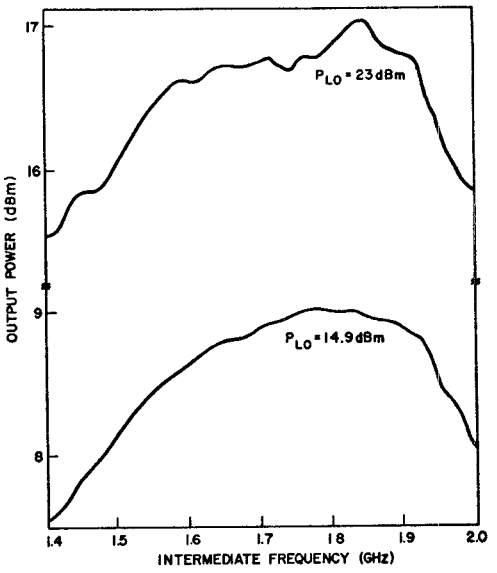

Fig. 2. Swept - IF frequency response. LO frequency is 30.1 GHz.