A BALANCED 11 GHz HEMT UP-CONVERTER

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ABSTRACT

A 70 MHz to 11 GHz balanced up-converter circuit is described. HEMTs were found to be very suitable for this application due to their high gain at 11 GHz. The measured results show 7 dBm 1 dB gain compression point, 15 dBm third order intercept point, 3 dB conversion gain and 35 dB LO suppression.

INTRODUCTION

The main disadvantage of diode up-converter circuits are IF to RF conversion loss and poor linearity. Typically, conversion loss of 5 to 6 dB and third order intermodulation intercept point of 10 dBm are measured. A GaAs FET offers both conversion gain and a higher intercept point. However, unless FETs with gate length of 0.3 microns (or shorter) are used, any conversion gain at 11 GHz may be hard to obtain. As HEMT technology is maturing rapidly, the commercially available devices offer superior performance at a cost below that of a diode or FET up-converter. A balanced HEMT up-converter configuration offers excellent performance due to its high linearity when used in 64 QAM digital microwave radio.

THEORY OF OPERATION

There are two highly non-linear regions in HEMT operation:
1) gate pinch-off voltage and 2) drain current saturation (fig. 1). Gate pinch-off mode offers an inherent isolation between the up-converted signal output and the local oscillator (LO) input. It also requires less LO power to drive the HEMT current to the saturated value I_{dss}.

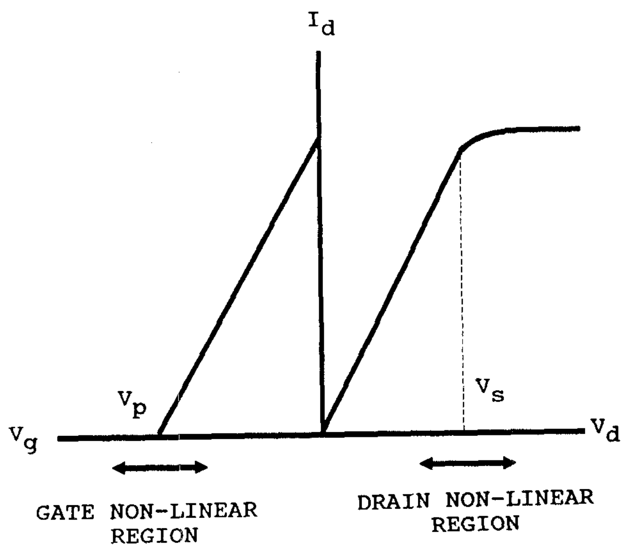

Figure 1: HEMT Non-Linear Regions

With HEMT biased at the gate pinch-off no drain current flows in the absence of LO drive. When a large LO drive is applied to the gate the drain current reaches I_{dss} value on positive LO half cycles. Thus the HEMT transconductance g_m is in effect pulsed at LO rate between zero and its maximum value.
The transconductance waveform approaches a square wave with the fundamental frequency component (ω_o) given by (fig. 2)

$$g_m(t) = 1/2\ g_m + 2/\pi\ g_m \sin \omega_o t + \ldots$$

Substituting this in the simplified equivalent circuit (fig. 3), the following expression may be derived for the conversion gain:

$$G_c = 1/4\ (g_m / \pi\, \omega_1\, \bar{c}_g)^2\ R_d/R_g$$

Where ω_1 = input frequency
$\bar{c}_g$ = time average of gate capacitance

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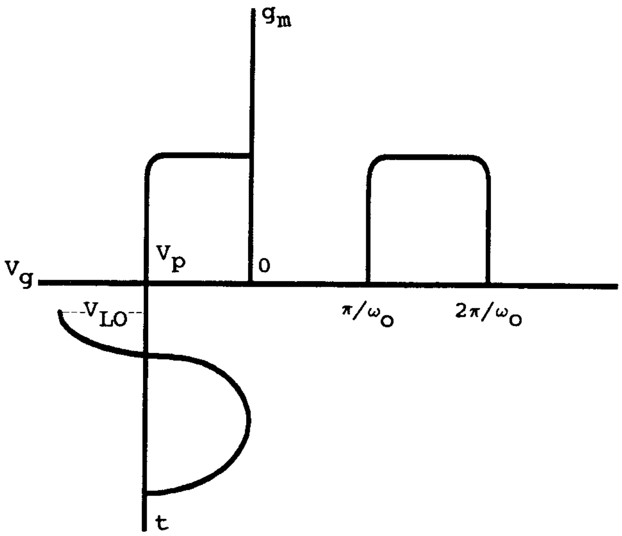
and the load resistance R_L is equal to the drain resistance R_D for maximum power transfer.

Compared with the expression for gain when used as an amplifier the conversion gain is lower by approximately, π^2 or 10 dB.



$$g_m(t) = 1/2\ g_m + 2/\pi \sin \omega_o t + \ldots$$

Figure 2: Transconductance Waveform

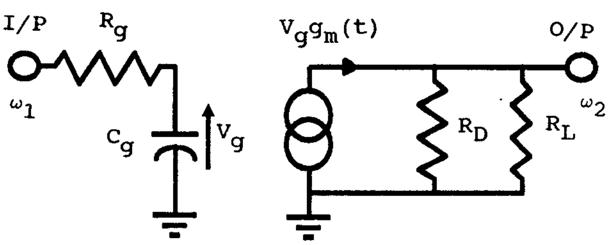


Figure 3: Up-Converter Equivalent Circuit

BALANCED CIRCUIT DESCRIPTION
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The up-converter schematic and microstrip lay-out are shown in figures 4 and 5.

In order to cancel out a large LO signal in the up-converter output, a balanced circuit must be used. This consists of two HEMTs with the LO signal applied in antiphase to the two gates. This is achieved by means of an 180^o splitter ("rat race" hybrid).When the outputs from the two drain circuits are now combined in-phase (Wilkinson combiner), a cancellation of the LO signal will take place in the up-converter output.

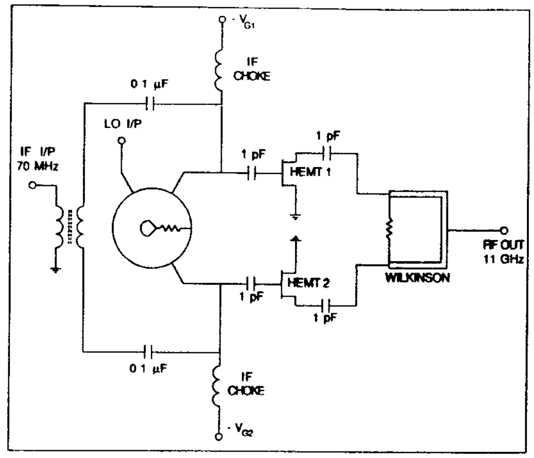

Figure 4: Up-Converter Circuit Schematic

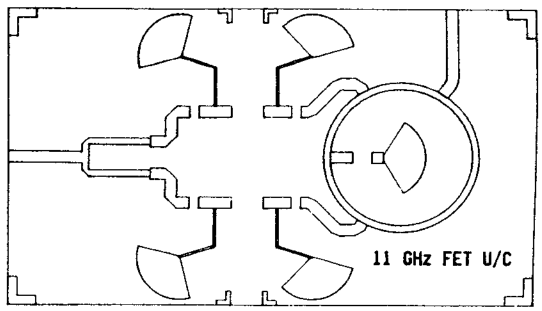

Figure 5: Up-Converter Lay-out on Microstrip

For the up-converted signals to add in phase in the Wilkinson combiner, the IF inputs to the gates of the two HEMTs must be in anti-phase. This is readily achieved by means of a balanced IF transformer.

IF chokes and 1 pF DC blocking capacitors prevent the IF signal from being shorted by the bias supply and the RF hybrid respectively. The HEMTs used were 2SK878. They were selected on the basis of their saturation output level and gain at 11 GHz. These were 13 dBm and 8 dB respectively, thus 5 dBm LO input to the gate was required to drive the HEMT to saturation level. The total LO drive of 10 dBm was required in order to account for hybrid and matching circuit losses and the fact that two HEMTs were used.

The conversion gain is typically 9 dB below the linear gain available in an amplifier circuit. This was typically 12 dB and ,therefore, 3 dB conversion gain was expected.

TEST RESULTS

The up-converter circuit was tested over the 10.7 to 11.7 GHz frequency band. In addition to the conversion gain, the third order intermodulation products (intercept point) and LO suppression in the output were measured.

The up-converter can be optimised for conversion gain or linearity. The optimisation is accomplished primarily by means of gate bias adjustment. The improved linearity, as measured by the third order intermodulation ratio (IMR), requires more negative gate bias and , therefore , operates at lower average drain current.

a) Maximum gain mode

Figs. 6 and 7 show typical up-converter gain and intermodulation performance. Over the 10.7 to 11.7 GHz frequency range the up-conversion gain varies from 2.8 dB to 3.5 dB. The 1 dB compression point is 7 dBm and the third order intercept point is 15 dBm. The HEMTs operated at 4 V and 10 mA and the LO drive was 17 dBm.

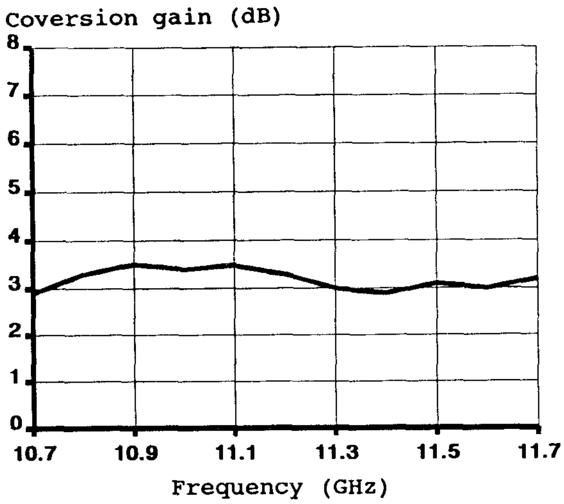

Figure 6: Up-Converter Conversion Gain

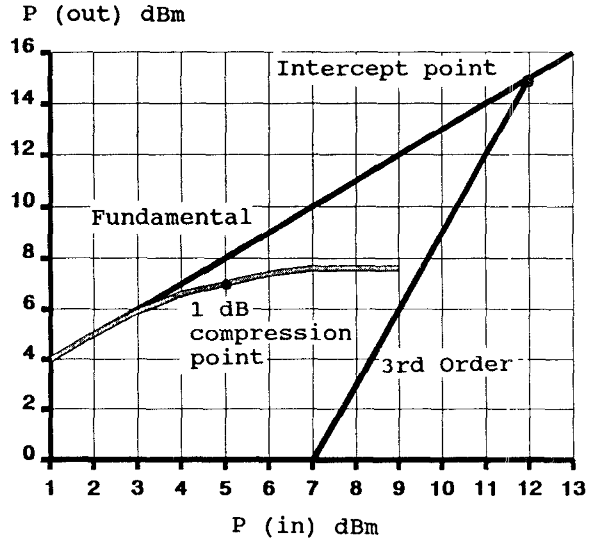

Figure 7: Up-Converter 1 dB Compression point

b) Linearised mode

Since there are two sources of non-linearities (gain and drain circuits) it was found possible to adjust HEMT bias so that partial cancellation of intermodulation products takes place. With larger negative bias on the gate, the transconductance waveform looses its square wave shape and becomes a series of short duration pulses.

The intermodulation ratio (IMR) as a function of the output level (single tone) is shown on fig. 8

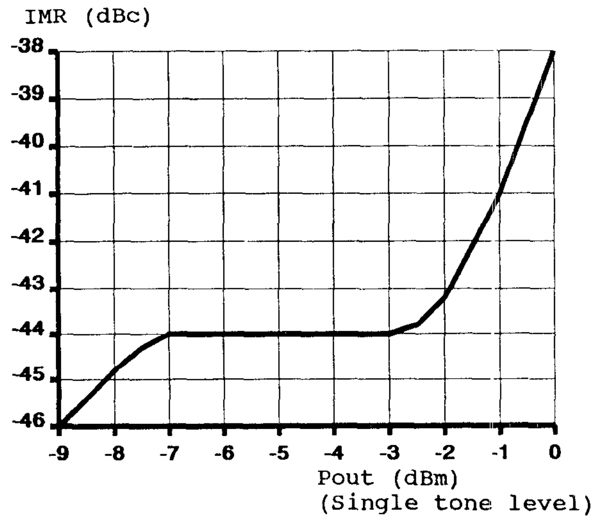

Figure 8: Linearised mode IMR

From -8 dBm output level (single tone) to 0 dBm , the IMR remains constant below -40 dBc. This is clearly not a third order behavior, hence the third order intercept point cannot be defined. However, comparing the IMR at -1 dBm output level there is more than 10 dB improvement in the IMR in the linearised mode.

The conversion gain and the 1 dB compression point have been reduced to -1 dB and 6 dBm respectively. As the result of increased negative gate bias, the average drain current was 7 mA. The LO suppression in both modes is greater than 25 dB with unmatched HEMTs and can be easily optimised to 35 dB.

CONCLUSION

Excellent performance was achieved with HEMT up-converter circuit. Conversion gain of 3 dB was measured compared with 6 dB loss for a typical diode up-converter with correspondingly higher 1 dB compression and intercept points.

In a linearised mode the up-converter exhibited IMR of better than -40 dBc up to 0 dBm single tone output level. A diode up-converter IMR of -40 dBc is typically measured at -6 dBm output level (single tone). The HEMT up-converter operates with the same linearity at 6 dB higher level than the diode up-converter for the same LO drive. The higher linear output level is important for digital QAM radio applications, as the gain of the transmitter power amplifier can be correspondingly reduced.

Finally, the cost of HEMTs is comparable to that of a pair of matched diodes.

REFERENCES:

[1] P. BURA "70 MHz to 6 GHz FET Up-Converter" 1981 European Microwave Conference Proceedings, pp. 215-219

[2] P. BURA and D. GELERMAN "Balanced FET Up-Converter for 6 GHz 64 QAM Radio" 1988 IEEE MTT-S International Microwave Symposium Digest, pp. 941-943