HIGH-POWER UPCONVERSION FOR SSB-AM SIGNALS

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Negative feedback is used to linearize the upconverter of an SSB-AM transmitter. The upconverter is realized with evanescent mode resonators and contains two MIS varactors. An output power of 5 W with an IM-level, which is -55 dB down, have been achieved.

Introduction

Frequency spectrum conservation (and possibly a better noise performance) makes microwave transmission systems with single sideband amplitude modulation attractive for the near future /1/. The key problem, which must be solved for such systems, is an efficient means for a broadband suppression of (mainly third-order) intermodulation distortion products. Three schemes of linearization of the transmitter output stage have as yet been proposed and partly implemented in practice: negative feedback /2/, feedforward /3/, and predistortion /4/. These systems mainly differ from each other in the bandwidth which could be achieved and especially in the circuit complexity. This contribution deals with the earliest solution to the problem: negative feedback, which inherently leads to a relatively simple circuit.

Definition of the Problem

An all solid-state output stage for an SSB-AM transmitter shall be realized, which does not contain an output power amplifier. Hence the upconverter itself must deliver an rf-power of several watts, what is only achievable if it is operated near saturation. To improve the S/IM-ratio negative feedback shall be used. A small portion of the output signal is extracted, mixed down, and fed with proper phase into the if-amplifier. Design goals are an output power of more than 5W at 7GHz, a loop gain of 20 dB in order to achieve an intermodulation level of -55 dB relative to the output power, and an if-bandwidth of 10 per cent at 450 MHz.

Theoretical Background

In order to recognize the origin of intermodulation distortion, a simple model of an upconverter with quadratic charge-voltage characteristic has been studied /5/. The procedure is sketched in Fig. 1. It is assumed,

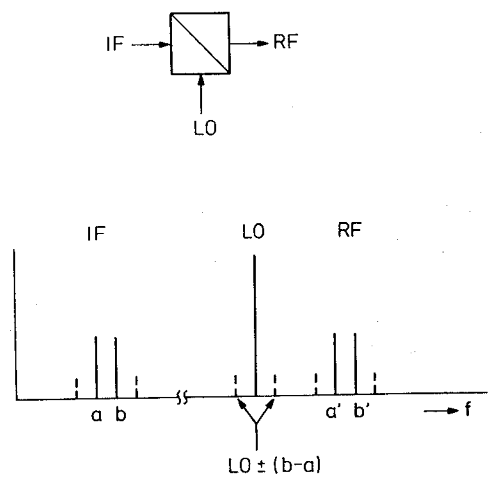

Fig. 1 Frequency scheme of an upper-sideband upconverter with two input signals a and b

that two input signals of frequencies a and b are fed in giving rise to the wanted output signals at frequencies a' and b', respectively. Even for a quadratic charge-voltage characteristic of the varactor diode, there do arise, however, two sideband signals around the LO frequency (dashed lines in Fig. 1) which in turn cause intermodulation signals both at if and rf. Hence any IM-distortion can be avoided if these sidebands can be suppressed. This would, however, require a pump filter with zero bandwidth. The calculations show that any increase in both circuit complexity (an idler circuit, e.g., or a two-diode balanced configuration) and degree of nonlinearity of the diode characteristic will always enhance the IM-level. The effect of even a small mismatch at the if- or at the rf-port on the IM-level is similar, while the distortions can, however, be decreased by mismatching the pump port (a SWR of 1.7 reduces the IM-level by 5 dB /5/). Hence the theory yields the following guidelines: The circuit should be as simple as possible allowing current flow only at if, pump frequency and rf; perfect match at both the if- and rf-ports; the pump port should be as strongly mismatched as is tolerable with respect to power requirements; and the diode characteristic should be quadratic.

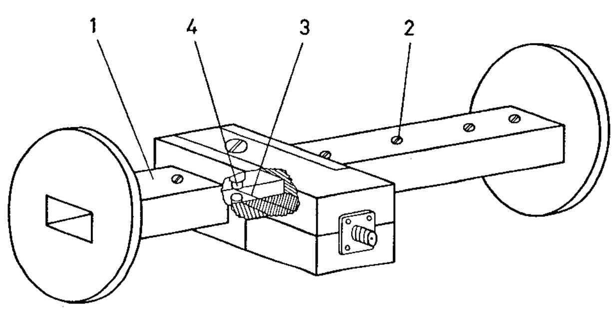

Fig. 2 Upconverter with pump filter (1), rf filter (2), if input (3), and stacked MIS varactor diodes (4)

Realization of the Upconverter

These theoretical requirements are best met in a circuit technique which utilizes evanescent mode resonators as basic elements. In this technology inductances are realized by short sections of a rectangular waveguide operating below cutoff, while capacitances are realized by tuning screws (or by the depletion-layer capacity of a varactor diode). There is no wave propagation at all, hence these basic elements are of lumped character. This technology has recently been demonstrated to yield active microwave components of excellent performance /6/. Its main advantage in conjunction with an upconverter is that it prevents any current flow at parasitic sidebands or at harmonics of the if, what is very important regarding low intermodulation distortion.

The upconverter consists of a two-section pump filter (30 MHz bandwidth, 0,5 dB insertion loss), a five-section rf-filter (200 MHz bandwidth, 0.8 dB insertion loss), and the diode mount in between the two filters. The circuit resembles that reported in /7/ with the main difference that two varactor diodes connected in series have been used. This was due to the high power operation. The upconverter assembly is sketched in Fig. 2. The diodes are MIS-varactors (metal-insulator-semiconductor) fabricated in our laboratory, because their charge-voltage characteristic can be taylored to be perfectly quadratic. The physical structure of the MIS varactor has been described in /8/ together with the electrical performance of an upconverter. The most interesting result for our application is that the multiplication efficiency for the if is poor in comparison to that of a pn-junction varactor. Furthermore, a purely quadratic charge-voltage characteristic can easily be realized. (In the case of a pn-junction varactor this would put severe problems). Punch-through voltages of 50 V with cutoff frequencies ranging between 150 and 200 GHz could be achieved.

The upconverter is tuned by means of a (capacitive) screw beneath the diodes and by varying the distances between the diodes and the filters. The relations between the if, rf, and pump power are displayed in Fig. 3. The maxi-

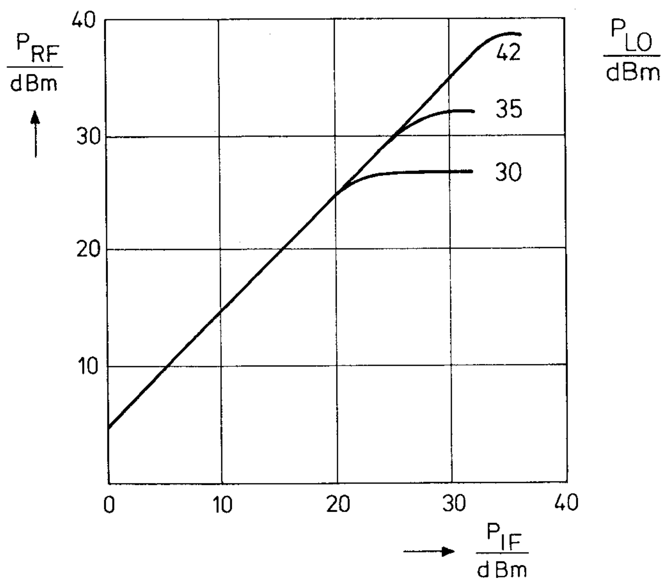

Fig. 3 Output power of the upconverter versus input power at if with the local oscillator power as parameter

mum output power is slightly in excess of 5 W, the rf-efficiency amounts to -3 dB including filter losses in the linear range. It decreases to -5 dB at saturation.

The output power is shown versus frequency in Fig.4. It is flat over nearly 100 MHz bandwidth with deviations staying below 0.2 dB.

The third-order intermodulation products have been measured and are displayed in Fig. 5. A common curve is valid for all power levels, if P_{IM}, the power of the intermodulation signal, is normalized against the rf power P_{RF} and plotted versus the ration of rf power to its saturated (maximum) value. Operating -6 dB below saturation yields an S/IM-ration of 35 dB (solid line). In the case of a single pn-junction varactor, which had also been tried in the circuit, the S/IM-ratio decreases (in accordance with theory) by about -3 dB (dashed line). The characteristic exponent of this varactor was 0.45 between 0 and -16 V and 0.2 between -16 V and -80 V.

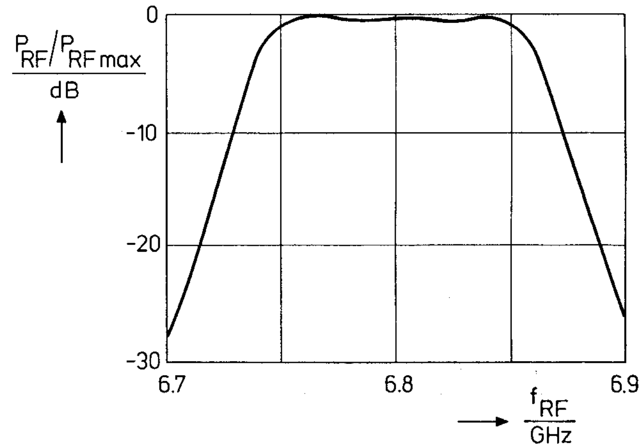

Fig. 4 Output power versus frequency

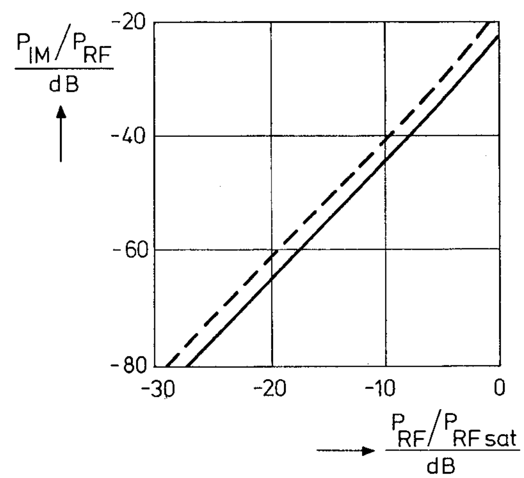

Fig. 5 IM-power versus rf-power in the case of two MIS-varactors (solid line) or a single pn-junction varactor (dashed line)

Two possible operating points with an S/IM-ratio of 35 dB for the two series-connected MIS-varactors are: 30 dBm output power with 35 dBm pump power or 37 dBm output power with 42 dBm pump power.

Performance of the Feedback Loop

A small amount (typically -10 dBm) of the output power is mixed down to the if-band in a balanced downconverter, amplified and again injected into the upconverter thus establishing negative feedback. The block diagram of this feedback loop is shown in Fig. 6. The phase and magnitude relationships are set by the phase shifter in the LO-branch and by the attenuator, respectively.

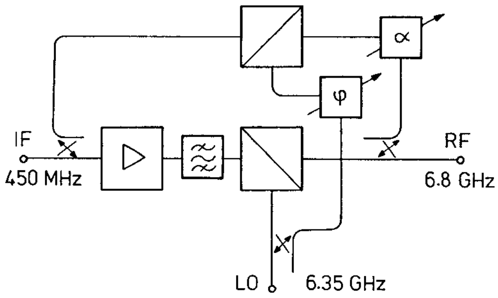

Fig. 6 Block diagram of the feedback loop (α...attenuator, φ...phase shifter)

The main problem is the design of the feedback loop, for which a compromise between broadband performance and high loop gain has to be found. The essential features shall now be discussed with the help of Fig.7 showing phase and magnitude of the open loop transmission versus frequency. f_m means midband frequency, B useful bandwidth, and g_{max} maximum loop gain. g_{max} is equal to the increase of the open loop attenuation a between f_m and f_{c1} (or f_{c2}). The critical frequencies f_{c1}, f_{c2} are defined by the phase b increasing to $+\pi$, $-\pi$. The useful bandwidth B is determined from the still tolerable decrease of the loop gain at the boundaries of the passband. This decrease typically lies between -3 to -6 dB /2/, because the IM decreases at the boundaries by this amount.

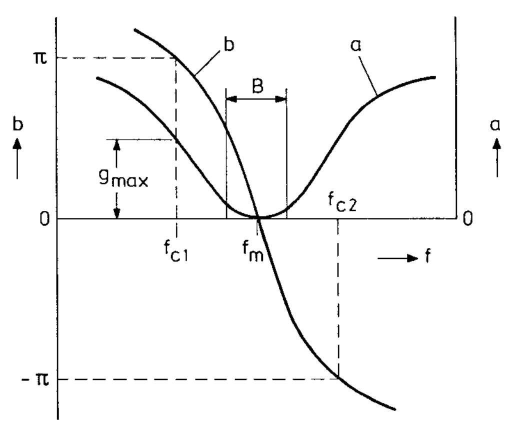

Fig. 7 Magnitude a and phase b of the open loop transmission versus frequency f (f_m...midband frequency, f_c...critical frequency, B...useful bandwidth, g_{max}...maximum loop gain)

In designing the feedback loop all unnecessary phase shifts must be avoided. The small portion of the output power should hence not be extracted behind the 5-section rf-filter but preferably at its input. This is, however, not possible because of the LO signal which is still present here. As a compromise, we have separated the rf-filter into 2 parts: a two-section broad-band and a three-section narrow-band component. The loop branches off at the second resonator with a capacitive probe. The attenuator has partly been integrated into this probe and partly been shifted to the local oscillator branch of the downconverter.

The microstrip downconverter is a double-balanced broadband component. Schottky diodes, pn-junction varactors, and MIS varactors have been tried as mixing elements. Their performance differed in conversion loss (of course) and intercept point. Typical results are 5, 30, and 30 dB for the conversion loss and 30, 40, and 54 dBm for the intercept point in case of Schottky diodes, pn-junction, and MIS varactors, respectively /9/. The higher losses of the varactor mixers could indeed be compensated with the if-amplifier, but this would, on the other hand, increase the phase shift, because more amplifier stages are needed. The Schottky mixer has hence been preferred. A max. loop gain of 25 dB has been achieved. It seems hence possible to realize a stable feedback gain of 20 dB. The useful bandwidth amounted to 24 MHz, which is only 50 per cent of our design goal. This could be attributed to the if-amplifier. Work is in progress now to improve its performance. To this end a relatively high Q-factor is assigned to its last stage. Thus the amplifier gain can strongly be reduced at out-of-band frequencies. Finally another remedy could be the utilization of phase-compensating (lossy) networks.

Conclusions

A well-known principle has been applied in order to linearize the upconverter of an SSB-AM transmitter. The upconverter has been realized with two MIS varactors and with evanescent mode resonators, which prevent current flow at spurious sidebands. Thus high output power (5 W) could be achieved while the IM-level is 35 dB down. It is then demonstrated how this distance can be further improved to an amount of -55 dB by using negative feedback.

Acknowledgement

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