AN EXPERIMENTAL LINEARIZED POWER UPCONVERTER FOR SSB SIGNALS

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ABSTRACT

An experimental J-band varactor diode power upconverter for SSB-AM communications has been linearized by predistortion at IF. Several types of simple predistortion linearizers have been tested and compared. Linearization factors from 10 to 22 dB have been achieved within a frequency band of 40 MHz or a dynamic range of 10 to 20 dB.

INTRODUCTION

SSB-AM transmission has become attractive for capacity enhancement of radio relay links for voice and /or TV signals. Either long-haul /1/ or distribution systems can be realized. Up to now, the conventional solution to the linearity problem of SSB transmitters has been a cascade of low-power upconverter and TWT amplifier, the latter being linearized in some cases /2/.

For systems requiring a moderate power-bandwidth product, it is proposed here to replace the cascade by a linearized power upconverter. This paper deals with the linearization of a power upconverter by predistortion /3/ at IF, that means by inserting a linearizer circuit at the IF input of the upconverter. A variety of simple predistortion linearizers has been investigated.

SYSTEM REQUIREMENTS

The order of magnitude of required transmit power and linearity can be evaluated from Table 1, which is resulting from SSB radio relay system calculations based on the CCIR recommendations. A noise figure of 5 dB has been assumed for the receivers.

POWER UPCONVERTER

The layout of the upconverter is shown in Fig. 1. A waveguide segment (R 140) containing a single varactor is included by matching LO and RF filters in waveguide-below-cutoff technique. The IF port has been connected to a 3-stage driver amplifier (not shown), which is matching the low-impedance IF interface of the upconverter. The measured specifications are:

450 MHz to 6.8 GHZ upper-sideband upconversion
35 dBm saturated output power (50% RF effic.)
42 dBm PI_3
100 MHz bandwidth (-1 dB)
5 dB conversion gain w/o driver amplifier
38 dB gain including driver amplifier.

The upconverter meets the transmit power requirements for all of the given model systems.

UPCONVERTER LINEARIZATION

The nonlinear behaviour of the upconverter, Fig.2, is uncomplicated, its AM/PM-conversion is extremely low even near saturation. Hence only AM linearization is necessary, which would also reduce the rest of AM/PM-conversion. The required linearization factors at average transmit power are 28, 16, 22, and 22 dB for model systems M1 to M4, respectively.

The block diagram of upconverter linearization at IF is shown in Fig. 3. The transfer characteristic of the linearizer must be complementary to the nonlinear upconverter characteristic, e.g. saturation can be compensated by an expansive linearizer characteristic. It is important to match the S/IM ratio of the linearizer to that of the upconverter. For this reason, a preamplifier P and a variable attenuator have been inserted occasionally. As pointed out by /4/, the time delay between the linearizer and the upconverter should be constant for efficient broad-band linearization. Amplifiers and attenuator have been designed

model system	M1	M2	M3	M4	
frequency	6800	6200	6800	6800	MHz
signal	voice	voice	TV	TV	
no. of channels	6000	1800	1	7	
length of system	2500	2500	2500	20	km
no. of hops	54	54	54	2	
transmit power, average	25	19	17*	20	dBm
peak	35	29	26	23	dBm
PI_3: 3rd-order intercept point, 2-tone method	56	50	53	53	dBm

Table 1: SSB system requirements *: video signal alone

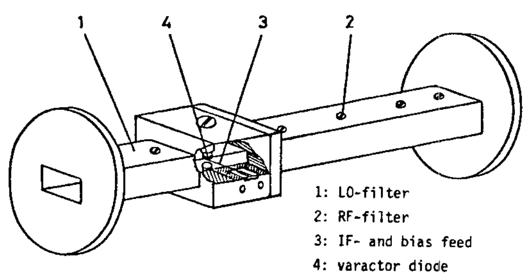

Fig. 1: Power upconverter in waveguide-below-cutoff technique

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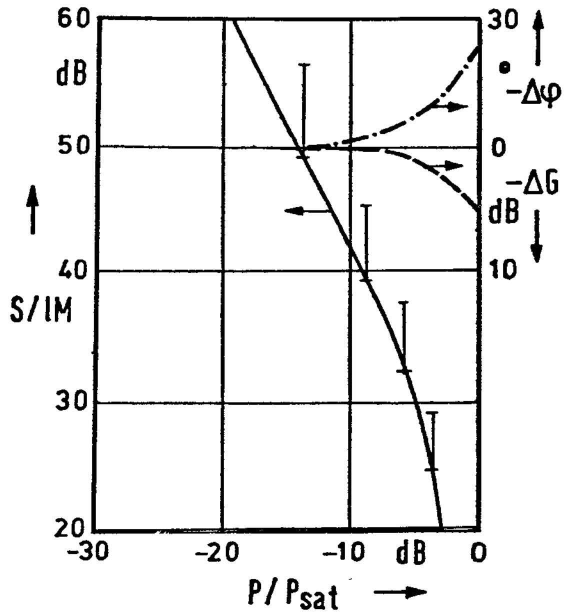

Fig. 2: Measured single-tone gain compression ΔG, AM/PM conversion $\Delta\varphi$, and worst-case 2-tone S/IM ratio of the upconverter. P: total RF signal power. P_{sat}: single-tone RF saturation power.

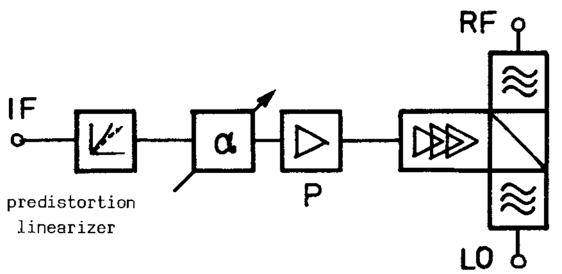

Fig. 3: Upconverter linearization by IF predistortion

for this goal. The IF driver amplifier has not shown any measurable influence on the intermodulation products. It allows, however, for cost-effective linearizers working at low power level.

PREDISTORTION LINEARIZERS

The upconverter shows amplitude saturation, hence appropriate linearizers had to be realized with expansion characteristics. In order to provide for flexible adjustment, the linearizer is essentially a bridge circuit consisting of a linear and a nonlinear path, Fig. 4. 'E' stands for any of three different types of predistortion linearizers with various degrees of expansion, which have been built and tested with the upconverter. The frequency band of design extends from 400 to 500 MHz.

Diode expanders

Circuit 'T' (Fig. 5) resembles to the well-known transmission-type diode expander. Two microwave Schottky barrier diodes mounted back to back have been additionally shunted here by a pin-diode to allow for simple drive control of the nonlinearity. The graphs in Fig. 5 show computed single-tone transmission coefficients of the diode triplet. Only the fundamental has been taken into ac-

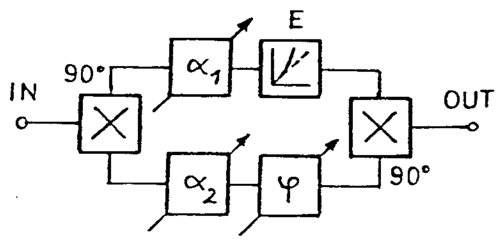

Fig. 4: Predistortion linearizer bridge
E: diode expander or distortion generator

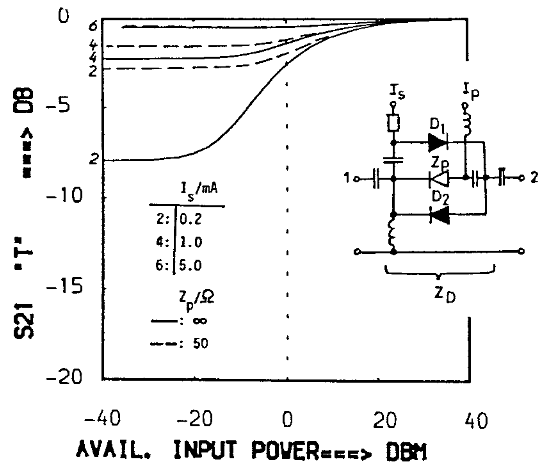

Fig. 5: 'T'-type diode expander and its computed transmission. D : Schottky diode, Z_p: pin-diode, Z_D: total impedance of diodes in parallel

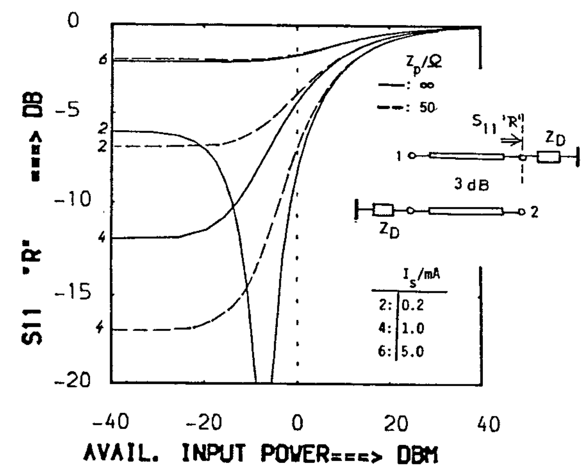

Fig. 6: 'R'-type diode expander and its computed transmission. Z_D, Z_p, I_s: see Fig. 5.

count in the computations. Several triplets can be connected in series /2/,/5/ in order to increase expansion range and tuning flexibility.

For the reflective circuit 'R' of Fig. 6, two equally biased diode triplets like above have been connected to the coupled arms of a 3-dB coupler. The circuit exhibits stronger expansion over a higher dynamic range than the transmission-type circuit, at the expense of increased transmission loss at low power levels. The termination impedance Z_D must stay somewhat lower than the 50 Ohms system impedance in order to avoid a transmission zero of the entire circuit, see the computed reflection coefficient of Z_D in Fig. 6.

The 2-tone 3rd-order intermodulation characteristics of experimental diode expanders 'T' and 'R' have been measured, Fig. 7. At low power levels, an expansive 3rd-order nonlinearity can be detected from the curves. Expander 'R' shows again stronger expansion within a larger dynamic range than expander 'T', which is exhibiting compression at higher power level. Hence expander 'R' promises better compensation of nonlinear characteristics driven near to saturation.

Distortion generator

Another useful circuit which has been tested, consists of a bridge of two couplers with two identical amplifiers, Fig. 8 /5/,/6/. At the output of the subtractive bridge, the signal is cancelled in the ideal case, while the distortions generated by the overdriven amplifier in the upper branch remain. Fig. 9 shows the measured typical 2-tone intermodulation spectrum of an experimental distortion generator, where the 2-tone output signal has been reduced by 48 dB.

The circuit has been inserted into the linearizer bridge, instead of diode expanders. By virtue of additional attenuators and phase shifters, the distortions can be added with appropriate amplitude and phase to the signal in the linear path of the linearizer (Fig. 4), thus featuring separate adjustment of signal and distortions. In this work, the distortion generator has been equipped with broad-band amplifier modules /7/. Instead of amplifiers, diode pairs can be used /8/. In Fig. 10, the implementation of the distortion generator and the complete linearizer are displayed.

Control components

The linearization factor is limited by amplitude and phase errors within the bridge /4/. Electronically variable precision attenuators and phase shifters have been built accordingly. The attenuators are exhibiting maximum deviation from midband attenuation of ± 0.05 dB within the 100 MHz frequency band. The reflective phase shifters have been structured with varactor diodes and 3-dB-couplers using Wireline /9/. They perform continuous line stretching equivalent to 7 cms of conventional cable. Deviations from linear phase slope vs. frequency are below $\pm 0.25^{\circ}$. The control components did not contribute to the distortions.

MEASUREMENT RESULTS

A maximum improvement of the output S/IM ratio can always be obtained at a specific tuning level. Im-

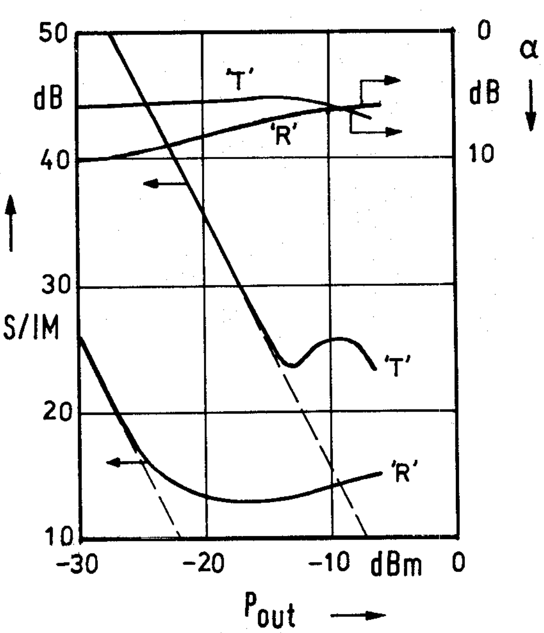

Fig. 7: Measured typical transmission loss and 2-tone S/IM ratio for diode expanders 'T' and 'R'.

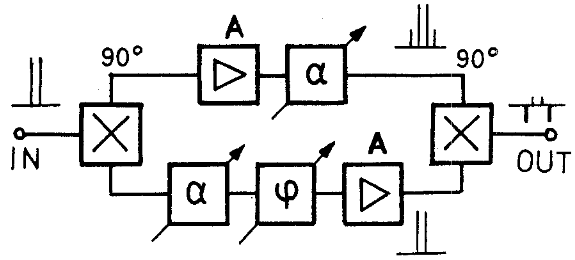

Fig. 8: Distortion generator bridge cicuit. Upper path: nonlinear operation. Lower path: linear operation.

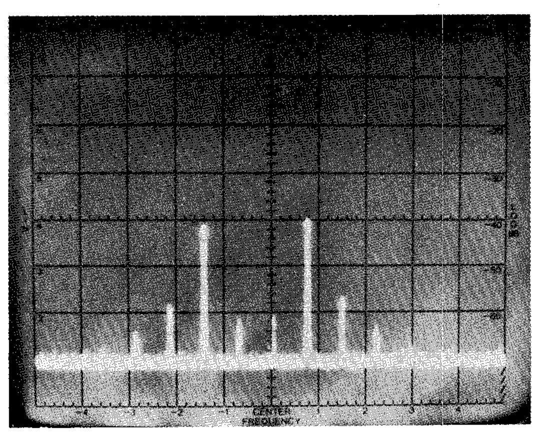

Fig. 9: 2-tone IM output spectrum of the distortion generator. Signal suppression is 48 dB.

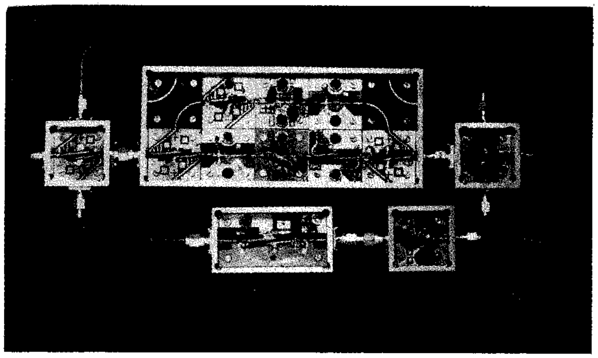

Fig. 10: Predistortion linearizer including distortion generator. Top: distortion generator. Bottom: linear bypass. Left and right: 3-dB-couplers.

provements have turned out to be harder to realize close to saturation, generally. The goal of the measurements has been set to obtain minimum distortions close to saturation, in this case at 29 dBm output power of the upconverter. Linearizing at tuning level should never cause increased distortions far below this level.

Fig. 11 shows samples of typical measured improvements of the S/IM ratio. The curves are valid for a frequency band of 40 MHz. Increased improvement can be exchanged for bandwidth, since unbalance in the linearizer bridge, or the nonlinear characteristic, is depending on frequency. For comparison, linearization requirements for the four model systems are mapped in Fig. 11.

Linearizers containing diode expanders have exhibited only moderate improvements of the S/IM

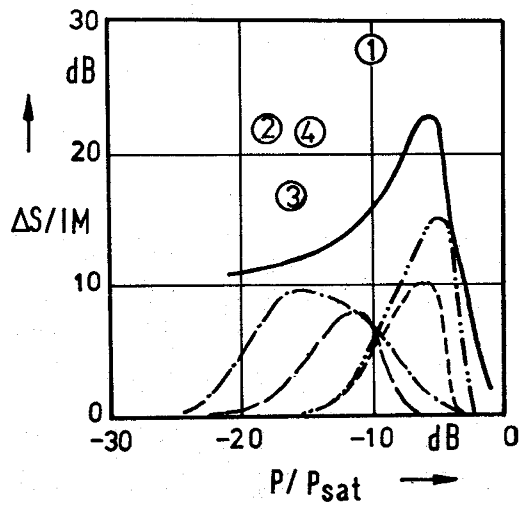

Fig. 11: Improvement S/IM of the S/IM ratio of the upconverter, with linearizer bridge including:
——— ——— transmission-type diode expander
— — — — 2 cascaded transmission-type diode expanders
— • — • reflection-type diode expander
— •• — •• reflection-type diode expander using amplifier P
————— distortion generator.
P, P_{sat}: see Fig. 2.

ratio, within limited dynamic range. Both properties are influenced by diode parasitics and unsuitable diode nonlinearity. With a single or 2 cascaded transmission-type diode expanders, linearization of more than 10 dB over a 40 MHz band could not be achieved near saturation. However, the predicted superiority of the reflection-type diode expander over the transmission-type has been confirmed. Using the former type, the S/IM ratio near saturation has been increased by 15 dB within a frequency band of 40 MHz.

Best performance has been obtained using the distortion generator, resulting in 22 dB of linearization in the 40 MHz frequency band, and a very large dynamic range. Within a 20 MHz frequency band, or at a lower tuning level, the maximum linearization has increased to 27 dB. The promising features of this type of linearizer are explainable by the use of broad-band amplifier modules in the distortion generator.

With all types of linearizers, the 3rd-order intermodulation has been reduced. Intermodulation of higher order was never prevailing. However, it has been increased slightly by linearizers using diode expanders, while it has been reduced by a distortion generator.

CONCLUSIONS

The experimental linearization by IF predistortion of a J-band power upconverter for SSB communications has been succesfully performed. A linearizer using a distortion generator has exhibited the most promising features, thus enabling the application of power upconverters in SSB radio relay communications. Limitations in bandwidth and amount of linearization have occurred, which could be overcome by computer-aided optimization of the entire circuit.

ACKNOWLEDGEMENT

The author is indebted to the Deutsche Forschungsgemeinschaft for financial support.

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