A LINEARIZED HIGH POWER MICROWAVE DIGITAL PHASE MODULATOR+

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+ A patent based on this work is under application

ABSTRACT

A new technique for linearizing the reflection characteristics of PIN diodes in a high-power microwave digital modulator is described. The application of this technique in low data rate systems permits the use of less costly microwave hardware and results in efficient utilization of the transmitter power.

INTRODUCTION

Conventional microwave Phase-Shift-Keyed (PSK) modulators are designed to operate at low power levels ($\leq$0 dBm) using FET devices or switching diodes[1]. Such arrangements require subsequent power amplification and RF bandpass filtering to control the spectrum before transmission. In some cases, direct RF modulation after power amplification of a carrier can be effected. However, bandpass filtering is still required to suppress the sidebands of a constant envelope PSK-modulated signal. These modulators work well for high data rate systems where the bit rate is $\geq$20 Mb/s.

For narrow-band low data rate systems (e.g. 64 kb/s), RF bandpass filtering at the carrier frequency is impractical. This is largely due to the difficulty of fabricating a low-loss microwave bandpass filter with a bandwidth of less than 100 kHz. A common technique that solves this problem is to perform modulation and filtering at a low IF frequency. Linear up-conversion and power amplification is then necessary to prevent the signal spectrum from spreading. The result is inefficient utilization of the available transmitter power, e.g. a backed off TWTA for the transmitter. All this implies higher microwave equipment costs.

This paper describes a microwave high power BPSK modulator for low data rate applications. The design allows a reduction in costly microwave hardware, and utilizes the available RF power to the fullest extent without backoff. PSK modulation on the carrier is performed at high power levels (4 watts) and spectrum spreading is prevented by filtering the data and linearizing the reflection characteristics of the diodes in the modulator.

B-PSK PIN MODULATOR

The schematic of the microwave high-power BPSK modulator is shown in Fig. 1. The 3 dB branch line hybrid was designed using a well-established MIC technique[3], and measured results show the phase and power imbalance over a 12% bandwidth to be less than $\pm3^\circ$ and ±0.2 dB respectively. Suitable PIN diodes were chosen to terminate the 3 dB, 90° branch line hybrid. These diodes are matched[2] to provide an open or a short circuit termination, depending on their bias voltages. An insertion loss of about 1.5 dB for the RF signal was observed in the modulator due to imperfect reflection from the diodes at the extreme "ON" and "OFF" states. In addition, about 0.6 db is attributable to the hybrid two-trip loss. This 6 dB of hybrid loss can be reduced to less than 0.3 dB if a low-loss stripline structure is used. The loss due to imperfect reflection from the diodes may be improved by a careful choice of diodes. However, even with a crude circuit in the broadband stage, it is shown that the modulator does not suffer from excessive loss.

LINEARIZATION OF THE MODULATOR

A filtered baseband Non-Return-to-Zero (NRZ) digital format will have amplitude fluctuations that modulate the amplitude of the carrier. The non-linearity of Γ with respect to V_b becomes significant if direct baseband-to-RF PSK modulation is performed.

In a conventional BPSK modem where the filtered (or band-limited) NRZ data $V_d(t)$ is mutliplied by the IF oscillator frequency, $A\cos(\omega_o t+\phi_o)$, the output signal $V_o(t)$ of the modem is:

$$V_o(t) = V_d(t)\, A \cos(\omega_o t + \phi_o) \quad (1)$$

where

$\omega_o = 2\pi f_o$

f_o = frequency of the local oscillator

ϕ_o = phase of the local oscillator

Since ϕ_o is fixed, bi-phase modulation arises from the fact that $V_d(t)$ changes sign. Also

$$|V_o(t)| = A\,|V_d(t)| \quad (2)$$

i.e. the magnitude of the local oscillator carrier is now modulated by the absolute magnitude of the time domain waveform of the band-limited NRZ bit pattern. This situation can be reproduced exactly at RF using the PIN diode microwave modulator if (i) the magnitude of the reflection coefficient versus bias voltage characteristic is known and (ii) if the band-limited NRZ waveform can be altered in some way to compensate for the non-linear behaviour of the reflection coefficient with respect to the bias voltage V_b.

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Fig. 2 shows the measured reflection coefficient of the matched PIN diodes at 6 GHz with respect to V_b, the bias voltage of the diodes. Although highly non-linear, the Smith Chart shows that the locus of the reflection coefficient is a straight line superimposed on the purely resistive line. Since the data rates are assumed to be those typical of an SCPC earth terminal i.e. <1 Mb/Sec, the measured steady state characteristics of the reflection coefficient are assumed to be applicable to the dynamic situation when the bias voltage V_b is time variant. This assumption is usually valid if suitable PIN diodes have been chosen for the application. The magnitude of the reflection coefficient Γ is seen to be highly non-linear with respect to V_b.

Let Γ be represented by

$$\Gamma = g(V_b) \qquad (3)$$

where $g(V)$ is a function of V.

It is now necessary to find a non-linear circuit that will linearize Γ with regard to an input voltage $V_d(t)$, i.e.

$$\Gamma = k_o + k\, V_d\, (t) \qquad (4)$$

where k_o and k are circuit constants. For exact linearization of Γ with respect to V_b, it is necessary that

$$V_d = (1/k)\ g\ (V_b) \qquad (5)$$

or

$$V_b = g^{-1}\ (kV_d) \qquad (6)$$

where $g^{-1}(V)$ is the inverse function of $g(V)$. The constants k_o and k are used in the hardware implementation phase to adjust respectively the dc offset and the scaling factor. The function $g^{-1}(V)$ can be found from Fig. 2 using numerical or graphical methods, and subsequently a non-linear circuit can be built to approximate the function.

THE NON-LINEAR CIRCUIT

Synthesis of the non-linear transfer function was accomplished using an array of analog voltage comparators controlling dedicated current switches (Fig. 3). The reference bias for each comparator was chosen such that approximately one-half of the comparators function over the steep slope of the curve (Fig. 2) with the remaining comparators split between the two shallow slope areas. Hysteresis incorporated at the bias nodes guarantees operating stability when processing slow rise-time input signals.

The current switches were interfaced to the comparators using digital logic gating, which ensured that no current switch would turn on unless the preceding lower order switch had been activated. Conversely, the logic also ensured that no current switch would turn off unless the immediate higher order switch had been de-activated. The value of current for each switch was adjusted to generate the corresponding desired voltage step thus implementing the transfer function shown in (Fig. 4).

RESULTS

To demonstrate the validity of this technique of high-power microwave digital modulation, the test set-up shown in Fig. 5 was implemented. The RF power to the modulator was adjusted to 4 Watts CW, and was the highest level tested. Fig. 6 shows the response of the modulator to 64 kbit/s unfiltered pseudo-random NRZ data. The low-pass filter was adjusted to have a very broad passband such that the effect on the signal was negligible. Spectrum shaping is demonstrated when the low-pass filter begins to limit the baseband NRZ signal spectrum. Fig. 7 shows the shaped spectrum of a 6 GHz BPSK-modulated signal where the sidebands are considerably suppressed when compared to those shown in Fig. 6. The waveforms at the output of the low-pass filter and the non-linear circuit are shown in Fig. 8.

CONCLUSION

A circuit has been described which compensates for non-linear switching behaviour of a PIN-diode BPSK direct RF modulator. The high power handling capability of the PIN diode makes a linear modulator even more attractive, as it can be placed after a saturated high-power RF amplifier. The desired spectrum shaping is achieved by filtering the input baseband data to the modulator. The power spectrum of the filtered baseband data is translated to the carrier frequency by the modulator.

The technique described has the advantage of i) significantly saving RF power, ii) avoiding the effects of TWTA or solid-state power amplifier non-linearities, and iii) lowering the microwave equipment cost by eliminating up-conversion equipment. It is expected that the technique can be applied to a baseband bit rate of up to 10 Mb/s with off-the-shelf IC components. This technique is particularly suitable for SCPC operation with telephony or data terminals.

ACKNOWLEDGEMENT

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REFERENCES

[1] C.L. Cuccia and E.W. Matthews: "PSK QPSK Modulators for Gigabit Data Rates", MTT-S, 1977.

[2] K. Kurokawa et al: "An Experimental MM-Wave Path Length Modulator", BSTJ, Nov. 71.

[3] M. Cuhaci and G.J.P. Lo: "High Frequency Microstrip Branch-line Coupler Design with T-junction Discontinuity Compensation" Electronics Letters, Vol. 17, No. 2, 22 January 1981.

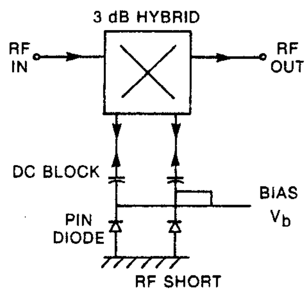

Fig. 1. Reflection Type Phase Modulator

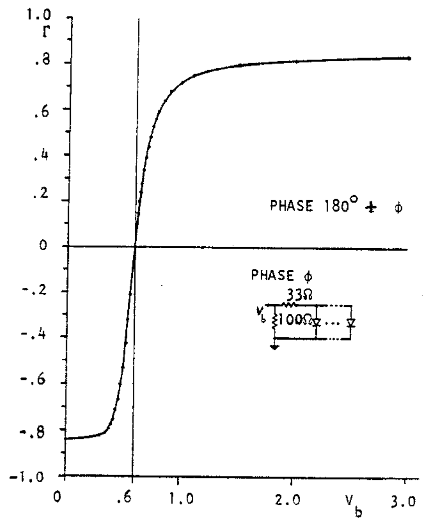

Fig. 2. Reflection Coefficient of Matched Diodes with Respect to Bias Voltage.

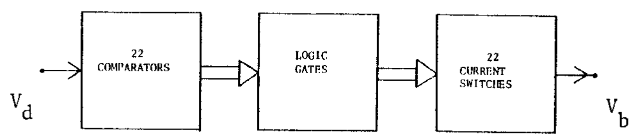

Fig. 3. Block Diagram of the Non-Linear Circuit.

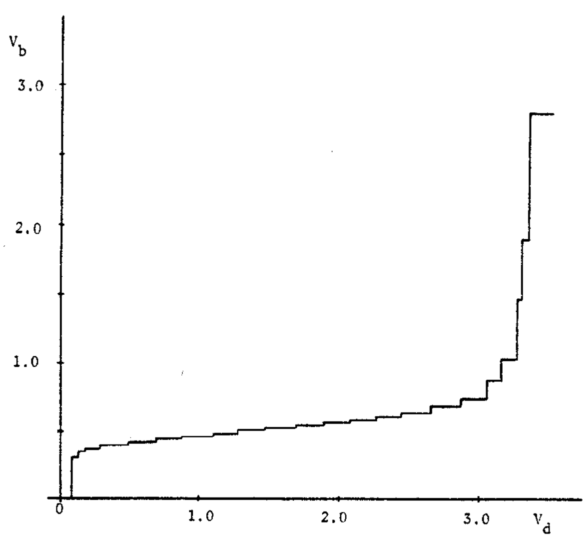

Fig. 4. Transfer Function Obtained with the Non-Linear Circuit.

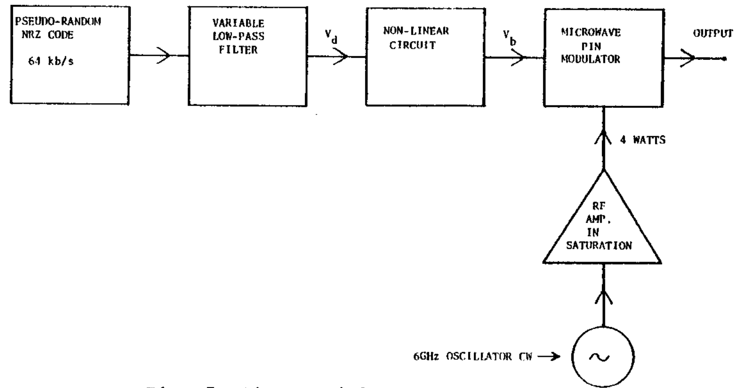

Fig. 5. Linear High Power Phase Modulator Demonstration Set-up.

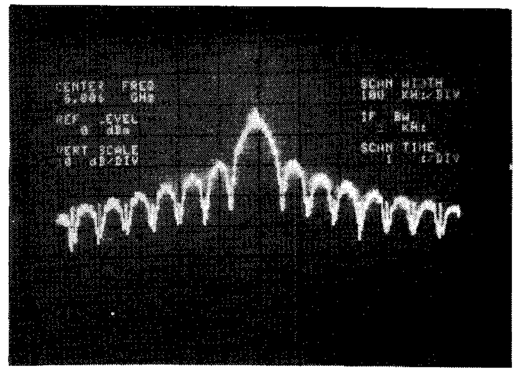

Fig. 6. Power Spectrum Observed with Unfiltered 64kb/s Pseudo-random NRZ Data.

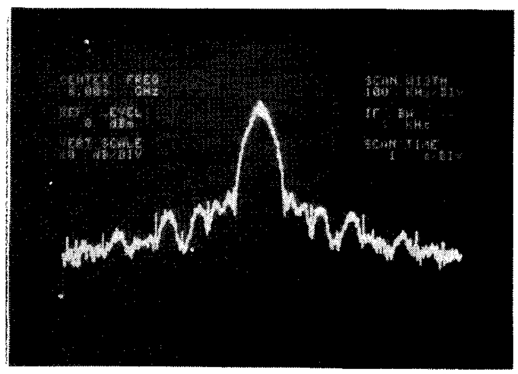

Fig. 7. Power Spectrum Observed After Introducing Filtering.

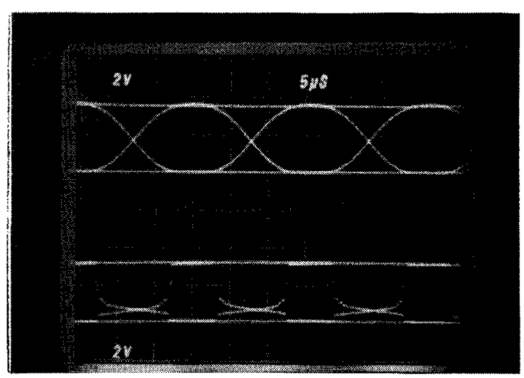

Fig. 8. Filtered Pseudo-random NRZ Data (V_d) (upper trace)
The Response of the Non-Linear Circuit (V_b) (lower trace)