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GHz BAND MONOLITHIC MODEM ICs

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ABSTRACT

A double balanced mixer IC, a 90° phase shifter IC and a carrier switch IC for high speed QPSK modems have been developed using monolithic lumped constant circuit techniques and advanced Si-bipolar process technology. These ICs are applicable to QPSK modems transmitting baseband signals in excess of 400 Mb/s at 1 GHz local frequency.

INTRODUCTION

High speed transmission systems in digital microwave and satellite communications are intended for the purpose of increasing channel capacity and constructing more flexible networks. In order to realize these systems, one of the key technologies is development of small, high speed modems with low power dissipation and high reliability, utilizing integrated circuit technologies. Modulators were previously developed with hybrid microwave integrated circuit technology.(1) However, they are ineffective in reducing modems hardware size in the GHz band.

A QPSK modem system is widely used for digital microwave and satellite communication systems because of its high power efficiency. QPSK modem ICs were developed to realize QPSK modem systems which can transmit a baseband signal of more than 200 Mb/s at 1 GHz local frequency and are required for regenerative satellite communication systems (2) This paper describes circuit designs for these QPSK modem ICs utilizing monolithic integrated circuit technologies and fabricated IC performance.

QPSK MODEM CONFIGURATION

A QPSK burst modem block diagram is shown in Fig. 1. As indicated, double balanced mixers (DBMs) and 90° phase shifters for a QPSK modem, and a carrier switch used in TDMA systems for generating a burst signal are integrated. A two chip DBM set is designed for each QPSK modulator and demodulator for reducing crosstalk between I and Q channels. These three key components of QPSK burst modems are designed using monolithic integrated circuit techniques which utilize a lumped constant circuit and can suppress signal leakage.

To realize QPSK modems with an Eb/No (bit energy-to-noise density ratio) degradation of less than 0.2 dB at Pe(probability of bit error) = 1×10^{-4} and construct burst modem systems which accommodate more than 100 earth stations, following performance characteristics are required for these three ICs.

(1) DBM and 90° phase shifter amplitude error should be less than ±0.2 dB. DBM and 90° phase shifter phase error should be less than ±2 degrees. These are at 1 GHz local frequency.

(2) Amplitude variation at the frequency conversion characteristics for the DBM should be less than 1 dBp-p over the range of 1 GHz ± 100 MHz.

(3) Carrier switch ON/OFF ratio should be greater than 60 dB at 1 GHz band.

CIRCUIT DESIGN

A four quadrant analog multiplier(3) with a predistortion circuit having an inverse hyperbolic function is used for the DBM, as shown in Fig. 2. It is used because of low distortion and high local suppression characteristics in a low frequency range. To improve the high DBM frequency performance, the following circuit techniques have been developed. Unbalance-balance converters consisting of differential stages are used to suppress leakage of the multiplier's local and baseband signals. The common-mode feed back circuit is used for the differential stage at the local port to reduce phase error caused by amplitude and phase imbalance of local inputs for the multiplier.

Monolithic variable RC phase shifters using a lumped constant circuit technique are proposed for developing the 90° phase shifter, as shown in Fig. 3. The phase shifters output phases are controlled by varying the bipolar transistor's base-collector junction capacitors with control voltage V_C . Phase shifters (A) and (B) are designed so that their output phases may vary toward the opposite phase directions from each other. The phase difference between two outputs can be adjusted to 90° even with device characteristic deviation. Amplitude balance between outputs can also be tuned by controlling differential stage current in output circuits with V_{RA} or V_{RB} voltage.

A basic analog switch for the carrier switch is shown in Fig. 4. A transistor controlling the current source of the differential stage and the cascode circuits are used so that the carrier switch can decrease switch signal leakage in the OFF state. Furthermore, the carrier switch consists of the cascade connection of two basic switches and their power supply lines are separated on the IC chip to realize a higher ON/OFF ratio.

CIRCUIT FABRICATION

These three ICs are fabricated by Si-bipolar SST (Super Self-aligned process Technology)[4]. The SST device having high transient frequency f_T, small base-collector junction capacitance and low base resistance is suitable for developing high speed modem ICs which require the precise amplitude-phase characteristic. The base-collector capacitance, base resistance and f_T of a transistor with 0.35 x 5μm^2 emitter are 7.4 fF, 310 ohms and 17 GHz , respectively. The DBM microphotograph is shown in Fig. 5. Chip size is 1.8 x 1.0 mm^2 and the chip size of the 90° phase shifter and the carrier switch are 1.5 x 2 mm^2 and 1 x 1.2 mm^2, respectively.

Output power versus DBM baseband voltage at 1 GHz local signal is shown in Fig. 6. The DBM has an amplitude error of less than 0.2 dBp-p and a wide dynamic range over 30 dB. The amplitude-phase characteristic at 1 GHz local signal is shown in Fig. 7. A phase error of less than 1.7 degree p-p is achieved under the condition that input baseband voltage is within the -0.2 V and +0.2 V range. Frequency conversion characteristics from baseband to IF signal and from IF to baseband signal are also measured at 1 GHz local signal. Each amplitude variation is less than 1 dBp-p above the 10 to 200 MHz range of the baseband signal. The frequency range of this DBM is improved to about seven times that of the most recent monolithic DBM for a modulator and a demodulator.

Phase difference and the amplitude characteristics versus a control voltage V_c of the 90° phase shifter at 1 GHz are shown in Fig. 8. The phase difference between two output signals, V_{outA} and V_{outB}, can be adjusted to 90° ± 2° and amplitude balance can be less than 0.2 dB when $V_C = -0.1\ V \pm 50\ mV$. This 90° phase shifter has less phase error than 90° Hybrid fabricated by microwave integrated circuit technology.

The insertion loss versus carrier switch frequency is shown in Fig. 9. The ON/OFF ratio of more than 65 dB below 1 GHz has been achieved. The 3 dB-down bandwidth is 5 GHz. Carrier switch ON/OFF ratio is about 20 dB higher at 1 GHz band than that of previously developed monolithic analog switch.

The DBM power consumption, the 90° phase shifter and the carrier switch are 540 mW, 420 mW and 250 mW at V_{CC} = 5 V, respectively. Radiation hardness tests using gamma-ray (^{60}Co) were performed for on-board modems application. There is no significant performance degradation on the prototype DBM and the carrier switch ICs after irradiation of 10^6 rads (Si).[5] This performance has been achieved by operating the bipolar transistor in the relatively high current range and designing these ICs with low gain.

CONCLUSION

Three key component ICs for high speed QPSK modems have been successfully developed adopting monolithic integrated circuit techniques, which utilize a lumped constant circuit and can suppress signal leakage, and the Si-bipolar SST. Experimental results show that these ICs are applicable to QPSK modems transmitting baseband signals in excess of 400 Mb/s at 1GHz local frequency. Furthermore, the DBM and the carrier switch ICs have a total dose immunity up to 10^6 rads (Si) for QPSK on-board modem applicaition.

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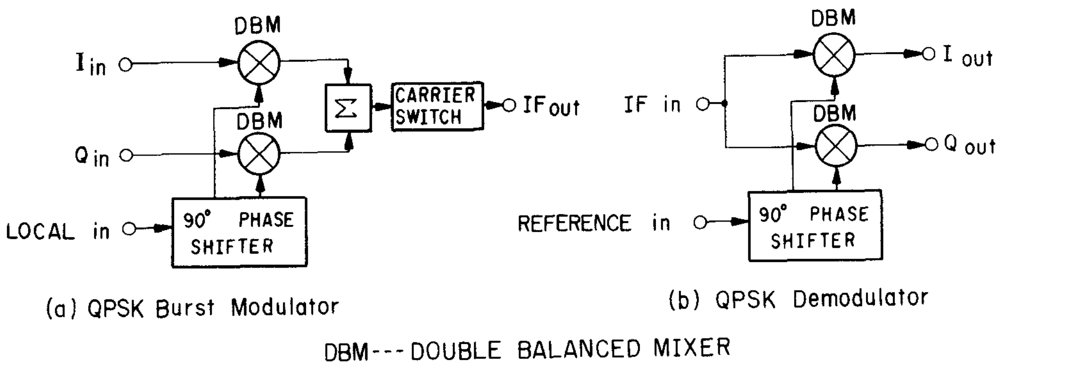

Fig. 1 QPSK Burst Modem Block Diagram

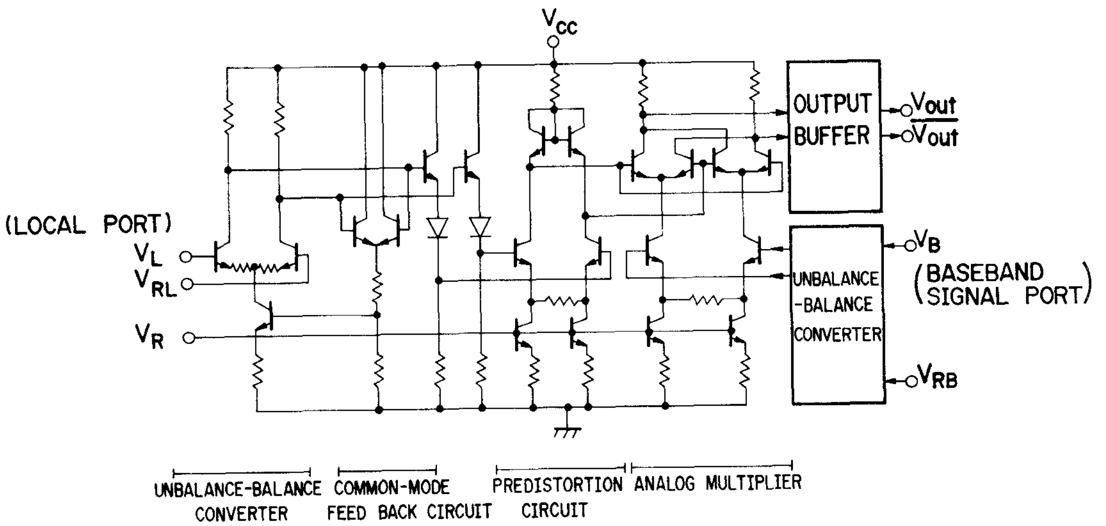

Fig. 2 Double Balanced Mixer

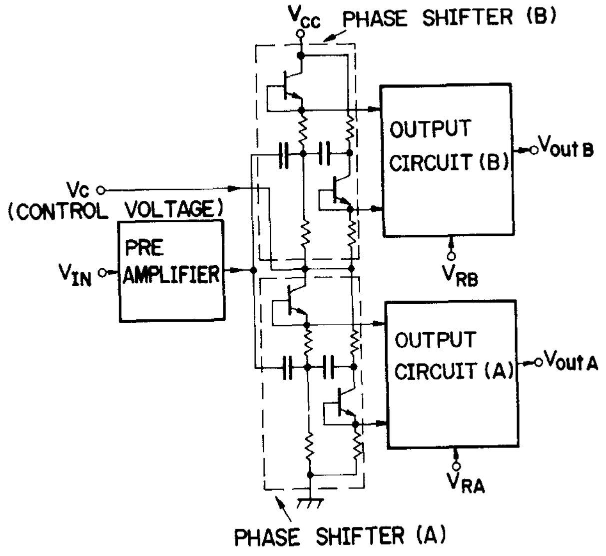

Fig. 3 90° Phase Shifter

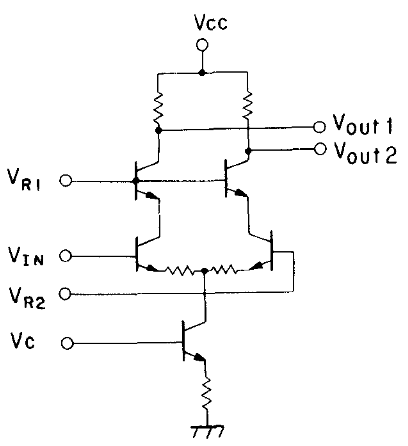

Fig. 4 Basic Analog Switch

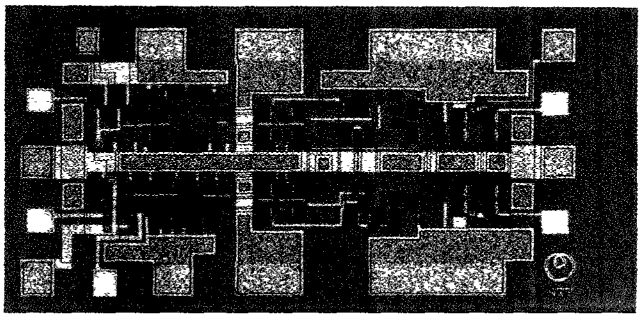

Fig. 5 Microphotograph of Double Balanced Mixer

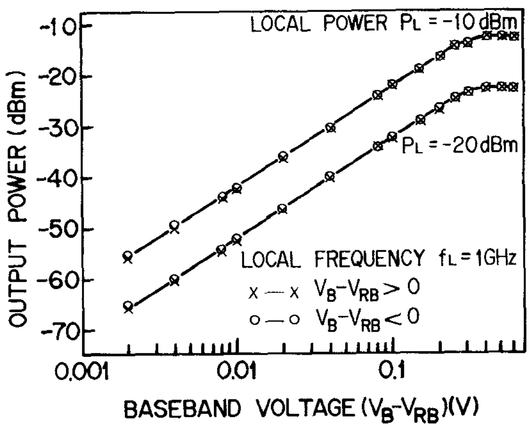

Fig. 6 Output Power vs. Baseband Voltage of Double Balanced Mixer

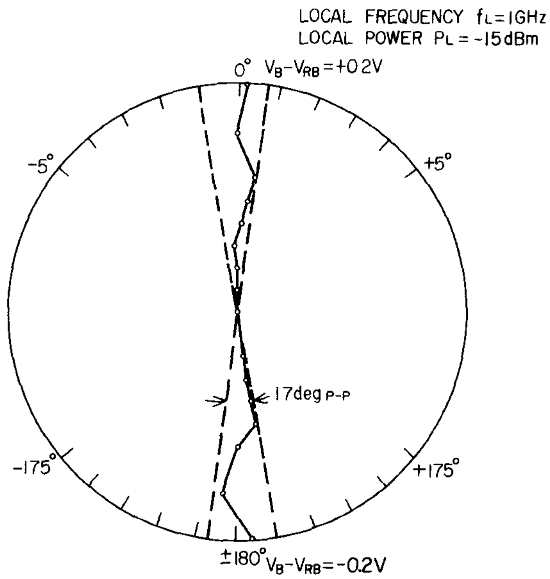

Fig 7 Amplitude-Phase Characteristic of Double Balanced Mixer

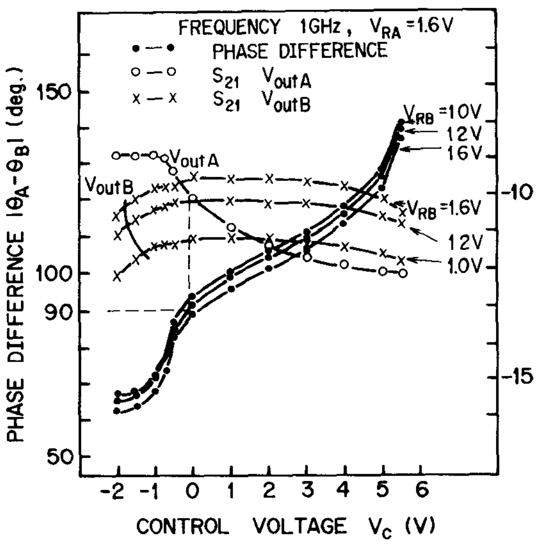

Fig. 8 Phase Difference and Amplitude Characteristics vs. Control Voltage of 90° Phase Shifter

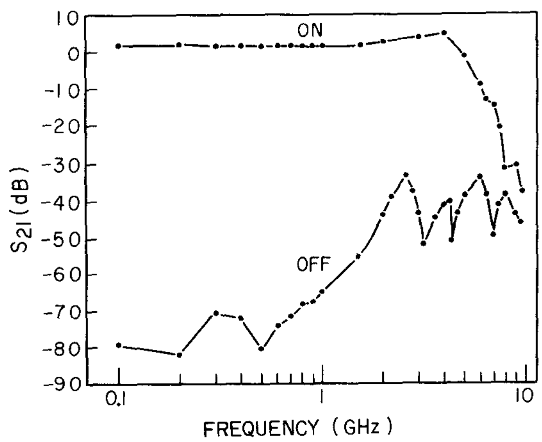

Fig. 9 Insertion Loss vs. Frequency of Carrier Switch