A 26-GHz High-Performance MIC Transmitter/Receiver for Digital Radio Subscriber Systems

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***Abstract*—A high-performance 26-GHz microwave integrated circuit (MIC) transmitter/receiver using frequency-shift-keying (FSK) modulation has been developed. All RF components are fabricated using MIC technology and integrated into a single compact module. Newly developed MIC components include an FSK modulator, a time division multiple access (TDMA) switch, and a single-balanced mixer. The FSK modulator is composed of an IMPATT diode, a varactor diode, and a dielectric resonator. A high-frequency stability of 50 ppm is obtained in the temperature range of −10–45°C. The configuration and performance of the TDMA switch with a high ON/OFF ratio and a low insertion loss are described. A transmitting power of 21 dBm and a receiving noise figure of 8.7 dB are obtained. The bit error rate is measured to evaluate the overall transmitter/receiver performance. The required carrier-to-noise ratio (CNR) has been considerably improved by adopting FSK modulation and by using the MIC transmitter/receiver described in this paper.**

I. Introduction

In recent years, there have been increasing demands for high-speed digital communication services, including computer data, facsimile, and video transmission. In order to meet these demands, the Dendenkosha Subscriber Radio (DSR) system has been developed at the Yokosuka Electrical Communication Laboratory [1], [2]. This system is a point-to-multipoint communication system using time division multiple access technology (TDMA) in the 26-GHz band [1]. It was necessary to build a compact and inexpensive transmitter/receiver, in order to realize this system. The application of microwave integrated circuits (MIC's) was considered to be the best method for meeting these space and cost requirements. A 26-GHz MIC transmitter/receiver using amplitude-shift-keying (ASK) modulation was previously reported [3]. The purpose of this paper is to present the improved design and performance characteristics of the 26-GHz MIC components and transmitter/receiver module which have been achieved using frequency-shift-keying (FSK) modulation. The main features of the present work follows:

1) An FSK modulation method has been adopted to reduce the required carrier-to-noise ratio (CNR). The modulator, TDMA switch, and single-balanced mixer have been designed and developed using MIC technology.

2) Transmitting power and receiving noise figures have been improved by minimizing circuit losses which are usually fairly large in high-frequency MIC's.

3) A highly reliable and high-performance transmitter/receiver module has been constructed by integrating the MIC components. Measurement of bit error rate confirm excellent overall performance.

II. Transmitter/Receiver Configuration

The configuration of the MIC transmitter/receiver is shown in Fig. 1(a). It is composed of an MIC transmitter/receiver, an antenna and transmit/receive branching filters, and an IF/baseband (BB) section. The MIC transmitter/receiver consists of an FSK modulator, TDMA switch for TDMA control, transmitting power monitor, receiving mixer, receiving local oscillator, and circulators. These components are integrated using MIC technology. The FSK modulator is driven by a 16.384-MHz pulse driver in the IF/BB section. The modulated signal is switched by the TDMA switch and then converted into the burst mode for the TDMA system. The data stream in the transmitter/receiver is shown in Fig 1(b).

The transmit-receive branching filters are constructed using waveguide circuits. These filters are connected to the MIC transmitter/receiver by means of antenna-type waveguide-to-microstrip transitions [4].

III. MIC Components

A. FSK Modulator

The FSK modulator is composed of an IMPATT diode, a dielectric resonator, and a varactor diode. Its circuit configuration is shown in Fig. 2. A band-reflection-type oscillator has been adopted because stable oscillation can be easily obtained with low stabilization loss [5]. The IMPATT diode used here is an encapsulated Si DDR type with a diamond heatsink. The diode is embedded into a dielectric substrate and connected to microstrip lines by Au ribbons. The dielectric resonator is made of $Ba(Zn_{1/3}Nb_{2/3})O_3$–$Ba(Zn_{1/3}Ta_{2/3})O_3$ and has an unloaded Q of 3000 [6]. A quartz spacer is inserted in order to avoid degradation of the unloaded Q.

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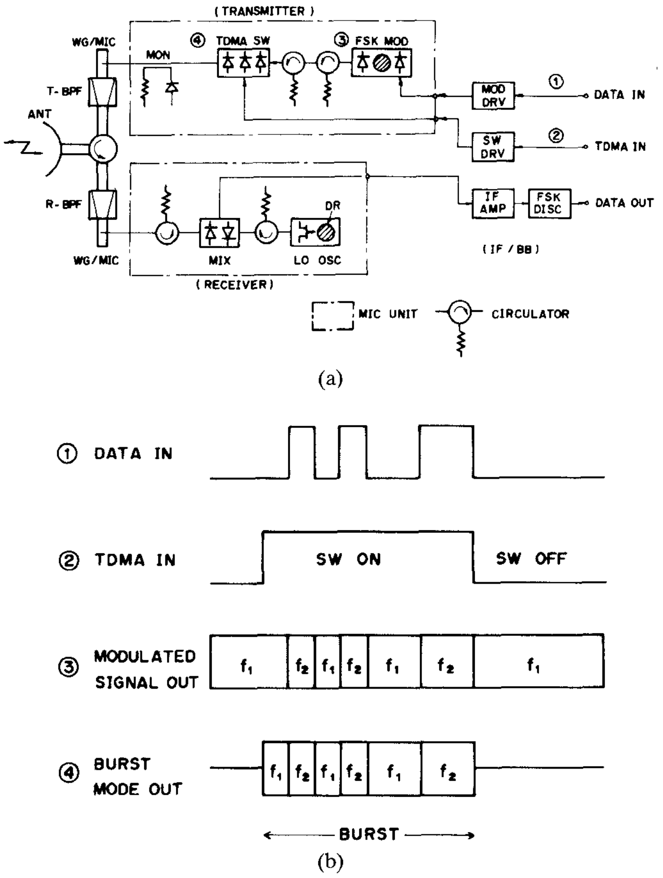


Fig. 1. MIC transmitter/receiver. (a) Block diagrams. (b) Data stream.

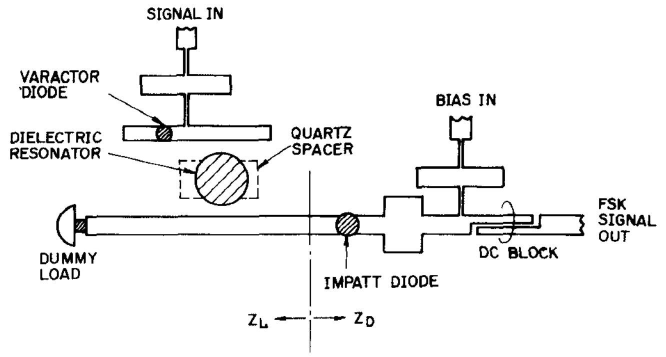


Fig. 2. MIC FSK modulator. The circuit is fabricated by conventional photolithographic techniques on an alumina substrate with a relative permittivity of 9.6.

In order to achieve stable oscillation, the device line ($-Z_D$) and load line (Z_L) were measured and plotted on a Smith chart, as shown in Fig. 3. The intersection of the lines corresponds to the load impedance at the point where an oscillation occurs.

FSK modulation is achieved using a resonance circuit consisting of a varactor diode and a microstrip line. Linearization of differential modulation characteristics has been achieved by optimizing the coupling between the varactor diode and the dielectric resonator [7]. Fig. 4 shows output power and oscillation frequency deviation versus varactor bias voltage. A modulation sensitivity of 3.7 MHz/V and an output power variation of less than 0.6 dB are obtained. Modulation linearity is better than 1 percent in the frequency deviation range of ± 8 MHz.

Oscillation characteristics as a function of temperature are shown in Fig. 5. An output power of 24 dBm, a power deviation of 1.5 dB, and a frequency variation of 50 ppm are obtained in the temperature range of -10–45°C. The operating diode junction temperature is less than 150°C

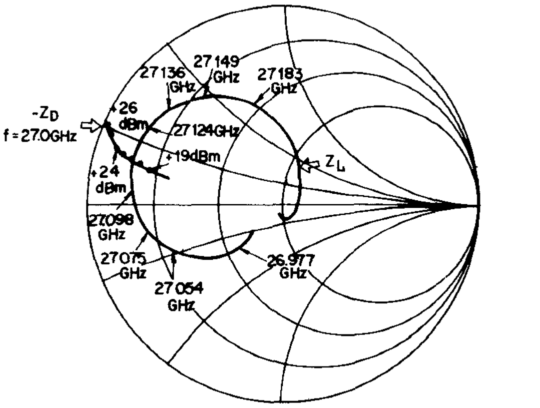


Fig. 3. Relation between device line ($-Z_D$) and load line (Z_L).

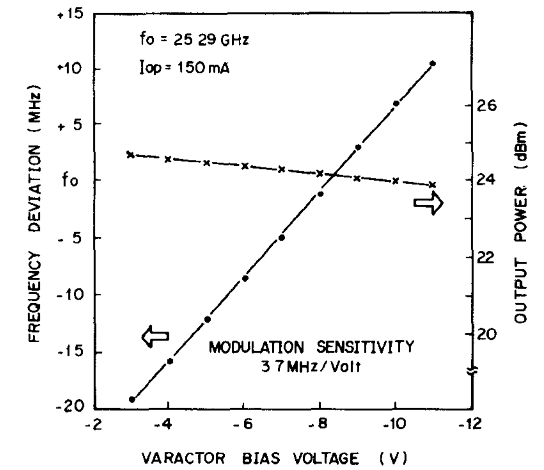


Fig. 4. IMPATT FSK modulator modulation characteristics. The IMPATT diode current (I_{op}) is 150 mA and the center oscillation frequency is 25.29 GHz.

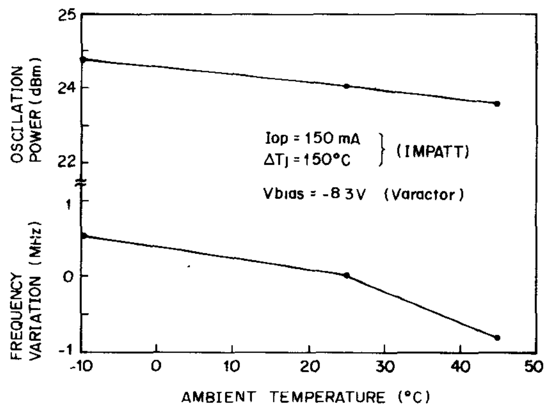


Fig. 5. Temperature dependence of an FSK modulator power and frequency. The junction temperature (ΔT_j) of the IMPATT diode is estimated to be 150°C and the varactor bias voltage (V_{bias}) is -8.3 V.

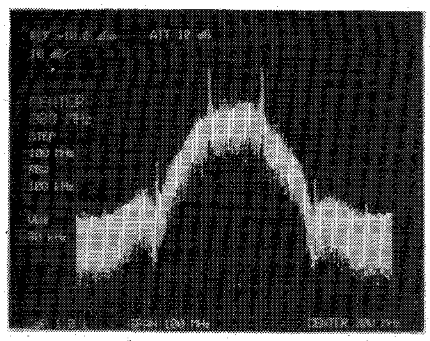


Fig. 6. Output spectrum of an FSK modulator (modulation index = 1.0). Horizontal scale: 10 MHz/div. Vertical scale: 10 dB/div.

above ambient (ΔT_j), which ensures high reliability. The RF spectrum of the FSK modulator is shown in Fig. 6 (modulation index of 1.0).

B. TDMA Switch

An ON/OFF switch, referred to as a TDMA switch, is used to transmit signals in the burst mode. This switch must attain a high ON/OFF ratio and a low insertion loss in order to prevent burst-signal interference, as well as to effectively utilize the FSK modulator output. The switch consists of three p-i-n diodes and Au wires, as shown in Fig. 7. It operates as a low-pass filter when the diodes are in the OFF state and as a short circuit when they are in the ON state [8].

Fig. 8 shows the equivalent circuit in the three-stage TDMA switch, where Z_0 indicates the characteristic impedance of the input/output microstrip lines. Wire inductance is represented by L. The parallel elements R_s, C_j, and R_j correspond to the equivalent circuit of a p-i-n diode. The notations R_s, C_j, and R_j represent series resistance, junction capacitance, and junction resistance, respectively.

The theoretical characteristics of the switch are shown in Fig. 9. Theoretical investigations indicate that the performance of the switch in the millimeter-wave band is greatly dependent on the wire inductance and diode parameters (C_j, R_s). In order to achieve an ON/OFF ratio greater than 60 dB and an insertion loss less than 1 dB, a high-quality diode ($C_j = 0.1$ pF, $R_s = 1.5\ \Omega$) and low inductance wire ($L = 0.15$ nH) are necessary.

The experimental results are also shown in Fig. 9. An ON/OFF ratio greater than 60 dB, an insertion loss of less than 1.5 dB, and a VSWR of less than 2 are attained for the frequency range of 24–28 GHz. The increase in insertion loss is attributed to wire inductance and the increase in R_s. The switch circuit, including diodes, wires, and microstrip line portions, has been packaged and high reliability has been verified.

C. Receiving Mixer

A single-balanced mixer is used as the receiving mixer, in order to reduce the size of the circuit pattern and the number of diodes. Fig. 10 shows the configuration of the mixer which consists of microstrip lines, slotlines, an Au wire, and two beam-lead Schottky barrier diodes. In this

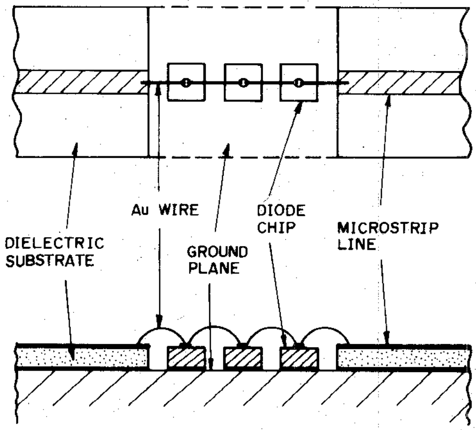


Fig. 7. A TDMA switch. Three p-i-n diodes are bonded on the ground plane with solder and are connected to microstrip lines with Au wires.

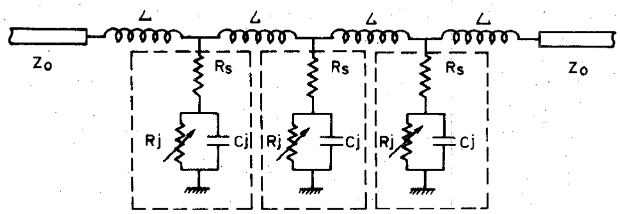


Fig. 8. Equivalent circuit of a TDMA switch. Z_0: characteristic impedance of microstrip lines; L: inductance of wire; and R_s, C_j, R_j: series resistance, junction capacitance, and junction resistance of a p-i-n diode, respectively.

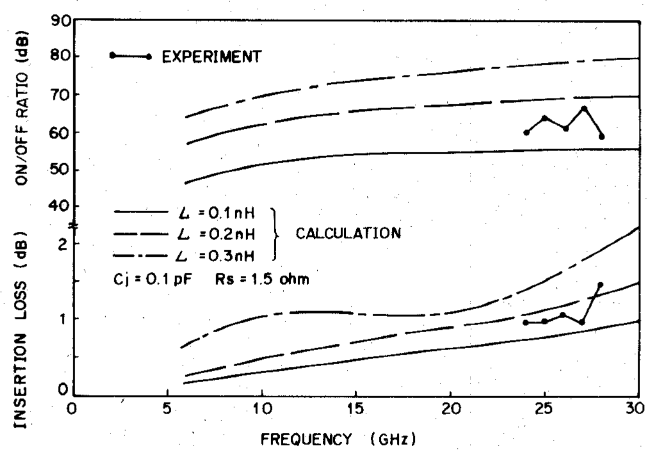


Fig. 9. Performance characteristics of a TDMA switch. Fine lines represent calculated values on condition that the p-i-n diode has a junction capacitance of 0.1 pF and a series resistance of 1.5 Ω, and that the wire inductance is varied from 0.1 to 0.3 nH. The heavy lines containing dots represent experimental results.

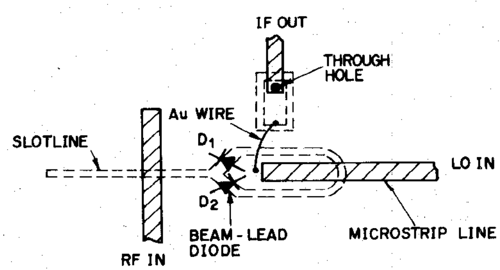


Fig. 10. Circuit configuration of single-balanced mixer. Solid lines show microstrip lines on the substrate, dotted lines show slotlines on the reverse side of the substrate. Two beam-lead diodes are bonded on the slotline.

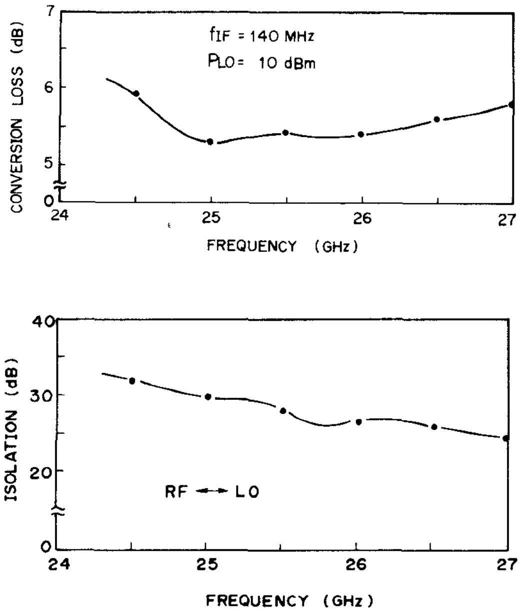


Fig. 11. Conversion loss of balanced mixer, with a fixed intermediate frequency of 140 MHz and a local oscillator power of 10 dBm.

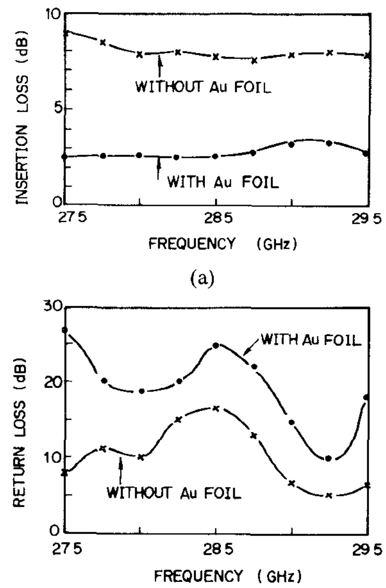


Fig. 12. Transmission characteristics of eight cascaded microstrip lines. With Au foil and without Au foil correspond to the cases, where an Au foil is or is not inserted under the substrates, respectively. (a) Insertion loss. (b) Return loss.

figure, solid lines indicate microstrip lines on the substrate surface, while dotted lines indicate slotlines on the reverse side. Since the Au wire behaves as a low-pass filter due to its series inductance, and the RF electromagnetic field is concentrated in the slotline, the IF circuit composed of an Au wire, coplanar line, and microstrip line is isolated from the RF circuit. Two beam-lead diodes are bonded on the slotline.

The measured conversion loss for a fixed intermediate frequency of 140 MHz is presented in Fig. 11(a). A conversion loss of less than 5.5 dB is obtained over a 1-GHz bandwidth. Isolation between the local oscillator and signal input ports is greater than 20 dB, as shown in Fig. 11(b).

IV. MIC Transmitter/Receiver Performance

MIC components are assembled and integrated in the transmitter/receiver module. Connection losses are fairly large in millimeter-wave bands due to imperfect electrical contact at the substrate ground conductor [3]. In order to evaluate the connection loss between the substrate, eight sections of microstrip lines are cascaded and measured with and without Au foils. Fig. 12 shows the transmission characteristics of microstrip lines having seven connection points. The insertion loss between the substrates is improved by inserting the Au foil under the substrates. The measured loss when the Au foil is under the substrates is evaluated to be less than 0.1 dB per one connection point.

Other causes for the fairly large loss may lie in the MIC circulators and WG filters. Ferrite-disk-type circulators [9] and cylindrical cavity-type (TE^0_{011}) filters [10], [11] have been adopted to reduce excess losses. The cylindrical cavity-type filter is suitable for constructing the compact subscriber radio equipment, because the input/output port location of the filter can be optionally chosen due to its configuration.

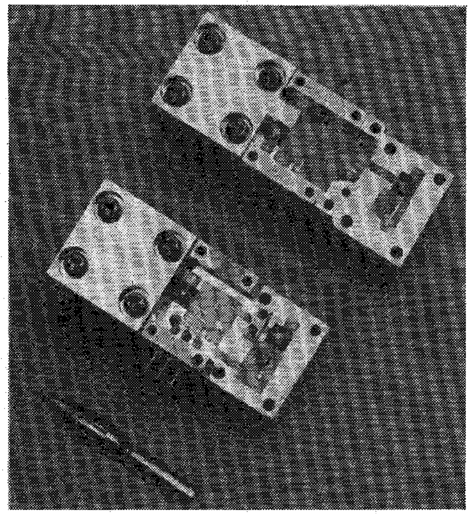
Careful consideration has been given to ensure the reliability of the transmitter/receiver. Encapsulated IMPATT and varactor diodes are used. p-i-n diodes are packaged together with the surrounding circuits, and the beam-lead diodes are sealed using Si coating materials. Narrow gaps in microstrip line circuits, e.g., the dc block, are also sealed. Photographs of the subscriber radio equipment are shown in Fig. 13. The sizes of the MIC transmitter and receiver themselves are 2.7 and 3.2 cm^2, respectively. This compact MIC transmitter/receiver is located at the rear of the antenna.

The major characteristics of the transmitter/receiver are summarized in Table I. The transmitting power is 21 dBm and the frequency stability of the transmitter is within 50 ppm for the temperature range between -5–45°C. The ON/OFF ratio of the transmitting power is greater than 60 dB. The receiving noise figure is 8.7 dB.

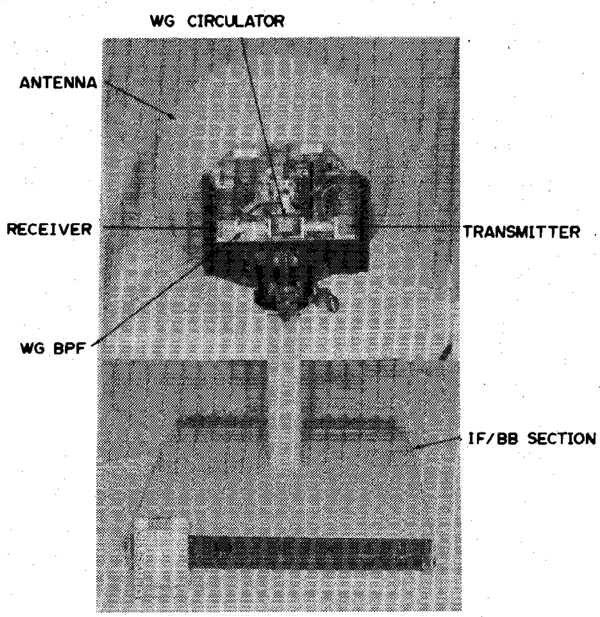
Fig. 14 shows the measured bit error rate of the newly developed FSK equipment compared with that for previously reported ASK equipment. The required CNR for FSK at an error rate of 10^{-4} is about 7 dB smaller than that for ASK. The FSK modulation method is excellent for constructing subscriber radio equipment.

V. Conclusion

A new 26-GHz band MIC transmitter/receiver employing FSK modulation has been developed for the DSR system. MIC technology has been adopted in all RF active and passive circuits, thereby realizing very compact and inexpensive subscriber radio equipment with excellent performance and high reliability. The new equipment has been successfully tested in a year-long field trial. MIC technology can be further extended to develop a transmitter/receiver which can operate in even higher frequency bands.



(a)



(b)

Fig. 13. Photographs of subscriber radio equipment. (a) Internal view of MIC transmitter/receiver. (b) External view of radio equipment.

TABLE I
MIC TRANSMITTER/RECEIVER CHARACTERISTICS.

Item	Characteristics
RF frequency	26-GHz band
Modulation method	FSK
Modulation index	1.0
Clock rate	16.384 MHz
Transmitting power	21 dBm
ON/OFF ratio	60 dB
Frequency stability	50 ppm (-10°C ~45°C)
Power variation	1.5 dB (-10°C~45°C)
Receiving noise figure	8.7 dB
Local oscillator leakage	-50dBm
IF frequency	300MHz
Power consumption	30 W
Dimensions	6.5cm x 3.9cm x 1.5cm

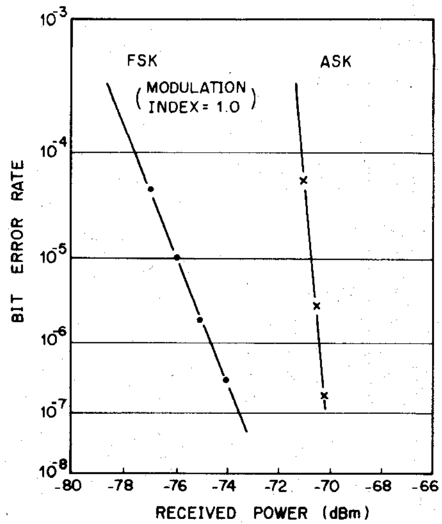


Fig. 14. Measured bit error rate for FSK and ASK. Modulation index for FSK is set to 1.0.

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Analysis and Design of a Single-Resonator GaAs FET Oscillator with Noise Degeneration[1]

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***Abstract*— This paper presents an analysis of a low-noise dielectric resonator GaAs FET oscillator in a frequency-locked loop (FLL), which is used for FM noise degeneration. In this circuit, one resonator serves both as the frequency-determining element of the oscillator and as the dispersive element of the discriminator.**

The results of the analysis are used to generate design guidelines. These guidelines were followed in an experimental realization of an X-band circuit. The measured FM noise was −120 and −142 dBc/Hz at 10- and 100-kHz offset frequencies, respectively, and corresponded closely to predicted results.

I. Introduction

THE increased sophistication of missile and ground radar systems has created the need for stable low-noise solid-state microwave sources with associated FM noise levels that are lower than those realizable with conventional crystal or SAW oscillator-based synthesis techniques.

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[1] Patent pending.

Various source configurations were considered for this application and compared from the standpoint of FM noise, output power (without post-amplification) complexity, performance sensitivity to extreme environmental conditions, and projected cost. The results favored the use of stable bipolar transistor or GaAs FET fundamental oscillators.

Bipolar transistor oscillators exhibit low FM noise and, in conjunction with high Q resonators, are excellent candidates for radar applications at frequencies up to X-band. The superior high-frequency performance of GaAs FET oscillators has made them attractive for use at X-band and above, but their FM noise performance has been demonstrated to be inferior to that of their bipolar transistor counterparts. The FM noise of GaAs FET oscillators may be reduced with high Q resonators and, in this application, the dielectric resonator was deemed most suitable because of its high Q_U (unloaded Q), small size, ruggedness, low cost, and its compatibility with microstrip circuits.

The improvement in the FM noise of a dielectric resonator GaAs FET oscillator, compared to the FM noise of

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