A 7 GHz FM TRANSMITTER UTILIZING GaAs POWER MESFETS

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Abstract

An FM transmitter with a power efficiency of 11.5 % was developed utilizing GaAs power MESFETs for a 7 GHz FM radio-relay equipment. The transmitter, which consists of an FM modulator and power amplifiers, provides an output power of 1 watt and transmitting capability of 960 telephone circuits.

Introduction

High-power, high efficiency amplification[1] and oscillation[2] using GaAs FETs have been reported recently in the C and X bands.

These papers suggest that a high power and high efficiency transmitter of an FM radio relay system can be realized using GaAs power FETs. In this paper, the circuit development of GaAs power FETs for a transmitter of a 7 GHz band base-band remodulating type FM radio relay system is described.

The transmitter consists of an FM modulator, a 2-stage power amplifier, a frequency discriminator and a power monitoring circuit. Two kinds of GaAs power FETs[3] are used in these circuits according to the power level. The transmitter delivers an output power of 1 watt with a power efficiency of 11.5 % and also has a capability of transmitting 960 telephone circuits.

System Configuration

Figure 1 shows the block diagram and level diagram of the developed transmitter of a 7 GHz (6.57-6.87 GHz)band remodulating type FM radio relay system. The FM signal from the modulator is amplified, up to a power level of 1 watt, by the following 2-stage power amplifier. In both the FM modulator and power amplifiers, GaAs power FETs are used. A small amount of the amplified signal is extracted through one of the arms of a dual type directional coupler and fed to a frequency discriminator which operates at 7 GHz. This discriminator is used in an AFC circuit for the FM modulator and a frequency stability of $\pm 5\times10^{-5}/°C \sim 50°C$ is obtained in this transmitter.

A transmitting power monitor is incorporated in the other side of the dual type directional coupler.

The designs of the FM modulator and the power amplifiers will be described.

Design

a) FM Modulator Figures 2a and 2b show the schematic diagram and a simplified equivalent circuit of the 7 GHz FM modulator.

Several circuit configurations[2,4] can be considered as a GaAs FET oscillator, according to its feedback network to be used. In this FM modulator, the drain is grounded and an external resonator is connected between the gate and the ground (the drain). This external resonator not only plays as an feedback network but also reduces the FM noise of the oscillator.

To obtain a good modulation linearity, a double tuned resonant circuit was used, which consists of a main resonator (TM010 mode cavity with a resonant frequency of $\omega 1$) and a sub-resonator ($\omega 2$)which includes a varactor diode. This sub-resonator is built in a metal pipe with a screw thread as shown in Fig. 2a. The coupling to the main resonator is primarily magnetic and it can be adjusted by rotating the pipe. The longitudinal motion of the pipe into the cavity is incidental. The base-band signal is fed to the varactor diode through a low pass filter which is installed in the metal pipe.

In the equivalent circuit in Fig. 2b, the oscillating frequency of the modulator can be expressed in a polynominal as shown below

$$\omega=\omega o(1+a_1v+a_2v^2+a_3v^3+ ---) \qquad (1)$$

where ωo is the oscillating center frequency of the modulator when the D. C. bias voltage to the varactor diode is Vop and V is the normalized base-band signal voltage δ V/Vop

The ai (i=1,2,3---)values are the function of $\omega 1/\omega 0$, $\omega 2/\omega 0$, coupling coefficient k, capacitance ratio Co/Cjop and varactor capacitance VS. voltage exponent γ. The condition for a good modulation linearity is both a2 and a3 equal zero. The typical values of the used varactor diode parameters are cutoff frequency :fc=250 GHz, break-down voltage:VB=40 V, Cjo(V_b=0)=0.79pf Ls=0.15 nh and γ=0.44.

Using these given diode parameters, numerical calculations were carried out by a computer to find the optimum design circuit parameters. The calculated results are $\omega 1/\omega 0=0.98$, $\omega 2/\omega 0=0.91$, K=0.074 and Co/Cjop=2, at the operating bias voltage of 12 volts. As seen in Fig. 2a, $\omega 1$ can be varried by a frequency adjusting screw, and the magnetic coupling coefficient k between the sub-resonator (varactor loop)and the main cavity is also changeable from 0 to about 0.10 by rotating the pipe. This coupling adjustable mechanism makes it easier to get good modulation linearity. The external Q of the modulator was experimentally set to about 90 to keep the S/N at 70 KHz from the carrier at more than 76 dB (test tone deviation:200 KHz r.m.s, and bandwidth:3.1 KHz)

b) Power Amplifier Stage The design objective of this amplifier is an output power of more than 1 watt, with a gain of 8 dB over the frequency range of 6.5-6.9 GHz. Two MESFETs with different power levels are used with common source. The typical output power of these FETs is 27 dBm with a 5 dB gain for the 1st stage, and 31 dBm with a 4 dB gain for the 2nd stage. The dynamic impedances of these MESFETs were measured by a substitution method. Using the measured impedances, matching circuits were disigned by a computer optimization procedure.

Since the devices are conditionally stable below 4 GHz, ingenious matching circuits are necessary for the multistage amplifier to avoid any instability below 4 GHz.

A stabilizing circuit shown in Fig. 3a has been developed for this purpose. This circuit, incorporated in the input circuit, provides a constant resistive termination to the gate of the FET in a wide frequency range below 4 GHz, even if the load is open-or short -circuited. This stabilizing circuit provides another function as a biasing network to the gate of the FET. The gate bias voltage can be supplied through a chip resistor in the stabilizing circuit and a low pass type biasing network. Figure 3b shows the insertion loss and return loss (looking from the gate side) characteristics of this circuit (terminated by a 50 Ω load). The insertion loss at center frequency is less than 0.4 dB.

This amplifier stage is constructed on a microstrip circuit using a Teflon-glass-fiber printed board, with a thickness of 0.8 mm.

c) Discriminator The discriminator is composed of a microstrip circuit section and a re-entrant type high Q cavity. The cavity is temperature-stabilized by a combination of metals such as iron and super-invar. The microstrip circuit includes a MIC circulator, a 180° hybrid and two detecting circuits.

Performance

The typical characteristics of the FM modulator and the power amplifier are as follows:

a) FM Modulator

operating frequency	:6.5-6.9 GHz
Output power	:22dBm
Differencial gain(DG)	:<1 % at fo±10 MHz
Differencial phase(DP)	:<1 ns at fo±10 MHz
Frequency stability	:within±250 KHz with AFC and ±3 MHz without AFC
Modulation sensitivity	:4.5 MHz/V
Operating bias voltage	:-8 volts
Efficiency	:10 %

The temperature characteristics of DG and DP are shown in Fig. 4.

b) 2 Stage Power Amplifier

Operating frequency	:6.5-6.9 GHz
Output power	:30.5 dBm at 1 dB compression
Input power	:22 dBm
Efficiency	:21.5 %

The operating drain-source voltage of these FETs is typically 8 volts, which is soft enough to leave a sufficient margin, considering it has a break-down voltage of more than 15 volts.

The internal view of this amplifier is shown in Fig. 5. The result of the 960 channel noise loading test for this transmitter is shown in Fig. 6. From this figure, it is shown that the performance satisfies the specifications required for the transmitter of a 960 channel radio relay system.

Conclusion

The design and performance of a 7 GHz band FM transmitter utilizing GaAs power MESFETs have been described. GaAs power MESFETs are used in the FM modulator and high power amplifiers in the transmitter. The transmitter delivers an output power of more than 1 watt with an efficiency of 11.5 % over a bandwidth of 400 MHz.

Reference

1) H. Q. Tserng, etal, "X-Band MIC GaAs FET Power Amplifier", pp 101-103, 1976 IEEE-MTT-S International Microwave Symposium.
2) H. Abe, etal, "A High-Power Microwave GaAs FET Oscillator", pp 164-165, Digest of technical paper, 1976 IEEE International Solid-State Circuits Conference.
3) M. Fukuta, etal, "X-Band GaAs Schottky Barrier Power FET with a High Drain-Source Breakdown Voltage", pp 166-167, 1976 IEEE International Solid State Circuits Conference.
4) M. Maeda, etal, "Design and Performance of X-Band Oscillators with GaAs Schottky-Gate Field-Effect Transistors", IEEE Trans. Microwave Theory Tech., vol. MTT-23, pp 661-667, August 1975.

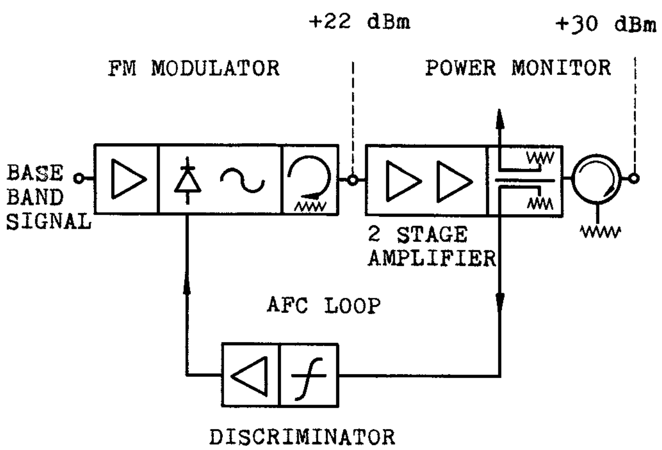


Figure 1. Block Diagram and Level Diagram of the 7 GHz band Transmitter

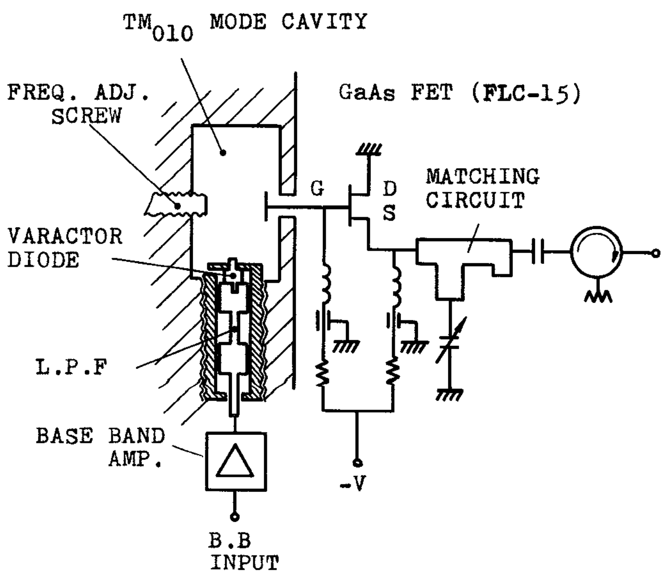
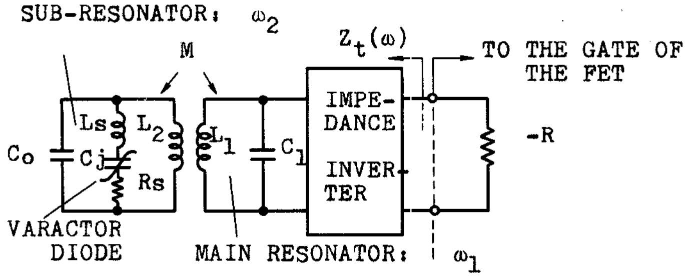


Figure 2(a). Schematic Diagram of the 7 GHz FM Modulator



$M = \sqrt{L_1 \cdot L_2}$

ω_o : CENTER FREQUENCY i.e. $Z_t(\omega)\big|_{\omega=\omega_o} = 0$

ω_1/ω_o : NORMALIZED RESONANCE FREQUENCY OF MAIN RESONATOR

ω_2/ω_o : NORMALIZED RESONANCE FREQUENCY OF SUB-RESONATOR

Figure 2(b). Simplified Equivalent Circuit of a Double Tuned FM Modulator

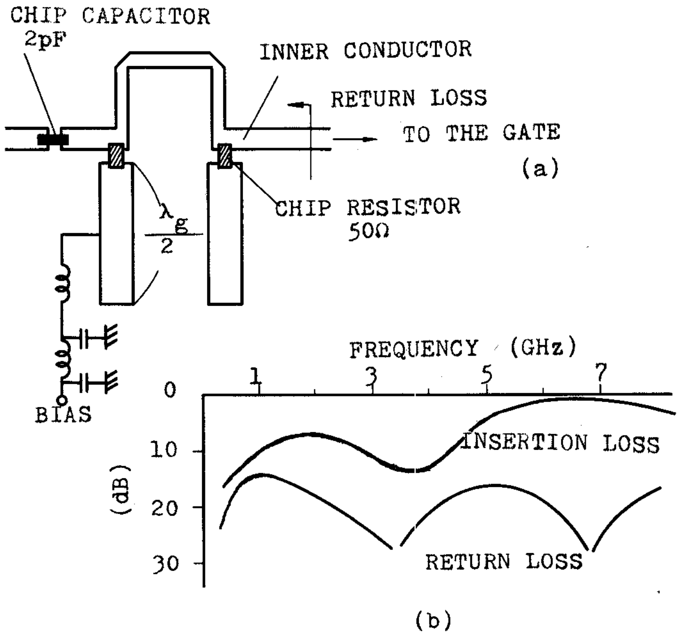


Figure 3. A Stabilizing Circuit (a) and its Characteristics (b)

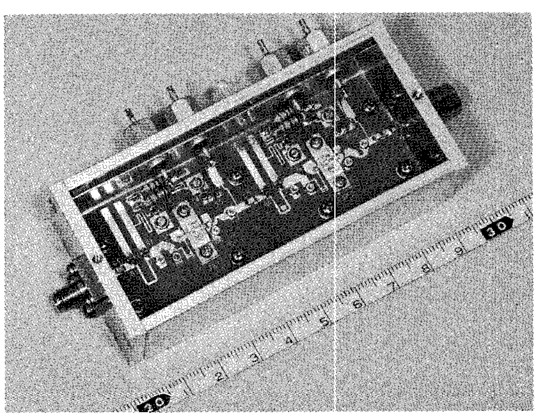


Figure 5. 2 Stage 1 W GaAs MESFET Power Amplifier

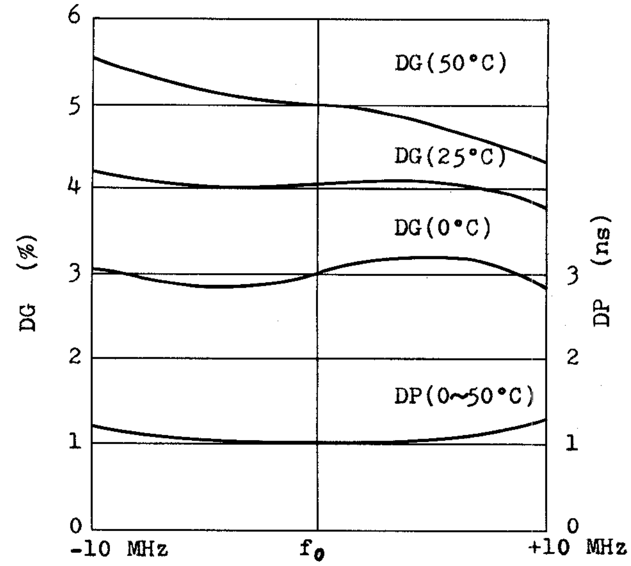


Figure 4. Differential Gain (DG) and Phase (DP) Characteristics of the 7 GHz Band FM Modulater

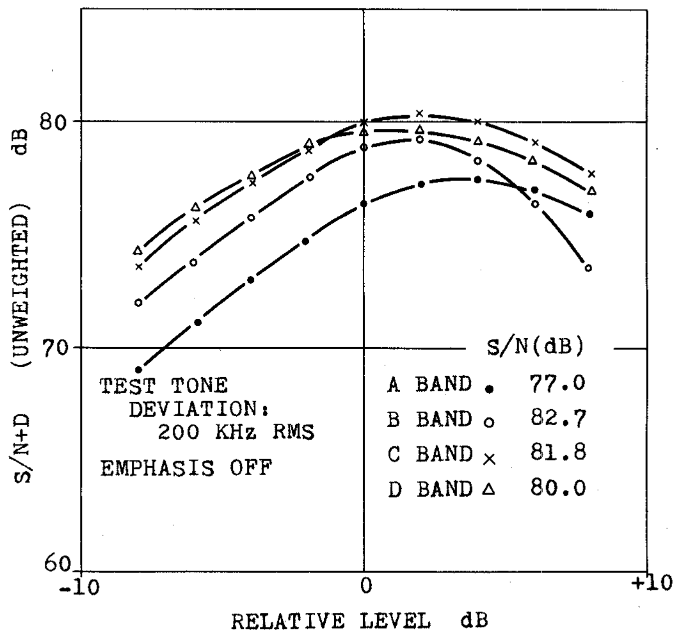


Figure 6. Noise Loading Test Results of the 7 GHz Transmitter