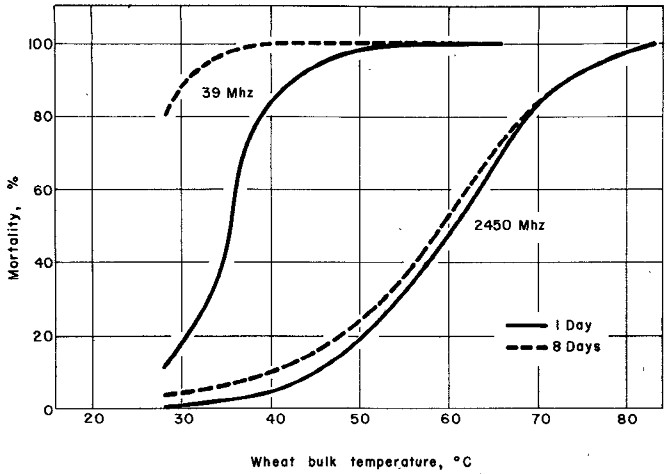

Fig. 3. Comparison of mortalities of adult rice weevils treated in hard red winter wheat at frequencies of 39 and 2450 MHz. (Mortalities observed 1 and 8 days after treatment.)

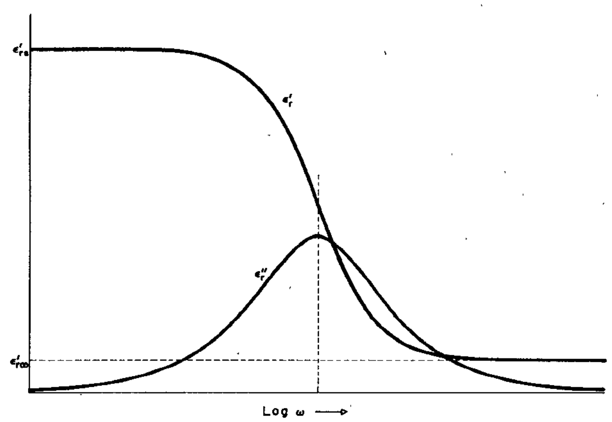

Fig. 4. Dispersion and absorption curves representing the Debye relaxation process for polar molecules.

Cost estimates for RF insect control in grain, based on fixed-frequency equipment operating at one frequency, indicate that RF methods might be three to five times more expensive than chemical controls currently in use. Various other factors that influence practical application have also been considered [7]. A major improvement in the efficiency of RF treatment could materially change the economic picture. Therefore, a survey of the frequency and temperature dependence of the dielectric properties of insects and host materials for any particular application may provide important information on which to assess the practicability of an RF insect-control application.

Continually increasing concern about environmental aspects of chemical control methods is another factor that should be considered. RF insect-control methods offer two unique advantages—speed of treatment and a lack of potentially harmful chemical residues. Establishment of any nonthermal effects, which might be exploited for insect-control purposes, should substantially improve chances for practical application. On the basis of differential dielectric heating alone, however, it may be possible, with improvements in effectiveness and with developing technology, to apply RF insect-control methods for certain applications for which the techniques may be especially well suited.

REFERENCES

[1] A. M. Thomas, "Pest control by high-frequency electric fields—Critical resume," British Electrical and Allied Industries Research Association, Thorncroft Manor, Dorking Road, Leatherhead, Surrey, England, Tech. Rep. W/T23, 1952.

[2] H. Frings, "Factors determining the effects of radio-frequency electromagnetic fields on insects and materials they infest," *J. Econ. Entomol.*, vol. 45, pp. 396–408, 1952.

[3] A. A. Peredel'skii, "The problem of electrotechnical measures for combatting harmful insects" (in Russian), *Usp. Sovrem. Biol.*, vol. 41, pp. 228–245, 1956.

[4] F. L. Watters, "Control of insects in foodstuffs by high-frequency electric fields," *Proc. Entomol. Soc. Ontario*, vol. 92, pp. 26–32, 1962.

[5] S. O. Nelson, "Electromagnetic and sonic energy for insect control," *Trans. ASAE*, vol. 9, pp. 398–403 and 405, 1966.

[6] ——, "Electromagnetic energy," in *Pest Control—Biological, Physical, and Selected Chemical Methods*, W. W. Kilgore and R. L. Doutt, Ed. New York: Academic, 1967, pp. 89–145.

[7] ——, "Insect-control studies with microwaves and other radiofrequency energy," *Bull. Entomol. Soc. Amer.*, vol. 19, pp. 157–163, 1973.

[8] R. L. Carpenter and E. M. Livstone, "Evidence for nonthermal effects of microwave radiation: Abnormal development of irradiated insect pupae," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Biological Effects of Microwaves*), vol. MTT-19, pp. 173–178, Feb. 1971.

[9] S. O. Nelson and W. K. Whitney, "Radio-frequency electric fields for stored-grain insect control," *Trans. ASAE*, vol. 3, pp. 133–137 and 144, 1960.

[10] S. O. Nelson and B. H. Kantack, "Stored-grain insect control studies with radio-frequency energy," *J. Econ. Entomol.*, vol. 59, pp. 588–594, 1966.

[11] S. O. Nelson, L. E. Stetson, and J. J. Rhine, "Factors influencing effectiveness of radiofrequency electric fields for stored-grain insect control," *Trans. ASAE*, vol. 9, pp. 809–815 and 817, 1966.

[12] H. H. Webber, R. P. Wagner, and A. G. Pearson, "High-frequency electric fields as lethal agents for insects," *J. Econ. Entomol.*, vol. 39, pp. 487–498, 1946.

[13] V. H. Baker, D. E. Wiant, and O. Taboada, "Some effects of microwaves on certain insects which infest wheat and flour," *J. Econ. Entomol.*, vol. 49, pp. 33–37, 1956.

[14] W. K. Whitney, S. O. Nelson, and H. H. Walkden, "Effects of high-frequency electric fields on certain species of stored-grain insects," Market Quality Research Division, AMS, U. S. Department of Agriculture, Marketing Res. Rep. 455, 1961.

[15] A. M. Kadoum, H. J. Ball, and S. O. Nelson, "Morphological abnormalities resulting from radiofrequency treatment of larvae of *Tenebrio molitor*," *Ann. Entomol. Soc. Amer.*, vol. 60, pp. 889–892, 1967.

[16] P. S. Rai, H. J. Ball, S. O. Nelson, and L. E. Stetson, "Morphological changes in adult *Tenebrio molitor* (Coleoptera: Tenebrionidae) resulting from radiofrequency or heat treatment of larvae or pupae," *Ann. Entomol. Soc. Amer.*, vol. 64, pp. 1116–1121, 1971.

[17] ——, Cytopathological effects of radiofrequency electric fields on reproductive tissue of adult *Tenebrio molitor* (Coleoptera: Tenebrionidae)," *Ann. Entomol. Soc. Amer.*, vol. 67, pp. 687–690, 1974.

[18] S. O. Nelson and L. F. Charity, "Frequency dependence of energy absorption by insects and grain in electric fields," *Trans. ASAE*, vol. 15, pp. 1099–1102, 1972.

[19] S. O. Nelson and L. E. Stetson, "Comparative effectiveness of 39- and 2450-MHz electric fields for control of rice weevils in wheat," *J. Econ. Entomol.*, vol. 67, pp. 592–595, 1974.

A More Than 4-Percent-Efficiency Solid-State Transmitter for a 4-GHz Radio Relay

YUJI KITAHARA, TSUTOMU KYUZAKI, AND RYOJI TAMURA

***Abstract*—An FM transmitter having 220-mW output power and 5-W total dc input power and operating in the 4-GHz band has been developed. This transmitter provides a dc-to-RF signal-conversion efficiency of more than 4 percent. Featuring low power consumption and high reliability, this transmitter is suitable for use as a transmitter or an exciter for radio relay of a maximum of 1380 channels.**

INTRODUCTION

This transmitter has been developed with consideration for the use of batteries and elimination of maintenance servicing. In order to achieve low power consumption and high-reliability transmitter performance it may be inevitable that one must reduce the number of active devices and improve the efficiencies of these devices. For this purpose, it may be most desirable to use a high-gain transistor injection-locked amplifier in combination with a low-level up converter driven by a low-power local oscillator.

A transistor injection-locked amplifier which employs a transistor

Manuscript received May 6, 1974; revised August 26, 1974.
The authors are with the Microwave and Satellite Communication Division, Nippon Electric Company, Ltd., Yokohama, Japan.

as a two-terminal element is used. Although the conventional transistor amplifiers used as 4-GHz band RF amplifiers employ a transistor as a three-terminal element and are being developed in performance [1], no amplifier that provides a gain over 14 dB and an output power over 200 mW by one transistor has yet been put into practical use. A simple alarm circuit is provided to indicate locking failure without affecting the transmitter performance.

DESIGN CONSIDERATION

The most essential requirements in designing transmitters for radio relay use may be not only high electrical performance but high reliability, economy, and, particularly, low power consumption. When the transmitting power need of a transmitter is determined by the system design, the gain required of the RF amplifier should be obtained with the minimum number of active devices able to meet these requirements effectively.

Use of a transistor as an RF amplifier in the 4-GHz band may be realized in the conventional amplifiers and injection-locked configurations. At present, the use of a transistor as an injection-locked amplifier is more suitable than its use as a conventional amplifier for obtaining high gain at high frequencies in the microwave band. Since the injection-locked amplifier is designed on the basis of an oscillator, the emitter need not be grounded directly as in the conventional amplifiers, and a dc power supply of a negative polarity can be used without taking care of the lead inductance of a bypass condenser connected to the emitter. Fig. 1 shows the gain and output-power characteristics obtained when a transistor is used as an injection-locked amplifier.

The output power of the high-gain injection-locked amplifier is just that of an oscillator providing sufficiently low Q.

The gain characteristic of an injection-locked amplifier is limited only by the required bandwidth. The gain characteristic obtained at RF frequencies with the locking range being 80-MHz constant is shown in Fig. 1.

The bandwidth of the injection-locked amplifier becomes narrow with the decrease of the input power. Using this characteristic of the injection-locked amplifier, when the bandwidth becomes so narrow as to cause transmission characteristic degradation in the transmitter used for radio relay of 1380 channels, the power supply to the injection-locked amplifier is shut off so as to prevent emission of free-run oscillating power due to locking failure.

This transmitter uses a transistor multiplier oscillator (TMO) as the local oscillator for the following reason. At present, the efficiency of a 4-GHz transistor oscillator is lower than that of a 2-GHz transistor oscillator. According to our research, the efficiency of a 4-GHz cavity-controlled oscillator is approximately 10 percent, which is a little better than the efficiency of a 4-GHz cavity-controlled TMO (approximately 6 percent). Since, as is well known, 4-GHz transistors are more expensive than 2-GHz transistors, use of TMO as the local oscillator is very advantageous from the economical standpoint.

The up converter operates at low levels and requires no particular consideration for the diode junction temperature. Therefore, the microwave circuit of the up converter is composed of Teflon fiberglass microstrip line, and the diode is a ribon-case silicon varactor diode.

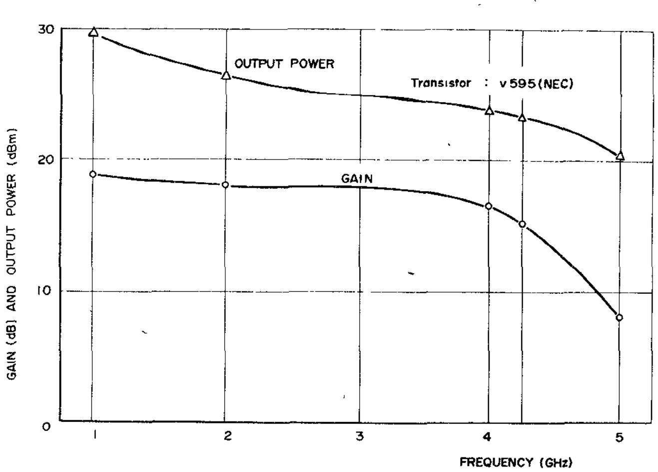

Fig. 1. Gain and output-power characteristics of an injection-locked amplifier.

CIRCUIT DESCRIPTION

The overall transmitter is composed of a local oscillator, an up converter, and a transistor injection-locked amplifier as shown in Fig. 2.

The 4-GHz local power is fed through an isolator and a circulator to the up converter to be mixed with a 70-MHz IF signal, thereby generating a 4-GHz RF signal. The 4-GHz RF signal is then passed through an isolator and a circulator to the transistor injection-locked amplifier to be amplified by a gain of approximately 14 dB. Then a transmitting signal of 23.5 dBm is obtained at the transmitter output terminal.

As noted earlier, a portion of the input power of the transistor injection-locked amplifier is detected and used as the alarm signal for automatic cutoff at locking failure.

DETAILED COMPONENT DESCRIPTIONS

A. 4-GHz Local Oscillator

Fig. 3 shows a circuit diagram of a 4-GHz local oscillator using a reentrant coaxial cavity made of super-Invar ($w1$) in the 2-GHz range. A 4-GHz-band local-oscillator signal, obtained by doubling the fundamental frequency of the same transistor, is fed through a 4-GHz coaxial cavity ($w2$) to the output terminal.

B. Up Converter

Fig. 4 shows the mechanical construction and equivalent circuit of an up converter. The varactor diode is mounted on a Teflon fiberglass microstrip line. The up converter is tunable over a 4-GHz frequency band by adjusting a tuning screw.

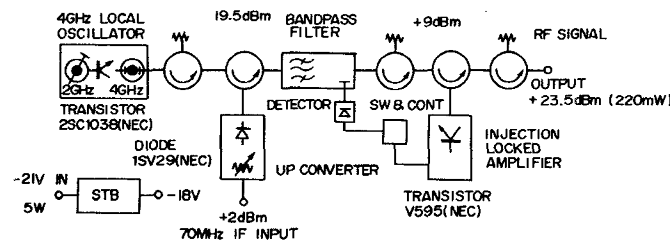

Fig. 2. Block diagram of the transmitter.

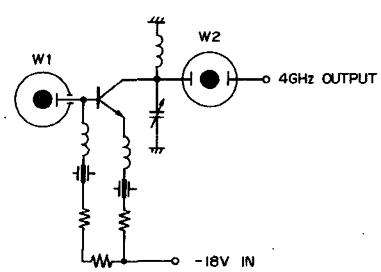

Fig. 3. Schematic diagram of the local oscillator.

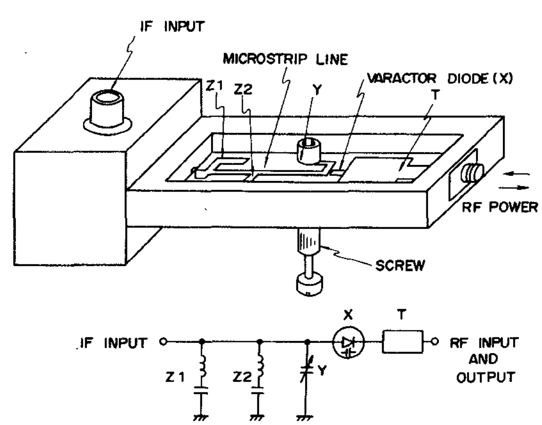

Fig. 4. Mechanical construction and equivalent circuit of the up converter.

In the equivalent circuit, X denotes the varactor diode, Y a variable capacitor, T a transformer, and $Z1$ and $Z2$ the 4-GHz-band rejection filters. The reactance component of the varactor diode X can be compensated by tuning with the variable capacitor Y over the 4-GHz frequency band. The impedance of the diode (approximately 10 Ω) and that of the 50-Ω transmission line are matched by the transformer T.

C. Transistor Injection-Locked Amplifier

Fig. 5 shows a circuit diagram of the transistor injection-locked amplifier which is composed of a four-port circulator and a 4-GHz-band transistor oscillator. In Fig. 5, $Y1$ and $Y2$ denote variable capacitors, T a transformer, and K the coupling coefficient of the transformer. Capacitor $Y1$ is used for adjusting the oscillation frequency of the 4-GHz oscillator and $Y2$ is a feedback capacitor.

PERFORMANCE

Output power, power consumption, and efficiency of transmitter and component panels are shown in Fig. 6. As shown in Fig. 6, the total efficiency of this transmitter is greater than 4 percent with output power of 220 mW.

The output-power and gain characteristics of the amplifier are shown in Fig. 7. The output-power characteristic shown was obtained by varying the input RF frequency with the RF input power being +9-dBm constant. The locking frequency range at the standard gain of 14 dB is approximately 2.2 percent.

The output power and AM–PM conversion of the up converter for 70-MHz IF input are shown in Fig. 8. The output power of the injection-locked amplifier as a function of the 70-MHz IF input power is also shown in Fig. 8. The output power of the transmitter at the standard IF input level of +2 dBm is +23.5 dBm (approximately 220 mW).

The AM–PM conversion shows the phase shift caused by varying the IF input level. Phase shift for a 4-dB variation in IF level is less than 10°. The differential characteristic and amplitude response of the transmitter are shown in Fig. 9. The 200-kHz delay of this transmitter was within 3 ns/±10 MHz. The differential gain and amplitude response of this transmitter were respectively 0.1 percent/±10 MHz and within 0.3 dB/±10 MHz.

The baseband frequency response of this transmitter is shown in Fig. 10. The solid line in the figure shows its frequency response at the standard IF input level of 2 dBm and the dotted lines show the frequency response at lower IF input levels. When the IF input level is +2 dBm, the deviation of the amplitude characteristic is within 0.05 dB over a 10-kHz–10-MHz range.

When the IF input level is lowered, the frequency response in the high-frequency range drops since the gain of the injection-locked amplifier is raised and the locking range is reduced.

When this transmitter is used in combination with a receiver, the

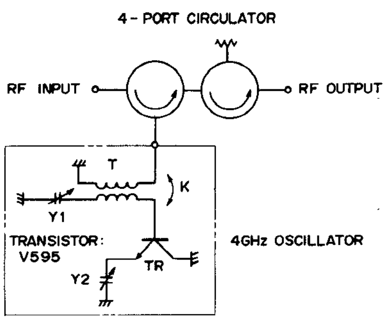

Fig. 5. Circuit diagram of the transistor injection-locked amplifier.

	OUTPUT POWER	POWER CONSUMPTION	EFFICIENCY
TRANSMITTER (TOTAL)	(RF) 220mW	(DC-21V) 5.0 W	4.4%
LOCAL OSCILLATOR	(RF) 90mW	(DC-18V) 1.6W	5.5%
INJECT. LOCK. AMP	(RF) 220mW	(DC-18V) 2.2W } 4.0W	10 %
SW & CONT		(DC-18V) 0.2W	
VOLTAGE STABILIZER	(DC-18V) 4.0W	(DC-21V) 5.0W	80 %

Fig. 6. Output power, power consumption, and efficiency of the transmitter and component panels.

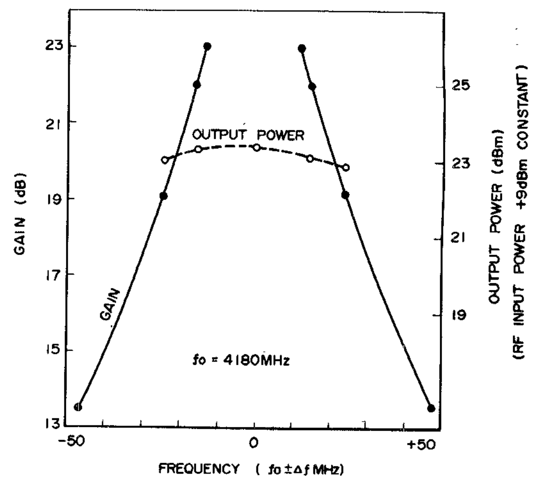

Fig. 7. Output-power and gain characteristics of the injection-locked amplifier.

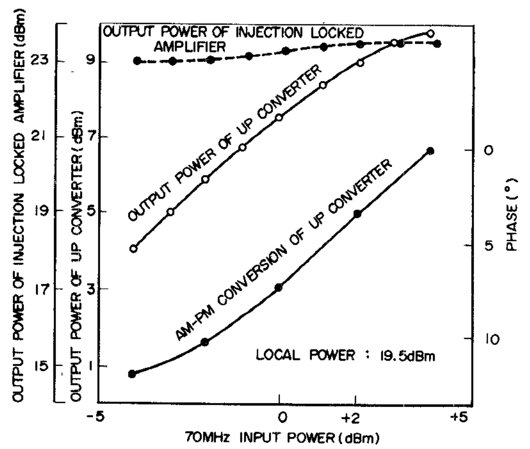

Fig. 8. Output power and AM–PM conversion of the up converter versus 70-MHz IF input power, and output power of the injection-locked amplifier versus 70-MHz IF input power.

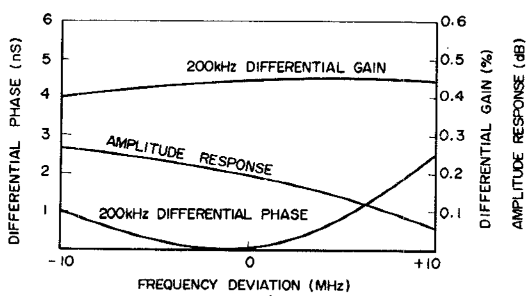

Fig. 9. Amplitude response and differential characteristics of the transmitter.

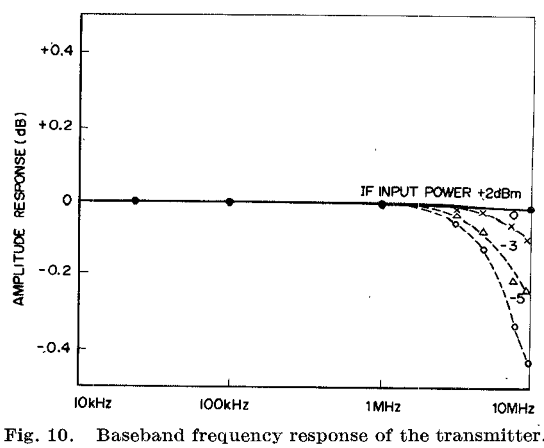

Fig. 10. Baseband frequency response of the transmitter.

$S/N + D$ and thermal noise caused in the noise loading test of 1380 channels were more than 75 dB and more than 78 dB, respectively.

CONCLUSION

A 4-GHz all solid-state 1380-channel FM transmitter using 5 W in total dc input, 220 mW in output power, and exhibiting more than 4 percent in dc-to-RF signal-conversion efficiency has been developed by using, in combination, a low-power local oscillator, a low-level up converter, and a high-gain transistor injection-locked amplifier.

Using only two transistors and a varactor diode together with a stabilizer and an alarm circuit, this combination provides a reliable and practical FM transmitter.

ACKNOWLEDGMENT

The authors wish to thank Dr. Y. Kaito for his valuable discussions and suggestions on this work. They also wish to thank I. Haga for his preparation of the transistor injection-locked amplifier and local oscillator.

REFERENCES

[1] a) P. T. Chen, "Design and applications of 2 ~ 6.5 GHz transistor amplifiers," in *1973 IEEE Int. Solid-State Circuits Conf. Digest Tech. Papers*, pp. P76–P77.
b) A. Presser *et al.*, "2.6 ~ 3.2 GHz transistor amplifier," in *Proc. 1971 High Frequency General Conf.* (Cornell Univ., Ithaca, N. Y., 1971), vol. 3, p. 445.

Development of a Pulse Compression Distance Measuring Equipment System Using Surface Acoustic Wave Devices

DONALD W. MELLON AND WILLIAM D. DANIELS, MEMBER, IEEE

***Abstract*—Proposed *C*-band distance measuring equipment (DME) requires the use of triodes to generate high-power *C*-band transmitted pulses. The inherent short life of these triodes necessitates placing this equipment in physically accessible areas of the aircraft, often long distances from the antenna. Losses incurred in transmitting the *C*-band pulse to the antenna can increase the power requirements of the system.**

A pulse compression system has been designed to solve the cost of maintenance problems by using reliable low-power solid-state transmitters and also allowing the equipment to be installed close to the antenna. The use of a pulse compression system allows a reduction in peak transmit power by a factor equal to the time bandwidth (BW) product of the transmit pulse. Size, weight, and reliability are also improved by implementing surface wave devices (SWD's) in the pulse compression airborne interrogator.

INTRODUCTION

Distance measuring equipment (DME) systems aid aircraft by providing long-range navigational data and short-range high-resolution landing information. Current systems, operating at *L*-band frequencies, do not meet the accuracy requirements of the proposed microwave landing system (MLS) [1]. A pulsed RF *C*-band system, identical in all significant respects to the *L*-band system except for channel bandwidth (BW), has been designed to meet these range resolution requirements.

A significant undesirable feature of the *C*-band system is the air to ground power requirements which necessitates the use of microwave triodes which typically have mean time between failures around 4000 h. Thus the tubes must be placed in easily accessible areas of the aircraft for maintenance. Available placement areas are long distances from the antenna, thus increasing the power generating requirement.

In this short paper we discuss an alternate *C*-band DME system which reduces the transmitted power requirements by a factor of thirty (30), thus allowing the use of low-power high-reliability [2] solid-state circuitry while providing the accuracy requirements of the MLS system. The pulse compression airborne equipment will occupy one half the volume and weigh one third as much as the pulsed *C*-band equipment. Due to reduced periodic maintenance this equipment can be located based on performance rather than accessibility.

SYSTEM DESCRIPTION

The basic elements of a DME system are the airborne interrogator, ground based transponder, and an airborne clock. Calculating the distance between interrogator and transponder is accomplished by determining the signal propagation time for the round trip. A block diagram of the complete surface wave device (SWD) DME system is shown in Fig. 1.

Interrogation of a particular ground station is done by transmitting a pulse pair and timing the reply interval. Reply identification is done in the aircraft by using random pulse position jitter and using this *a priori* knowledge for range gating the reply. That is, the aircraft transmits fixed pulse pairs at a random repetition rate and then processes only those replies which occur in a predicted range gate. Ground station channelization is done in the time domain by 10 different pulse pair spacings and in the frequency domain by 20 separate frequency bands. A description of present DME systems is given by Hirsch [3].

Although the performances of pulsed *C*-band DME and the pulse compression DME are similar, there are important implementation differences. First, the peak power requirement of the triode DME is 150 W to provide 30-nm range whereas the pulse compression system using SWD's with a 3-MHz BW and 10-μs expanded pulse length requires only 5 W of transmitted power. This power can easily be generated using a 40-W solid-state *L*-band amplifier and X-4 multiplier. Second, the signal dynamic range requirements dictate the use of a precision 60-dB dynamic range log amp in the pulsed DME receiver, whereas in the SWD system all signals are processed through a dynamic range equal to the signal to noise improvement ratio of 13 dB. Third, the spectrum BW of the transmitted RF pulse is several times larger than the channel BW requiring a frequency validation circuit in the receiver which limits adjacent channel selectivity to 8 dB. The SWD spectrum BW is concentrated resulting in an adjacent channel selectivity of 30 dB. Fig. 2 is a block diagram of the SWD DME interrogator and transponder IF sections.

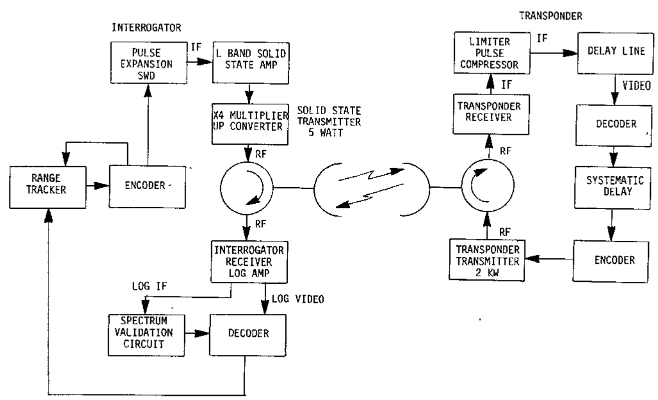

Fig. 1. Block diagram of the complete SWD DME system.

Manuscript received May 21, 1974; revised August 30, 1974.
The authors are with Texas Instruments, Incorporated, Dallas, Tex. 75222.