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R-F SIMULATOR FOR A LONG-PULSE RADAR

by

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ABSTRACT

An X-band radar target simulator possessing spectral purity, frequency stability, and precise calibration of output power is described. The simulator provides outputs at 9.720 Gc/s and 30 Mc/s and is tunable over a 1.2 Mc/s range. Output power is variable from $-75\ db_m$ to $-115\ db_m$ with an absolute accuracy of ± 0.6 db. Frequency stability at X-band is 1 part in 10^6/hr.

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Radar-target simulators are usually designed to meet the needs of a particular radar system, or class of radar systems. The need to test and evaluate a radar instrument for a space application has led to the design and construction of the X-band echo simulator described in this article. The radar instrument is intended for the measurement of the electromagnetic reflection coefficient of extended areas of planetary surfaces from a satellite or space probe. This measurement involves the accurate determination of the energy in both the transmitted pulse and the received echo. The following radar-system parameters provide the basis for the design of the simulator.

Transmitter Frequency	9.720 Gigacycles per second (Gc) ± 0.6 Megacycles per second (Mc)
Frequency Stability (long term)	better than 2 parts in 10^6
Intermediate Frequency	30 Mc
Transmitter Pulse Duration	1.0 Millisecond
Maximum Expected Doppler Shift	± 380 Kilocycles per second (Kc)
Maximum Expected Doppler Spread with an r-f pulse	± 35 Kc
Receiver Bandwidth (to accommodate Doppler shift)	1 Mc

Simulator Design Specifications

In order to permit accurate and meaningful testing of the radar, several special features are incorporated into the target simulator. A long-term stability of better than two parts in 10^6 is required to make the frequency stability of the simulated echo comparable to the transmitter frequency stability. The carrier frequency of the simulator can be tuned over a range of ± 600 kc by means of a variable frequency oscillator. This tuning capability provides complete coverage of the range of expected doppler shifts with some overlap at each end. A key feature of the radar is that it includes circuitry to measure the energies in the transmitted pulse and the echo pulse. Hence, the simulator output-power calibration circuitry is designed to be as accurate as possible with the calibration equipment available. The maximum probable error in measured output power is ± 0.5 db.

Simulator Configuration

Figure 1 shows a block diagram of the simulator. In order to attain the required radio-frequency stability while retaining the feature of continuous tuning over a 1.2-Mc band, a method of up-conversion using a stable microwave (9.690-Gc) source and a variable high-frequency (30-Mc) source was adopted. With this method of frequency control, the frequency stability is determined by the stability of the fixed-frequency microwave source. This source can be crystal-controlled or cavity-referenced to yield stabilities approaching one part in 10^6. The 30-Mc signal need not have stability much greater than 1 part in 10^3. The center frequency of the variable high-frequency source is adjustable in order to bring the signal into the receiver pass band, and the signal can be frequency and amplitude modulated to simulate the desired echo signal. The simulated echo-signal spectrum can be easily observed at 30 Mc before up-conversion to X band. An additional advantage of this choice of frequency synthesis is that the 30-Mc signal is of the proper frequency to be injected directly into the radar i-f amplifier for test purposes.

The variable high-frequency source consists of a tunable low-power transistorized 15-Mc oscillator and frequency doubler with output frequency variable from 29.4 Mc to 30.6 Mc. The nominal 30-Mc output signal is pulse-modulated to simulate an echo. The output frequency of this section is controlled by means of an L-C resonant circuit. The output of a series-tuned Colpitts transistor oscillator at 15 Mc is doubled to 30 Mc by means of a frequency doubler which is collector-modulated. This configuration ensures that the 30-Mc output of the variable high-

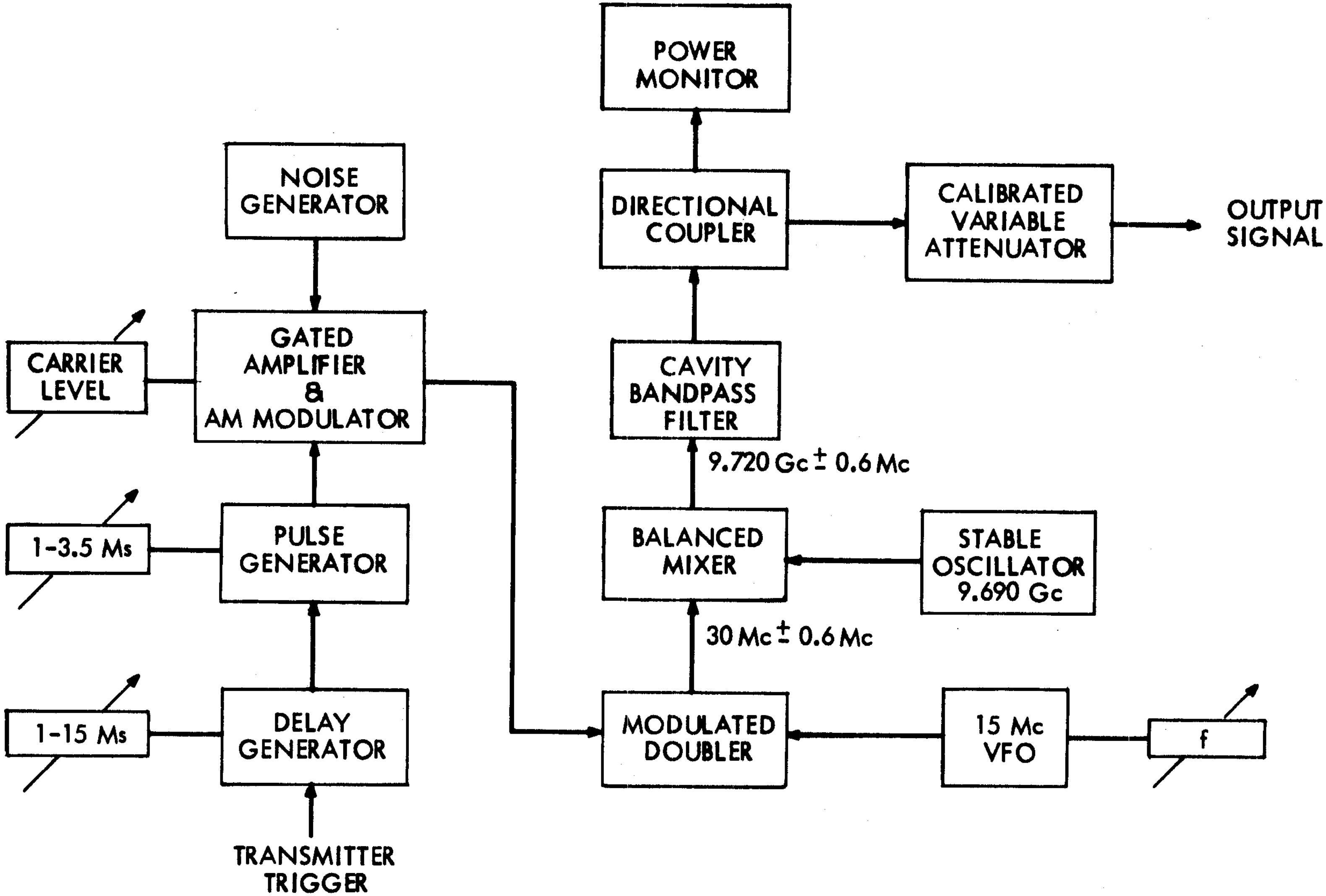

Figure 1 Doppler Simulator Block Diagram

frequency source is adequately suppressed during the inter-pulse periods.

The 30-Mc signal is up-converted to 9.720 Gc by means of an ortho-tee* balanced modulator (MA. 1134B- 1BE) which suppresses the carrier by more than 20 db. The output of the modulator is passed through a single-cavity bandpass filter (Varian BC 104) which further rejects the carrier by 22 db and rejects the unwanted lower sideband at 9.660 Gc by 29 db. Although the radar receiver does not respond to these unwanted frequencies, they could lead to serious errors in the simulator output-power calibration, particularly if a broad-band power monitor is used.

The output signal of the cavity bandpass filter is applied to a 40 db cross-guide directional coupler. The power output at the straight-through arm of the coupler is accurately measured by means of a power monitor consisting of a crystal detector and oscilloscope, and the power output at the -40 db arm is applied to a calibrated variable attenuator. The latter signal is, therefore, -40 db with respect to the signal power measured at the power monitor. The calibrated attenuator can be varied over a 40-db range with a maximum error of ± 0.2 db. The output of this attenuator is the simulated echo signal which is coupled through a 20-db side wall wave-guide coupler into the receiver of the radar system under test.

The delayed-pulse generator consists of a pair of emitter-coupled one-shot multivibrators and a gated amplifier. The first multivibrator is triggered by the transmitter pulse and produces a continuously variable delay period of 1 to 15 milliseconds. At the end of the delay period the second multivibrator is triggered. It produces a 1- to 3-millisecond pulse that simulates an echo signal. This pulse drives the gated amplifier into conduction. The output of the gated amplifier is zero except during the simulated echo pulse. A random noise signal may be applied to the external modulation terminals to amplitude

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*Microwave Associates trademark.

modulate the echo pulse and simulate typical returns from extended complex targets.

A more complicated delay generator using a Miller-integrator ramp generator and a threshold device to produce a variable delay was constructed but showed no advantages over the simple one-shot multivibrator delay generator. The minimum delay of 1-millisecond is commensurate with the 1-millisecond pulse width used in the transmitter. Thus, the echo pulse can be made to start as the transmitter pulse ends. The minimum simulated range of the echo signal is 93 miles; the maximum simulated range is 1395 miles.

Special Problems

The requirement for very accurate output-power calibration necessitated special attention in the calibration of the variable attenuator and directional coupler. A Hewlett Packard Model 413B direct-reading power meter was used to calibrate the microwave components. This instrument has a maximum error of ± 3 per cent of full scale (± 0.13 db) and a maximum dynamic range of 40 db. Because a maximum of 100 db of attenuation is required between the power monitor and the input to the receiver the attenuating system cannot be calibrated as a complete unit. The over-all calibration is determined by separate calibrations of the individual components. If all errors are systematic, an error of ± 0.3 db to ± 0.4 db can arise in this measurement.

A limited number of devices for the measurement of r-f power are available. A bolometer or other calorimetric power-measuring device is inherently more accurate and predictable than a microwave point-contact diode. However, microwave bolometers have thermal time constants of the order of a millisecond or more and are therefore of questionable value for measuring the instantaneous power in a 1-millisecond pulse. Therefore, a crystal diode designed specifically for power monitoring (1 N3143) is used to measure the microwave power output before attenuation. Operating into a 10-KΩ load, the particular 1N3143 employed produces 205 mv for a 1 mw incident power level and is closely square-law in operation. To increase the sensitivity of the monitor diode and to keep errors due to reflected power to a negligible amount, the crystal is matched to the waveguide using a single-screw tuner. Over the range of incident powers of interest (see Fig. 2) the VSWR is less than 1.4:1.

The most serious problem with a point-contact diode power monitor is that of obtaining repeatability of output voltage readings for given incident powers. Temperature cycling can leave the typical microwave detector diode permanently changed, and a temporary overload can markedly affect the sensitivity of a diode. However, if the monitor diode is not subjected to temperature extremes and is otherwise protected from abuse, a repeatability within 5 per cent or better can be achieved.

Several types of microwave sources having a frequency stability of one or two parts in 10^6 are available. An oven-regulated crystal-controlled varactor harmonic generator chain is the most satisfactory type of source because of its light weight, excellent frequency stability, small size, and low power consumption. However, a very stable cavity-reference kylstron was readily available and was consequently used in the simulator. After a warmup period this unit (LFE Model 814-X-21 Ultra-Stable Microwave Generator) exhibits a drift of only one part in 10^6 per hour which is more than adequate stability.

Conclusion

The simulator described produces simulated echo pulses of 1- to 3- milliseconds duration at X-band (9.72 Gc) with a long-term frequency stability of a few parts in 10^6. The output power is calibrated to ± 0.5 db, absolute, and the relative power calibration over the 40-db dynamic range of output power is ± 0.2 db. The output pulses have a variable delay of 1 to 15 milliseconds, and the output frequency is variable over ± 600 kilocycles per second in order to simulate expected doppler shifts. The most significant features of the simulator are its high-frequency stability, unusually long pulse duration, and high accuracy of power calibration.

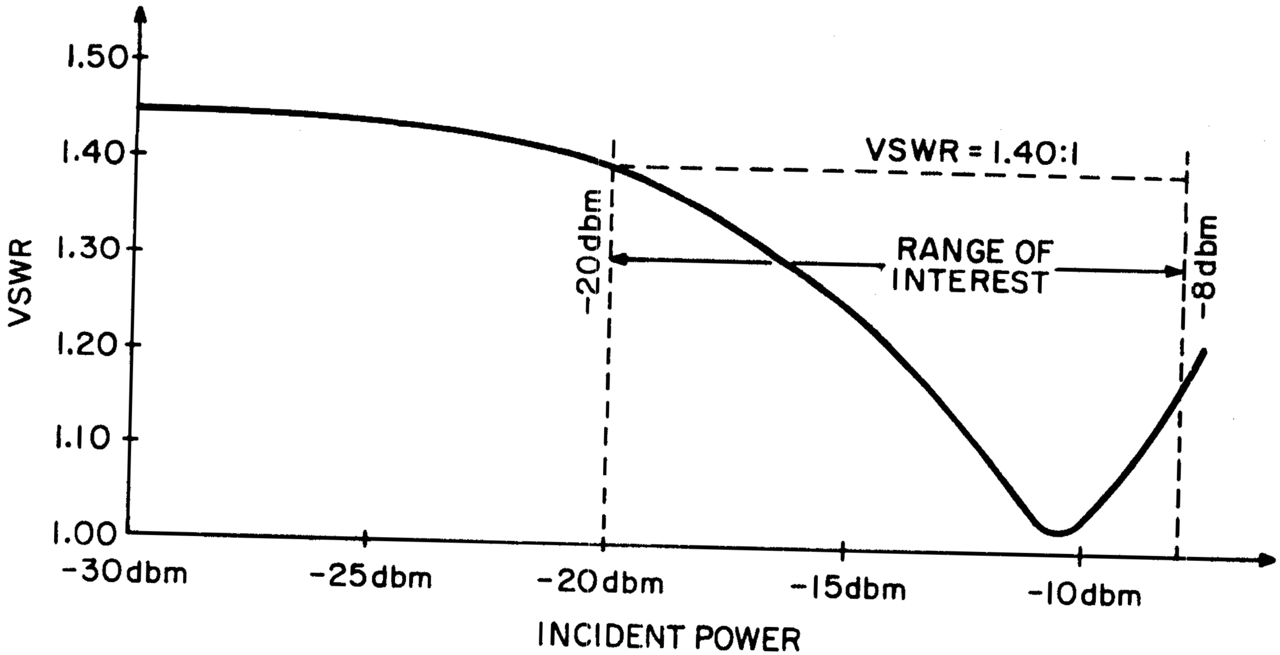

Figure 2. SWR of Power-Monitor-Diode and Mount vs. Power Entering Diode Mount
$f_o = 9.720$ Gc/s