Tech-notes

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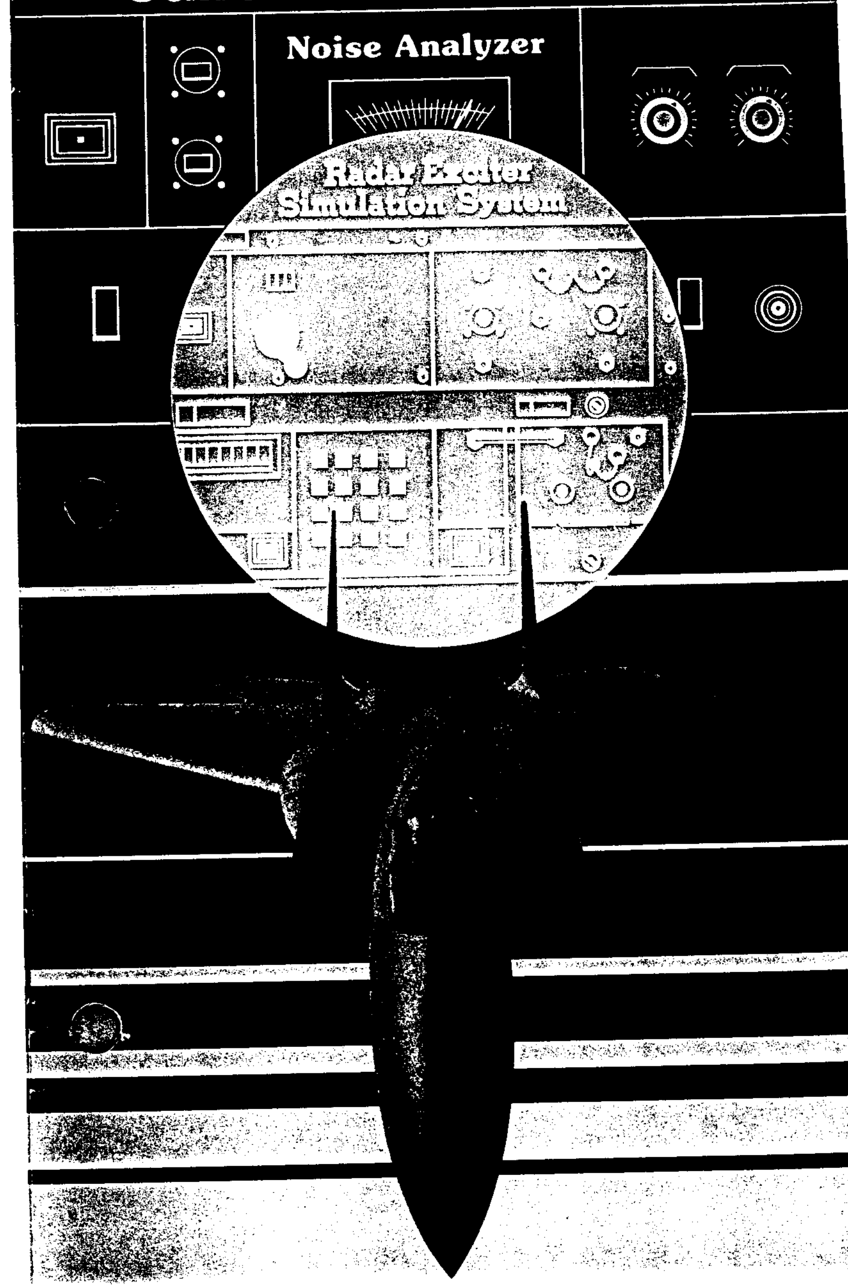
Ultralow-Noise Source for Noise Analyzer Calibration



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The increasing sophistication of radar technology has led to a corresponding demand for more accurate and intensive testing of the products of this technology. This article discusses the function of microwave noise analyzers and the performance required of a newly developed radar exciter simulation system that is used to test and calibrate them. Theory of operation, design trade-offs, noise measurement techniques, and applications are also included.

Microwave radar exciters require state-of-the-art AM/FM noise performance. High carrier stability and spectral purity needs are placed on the microwave signal by the velocity tracking modes and other special requirements of the radar and associated systems. Velocity tracking utilizes the low-level doppler returns, which lie only a few kHz from the carrier frequency, to acquire velocity information. Development of spectrally pure RF exciters and microwave power amplifiers has resulted in the development of special test equipment known as noise analyzers, which measure the power contained in sidebands close to the microwave carrier. To make these power measurements, noise analyzers must also perform tests requiring separate AM and FM sideband measurements, controlled detection bandwidths, measurement of sideband offset from a few kHz to as far away from the carrier as 30 MHz, and the ability to test pulse modulated systems as well as CW systems.

Field support and calibration requirements of the noise analyzers for recent aircraft radar test programs have led to the development of the Radar Exciter Simulation System (WJ-1221-23). This system tests the noise analyzer by applying simulated radar signals with known characteristics to it. A standard microwave frequency synthesizer forms the heart of the simulation system. Dual RF output, FM modulation, low AM noise (less than -113 dBc/1 kHz at 3 kHz removed from the carrier), and low FM noise (less than -115 dBc/1 kHz at 30 MHz removed from the carrier) are provided by a specially developed RF source. In addition, an amplifier/modulator was developed to provide low-level AM modulation, pulse modulation and +19 dBm (minimum) output power. Critical to the low noise performance are the Gunn diode Yttrium Iron Garnet (YIG) tuned microwave oscillator and the Gunn diode amplifier. In addition to supplying a microwave carrier with sidebands of known characteristics for calibrating noise analyzers, the system may be used to simulate radar exciters as a laboratory source to establish various radar parameters (i.e., frequency, pulse width, and pulse repetition interval).

Noise Measurement

Measurement of the noise performance of a stable, spectrally clean source, such as that used as a radar exciter, requires special measurement techniques. It is necessary to discriminate between the various types of noise modulation (e.g., AM, FM, PM) present in the signal. Discrimination between AM and FM noise is particularly important, since AM noise is considerably lower (20 to 40 dB) than FM noise. Maximum noise sideband levels in a given bandwidth versus frequency offset from the carrier are used to specify the AM/FM noise performance. Noise will be designated -dBc/BW (dB below the carrier measured in BW bandwidth) versus frequency. A typical spectrum analyzer will measure the combination of AM and FM noise, and is, therefore, inaccurate in measuring the relative level of AM noise.

The noise measurement system shown in Figure 1 responds only to AM noise. An envelope detector recovers the AM sidebands while rejecting the FM sidebands. Known AM sideband levels are injected by the calibration source for AM calibration of the measurement system. A low-noise amplifier is required to amplify the detector output to improve the system noise figure of

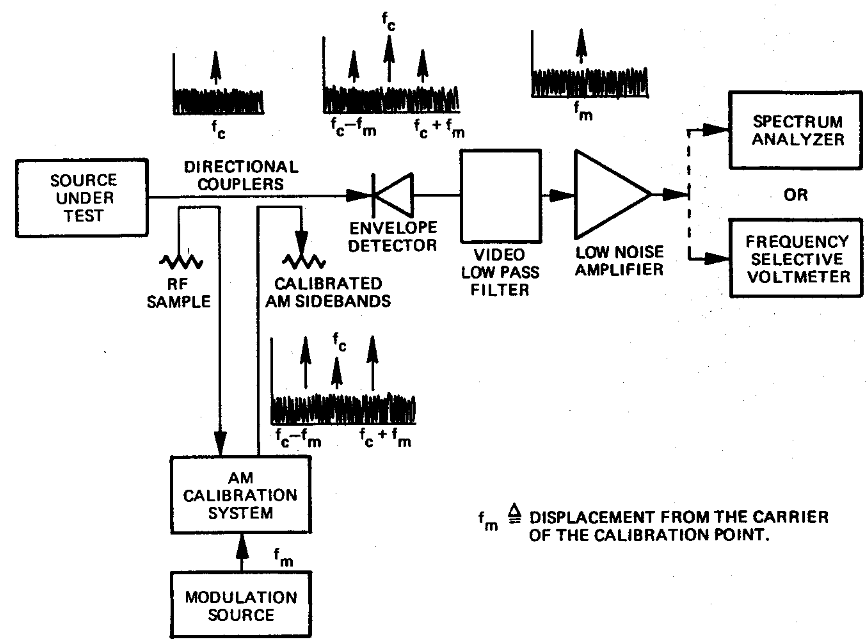

Figure 1. AM noise measurement.

the following analyzer and its measurement sensitivity. Detected sideband levels are determined by an instrument which measures noise power versus frequency, such as a spectrum analyzer or frequency-selective voltmeter. Overall sensitivity depends on the detector noise figure, amplifier noise figure/gain and the spectrum analyzer IF bandwidth characteristics.

The noise measurement system shown in Figure 2 responds to AM or FM as determined by the relative phasing at the mixer inputs. A sample of the signal to be measured is shifted 90 degrees and mixed against the test signal. This results in the FM sidebands output from the mixer and the AM sidebands suppressed. The directional coupler, mixer and cables provide an unknown amount of phase shift. Therefore, a variable phase shifter must be used. Proper phase is established by adjusting the phase shifter until the output of the mixer reads 0 volts DC or a null on an envelope detector. (Note: if the DC voltage were adjusted to maximum, the mixer would be combining two signals in phase, resulting in AM sidebands output from the mixer with the FM sidebands suppressed). The calibration source injects known FM sideband levels to calibrate the measurement system.

Low-noise amplification is needed to increase the amplitude from the mixer and improve the system noise figure of the following analyzer and its measurement sensitivity. Sideband levels are measured by an instrument which provides noise power versus frequency,

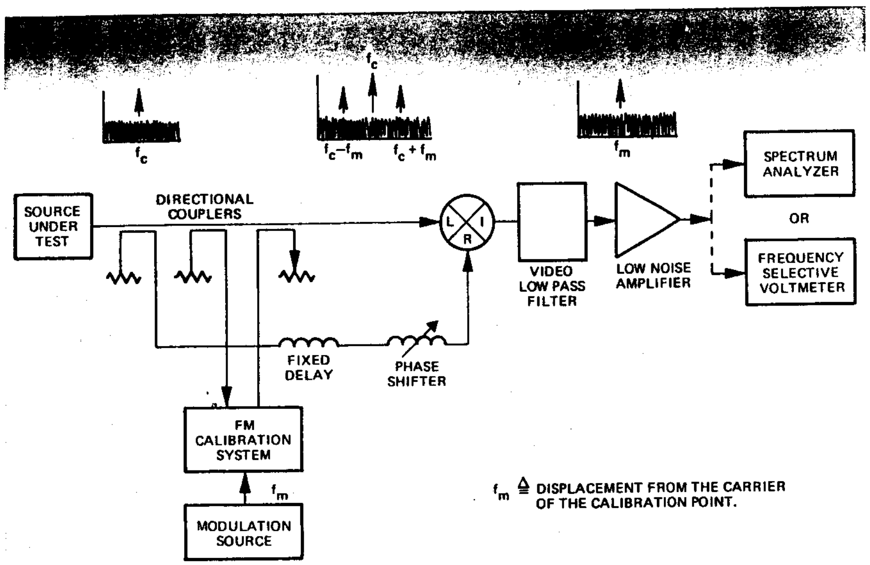

Figure 2. FM noise measurement.

such as a spectrum analyzer or frequency selective voltmeter. The overall measurement sensitivity depends on the mixer noise figure, amplifier noise figure/gain and the spectrum analyzer IF bandwidth characteristics.

Radar Transmitter Noise Measurement

A typical radar transmitter source is shown in Figure 3. It consists of a low noise microwave master oscillator (exciter), a master oscillator power amplifier (MOPA), a directional coupler to sample the output, and a transmitting antenna. The exciter provides a CW signal to drive the power amplifier and an LO signal to the radar receiver. Pulse modulation (at the pulse width and pulse repetition interval required by the radar system) is applied to the amplifier. To optimize the information obtained from the radar, it is necessary to place stringent electrical requirements on the exciter. Short-term stability specifications of the exciter are determined by the velocity tracking modes of the radar and special requirements of various missile systems. Velocity tracking utilizes the low-level doppler frequency shift up to several kHz caused when the reflecting target is moving relative to the radiating source. Excessive AM and FM noise requires the radar "threshold level" to be set too high, thus reducing the radar sensitivity. Noise spikes above "threshold level" cause false indications and complicate the detection of desired information. Radar transmitters are calibrated by measuring the noise sideband levels of the exciter in the CW mode and the additive noise sideband levels of the power amplifier in the pulse or CW mode.

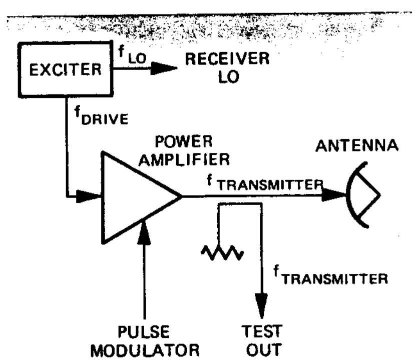

Figure 3. Radar transmitter source block diagram.

A microwave noise analyzer is used to calibrate/test the exciter (see Figure 4). Receiver LO (f_{LO}) and the RF drive to the power amplifier (f_{drive}) are input to the microwave noise analyzer to test the CW performance. The noise analyzer measures the AM/FM sideband levels (-dBc) in a given bandwidth at various frequencies offset from the carrier. Noise measurement techniques similar to those previously discussed are used. Some of the tests can be performed under computer control to minimize operator test and training time. AM noise levels are measured typically in a 1 kHz bandwidth at frequencies offset from audio to IF ranges. FM noise level is measured typically in a 1-kHz bandwidth at similar frequencies offset

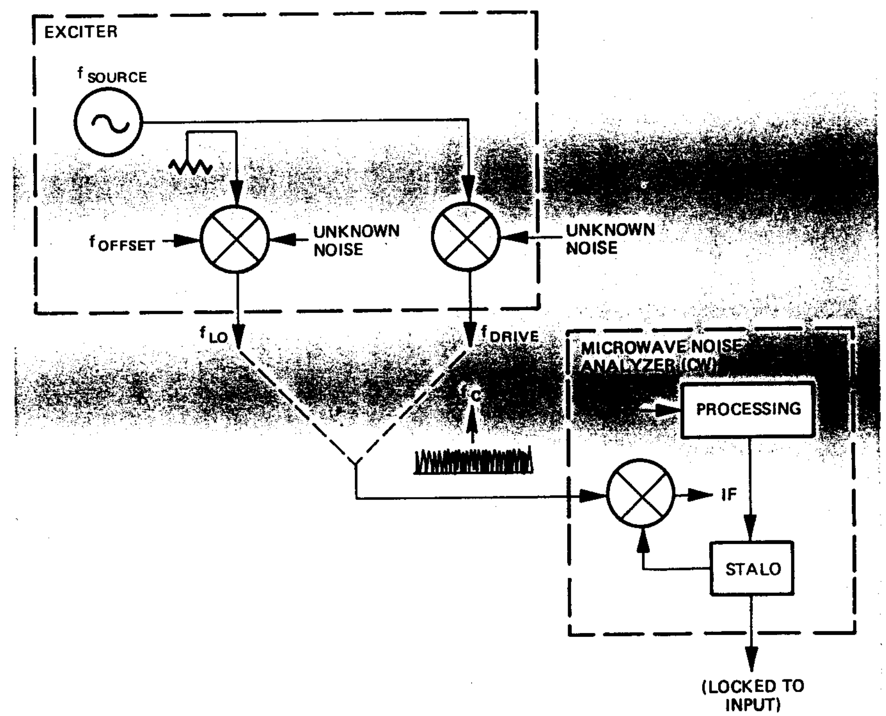

Figure 4. Exciter noise measurement.

from the carrier. The noise analyzer provides distinction between FM/AM modulation measurements. The results obtained may be compared with internal thresholds to make a GO/NO GO decision. For many tests, the noise analyzer will automatically calibrate and self test.

Noise in pulsed or CW microwave power amplifiers is performance-tested using an additive noise analyzer, as shown in Figure 5. A sample of the input (f_{drive}) and output (Test Out) of the microwave power amplifier is input to the additive noise analyzer. The analyzer measures both AM and FM noise close to the carrier, which is added by the high power amplifier of the radar transmitter, while rejecting the PRF sidebands of the pulse modulation.

The additive noise analyzer utilizes noise measurement techniques similar to those shown in Figures 1 and 2, but requires a PRF filter following the detector, and the use of a coherent reference derived from the source before noise is added by the power amplifier. Built in test signals for AM and FM calibration and a self-test function may be provided, depending on the manufacturer of the noise analyzer.

Radar Exciter Simulator

To evaluate the inherent noise floor which limits the measurement capbility of the noise analyzer under test, a microwave signal source of comparable noise performance to the radar system components must be used as

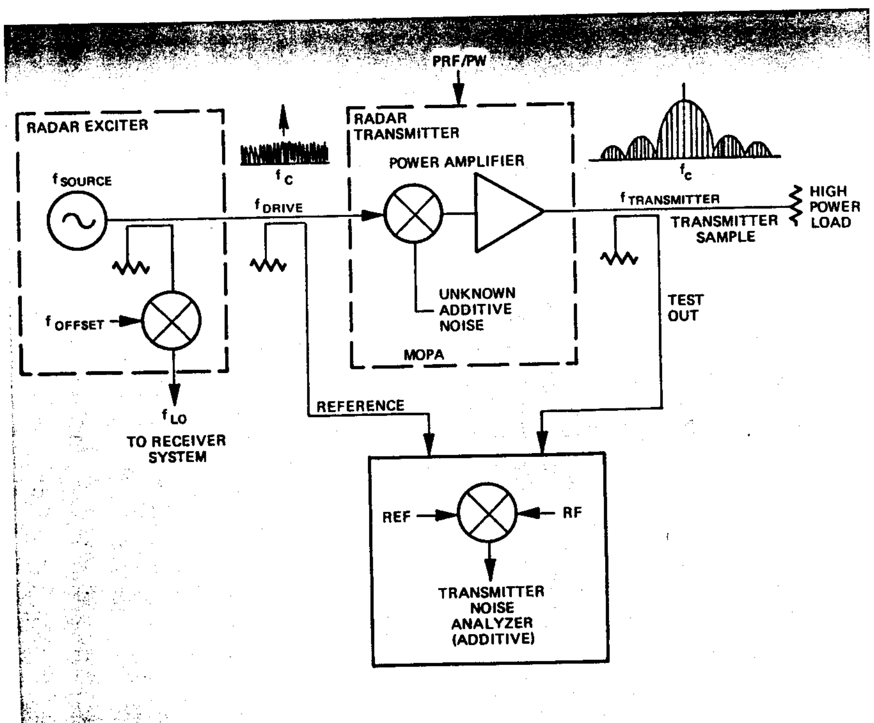

Figure 5. Transmitter power amplifier noise measurement.

the signal source. Sweep generators and microwave sources commonly used in electronics laboratories have high AM/FM sideband levels close to the carrier and are not stable or accurate in frequency. Power output of common sources rarely exceeds +6 dBm, which is insufficient excitation for power amplifiers or for a phase-sensitive detector.

The radar exciter simulator system was developed around an established modular microwave frequency synthesizer (WJ-1250/1251). A unique RF source was developed to provide dual RF output, FM modulation, and low FM/AM noise. In addition, an amplifier/modulator was developed to provide low-level AM modulation, pulse modulation, and output power greater than +19 dBm. The basic unit consists of a frequency synthesizer mainframe which can accommodate various standard plug-in RF sources from 1 to 18 GHz. Operation of the synthesizer system may be programmed manually by a front panel keyboard or remotely by digital commands. Variations on this approach include front-panel controls for programming a frequency step-sweep and frequency coverage from 0.1 to 40 GHz. By entering values for frequency range, step-frequency increment, dwell time, and direction of sweep, an automatic digital sweep is generated. Minimum programmable frequency steps are 100 kHz. Steps as low as 1 Hz are available as options. Frequency accuracy is determined by an internal 5-MHz crystal oscillator or an external 5-MHz reference.

The radar exciter simulator block diagram is shown in Figure 6. The microwave frequency is generated by an Yttrium Iron Garnet (YIG) tuned oscillator which is phase locked to a 5-MHz reference. Frequency resolution of 100 kHz is provided. Frequency accuracy is a function of the 5-MHz reference. FM noise performance within 4 kHz of the carrier is determined by the multiplied 100-MHz reference. At frequencies greater than 4 kHz removed from the carrier, the FM noise characteristics are a function of the YTO (YIG-tuned oscillator). Transistor oscillators are normally used for frequencies below 8-GHz and Gunn diode oscillators above 8 GHz. The transistor YTO typically provides a 10-dB improvement in noise performance over the Gunn diode YTO's. The inherent high Q of the YIG tuning element provides good noise performance.

RF is input to the power divider, which provides a 20-dB sample to the synthesizer for phase locking. In addition, the RF is split into two RF outputs (3 dB). One goes directly out through an isolator and is used as a CW reference (RF REF) as required for an additive noise analyzer input, or as a coherent reference for a receiver system. The other RF signal is input to a phase modulator which generates low-level FM at modulating frequencies from 3 kHz to 30 MHz. From the phase modulator, the signal is input to a directional coupler and to the output (RF MOD) of the RF source. The RF sample from the directional coupler is mixed with the modulating signal to obtain suppressed carrier AM. This is input through a phase shifter and recombined with the main RF through the normally terminated port of the directional coupler. The sidebands must be in phase to generate low-level AM. Proper phase shift is manually obtained using a variable broadband phase shifter. If the sidebands are 90° out of phase, low-level FM modulation results. An external envelope detector and low-frequency spectrum analyzer is used to adjust for proper phase shift. A detector peak establishes AM, and a null, FM. Normally, the low-level AM modulation function is used. The RF sampling and combining functions are accomplished using a single directional coupler to minimize uncontrolled phase shifts which could

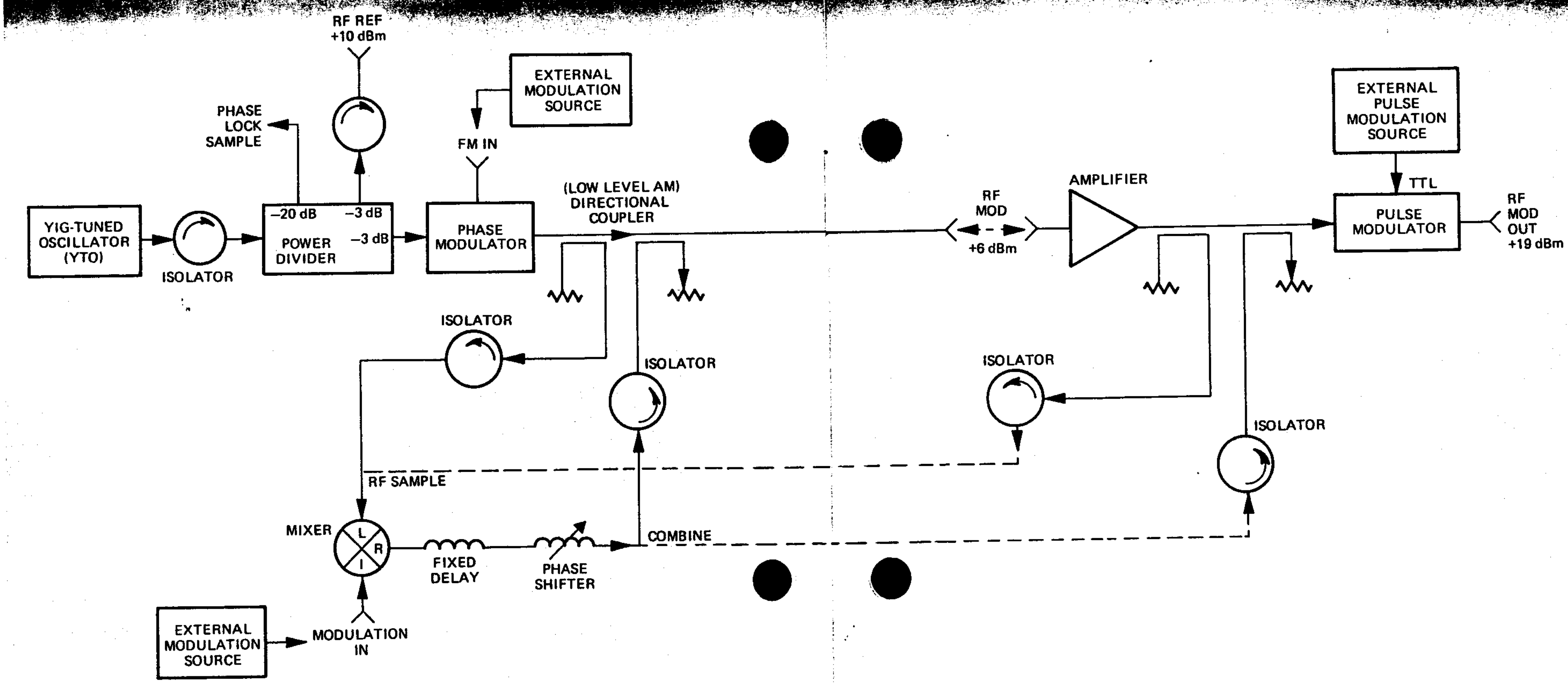

Figure 6. Radar exciter simulator block diagram.

result in poor modulation (i.e., simultaneous AM/FM when only one modulation is desired). The RF MOD output may be used for calibrating microwave noise analyzers. To provide higher output power, the RF MOD port is input to a saturated Gunn amplifier with 15-dB gain. A directional coupler samples and combines the amplifier RF output for generation of low-level AM. An absorptive pin attenuator is used to pulse modulate the AM signal. The low-level AM is used either at the RF MOD or RF MOD OUT ports, but not simultaneously. This method provides a CW reference and a modulation signal with simultaneous FM, AM and pulse modulation.

The critical performance parameter is AM noise, which requires optimization of the YTO and Gunn amplifier. External circuitry such as bias, power supply, and tuning have negligable effect on AM noise. AM noise characteristics are determined primarily by the YTO. Gunn diode geometry is a major factor. Bonding pressure and RF output loop coupling of the YTO are also significant factors.

Gunn diode bias voltage is a secondary factor and has little influence on AM noise performance. The Gunn amplifier is the other major factor determining AM noise performance. Here also, the Gunn diode geometry is the major factor. However, bias of the Gunn diode in this case significantly affects AM noise. Tuning of the stages (3-stage) is adjusted for optimum AM noise. Tuning for optimum AM noise is slightly different than tuning for maximum output power. Because of the saturation characteristics of the Gunn diode amplifier, some AM noise improvement (3-10 dB) is achieved in the amplifier. The resulting noise performance is shown in Figures 7 and 8.

Application

The Radar Exciter Simulator provides a spectrally pure source to calibrate microwave noise analyzers. In addition it may be used as a development tool in the radar laboratory to help establish the various radar parameters (i.e., frequency, pulse width, and pulse repetition interval). This also provides the radar designer with an RF stimulus which may be used as the radar exciter. The system will accept additional RF

CHARACTERISTIC	SPECIFICATION
FREQUENCY RANGE	9.2 – 10.2 GHz
POWER	
RF MOD (MODULATED)	+ 6 dBm (MIN.)
RF MOD OUT (MODULATED)	+19 dBm (MIN.)
RF REFERENCE	+10 dBm (MIN.)
FREQUENCY MODULATION	
RATE	1 kHz TO 30 MHz
SIDEBAND LEVEL	GREATER THAN –45 dBc* WITH 0 dBm MODULATION INPUT
AMPLITUDE MODULATION	
RATE	1 kHz TO 30 MHz
SIDEBAND LEVEL	GREATER THAN 40 dBc AND 50 dBc WITH 0 dBm MODULATION INPUT FOR THE RF MOD AND RF MOD OUT RESPECTIVELY
PULSE MODULATION	
ON/OFF RATIO	45 dB (TYPICAL
RISE/FALL TIME	TYPICALLY LESS THAN 150 nsec

*–dBc IS DEFINED AS dB BELOW THE CARRIER

Figure 7. Radar exciter simulator system specifications.

plug-in units from 1-18 GHz, which makes it ideally suited for test applications requiring stability, spectral purity and computer programmability. It finds wide use in automatic microwave test systems, receiver test stands, general laboratory work, metrology laboratories and near-field or far-field antenna measurements. It may also be used as a stable LO signal source in special-purpose receivers and for testing space communication systems.

FREQUENCY OFFSET FROM CARRIER	FM NOISE (dBc/1 kHz BW)*		AM NOISE (dBc/1 kHz BW)*	
	RF MOD OUT (+19 dBm)	RF MOD/RF REF (+6 dBm/+10 dBm)	RF MOD OUT (+19 dBm)	RF MOD/RF REF (+6 dBm/+10 dBm)
3 kHz	–30 TYPICAL	–30 TYPICAL	–110	–113
6 kHz	–40 TYPICAL	–40 TYPICAL	–113.5	–116.5
10 kHz	–45 TYPICAL	–45 TYPICAL	–116	–119
20 kHz	–50 TYPICAL	–50 TYPICAL	–116	–119
50 kHz	–54 TYPICAL	–54 TYPICAL	–116	–119
100 kHz	–58 TYPICAL	–58 TYPICAL	–116	–119
500 kHz	–70 TYPICAL	–70 TYPICAL	–116	–119
1 MHz	–70	–85	–116	–119
5 MHz	–80	–85	–116	–119
10 MHz	–85	–85	–116	–119
26 MHz	–90	–115	–116	–125
30 MHz	–90	–115	–116	–125

*–dBc IS DEFINED AS dB BELOW THE CARRIER

Figure 8. Radar exciter simulator system noise performance.

Author:
Richard S. Napier

Mr. Napier is presently Head of the Synthesizer Equipment Section within the Test Systems Department. His current responsibilities include general management and technical duties. Among his general management duties are the responsibility/authority/accountability for section sales/profit-loss, coordinating and scheduling the manpower and material requirements, assessments of the general business climate, generation of short and long term goals consistent with the desired business growth, and general sales support as required to expand sales, product base, and market. His technical responsibilities include: design, development, and management of commercial microwave frequency synthesizers and related products covering 0.1 to 40 GHz. He was recently involved as a company program manager on the WJ-1204 Synthesized Signal Generator. He was project/design engineer for the WJ-1221-23 Radar Exciter Simulation System which provided frequency stability, high output power, low level broadband AM/FM, pulse modulation, and low AM/FM noise. Other responsibilities have included synthesizer system sales support and customer interface as acting Applications Engineer.

Prior to the above assignments, Mr. Napier was Head, Synthesizer Products, Frequency Synthesizer Section, project/design engineer of WJ-1221-10 Precision Frequency and Calibration System, project engineer of the WJ-1250, Microwave Frequency Synthesizer product line, and project engineer on the WJ-1201 AM/FM Microwave Signal Generator. These earlier assignments included design, development, testing, sales and program management responsibilities.

Mr. Napier has written several articles dealing with frequency synthesizers. He is a member of Tau Beta Pi, Eta Kappa Nu, CSPE, NSPE, Association of Old Crows, and a 1979 biographer of "Who's Who in the West" (Marquis Publications). He received a B.S.E.E. from West Virginia University and a M.S.E.E. from Stanford University.

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