SIMRAR : SIMULATED RECEIVER AND RECORDER FOR STATISTICAL MEASUREMENTS *

by Dennis W. FIFE **

SUMMARY. — *Simrar* is an analog radio receiver simulator and statistical recorder. The simulator is composed of typical analog computer components which provide versatility in simulating receiving systems. A control circuit automatically cycles the machine through a preset number of statistical trials. On each trial, amplitude discriminator circuits determine if the input to the measurement system has exceeded a selected threshold level. Counters record the total number of trials on which each threshold level has been exceeded, and over a large number of trials an accurate estimate is obtained for the probability that a level will be exceeded.

The author describes the design and operation of *Simrar* in fixed time and sequential decision processes. Although its principal use has been in studies of signal detection, the versatility of *Simrar* makes it a useful device in more general statistical studies.

1. *Introduction.*

Simrar (SIMulated Receiver And Recorder) is an analog radio receiver simulator, which also incorporates circuits for statistical measurements and recording (1). The equipment was designed and built at the Cooley Electronics Laboratory of the University of Michigan. The original purpose of the device was to measure the performance of receivers in detecting the presence of signals in noise. It has since found application in other studies, e.g. a study of tracking errors in a fire control radar, and a study of the properties of pseudo-random waveforms. The versatility of the equipment makes it useful for statistical measurements, and the study of statistical decision processes involving a fixed level decision criterion with either a fixed or variable observation time.

Although the circuits employed are conventional in design, it is felt that the special purpose of the equipment will be of interest to the engineering community, especially in view of the importance of statistical analyses in the modern theory of communication.

2. *Description of Equipment.*

The following is a brief description of *Simrar*. Figure 1 is a front view, pointing out the major groups of the equipment.

2.1. *Receiver Simulator.*

Simrar is composed, in part, of the basic elements of a radio receiver : a band-pass filter-amplifier (analogous to the IF amplifier of a receiver) and a linear envelope detector. The band-pass amplifier has selectable center frequenties of 1 kc and 10 kc, with total bandwidths of 22 cps and 400 cps, respectively. The envelope detector incorporates a smoothing filter having a cutoff frequency of 400 cps. The input to the band-pass amplifier, which corresponds to the output of the mixer in an actual receiver, is usually obtained from an external simulation of the received signal. Wideband Gaussian noise, provided by a General Radio Company noise generator, is added to the simulated signal at the amplifier input.

The simulator also includes three operational amplifiers, each having a dynamic range of 60 volts and an

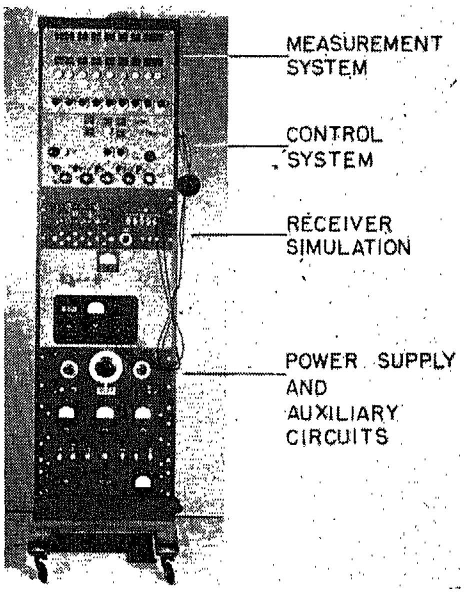

Fig. 1. — Simulated Receiver and Recorder (SIMRAR).

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open loop bandwidth of 1 kc. These are used to simulate additional gain and filtering in the receiver. A diode function generator makes possible the simulation of an arbitrary envelope detector law.

2.2. *Measurement and Recording System.*

The measurement system of *Simrar* consists of ten identical amplitude discriminator circuits connected in parallel. Each discriminator has an adjustable threshold level, with a maximum threshold of + 60 volts. The discriminator circuit is essentially a high gain RC coupled amplifier, tuned to 2 kc. When the input to the measurement system exceeds the discriminator threshold, a low level 2 kc signal is gated through the amplifier. The amplifier output triggers a thyratron counter control tube which actuates an electromechanical counter, advancing the reading by one. The 2 kc « perturbation » signal must be added to the input The input to this discriminator can be a timing wave provided by a voltage ramp generator in the control circuit, or some other source. The adjustable threshold level of the discriminator is used to set the time duration of each trial. The maximum available time duration per trial using the *Simrar* timing wave generator is 3.5 sec. The minimum usable time duration for continuous recording is 30 ms, but there is provision in the control circuit to allow recording only on the last 9 ms of each trial.

In addition to cycling, the control system provides the optional capability for switching both the input to the simulator or measurement system and the counter control on alternate trials, and also restoring one of the simulator amplifiers to a zero initial condition at the beginning of each trial.

The control circuit includes an electromechanical counter to record the total number of trials. Automatic termination of a sequence of trials is accomplished by a

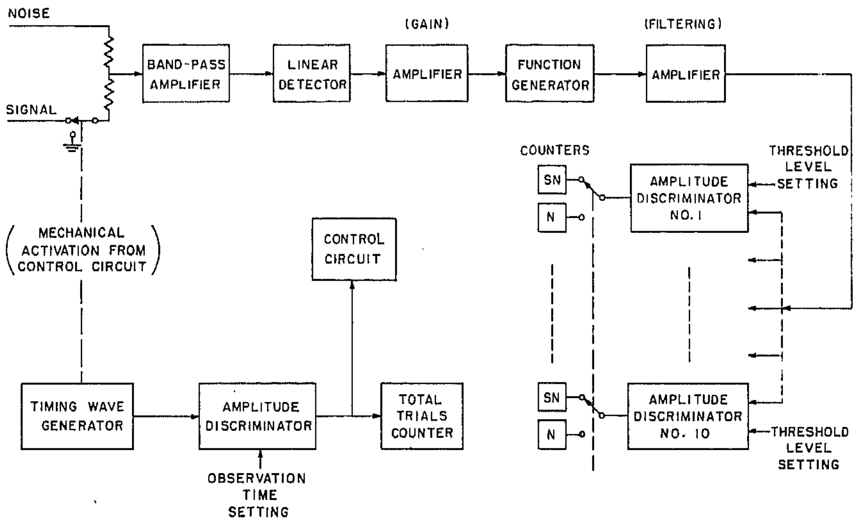

Fig. 2. — Block diagram of SIMRAR for a fixed observation time experiment.

signal of the discriminator. The discriminator responds to low pass input signals with a maximum frequency of about 1 kc.

Associated with each discriminator is a pair of electromechanical counters. The control circuit of *Simrar* is able to switch the thyratron control tube so that the thyratron controls each of the counters on alternate trials. The control circuit also has the capability to switch the input of the measurement system between two sources on alternate trials. Thus *Simrar* can concurrently test two hypotheses. The counters can record up to 9,999 counts.

2.3. *Control Circuit.*

The control circuit of *Simrar* automatically cycles the machine through a sequence of statistical trials, stopping when a preset number of total trials have been accomplished. Termination of an individual trial and recycling to begin another is accomplished by a system of relays, which is actuated by an amplitude discriminator circuit similar to those in the measurement system.

preset counter which utilizes glow transfer counter tubes. When the preset number of trials is reached a coincidence circuit activates a relay which stops the cycling.

3. *Operation of Simrar with fixed Observation Time.*

Figure 2 is a block diagram representation of *Simrar* as used in a signal detection problem involving a fixed time for observation of the receiver input on each detection trial. The received signal is simulated externally. For example, if the signal is to be a continuous, single-frequency sinusoid of arbitrary phase, an audio oscillator would be sufficient. Wide-band, white Gaussian noise is supplied from the noise generator in *Simrar*. The resistive adding circuit at the amplifier input can be scaled to give the desired range of input signal-to-noise ratio for the available range of variation of signal amplitude and noise power.

An operational amplifier provides the proper gain before the function generator, which simulates a nonlinear detector characteristic (e.g., square law). The last amplifier is used to simulate additional filtering. Frequently it is used as an integrator, in which case the control circuit must restore it to zero output before a new trial is begun.

The output of the simulated receiver is fed to the amplitude discriminator circuits, for which the threshold levels have been preset according to the expected distribution of amplitude. During operation of *Simrar*, the control circuit switches the receiver input from signal-and-noise (SN) to noise alone (N) on alternate trials, and also switches the discriminator circuits so that recording will occur on the counters which correspond to the input. Here an amplitude discriminator may be looked upon as a decision mechanism which trips a counter to indicate the decision « signal present » on each trial for which the maximum output amplitude of the receiver exceeds the threshold level. After a large number of trials, the ratio of the counter reading to the total number of trials having the corresponding input will be a good estimate of the probability that the threshold will be exceeded on any trial with that input. For the SN counters this is the detection probability, whereas for the N counters it is the « false alarm » probability.

At the completion of a trial, the control circuit sets the timing wave generator to zero output. At the beginning of the next trial, the sawtooth timing wave rises toward the threshold level of the control circuit discriminator. When the timing wave reaches this level, the discriminator operates, advancing the total trials counter, and setting the switching operation of the control circuit in motion. The control circuit terminates the trial, and recycles to begin the next.

4. *Operation of Simrar in Sequential Decision Processes.*

Another detection problem which may be simulated with *Simrar* is a sequential test, for which the receiver observes the input until sufficient information has been obtained to make a decision with a given level of performance (correct decisions vs. false alarms). In this case the observation time is not fixed, but depends on the time required to make the decision achieving the desired performance. *Simrar* then measures the distribution of the decision times.

Figure 3 illustrates the use of *Simrar* in a sequential test. Here the output of the simulated receiver is fed to two discriminator circuits, either of which terminates the trial when a decision occurs. These are two possible decisions : « yes » (the signal is present) and « no » (only noise is present). One discriminator acts as the « no » decision mechanism, and the total number of « no » decisions with both inputs is recorded. The other discriminator makes « yes » decisions, and the number of these is recorded for each of the alternatives.

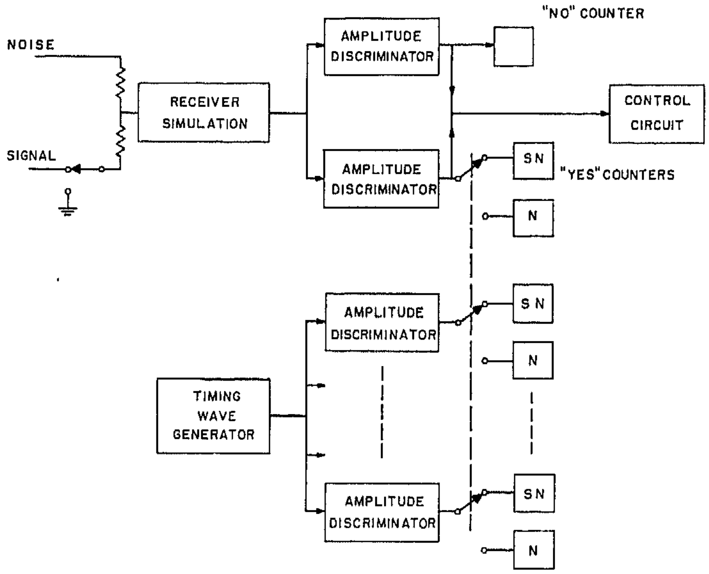

Fig. 3. — Block diagram of SIMRAR for a sequential decision experiment.

The timing wave generator output is now used as a time reference for measurement of the duration of each trial. The other amplitude discriminators serve to measure the probability distribution of the trial duration.

5. *Performance of Simrar in Statistical Measurements.*

The probability estimates obtained using *Simrar* are essentially the result of counting the number of « successes » in a series of Bernoulli trials. Hence the accuracy of the estimate for a given number of trials can be predicted theoretically from the binomial distribution. The percentage error in the estimate compared to the true probability of course increases as the true probability becomes small. To measure a probability of 0.5 to within a one standard deviation error of 15 percent requires at least 1000 trials. Depending upon the time duration of each trial, the total time required to make 1000 trials may run from less than a minute to as much as an hour.

The stability of the circuits employed in the receiver simulation is not outstanding. However, this does not present a significant problem in signal detection studies since the important consideration is the difference in the mean values of the amplitude distributions of the two alternative inputs (signal-and-noise and noise alone). The procedure of alternating inputs during a sequence of trials insures that the difference in mean values will remain relatively stable.

On the other hand, the stability of the circuits in the measurement system is adequate for most purposes. For example, the maximum apparent drift of threshold levels is about 100 mv per hour. If the full 60 volt range of the discriminators is used, this will not affect the accuracy of results significantly.

6. *Acknowledgements.*

The original design of *Simrar* was conceived in 1954 by W. W. Peterson and T. G. Birdsall. Particular credit however is due to R. R. McPherson who, more than any other individual, was responsible for bringing the original concept to a useful fruition.

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