NRL Report 7859

Sampling Wideband Nonrepetitive Radar Signals

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

Serial sampling of wideband radar signals in the manner of a sampling oscilloscope will provide inaccurate results to the extent that the signal is changing during the course of the sampling process.

An ideal but expensive solution to the problem is parallel sampling. A compromise approach is parallel-serial sampling, which combines the two techniques.

A parallel-serial sampling system has been developed at NRL and operates as part of the High Range Resolution Monopulse (HRRM) Radar.

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SAMPLING WIDEBAND NONREPETITIVE RADAR SIGNALS

INTRODUCTION

This report* is concerned with sampling wideband nonrepetitive radar signals for the purpose of analog-to-digital conversion, storage, digital processing, and display. The term wideband is used to mean video bandwidths of 100 MHz and above, well beyond the range of standard "high-speed" A-to-D converters. A nonrepetitive radar signal is one that is changing in amplitude, shape, or position and in general includes most radar signals of practical interest.

SERIAL SAMPLING

Serial sampling is the technique used by a sampling oscilloscope [1] and can be used to capture repetitive signals of bandwidths from DC to above 10 GHz [2]. This method, applied to a radar signal, is illustrated in Fig. 1. The radar and target are stationary, and each return is identical to the last. The target begins at a fixed range or time delay t_0 with respect to the transmitted pulse. A single sample is taken after each transmitter pulse at time delays

$$t_0,\ t_0 + \Delta t,\ t_0 + 2\Delta t,\ \ldots,\ t_0 + (N-1)\Delta t$$

for N consecutive transmitter pulses. In Fig. 1a, for $N = 9$, the delays and amplitudes of the N samples are shown.

If the samples are stored and displayed in the proper sequence (Fig. 1b), then the original signal can be reconstructed. The accuracy of the reconstruction depends on the closeness of the spacing of the samples, that is, on a sufficiently high value of N and low value of Δt. This method assumes that the sampled signal is unchanging for the duration of the sampling process. This time duration T_s is

$$T_s = (N-1)(T + \Delta t), \qquad (1)$$

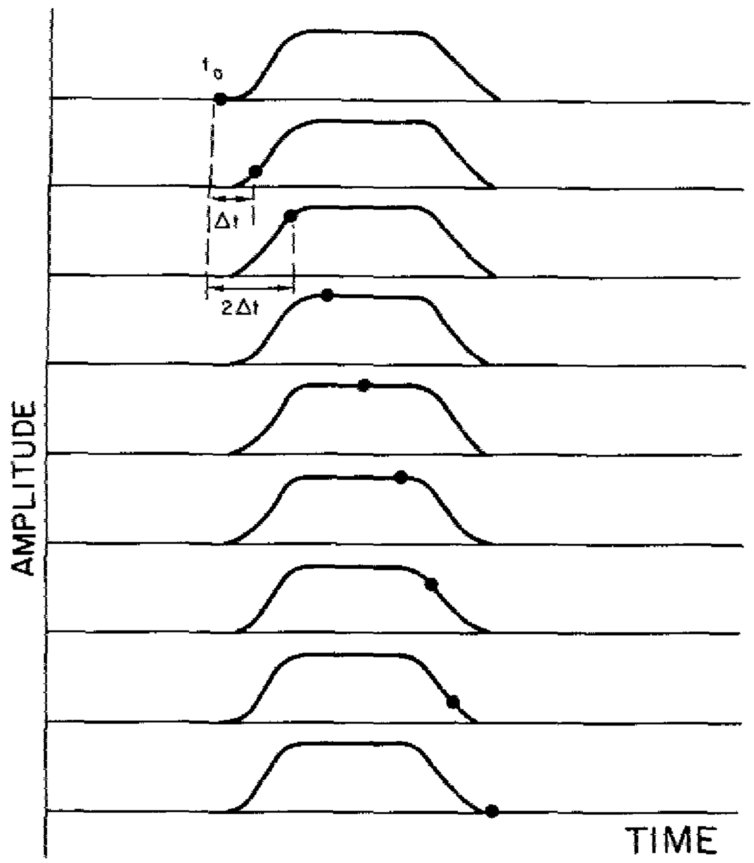
where T is the period of the radar pulse repetition frequency (PRF). For example, to sample a 100-ns target with 100 evenly spaced samples at a PRF of 1 kHz: $N = 100$, $T = 1\text{ms}$, $\Delta t = 1$ ns, and

$$T_s = 99\ (10^{-3} + 10^{-9})\ \text{s}$$
$$\approx 99\ \text{ms}.$$

In summary, the process is slow, simple, and relatively inexpensive and is done with a single wideband sampling channel operating at a low sampling rate. Note that the sampling rate $(1/T_s)$ on a single range cell Δt would be 10 Hz.

Note: Manuscript submitted January 6, 1975.

*When the work reported here was performed, Mr. Findlay was a member of the Search Radar Branch, Radar Division.



(a) Sample timing (N = 9)

(b) Reconstructed signal

Fig. 1 — Serial sampling

A target of interest with a radar return which was unchanging over a period on the order of 0.1 s, as in the previous example, frequently would be the exception rather than the rule. Common situations where radar returns may change significantly in a short time are:

- Any relative velocity between radar and target, which will cause a displacement of the return and a distortion of the reconstructed signal.
- Relative velocity between radar and target, which may cause large variations in

signal strength due to multipath propagation.

- A change in aspect angle, which can cause large signal amplitude changes due to interference between reflectors, where the target consists of more than one reflector.
- A moving component of a target such as an aircraft propeller, which will modulate the return signal.
- The return of a scanning radar, which will be amplitude modulated by the field strength of the antenna beam as the beam sweeps across the target.

Serial sampling under these conditions will result in two problems related to sampling rates. First, pulse-to-pulse signal changes during the sampling duration T_s will distort the reconstructed signal. Second, the repetition rate of the serial sampling process is too low to show pulse-to-pulse changes when they are of interest.

Another class of problems encountered with serial sampling is caused not by improper sampling but by the low information rate. For example, target information may be required at a certain rate to update the error signals of a tracking radar, or a search radar may be required to locate and identify large numbers of targets in a short time.

A scanning radar generally spends a relatively short time looking at any one target, and to collect a large number of samples on a single target would take several scans and an elapsed time of several seconds. This situation magnifies, for a scanning radar, the problems of both target motion and low information rate.

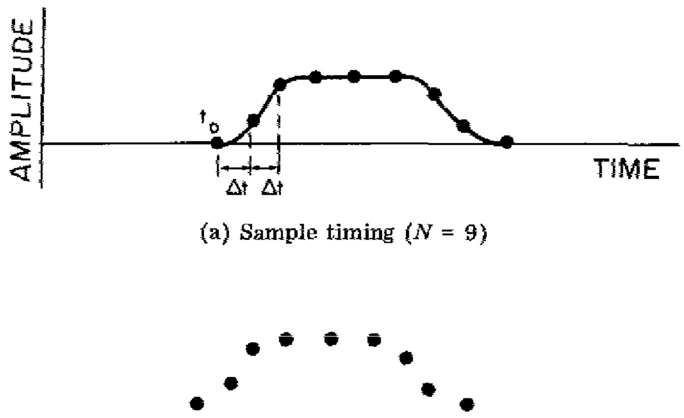
When signal averaging is used to detect a small signal in noise or for a similar application, the returns from many transmitter pulses are averaged. This may be impractical if for example 100 returns are required to construct a replica of a single return.

PARALLEL SAMPLING

All of the problems described, whether due to target motion or low information rates, whether a scanning radar is involved or not, can be eliminated or reduced by parallel sampling. Parallel sampling, sometimes called "one-shot" sampling, (Fig. 2) consists of taking all N samples of a target of interest from the return of a single transmitter pulse. This shortens the time interval during which sampling takes place and therefore eliminates the errors resulting from this delay. For parallel sampling the time duration for a complete set of samples on a single target return is

$$T_s = (N - 1)\Delta t. \tag{2}$$

Applying the numerical values of the example used previously, $N = 100$, $T = 1$ ms, and $\Delta t = 1$ ns, results in $T_s = 99$ ns. Recall the time duration of 99 ms using serial sampling. Note also that the sampling rate on an individual range element is 1 kHz here vs 10 Hz using serial sampling.



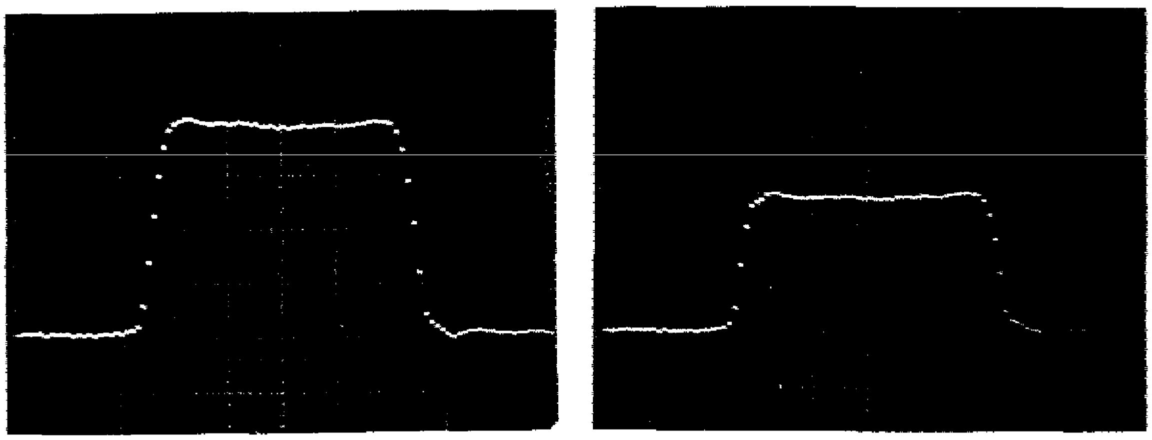
(a) Sample timing (N = 9)

(b) Reconstructed signal

Fig. 2 — Parallel sampling

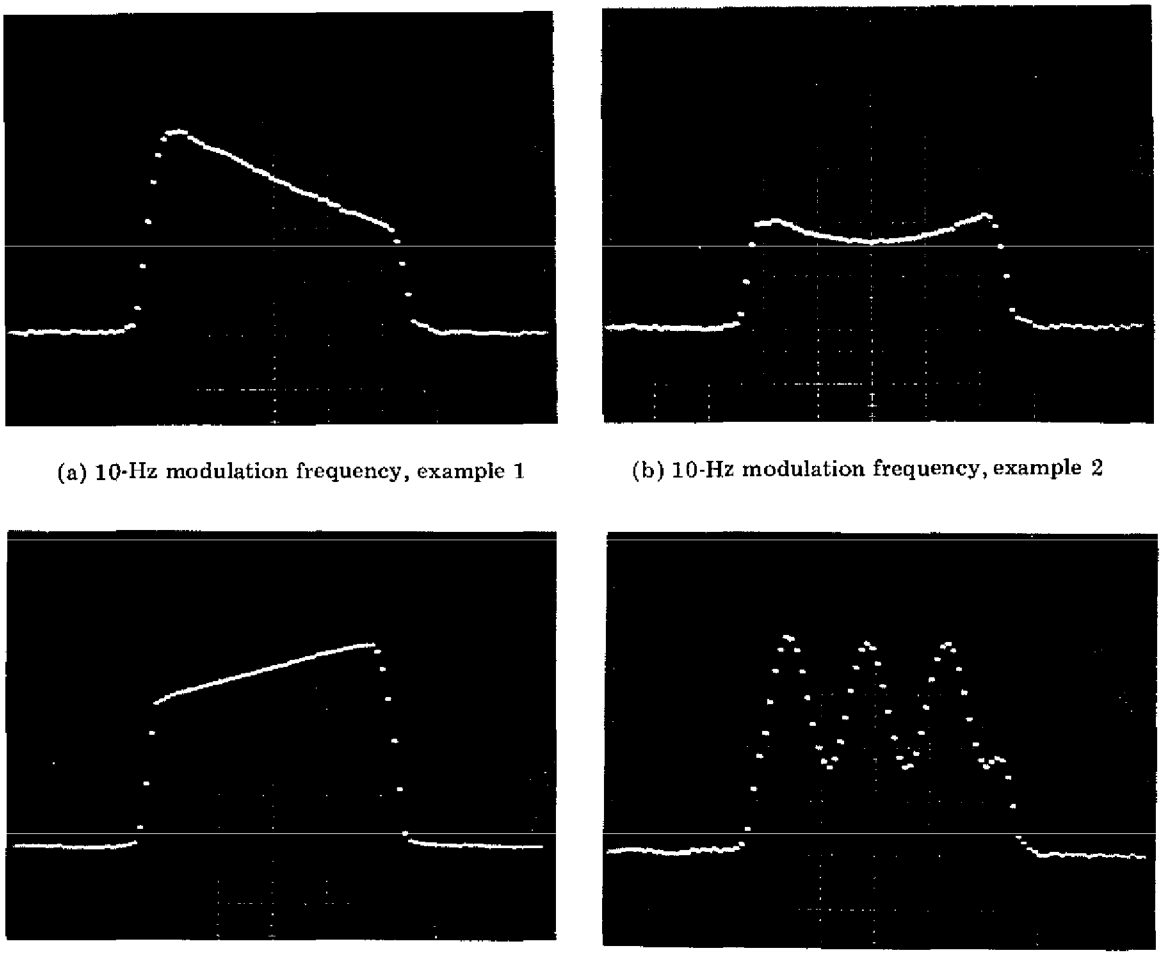
This process requires either a single channel with an extremely high sampling rate or a great many parallel channels with low sampling rates. (The designation "parallel" comes from the latter approach.) The prior approach is that often used by conventional A-to-D converters, which are quite satisfactory for narrowband signals. However, as signal bandwidth increases, they are limited in sampling rate and channel bandwidth.

For a comparison of serial and parallel sampling, refer to Figs. 3 and 4. Simulating parallel sampling, the signal is sampled twice and shown in Figs. 3a and 3b. The signal is a rectangular pulse 50 ns in length, varying in amplitude. The same signal is then sampled by the serial sampling method. Figures 4a, 4b, and 4c are three results from a 10-Hz sinusoidal amplitude modulation of the pulse, and Fig. 4d corresponds to a 100-Hz modulation frequency. In all cases involving serial sampling, the pulse shape was distorted. The distortion is more severe at the higher modulation rate.



(a) Example 1 (b) Example 2

Fig. 3 — Simulated parallel sampling of an amplitude-modulated pulse (scale: vertical — 1 V/div.; horizontal — 10 ns/div.)



(a) 10-Hz modulation frequency, example 1

(b) 10-Hz modulation frequency, example 2

(c) 10-Hz modulation frequency, example 3

(d) 100-Hz modulation frequency

Fig. 4 — Serial sampling of an amplitude-modulated pulse
(scale: vertical — 1 V/div.; horizontal — 10 ns/div.)

In many situations, the additional expense and complication of parallel sampling is not necessary, even with moving or fluctuating targets. This is true if only target detection or location is required. However, if target identification is required or if target fine structure or modulation is of interest, then parallel sampling may be necessary to reproduce the return accurately.

In other applications, the ability to sample, digitize, and store a complete target return from a single transmitted pulse may be required.

In the case of target identification, a comparison of returns which have been parallel sampled during several PRF cycles will, in a few milliseconds, pinpoint fluctuating target elements and confirm the position and strength of fixed target elements. This can form the basis for a reliable target signature. Serial sampling of the complete target one time takes about 100 ms in the example cited, and the result is of little value as a target signature since, in addition to the presence of distortion, there is no way to distinguish between fluctuating and fixed target elements.

To generalize the previous discussion: It is well known that a pulse radar is fundamentally limited in range resolution by the pulse length and limited in angle resolution by the antenna beamwidth. Similarly since radar return signals are in general nonrepetitive, a pulse radar has a fundamental resolution in time (not range) limited by the PRF. The PRF is in effect the sampling rate at which the radar looks at the target. If serial sampling is used to capture or store the target image of N range elements, then the effective sampling rate on a single range element is now reduced to PRF/N.

If consecutive returns are integrated by the CRT display or the eye and cannot be separately distinguished or if a sampled replica of a moving or fluctuating target takes many milliseconds to complete, then radar target information is being thrown away, and the full resolution in time of the radar is not being used. In the cases noted where parallel sampling is required, sampling and storage of the results with display and computational capability will permit use of the full time resolution of the radar.

The previous discussion does not conflict with the requirements of the well-known Sampling Theorem [3]. However, confusion does occur in practice over sampling rates and over what it is that is actually being sampled. In a particular application it may be required to sample one of the following:

- Target amplitude vs range at a given time
- Target amplitude at a given range vs time
- Target amplitude vs range and time

These cases could be generalized by extension of the Sampling Theorem to two dimensions: range and time. However, it is usually sufficient to carefully consider the difference between the signal that it is desired to sample and the signal that will actually be sampled by a specific hardware mechanization.

HYBRID PARALLEL-SERIAL SAMPLING

Hybrid parallel-serial sampling can be used as a compromise between serial sampling, which is inadequate for many uses, and parallel sampling, which is very complex and expensive. This approach combines the two forms of sampling in the following way: The return from each transmitter pulse is sampled n times for m consecutive pulses. The n samples are shifted in range with each transmitter pulse, as shown in Fig. 5a. The result is that after m transmitter pulses have occurred, a total of N = mn samples have been taken evenly spaced in range. In Fig. 5b the signal is reconstructed from the N samples.

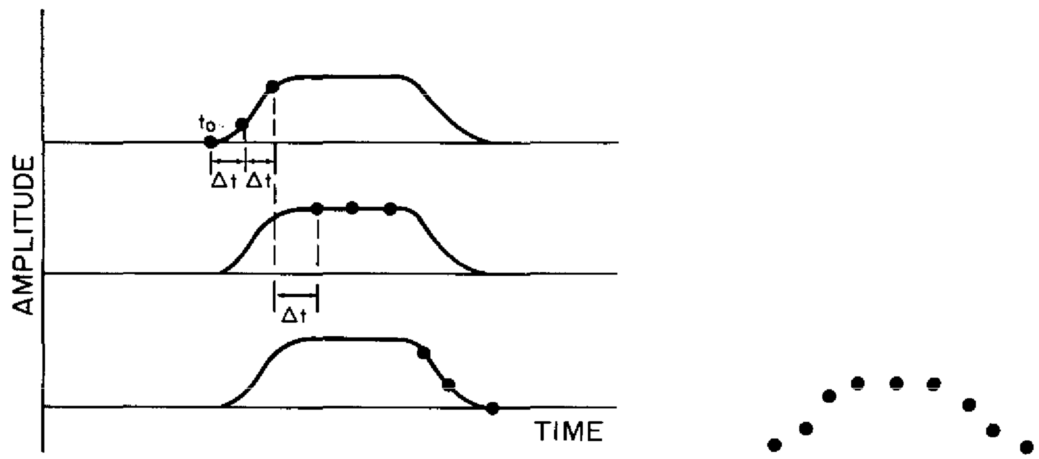
The duration of the sampling process using this technique is

$$T_s = (m - 1)T + (N - 1)\Delta t. \tag{3}$$

Repeating the previous numerical example $N = 100$, $T = 1$ ms, $\Delta t = 1$ ns, let n = 10 and m = N/n = 10, which gives

$$T_s = 9\ (1\ \text{ms}) + 99\ (1\ \text{ns}) \approx 9\ \text{ms}.$$

This is much slower than parallel sampling but considerably faster than serial sampling, which required 99 ms to sample the same signal. This sampling technique can be implemented with a few parallel channels having low sampling rates.



(a) Sample timing (N = 9, n = 3, m = 3) (b) Reconstructed signal

Fig. 5 — Hybrid parallel-serial sampling

The advantage of parallel-serial sampling over serial sampling is illustrated in Figs. 6 and 7 using the fluctuating 50-ns pulse from Figs. 3 and 4. Parallel-serial sampling is simulated to represent ten samples taken from each of ten consecutive pulses (n = 10, m = 10). With 100-Hz amplitude modulation, the distortion due to serial sampling (Fig. 6a) is greatly reduced by parallel-serial sampling (Figs. 6b and 6c) but is still excessive. With 10-Hz modulation frequency (Fig. 7), the distortion is almost entirely eliminated. In this case full parallel sampling would offer little improvement.

For an arbitrary signal, depending on the bandwidth of the expected signal fluctuations, the distortion may be reduced a greater or lesser amount by varying the parameters m and n. In this way results equivalent to parallel sampling may be achieved by the compromise parallel-serial approach.

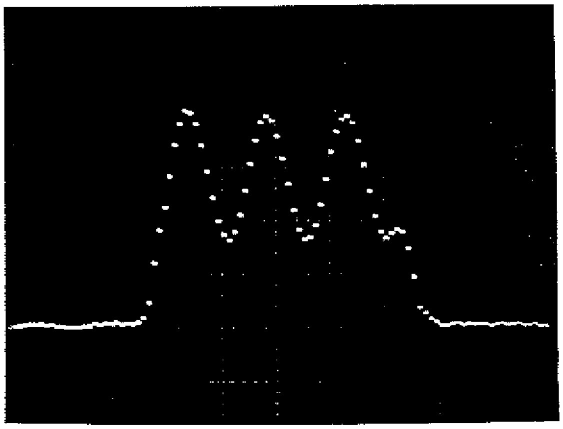
HYBRID SAMPLING SYSTEM

A sampling system using the hybrid parallel-serial technique has been developed at NRL and is a part of the High-Range-Resolution Monopulse (HRRM) Radar [4-6], which is installed at the NRL facility on the Chesapeake Bay. Figure 8 is a block diagram of the sampling system and associated equipment. System characteristics are shown in Table 1, and some of the hardware is shown in Fig. 9. Both range video and angle video are sampled over a range interval corresponding to the range gate of the range tracking loop. The samples are multiplexed and digitized for display and computation of range and angle tracking error. This application is described in more detail in Refs. 4 through 6.

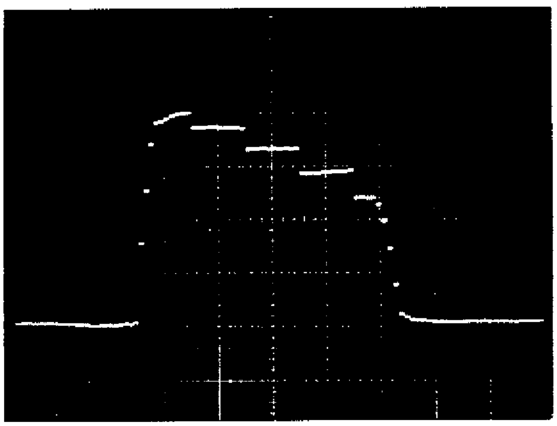
A timing diagram illustrating the sampling sequence is shown as Fig. 10. Eight samples (n = 8) are taken at a sampling rate of 333 MHz (Δt = 3 ns) after each of ten consecutive transmitter pulses (m = 10) for a total of 80 samples (N = 80). This is done simultaneously for both range and angle signals. In an optional mode, the eight samples may be taken of the same range interval at the full PRF rate for true parallel sampling (n = 8, m = 1, N = 8).

Figure 11 is a simplified block diagram illustrating the sampling of one signal. The signal is fanned out to eight identical signals, each of which is routed to one channel of the eight-channel sampler. There the signal is sampled and held until routed through the multiplexer to the analog-to-digital converter. Multiplexing, digitizing, and storage of the eight samples is accomplished before the next transmitter pulse. The combination of the delay generator and the trigger distribution network provides sample trigger pulses timed so that the 80 samples taken over 10 PRF cycles are evenly spaced in range.

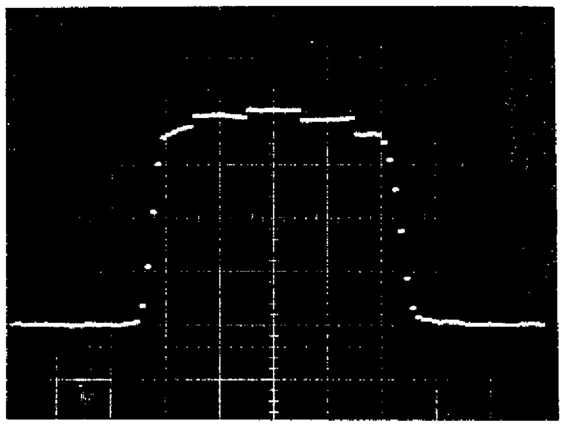
The eight-channel sampler is shown in an expanded block diagram in Fig. 12. It accepts a video signal, which may be bipolar or unipolar, from the radar receiver. The fanout is shown in more detail in Fig. 13. The input signal level is ±2 V peak, and the eight parallel outputs are ±0.5 V peak. All inputs are 50 ohms, and all outputs are intended to drive 50-ohm loads. The amplifiers are LeCroy Research Systems Corporation, Model 133-B, bipolar, DC-to-200-MHz linear amplifiers.



(a) Serial sampling

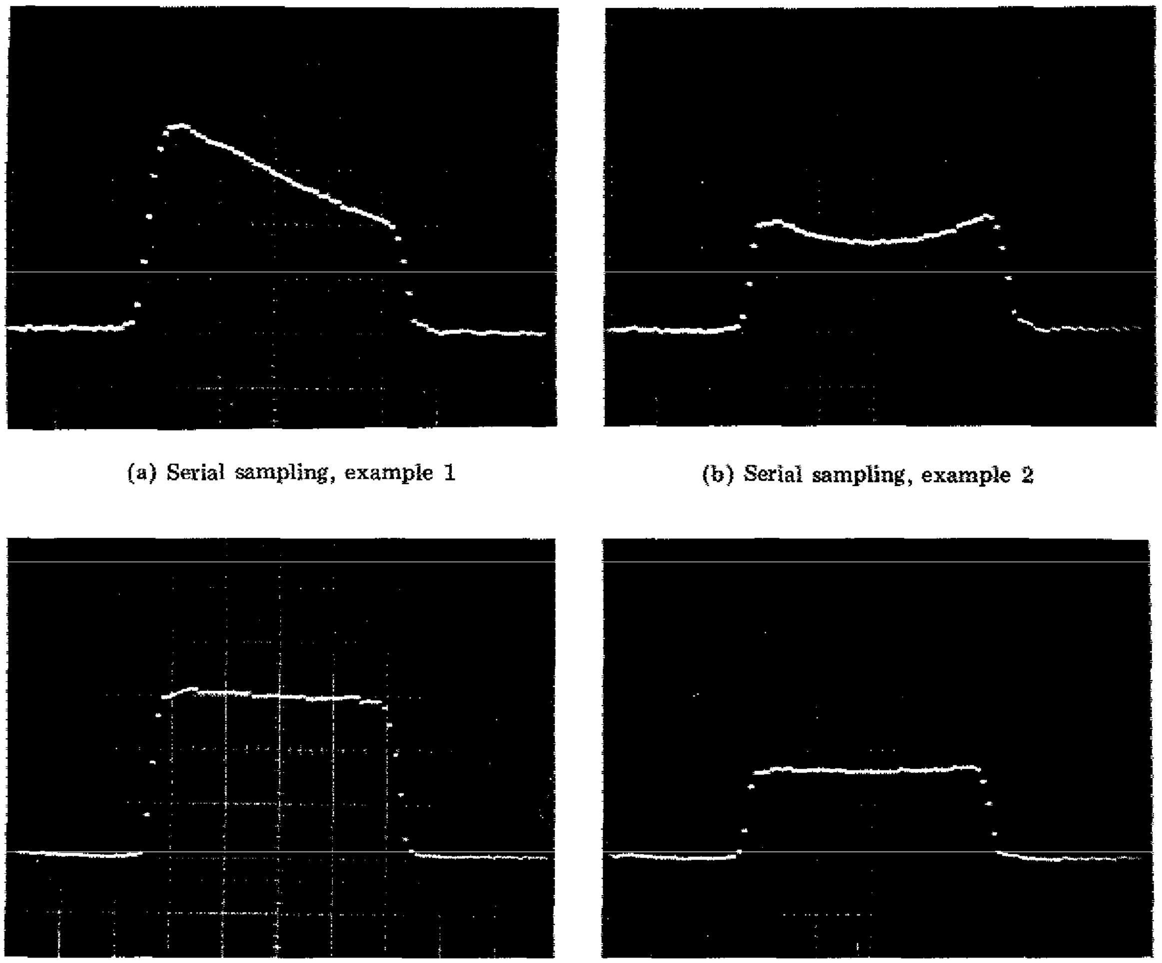


(b) Simulated parallel-serial sampling, example 1



(c) Simulated parallel-serial sampling, example 2

Fig. 6 — Comparison of serial sampling and parallel-serial sampling of an amplitude-modulated pulse. Modulation frequency = 100 Hz. (Scale: vertical — 1 V/div.; horizontal — 10 ns/div.)



(a) Serial sampling, example 1

(b) Serial sampling, example 2

(c) Simulated parallel-serial sampling, example 1

(d) Simulated parallel-serial sampling, example 2

Fig. 7 — Comparison of serial sampling and parallel-serial sampling of an amplitude-modulated pulse. Modulation frequency = 10 Hz. (Scale: vertical — 1 V/div.; horizontal — 10 ns/div.)

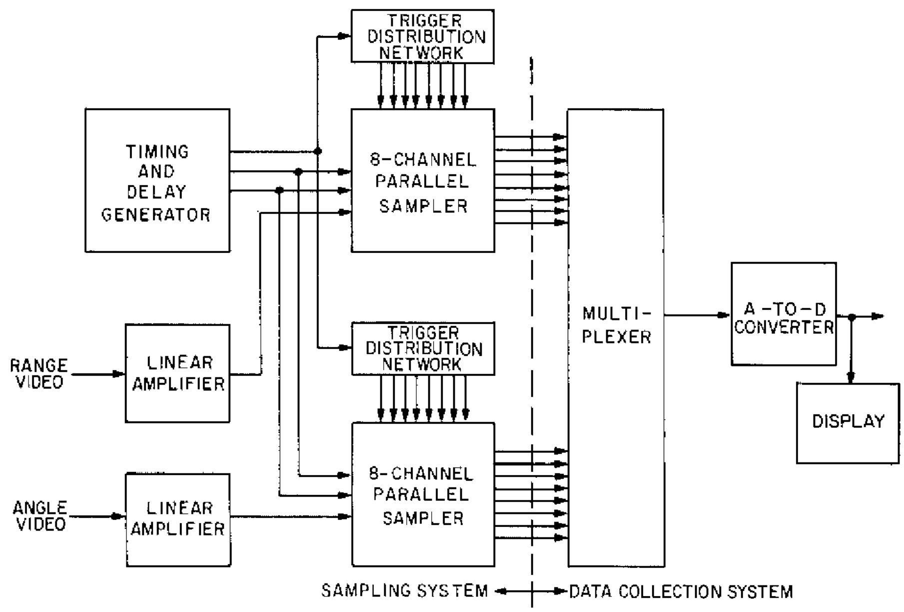


Fig. 8 — Sampling-system block diagram

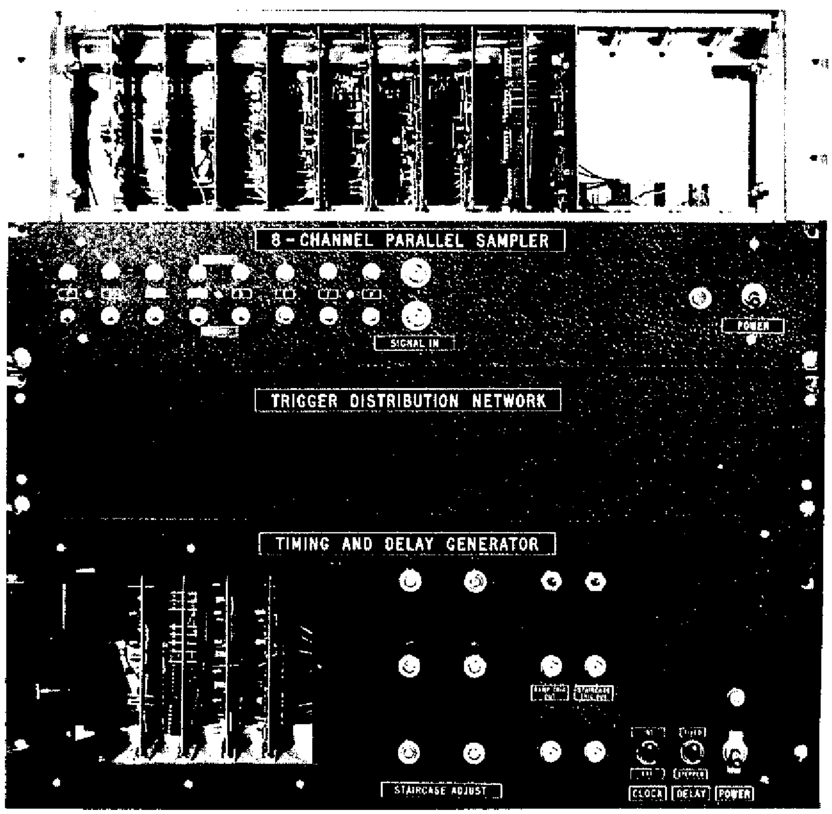
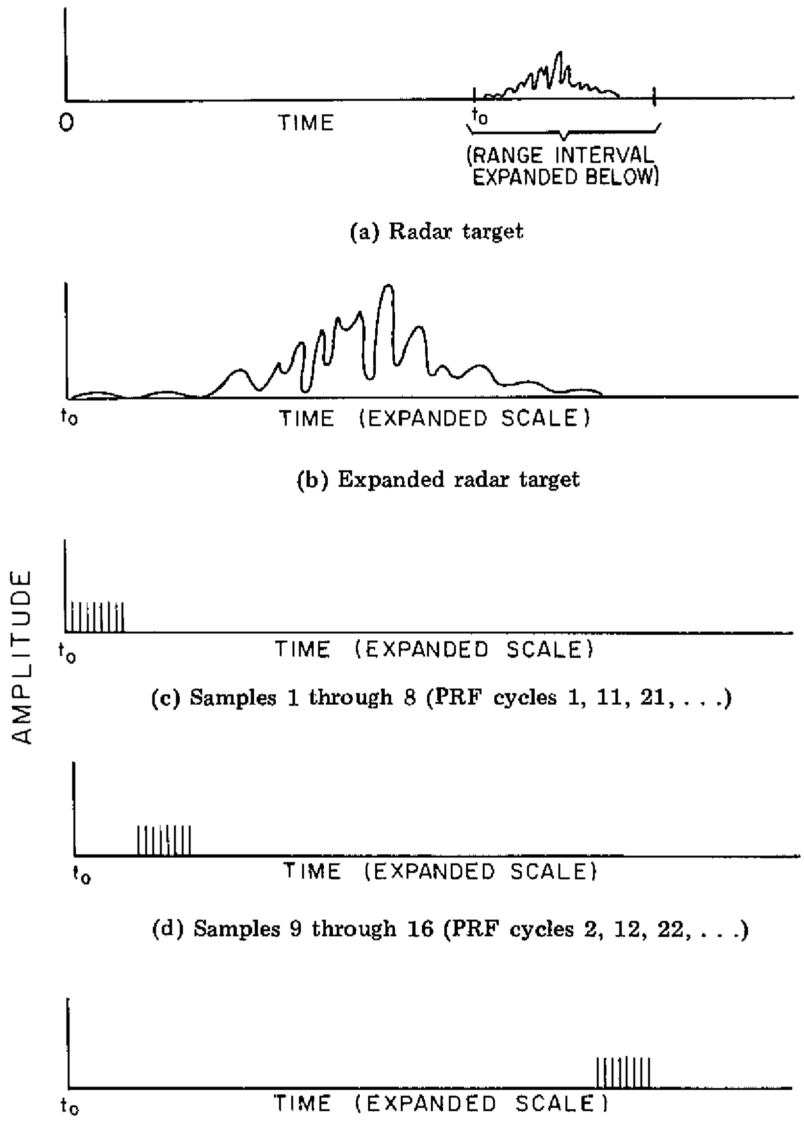


Fig. 9 — Sampling system, partial view

Table 1
Sampling System Characteristics

Number of signals simultaneously sampled	2
Number of parallel sampling channels (n)	8
Number of consecutive returns sampled (m)	10
Total number of samples (N)	80
Sampling gate width	350 ps
Sample spacing (Δt)	3 ns
Time jitter in sample spacing	0.3 ns
Radar pulse repetition frequency (PRF)	1 kHz
Input signal range	Bipolar ± 2 V
Input impedance	50 ohms
Input signal bandwidth (3-dB point)	DC to 200 MHz
Reconstructed signal dynamic range	34 dB



(e) Samples 73 through 80 (PRF cycles 10, 20, 30, . . .)

Fig. 10 — Sampling-system timing diagram

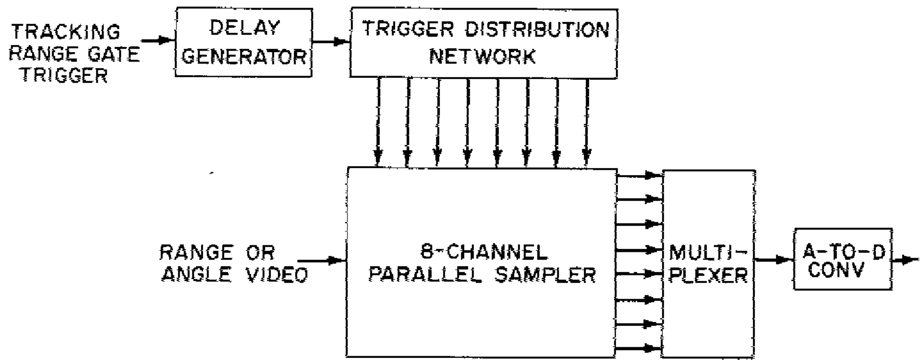


Fig. 11 — Simplified sampling system

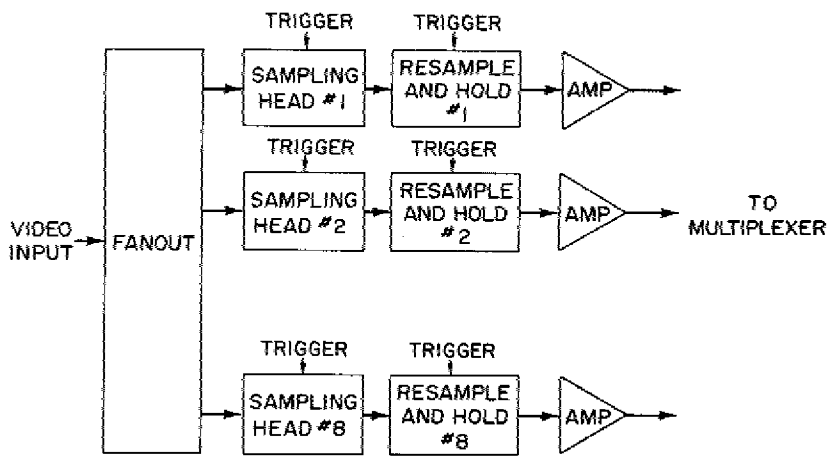


Fig. 12 — Eight-channel sampler

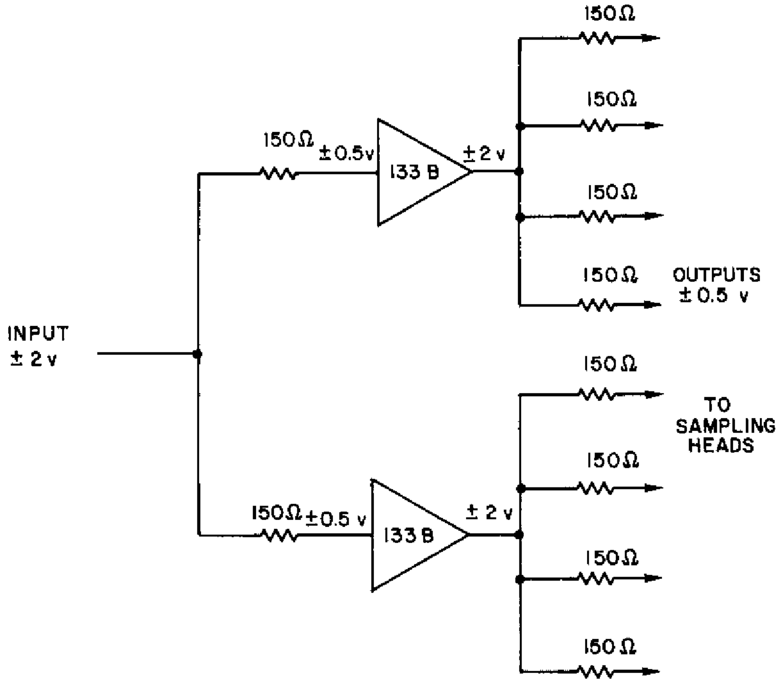


Fig. 13 — Fanout

Following the fanout, each channel performs two separate sample-and-hold operations. The sampling head is a Tektronix Type S-2 unit which has been modified to operate with a sampling gate of 350 ps. The resample-and-hold circuit samples the stretched output of the sampling head and holds it at a constant level for the duration of the PRF cycle. This is followed by an operational amplifier which provides gain and DC-level adjustment.

The trigger distribution network is shown in Fig. 14. It receives a pretrigger pulse from the delay generator and converts it into eight separate pulses, staggered in time, which trigger individually the eight channels of the parallel sampler. Tektronix type CT-3 Trigger Pickoff Units are used which allow a trigger to be derived from a signal on a 50-ohm transmission line with a minimum disturbance of the signal. The delay between triggers is 3 ns and is determined by the length of transmission line which joins adjacent pick-off units.

Figure 15a is the delay generator block diagram, and Fig. 15b is a timing diagram. The delay generator provides a pretrigger pulse for the trigger distribution network, delayed progressively after each of ten consecutive transmitter pulses. The method of delay generation used is to compare a linear ramp voltage with a staircase voltage, which is increased by one step each PRF cycle. The ramp is initiated after each transmitter pulse at the start of the range gate of the tracking loop. Each comparison, and therefore each pretrigger pulse, will occur at a greater range than the preceding one. As shown in Fig. 15b, one volt between steps of the staircase and a ramp slope of approximately 40 V/μs corresponds to a 24-ns pretrigger delay increment.

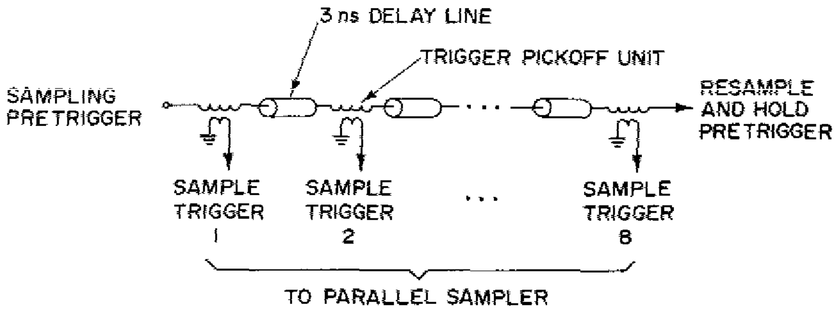
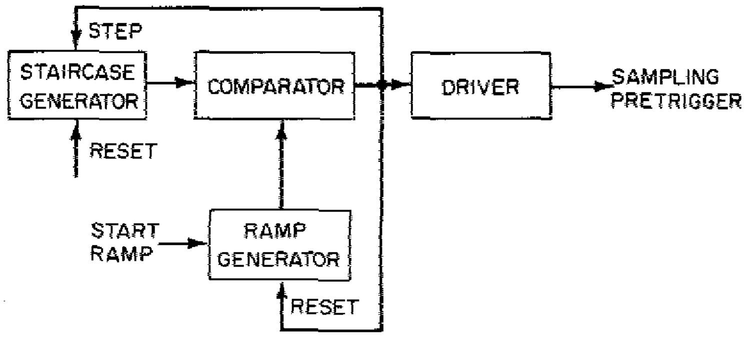
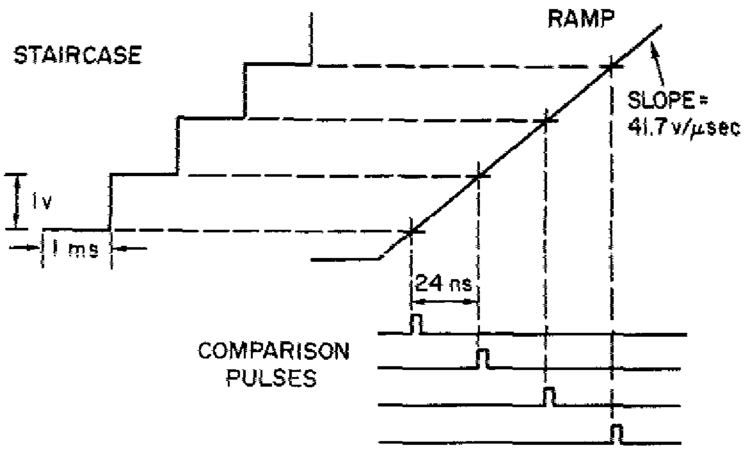


Fig. 14 — Trigger distribution network



(a) Block diagram



(b) Timing diagram

Fig. 15 — Delay generator

The multiplexer, A-to-D converter, memory, magnetic tape unit, and computational capability are not related to the development of the sampling system and are described elsewhere [4-6].

The display unit presently used is a Hewlett-Packard Model 143-A Cathode Ray Tube, which gives an XY display of amplitude vs range of a complete set of 80 consecutive samples.

SAMPLING-SYSTEM OPERATION

Figure 16 demonstrates a single channel of the eight parallel channels sampling a 40-Hz triangular waveform at a 1-kHz rate. The input and output signals are shown at full amplitude in Fig. 16a and attenuated by 40 dB in Fig. 16b. The figures illustrate the linearity and dynamic range of a single channel.

In Fig. 17 the full eight-channel sampler is used in parallel-serial operation against test signals, with input and reconstructed output waveforms shown. Figure 17a shows a rectangular pulse, and Fig. 17c shows the same pulse with reflections caused by attaching a length of shorted transmission line to the pulse source. The reconstructed signal (Figs. 17b and 17d) consists of the full 80 samples taken from ten consecutive repetitions of the pulse.

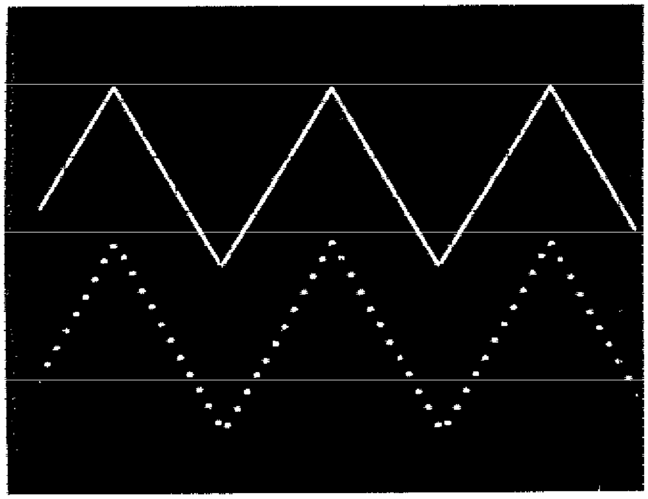
The result obtained from application of the parallel-serial sampling technique to a typical radar return from the HRRM Radar is shown in Fig. 18. The radar return is from some metal objects on a wooden platform mounted in the Cheseapeake Bay.

CONCLUSIONS

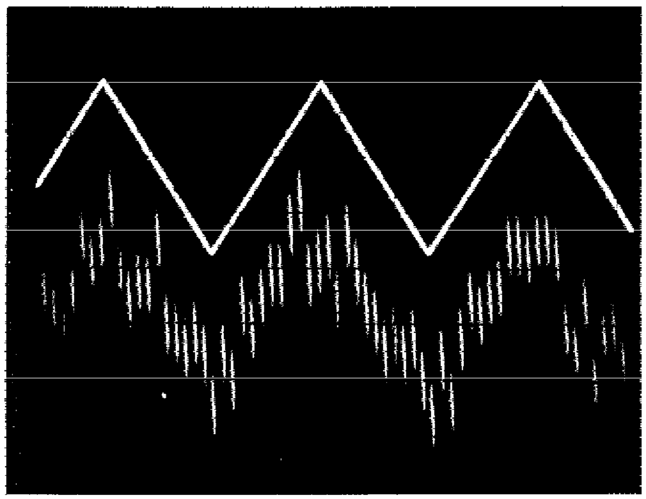
The sampling system in the configuration shown in Fig. 8 has successfully performed as part of the HRRM Radar, enabling many of the experimental goals of the program to be achieved. The results, including those directly related to the sampling technique, are to be described in other reports.

The principal problem area in the sampling system is a nonuniform DC-level drift from channel to channel that causes an effective reduction in dynamic range. The problem is due to thermal drift in various components which were not thermally matched for all channels. It was intended that the DC drift be eliminated with a new resample-and-hold circuit using a high-speed operational amplifier which could provide excellent DC-level stability, but this has not been done.

Many of the operating parameters of the sampling system do not represent limitations but are dictated by the HRRM Radar (Table 1). Furthermore, the system is quite flexible, and some of the parameters can be changed with only minor modifications to the hardware.

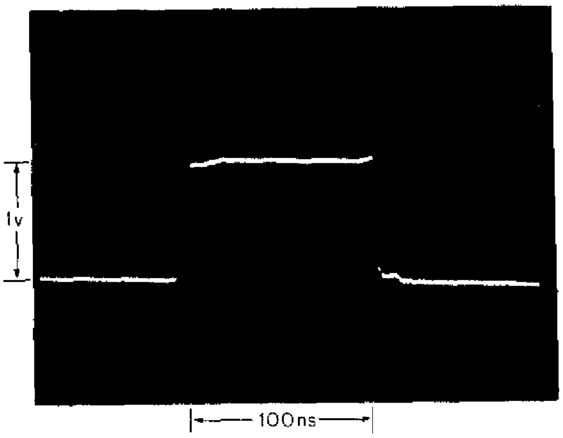


(a) Upper trace: input signal (2 V, peak to peak; 40 Hz.)
Lower trace: reconstructed signal.

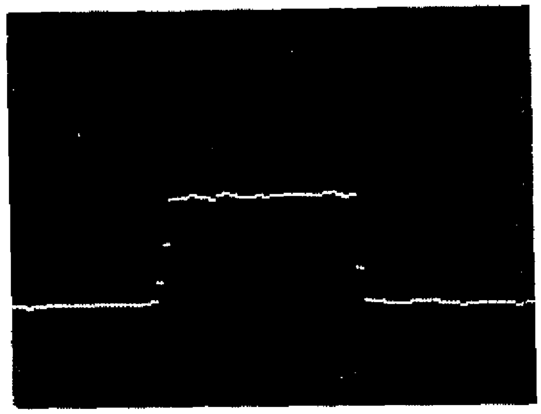


(b) Upper trace: input signal attenuated 40 dB. Lower trace: reconstructed signal.

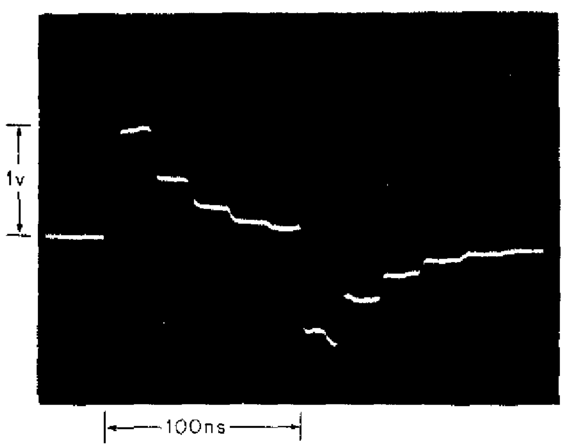
Fig. 16 — Sampler waveforms, single channel



(a) Signal in, example 1



(b) Reconstructed signal, example 1



(c) Signal in, example 2

(d) Reconstructed signal, example 2

Fig. 17 — Sampler waveforms

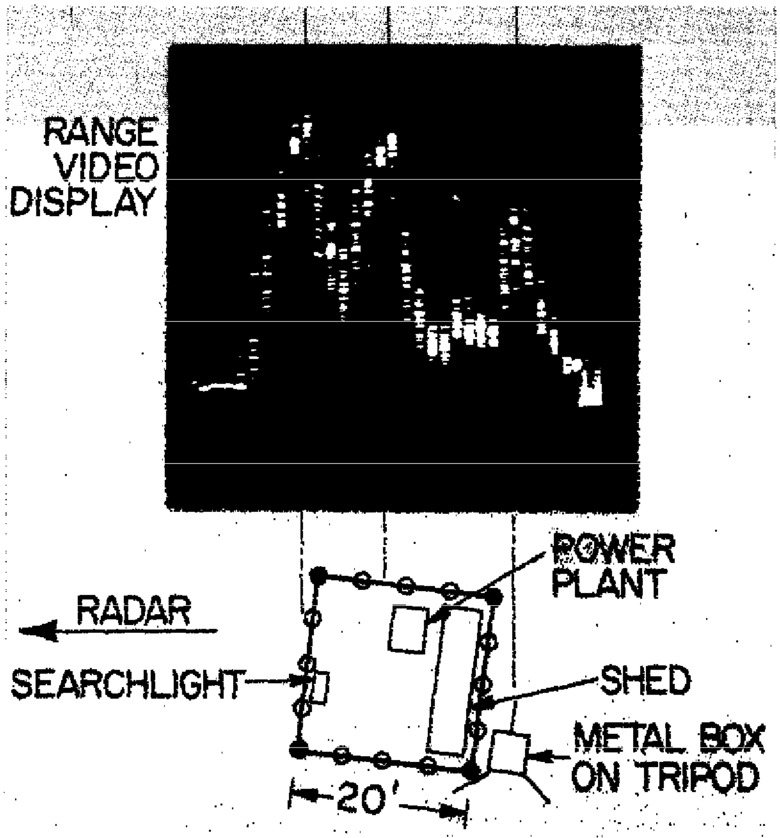


Fig. 18 — Sampler waveform, HRRM Radar return

The sampler will operate with a maximum PRF of 100 kHz, limited by the sampling heads, although not with the present multiplexer and A-to-D converter. The sampling rate may be increased from its present effective rate of 333 MHz up to approximately ten times that rate, with the limitation being the time jitter occurring in the delay generator, which smears the location of a given sample. The input bandwidth may be raised accordingly with a 6-dB loss in dynamic range by replacing the active fanout with a passive one.

Increasing the sampling rate without other modifications will reduce the range interval being sampled. This can be offset by increasing m, that is, the number of PRF cycles required to sample the full range interval of interest. This can be done easily but of course takes more time. An alternative is to increase n, the number of parallel channels, but this cannot be done without major modification and expense. However, if it was desired to sample one signal instead of two (as in Fig. 8), the two eight-channel samplers of the present system can be combined into a 16-channel parallel sampler with very little modification.

REFERENCES

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