MAGNETIC RECORDING OF RADAR DATA

RONALD E. YOUNG
Senior Application Engineer
Ampex Corporation

Summary The methods presently utilized for magnetic recording of radar data are explained with reference to basic radar types. The PPI radar has a time continuous video signal and generally requires a transient free recorder of moderate data bandwidth. In addition, means must be provided to record the azimuth information in either synchro, sine-cosine or digital form. Such means are available and recommended approaches for each type of data are given.

Time discontinuous radar such as the missile tracking monopulse group may utilize recorders normally designed for video service if certain pulse spacing criteria are observed. The wider data bandwidth of this type of signal makes the use of rotary head recorders mandatory.

There are many applications for radar recording. Some of those described include operator training, debriefing and scoring and operational evaluation of the radar facility. The radar recorder can be a significant aid in data analysis for signature determination of satellites and planetary mapping. The radar recorder also furnishes a close facsimile of the operating radar signal for system evaluation when there are no targets to observe or when the main radar is shut down for any reason.

As an illustration of the application of magnetic recording to the radar system an airborne data acquisition recorder is described along with a companion ground reproducer. These two units are presently in use in the evaluation of an airborne radar system and offer significant advantages over previously available recording equipment.

The development of time base stable magnetic tape recorders capable of handling data bandwidth in excess of 5 MHz has added another facet to the instrumentation field--that of recording radar data on a real time basis for analysis at a later time. The discussion that follows illustrates the methods used in magnetic recording of radar data and cites a typical recording system.

I Types of Signals Obtained from Radars Three general types of radar signals are recorded on magnetic tape. One type signal originates in radars which are used for area surveillance with data presented to the operator in the Plan Position Indicator (PPI) format. The video signal is relatively time continuous. Antenna azimuth and, in some cases, elevation needs to be recorded in addition to the video so the entire display can be recreated properly at a later time. The second type of signal is the single target, steerable antenna radar group exemplified by the missile-tracking, monopulse radars. In the case of these units, the video data is normally gated out only in close proximity to the target and thus has a time discontinuous nature. This type of data is ordinarily viewed on an A scope, and requires auxiliary recording of relatively wideband azimuth and elevation error signals as well as high accuracy train and elevation information (usually in digital format) in addition to the video signal. The third type of signal, which is classified separately because of the difficulty in recording it, is Moving Target Indicator (MTI) data. In some cases, this data is processed before recording and added to the basic presentation. This causes no trouble in recording; the problem comes when the moving target information must be extracted from the raw tape recorded signal. In this case, extreme time base accuracy is required due to the use of doppler techniques, phase comparison circuits, or delay and subtraction processing to extract the rate data. Each of these types of signals will now be considered in greater detail to illustrate the problems involved and methods for their solution.

A. Plan Position Indicator Radars (PPI) Most users prefer the PPI presentation for area surveillance applications. This type radar provides a circular display with the transmitter at the center. The picture is direction oriented with the top of the display usually corresponding to magnetic north. The distance of the target from the transmitter is indicated by the distance of the target blip from the center of the display or its position in reference to concentric range rings on the CRT face. An additional display resembling a quadrant can be made available on another scope for observing the altitude of a given target. (Range height indicator). This type of system is illustrated in Fig. 1.

To synchronize the display with the rotation of the antenna, antenna azimuth must be recorded. The azimuth information normally takes the form of synchro data, and the accuracy of the antenna position depends on the accuracy and type of synchro information presented. The normal synchro transmitter rotates once for each antenna revolution, but in some systems a 10/1 or 36/1 synchro ratio may be also provided.

Data Signal Requirements -Video The basic radar video data for PPI presentation resembles normal television video-type signals. If the radar is a short range, high resolution unit(i. e. a range of approximately 30 miles), the required data bandwidth may be up to 5MHz. If a longer range unit e.g. 100 to 300 miles is involved, longer transmitted pulses are used and the receiver bandwidth may consequently be limited to 400 to 500 kHz. On the low end of the frequency spectrum, near dc response is required. This is due to the nature of the signal involved, illustrated in Fig. 2. The main “bang” signal is the transmitted pulse and effectively saturates the radar receiver for a period after the initial transmission. This is normally due to leakage through the T/R tube used for switching the single antenna between the transmitter and receiver. An additional high level signal is provided by the ground return reflections near the antenna and this may continue for 10 to 30 miles(120 to 360 microseconds). Targets then appear farther along the sweep as signals above the residual noise level, and are indicated on the PPI screen as bright spots. The need for near dc response can be illustrated by the cloud return shown in Fig. 2. In practice, this return may be 50 to 100 miles long (600 to 1200 microseconds). In recorders such as most instrumentation units with restricted low frequency response, a sag will result on reproduction of this signal as shown in Fig. 3. Most PPI repeaters have circuits which clip signals that extend below the base line, so no presentation (black screen) results for the total time during which such signals are below the base line voltage. Thus, the small target appearing after the cloud on the original return will be lost with a restricted low frequency response recorder. To eliminate this problem, the necessary recorder lower bandwidth limit should be 5 to 10 Hz; otherwise some sort of clamping circuit will be required to limit the excursions below the base line.

Trigger An additional signal furnished by the radar, is the trigger pulse which fires the transmitter. This is the radar master timing pulse and is used for the start of the sweep time base in the indicator to furnish non-ambiguous timing information. The pulse is high amplitude, typically 10 to 100 volts peak. The minimum output voltage normally required from the tape recorder is 10 volts peak across 75 ohms, and this usually requires a special amplifier on the output of most existing tape reproduce electronics. The most critical point here is that the time delay of the trigger channel and the video channel must be identical. The trigger channel starts the running time of the electronic delay used to determine the target range, so any time delay between the trigger and video will result in an inaccurate range indication on the display.

Azimuth Co-ordinate Signals Azimuth signals available from radars are generally in one of three forms; synchro, sine-cosine or digital. Each of these signal types requires a somewhat different treatment, so they will be considered separately.

The normal PPI radar antenna transmits its azimuth position information thru the positional signals of a synchro generator. This generator revolves once for each antenna revolution and this repeats the antenna position information directly to points remote from the antenna mount. In addition to this 1/1 generator, another is sometimes used which rotates 10 times per antenna rotation or once every 36 degrees. This system is used to provable better azimuth accuracy at the remote station than the 1/1 unit can provide.

Synchro signals can be recorded in a rather straight forward manner if a few precautions are observed. The electrical diagram of a synchro transmitter and receiver is shown in Fig. 4. It can be seen that there are four important voltages to be recorded, the three stator signals and the rotor reference voltage. Each of the stator signals is a constant frequency waveform slowly amplitude modulated by the rotation of the rotor. The rotor voltage is a constant phase and amplitude at all times. To preserve the accuracy of the system through the record and reproduce process, the gains of the channels used for the stator signals must be identical and the delays thru each channel must be closely matched. Also the recorder channels must have good signal-to-noise-to prevent hunting of the synchro receiver. A satisfactory method of recording synchro signals directly has proven to be thru the use of frequency modulation. This recording method has the required gain stability and signal-to-noise ratio as well as excellent amplitude stability of the reproduced signal. With standard multiplex equipment now available, it is possible to multiplex the four required FM channels (3 stator and 1 rotor) on one auxiliary data track of 15 kHz bandwidth. A seven channel multiplex corresponding to a 1/1 and a 10/1 or 36/1 group can be handled effectively in 30 Kc of bandwidth.

In the generation of a circular sweep waveform for production generation of a CRT PPI display, the synchro signal just referred to is often converted to two signals of a sine-cosine relationship. Here the azimuth information is contained in only two separate signals, rather than in the four obtained when the synchro signal is used directly. In order to maintain the azimuth accuracy required in sine-cosine use, somewhat better amplitude stability is required in the synchro case. An excellent method for recording sine-cosine azimuth data which accurately preserves the basic data accuracy, is that of digitization of the signal. Standard digital encoders are available which will accept sine-cosine (or synchro) type signal formats, digitize them, and reproduce them from tape with an overall error accumulation of less than 0.25 degree. This is at least twice the accuracy that can be obtained by FM recording the synchro waveforms directly. In addition, the. digital system has much better in1herent stability, and will maintain it's basic accuracy over much longer periods of time with less maintenance than is required by an FM system.

The final azimuth signal possibility is one which is already encoded in digital form at the antenna. This digital signal may be recorded and reproduced thru many successive dubbing and processing operations with no degradation of the basic accuracy as long as it is kept in the digital form. The recording of this signal in digital form utilizes standard techniques.

Elevation Co-ordinate Signals Antenna elevation data may be required if the radar is a height finder. The video signal is normally the same as that of nonheight finders, and video data is presented for all heights on the PPI. To produce height information, the radar antenna pattern is nodded up and down either by physical antenna movement or by electronic beam phasing. The antenna or beam position is available at the radar output either as a slowly varying dc voltage, or as a synchro output which varies with antenna elevation angle. The rate of change of this signal is very low, so an FM track is needed to record it; it may again be multiplexed along with other data. Elevation synchro data is recorded in the same manner as azimuth synchro data described previously.

B. Monopulse Tracking Radars The typical monopulse type radar is intended for use in very accurate tracking situations where maximum data is needed on single targets or groups of targets. The units are used in conjunction with a computer, so the major output is a digital representation of target range, bearing, elevation, and some radar operating constants. These data are easily handled by existing digital tape transports and methods, so will not be covered in detail here.[1] In recent years, however, it has been found advantageous to record the raw video for later replay so that additional targets may be found around the one tracked and reported by the digital portions of the radar, and data may be gathered on signal fade and shape in the absence of AGC action to determine target type and orientation. This type of analysis requires a linear recorder of the rotary head type with some special modifications to adapt it to this type of data.

Since the monopulse is designed for accurate tracking and high resolution, short transmitting pulses maybe used, necessitating wide data bandwidths of 4 to 5 MHz. Thus, a rotary head recorder is used to obtain the recording bandwidth required. The main problem associated with recorders intended for television use in this service is the head switching transients involved. A normal TV-type recorder may be used if two conditions are satisfied. The first is that the video gate width, the portion of the signal after the pre-trigger pulse that we wish to examine, is 900 microseconds long or less: and second, the pulse repetition rate of the radar must be a multiple or submultiple of the recorder head switching rate, (or within 5% of it) in order that the video return may be positioned in the same place on each head scan. This will place the recorder head switching transients out of the data rEgion and eliminate them from further consideration. It does require that the recorder be synchronized by the same frequency source as that which triggers the radar. A typical example of this is shown in Fig. 5. In this case the radar is running at a prf of one third the head switching rate (960/3 = 320 pps.). In the event that the above criteria for interleaving the radar returns and head switching transients cannot be satisfied or the total time of the return to be observed is longer than the interval between switching transients, it becomes necessary to use a recorder with head switching transient elimination and time base correction.

In some cases these radars also incorporate other narrower bandwidth video data channels representing elevation and azimuth error to allow secondary target location in relation to the tracked target position. These may be multiplexed on the video data channel by special techniques and will be time base corrected by the same electronics which correct the main video channel.

Auxiliary Data The normal types of auxiliary data for this system are azimuth and elevation as well as range information, usually encoded in digital form. This can be handled on the auxiliary data tracks by the normal digital methods. In addition some range, azimuth, and height information may be received in synchro format, in which case the previously described method for recording synchro signals can be used.

C. Moving Target Indicator (MTI) Moving target indication signals, before detection, are relatively difficult signals to handle. In one form of MTI, target motion is indicated by a doppler shift of the returned signal frequency. This requires precise control of the playback speed so the very small percentage change can be reproduced very accurately to allow exact velocity determination. In other cases, the received signal is delayed through a delay line and added to the data obtained on the next scan, but out of phase. In this way, echoes which appear at th same position on each scan are cancelled, and targets which change position are presented in their true amplitude. Both of these applications require excellent time base stabilization to allow post-recording detection of the MTI information. This is available through electronic time base compensation of the wideband rotary head recorders which will allow long term time base stabilization on the order of 25 nanoseconds peak-to-peak for both short and long term errors.

II Applications of Radar Recorder The uses of magnetic tape recorders capable of handling radar data are many and varied. To illustrate, a few of the more common applications that are now in use or are being considered, are presented.

A. Training The use of a radar recorder provides invaluable experience in a training situation. In military environments, the opportunity is presented to play back actual operational exercises to train the entire complement in handling that particular exercise. The data may be presented in the same form in which it originally comes, an unknown target, and the whole exercise followed to completion. Jamming and other radar interference will be identical to that existing when it was recorded, and receiver and operator techniques for jamming elimination can be evaluated and proved under realistic conditions.

In a radar training school environment, either for operators or maintenance personnel, actual signals can be replayed without radiation from any device. The signals played each time are duplicates of the previous time, so each trainee receives the same presentation and can be taught the identical interpretation. Exercises can be replayed that are actual recordings involving large operating situations. These provide realism and experience in atmospheric unpredictabilities, fade patterns, false targets, etc., which are difficult to simulate.

In an evaluation situation, the evaluating officer has the capability of recording the tracking performance of an installation radar. During a debriefing and scoring situation, he then has the opportunity of replaying the data to illustrate to the personnel being scored what they did right and what targets they missed. No possibility exists of misinterpreting what the operators actually could have seen. Also, the possibility exists of playing a standard test exercise to a number of groups being evaluated for competitive purposes, on an equal basis. These have the additional possibility of being recordings of large scale attacks or exercises which would be operationally infeasible to repeat.

B. Data Analysis When used with a monopulse radar, a recorder affords the possibility of offline analysis of untracked targets which were not first presented in the digital portion of the tracking radar. It also allows analysis of signal waveform which is not provided for in the digital radar output. In PPI data, it allows repetitive replay of a selected segment of returns to determine if a fading target acquired for a few scans only is in fact a target.

A relatively new use, but one which is important in space tracking work, is the recording and subsequent replay without AGC of the radar return.[2] With the addition of radar signal strength calibration signals, it becomes possible to perform signal strength analysis for body reflectivity signature, recording. This type of measurement, in conjunction with anechoic chamber analysis of the particular body involved, may allow determination of the attitude and the degree of stabilization of the satellite.

Another use for which magnetic tape is uniquely suited is involved in low signal strength work such as radar mapping of other planets.[3] Here the returned signal is recorded from the receiver for later processing and analysis which is impossible in real time. The received signal may in some cases be slowed down or speeded up (in time) to fit the bandwidth requirements of the processing equipment. Analysis techniques, such as autocorrelation, may then be applied to the recorded data to achieve sufficient signal to allow identification of the return.

C. Equipment Checkout In both military and space tracking environments, the capability exists of exercising and testing the tracking and presentation equipment downstream of the receiver without operating the basic radar, or when no targets are available. This allows maintenance in radar silent periods and allows determination that needed monitoring gear will be fully operational when the radar can be energized. It also allows reproduction of a standard calibration tape to determine errors in the tracking computers and detect component malfunctions in off-line times.

D. History In area surveillance situations such as FAA terminal radars and airways control, it is sometimes necessary or desirable to preserve a record of the actual target returns for later analysis. This is used to observe traffic flow under bottleneck conditions to find better ways of handling peak traffic loads. It also provides an aid in accident prevention by showing the actual traffic situation existing at the time of the incident. It also provides more real traffic situations (including the accompanying weather clutter and interference) for study by controllers in a training environment.

Another application where the history recording feature is useful is the replay of missed targets. This allows the operator a second chance to acquire a target he missed the first time because his attention was directed elsewhere.

III Airborne Data Acquisition Recorder/Ground Based Reproducer System The following section describes an airborne recorder and a companion ground based recorder/reproducer developed for system evaluation recording in an airborne radar development program. The unit was designed as a high performance rotary head recording system capable of operation with a variety of signal inputs. The basic system performance parameters were as follows:

1. Two channels of wideband information (10Hz - 5.5 MHz).
2. Transient free reproduction of the recorded information.
3. Electronic time base control on the reproduce system to allow overall maintenance of 25 nanosecond peak-to-peak base error throughout the system.
4. Excellent interchannel time correlation to allow comparison of signals on the two wideband tracks with a high degree of timing accuracy(less than 25 nanoseconds observed in the final system).

Airborne Recorder The airborne recorder developed for this program is illustrated in Fig. 6. The total unit is contained in two cases. The recorder case contains the tape transport top plate and reels, reeling mechanism, tape guides, rotary and longitudinal head assemblies, signal electronics and head servo electronics. The auxiliary case contains control and monitoring circuits, power supplies and filtering, RFI filter and the radar servo digital encoding electronics.

The wideband signals are recorded in FM form. The incoming data is frequency modulated on an FM carrier with a frequency of 8.5 MHz. The resulting constant amplitude carrier and its associated sidebands are recorded on the tape. An additional time base reference signal is recorded along with the FM data on the wideband tracks. On reproduction this pilot signal is used as a time base reference for time base correction of the wideband data prior to final switching and before limiting and demodulation to allow transient free recombination of the wideband RF signal. The pilot is recorded at 500 kHz which is well below the FM spectrum to prevent interference with the main data.

Two auxiliary data channels are located along the edge of the tape. They are recorded in the conventional direct-with-bias method and are used for voice and time code information as well as radar synchro data.

An additional longitudinal track is recorded at the opposite edge of the tape for use as a control track for coarse play back head synchronization. When a recorded tape is being reproduced it is essential that the longitudinal motion of the tape and the transverse motion of the heads be accuragely controlled so that the recorded tracks are properly scanne. To accomplish this a control track is recorded which marks each revolution of the head drum during the recording process. The capstan is then servo controlled on reproduction so that one servo pulse is reproduced for each head drum rotation. This re-establishes the ratio of longitudinal to transverse tape motion which existed during recording and assures accurate registration of the reproduce heads on the recorded tracks. In order to provide time in the reproduce process for the electronic circuitry to sense the phase position of the signal from the oncoming data head while the previous head signal is still being used for the data, there is recorded overlap approximately 10% of the one millisecond head scan time. This data redundance also allows the slow switching necessary for elimination of the data switching transient between heads.

As previously mentioned it is necessary in a recorder designed for radar use to provide a means for recording azimuth information. The airborne recording system uses digital means to prevent degradation of the 1/1 synchro output by the usual translation errors apparent when using direct signal recording techniques. The block diagram of Fig. 7 illustrates the method used. The incoming synchro information is first converted to a sine-cosine type of signal by the “Scott T” transformer at the input. The sine and cosine outputs from the “Scott T” are then converted to a serial binary pulse train which specifies the sine and cosine of the synchro shaft angle. This pulse train is then recorded in serial data form by the magnetic tape recorder on one of the auxiliary tracks. The sine and cosine signals are encoded to an accuracy of 11 binary bits, assuring that the system specification of 0.25 degree maximum total error will De met easily.[4]

To record the radar trigger signal and assure its time coincidence with the wideband video data, a trigger addition circuit is utilized for the recorder. This is shown in block diagram form in Fig. 8. The high voltage positive going trigger is first attenuated to the normal I volt peak level of the rest of the system signals. It is then inverted. Radar video is a positive going signal, so the trigger will then be the only negative signal in the data and can be identified and separated in the reproduce process with relatively simple circuitry. The video channel is blanked at the time the trigger is added to prevent any noise on the video from interfering with the trigger addition process. Time compensating delay lines are included in the video path to equalize the time delay for the trigger and video paths..

Ground Based Reproducer System In order to simplify the reproduce system check out and provide additional flexibility for dubbing and data processing, the reproducer designed for use with the AR-550 also incorporates a full set of record electronics. The record system resembles closely the record system on the airborne unit, with the addition of built-in test signals for system check-out and performance evaluation. The recorder/reproducer configuration is shown in Fig. 9.

In order to achieve the high quality signal reproduction and time base stability of which the unit is capable, the FR-950 ground reproducer provides a sophisticated signal system of advanced design. This signal flow is shown in block diagram form in Fig. 10 for only one data channel; the other wideband channel has an identical set of electronics.

The reproduced signals are recovered from tape by the reproduce heads and coupled out to the head pre-amplifiers thru rotary transformers. The amplified signals are then routed to a group of equalizers. Here the amnlitude and phase response of each head is matched and adjustable delays are provided to allow static time matching of the signals from the heads. Pairs of heads 180 degrees apart on the head drum are connected in series, so the signals from each pair of heads is alternated with a period of silence as these heads are not simultaneously in contact with the tape.

Even the best time base correction obtainable at this time is not sufficient to allow a sudden switchover from one channel to the other. There is still too much phase difference left between the FM carriers in both channels. However, if the phase difference is always less than 90 degrees, a slow transition from one channel to the other (in such a way that one channel decays slowly in amplitude while the other increases at the same rate, both being added) will not produce a significant transient. The result will be a smooth and continuous transition from the phase condition in the first channel to that in the following channel, if the waveform of the signal approximates a sine wave. The electromechanical servo system on the head drum corrects the play back signal to within ± 150 ns with respect to the system master clock. This timing error is then reduced to less than 25 ns peak-to-peak in the voltage-controlled delay lines.

If the reproduced FM signals in two adjacent head channels are time base corrected to such a degree that, during the overlap time, identical portions of the signals are always less than 90-degrees phase difference, a slow switchover process will change the signal smoothly from the condition in the first channel to that in the second channel and little transient will appear in the output signal of the switcher.[5] There will be a change in the amplitude of the FM signal during the crossover period caused by the phase difference between the two channels. This is of no significance because the FM signal is limited before being demodulated. However, the change of the phase during the cross over time is equivalent to a slight change of the carrier frequency according to the relation w = de/dt. If the phase change from the condition in one channel to that in the following channel is a linear function of the crossover time, the carrier frequency will be ideally subjected to a step in one direction at the beginning of the slow switching process and to the same step in the opposite direction at the end of that process. For example, if the crossover time is made 80 uS and the time difference between the two signals is 25 ns (approximately 90 degrees for a 10 Mc carrier), the change in carrier frequency during the crossover time would be 80000/25 or 2.65 kHz. For a sensitivity of the demodulator of 1 volt peak-to-peak for 1.5 MHz deviation, the spurious signal would be 2.65/1500 or is down more than 50 db below full deviation.

After sufficient electronic time base correction, this signal combination is achieved in a special, slow-transition switcher which uses a trapezoidal gating waveform, two six-diode gates, and a signal adder as :shown in Fig. 11.

After the pilot frequency has been filtered out, the combined signal is passed through a limiter and an FM demodulator. At this point, the pilot has been time base corrected and can be used in a separate phase comparator to monitor the timing stability of the system during normal operation. The demodulated information signal still contains a pilot signal component by way of intermodulation caused by non-linearities of the system. This component cannot be filtered out, but to some degree it can be cancelled out in a compensation circuit which injects an equal amount of pilot frequency from the system clock in a phase which is opposite to the interference component. This is only possible because the signal is highly stabilized with respect to time.

In addition to the electronic time base control for fine adjustment of the electronic delay in the FM system, the 500 Kc pilot signal error is integrated and used to provide a control input for the rotary head servo. While coarse control of the rotary head position in relation to the recorded track is provided by control track phase comparison in, the capstan servo, the head drum angular velocity is controlled by the integrated 500 Kc error signal. This ensures that all signals coming off tape are reproduced at the same frequency that they were recorded and that residual time base errors do not exceed the correction range of the time base correction delay lines.

Reproduce electronics are also provided for the synchro signal previously recorded on the auxiliary track. These electronics connect the digital signal to a sine-cosine type output, and finally, thru the use of another “Scott T” transformer set, to synchro type outputs. Amplifiers are included on the synchro lines to facilitate driving a synchro repeater requiring a power input of 12 watts or less.

The developments typified by the above equipment show how equipment can be designed to cope with the majority of radar recording problems. Newer types of radar such as SLAR will require still finer refinement of the art of magnetic tape recording, but it is certain that a satisfactory method will be found.

REFERENCE

1. A Data Handling System for a Radar Installation, Harrison, J. E. A. and Chase, R. J., Transactions of the Society of Instrument Technology, September 1964, pp. 91-113.

2. Radar Video Data Handling, Thomas J. Burke, American Institute of Aeronautics and Astronautics, Space Flight Testing Conference, Cocoa Beach, Florida, Paper 63081-63.

3. Radar System Employed During Radar Contact with Venus in 1961 Various authors (Russian) Radio Engineering and Electronic Physics, Volume 7 November 1962, p. 1715-1722.

4. Airborne Angle Data Transmission System, Towson Laboratories Incorporated.

5. Transient Free and Time Stable Signal Reproduction From Rotating Head Recorder, Kietz, Erhard, Record of the 1963 National Space Electronics Symposium, IEEE Professional Technical Group on Space Electronics and Telemetry.

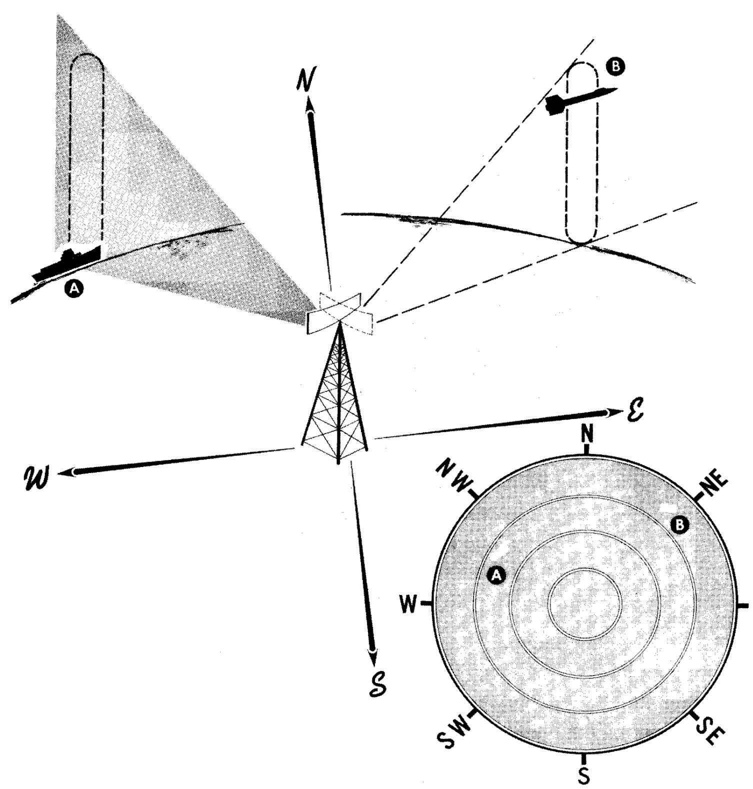

Fig. No. 1 Method of Generation of PPI Radar Display

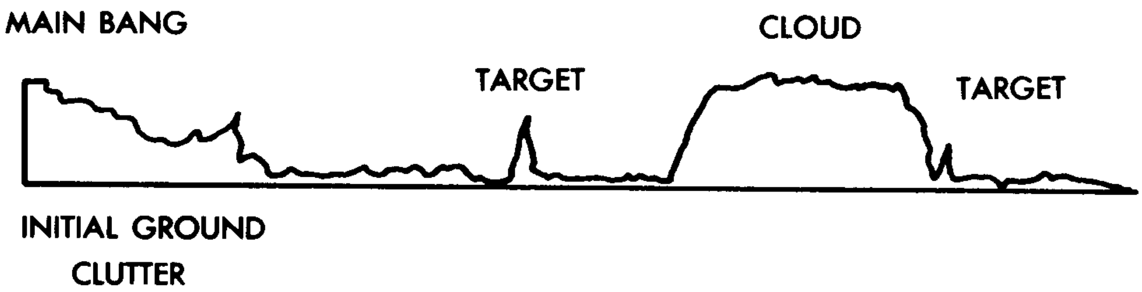

Fig. No. 2 Typical PPI Radar Presentation

Fig. No. 3 Typical PPI Radar Presentation When the Recorder Exhibits Restricted Low Frequency Response

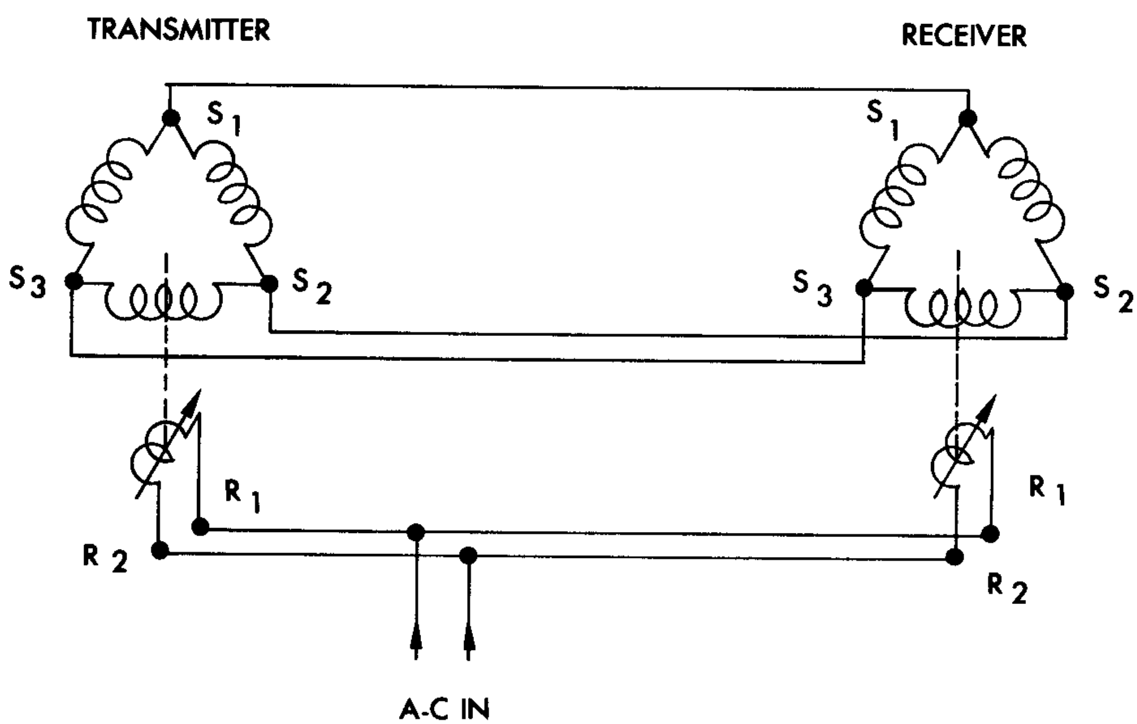

Fig. No. 4 Electrical Diagram of Synchro Transmitter and Receiver

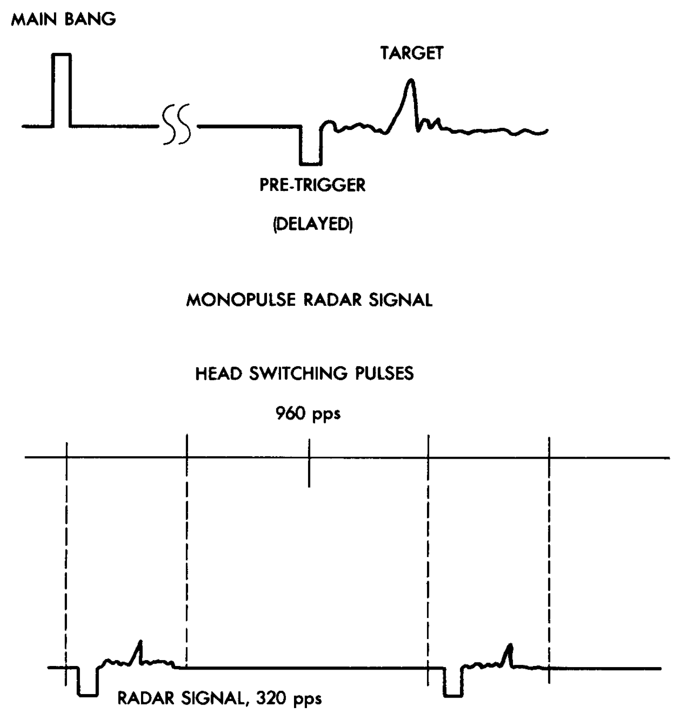

Fig. No. 5 Monopulse Data Interleaved with Head Switching

Fig. No. 6 AR-500 Configuration

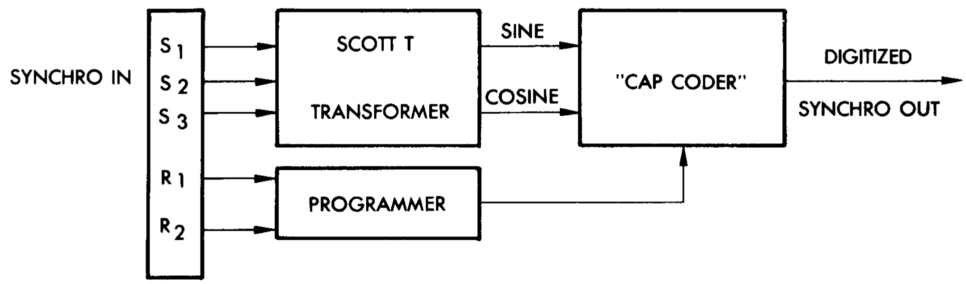

Fig. No. 7 Block Diagram - Synchro Encoder

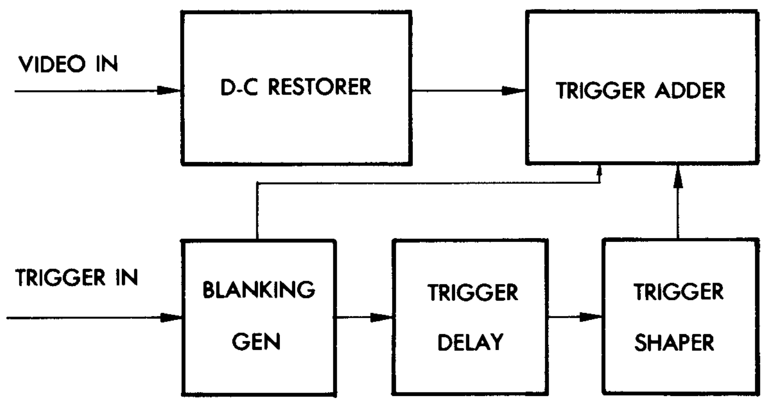

Fig. No. 8 Block Diagram - Trigger Adder Circuit

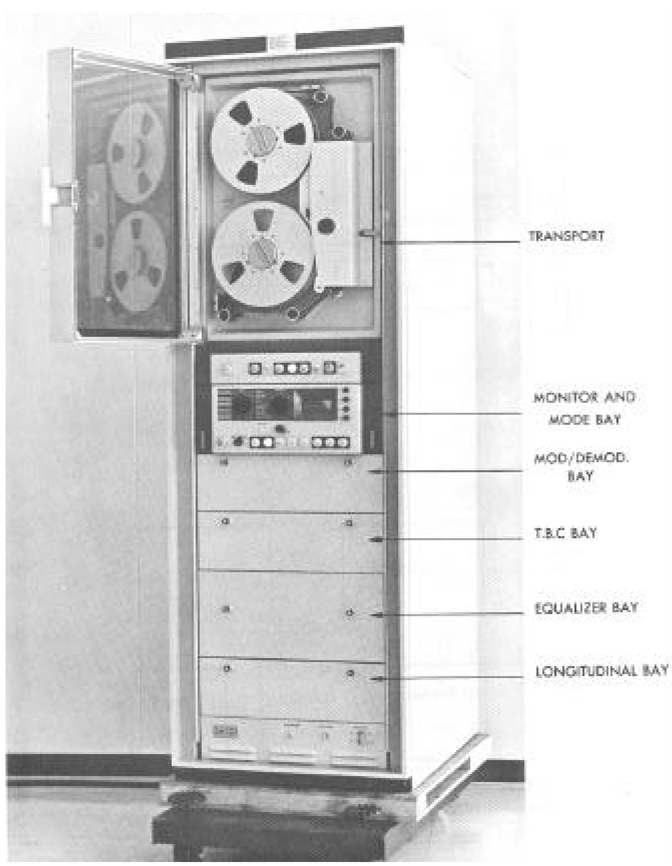

Fig. No. 9   Type FR-900 Recorder/Reproducer

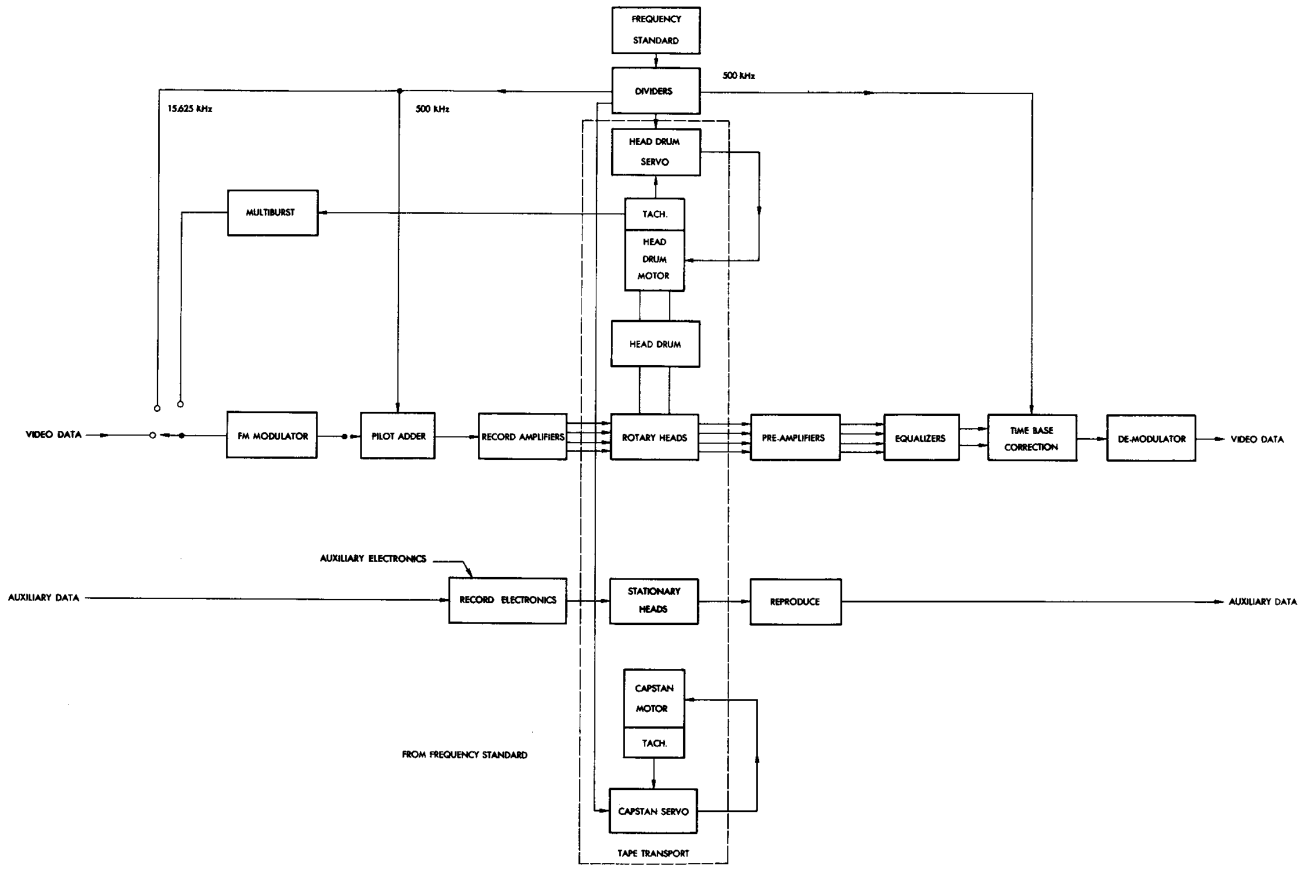

Fig. No. 10 Block Diagram - Signal Flow in One Data Channel of FR-950 Ground Reproducer

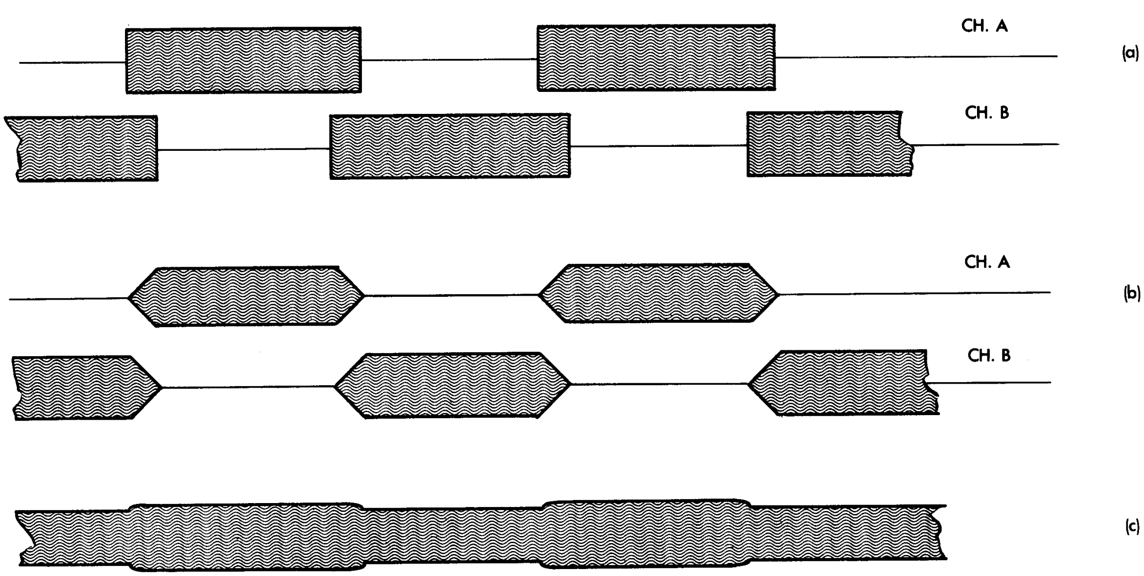

Fig. No. 11 Signal Combination Process in Slow Switcher System