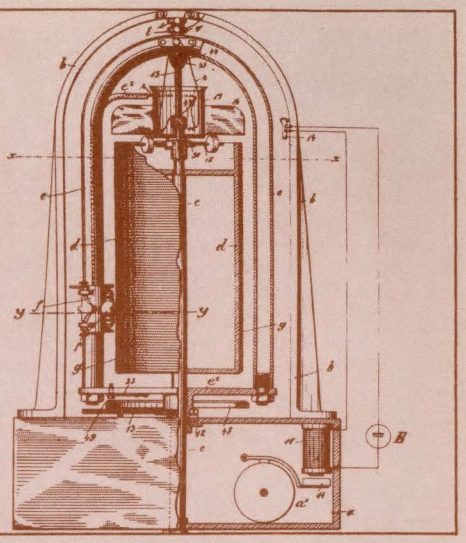
INSTRUMENTATION TECHNICAL INFORMATION NUMBER 1



ROTARY-HEAD INSTRUMENTATION RECORDERS: DESCRIPTION AND USES

By R. Horn

The bandwidth of any magnetic tape recorder is basically limited by the magnetic wavelength on tape. To record a bandwidth of more than a few MHz, recorders with stationary heads require excessively high tape speeds with correspondingly low recording time. The problem of extending signal bandwidth to 4 MHz and above was solved by Ampex engineers in 1956, with the first transverse scan rotary head in the VR-1000 Videotape Television Recorder. Since then, parallel rotary head development programs at Ampex have resulted in the high band VR-2000 (world standard for color broadcast and teleproduction) and a related generation of airborne and ground transient-free instrumentation recorders, the FR-900/AR-500 family.

ROTARY HEAD FUNDAMENTALS

A rotary head assembly has a drum with four magnetic transducers at its circumference rotating at high velocity. Effective head to tape speed with this technique is typically 1600 in/sec. With a rotary head, adjacent transversely recorded tracks are discontinuous (see Figure 1). Each transverse track has a duration of about one millisecond and contains about 100 microseconds of redundant or overlapping information also contained in the following track. In the playback process, the rotary head reproduces each track in sequence.

Small timing or phase errors and signal discontinuities in reproduction from track to track are caused by dimensional variations in the tape and head mechanical components, or differences in characteristics of the four heads. For television recording, these signal interruptions are timed to occur during the picture scan blanking intervals, and pose no problem. For instrumentation recording, spurious sidebands caused by the transverse track discontinuities can degrade the data. A solution was found with the introduction of the continuous-signal, transient-free, rotary-head recorders (Ampex VR-1006, FR-900, FR-950, AR-500, and AR-550.)

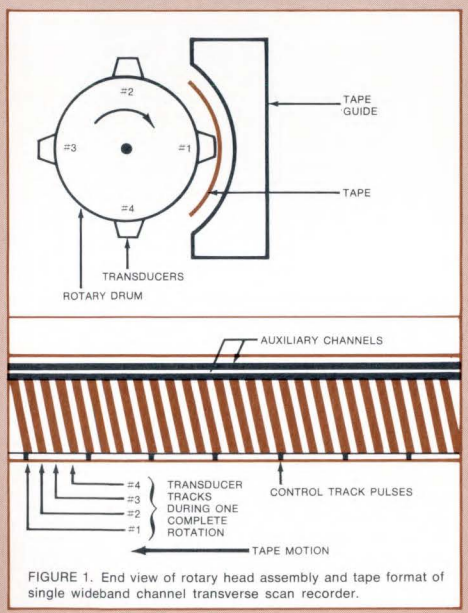


FIGURE 1. End view of rotary head assembly and tape format of single wideband channel transverse scan recorder.

An FM recording technique is used to assure wide dynamic range, high signal-to-noise ratio, and low frequency response (down to 10 Hz). Signal combination between one recorded track and the next is performed prior to limiting and demodulation of the FM signal. If it were necessary for instrumentation applications to keep transients generated through the FM detector to a value of 30 dB below the peak signal level, track-to-track phase errors would have to be held to within a few degrees at the carrier frequency. This would amount to only a very few nanoseconds. In the FR-900 recorder family, transients are avoided by making a slow transition between consecutive tracks (typically over an 80-microsecond duration), rather than a fast one (Figure 2). In order to make this slow transition without carrier cancellation during the switching process, the phase difference between the off-going and the on-coming signals is kept to less than 180° of the carrier frequency. For a typical system with an 8.5-MHz FM carrier, this amounts to 60 nanoseconds.

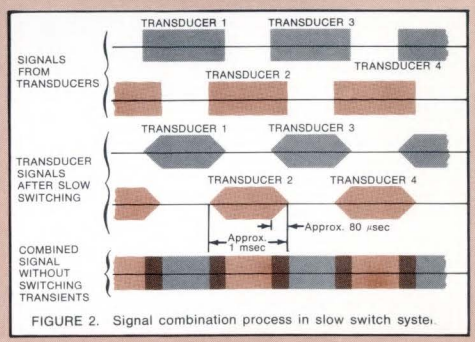


FIGURE 2. Signal combination process in slow switch syste.

To bring the two signals into phase, a pilot frequency from a stable crystal-controlled oscillator is frequency multiplexed with the FM signal during recording. (This frequency is located below the useful lower sidebands of the FM carrier so it does not interfere with the data.) On playback, the pilot is compared in phase and an error signal derived to vary the amount of delay in a voltage-variable delay line through which the four playback signals pass prior to commutation. By this means, the FM information in the on-coming channel is brought to within 15 nanoseconds of that in the off-going channel before the switching begins.

ROTARY HEAD RECORDER FAMILY

Current rotary-head instrumentation recorders such as the FR-900 provide a capability of recording 6 MHz on one channel for one hour. The reproduced signal is continuous and transient free. Signal-to-noise ratio is better than 40 dB peak-to-peak signal to rms noise. Time-base error is exceptionally low, within ±15 nanoseconds of the timing reference of the recorder/reproducer over the entire duration of the recording. Besides the wideband channel, the FR-900 records two longitudinal channels for additional data or voice logging. Each has a bandwidth of 300 Hz to 30 kHz.

Other machines in this family are the FR-950, a two-channel 6-MHz recorder/reproducer with a one-half hour recording capacity; the AR-500, a record-only, single-channel airborne counterpart to the FR-900; and the AR-550, a record-only, two-channel airborne counterpart to the FR-950.

APPLICATIONS

Multiple Instrumentation Radar Recording: A typical radar application involves recording video data of approximately 1.2-MHz bandwidth from two radars plus a radar trigger. Precise time correlation is required between the two video signals. Also, azimuth information from each radar is recorded. The FR-900 6-MHz wideband channel is split into two bands. One radar video and associated trigger are recorded directly. The second radar video is first frequency modulated on a 4-MHz subcarrier, then recorded.

This approach utilizes the wide bandwidth of the 6-MHz channel for two smaller bandwidth data channels. Close interchannel timing is achieved between the two radar video signals and the radar trigger since they are all recorded on the same channel. Coarse and fine azimuth synchro information including reference frequency from a single radar is frequency multiplexed on one of the two longitudinal channels.

Airborne Search Radar Recording: One of the original requirements for an airborne rotary instrumentation recorder was to record radar and moving target indicator video, of approximately 5.5-MHz bandwidth each, from an airborne search radar. Each of the two wideband channels of the AR-550 airborne unit records a video channel from the radar. The radar trigger is multiplexed onto one of the wideband channels.

The time-base stability of the rotary-head recorders is such that ranging errors caused by signal jitter are negligible for most radar systems. The ranging time for a radar mile is approximately 12 microseconds or 6.8 nanoseconds per yard. Since the AR-500/FR-900 family has a time-base stability of ±15 nanoseconds peak-to-peak, the maximum reproduced timing error between a radar trigger and video pair of pulses is 30 nanoseconds. This corresponds to a ranging error of 4.4 radar yards. Accurate data correlation of the two radar channels is also provided because the interchannel time displacement error between the two 6-MHz channels is 25 nanoseconds or less on the AR-550/FR-950 recorders. Data reproduced from an AR-550 tape is free of any head-switching transients when operated within the recorder's rather wide environmental limits. The dynamic range of the AR-550/FR-950 allows a minimum width pulse of approximately 200 nanoseconds, half amplitude duration, to be visible above noise level when 40 dB below full-level signal.

The AR-550 for this application included a digital synchro unit which digitizes radar azimuth synchro data, and records it on one of two longitudinal tracks. Upon reproduction, the synchro information is converted back to analog form and maintains an accuracy of 0.36°

Related applications of these airborne/ground systems are reconnaissance missions, training of radar operators, radar evaluation, and data computing systems evaluation.

Predetection Recording: Another important application of rotary instrumentation recorders is their use without the internal FM modulator/demodulator for predetection recording. Picture data from the Lunar Orbiter uses this technique on an FR-900 (see *Readout*, Volume 6, No. 3). Typically, the intermediate frequency output of a receiver is used for recording frequency modulated signals directly. The usable bandwidth in the predetection mode is 1 MHz to 10 MHz. When reproduced, the predetection output is fed to a limiter stage to provide a constant amplitude output over the recorded bandwidth for demodulation by external equipment. In this mode the pilot signal from the timing reference of the recorder can be recorded with the predetection signal for transient-free reproduction.

Recording Television Signals of Any Scan Rate: A rotary-head instrumentation recorder synchronizes the rotary head and tape speed to its own internal timing reference. (A standard television recorder synchronizes to the input signal.) This means a rotary instrumentation recorder can record a television signal of any vertical or horizontal scan rate whose signal bandwidth is within the recorder bandwidth. In some applications, such as aircraft with several sensor systems (infrared, side-looking radar, television cameras), each sensor system may have different scanning rates. The AR-500 can record these singly or in any sequence on one channel. The AR-550 can record any two signals simultaneously.

Digital Data Recording up to 20 Mbit/s and Higher: In digital data recording applications, the wide bandwidth, transient-free head switching, low jitter, (as well as a proprietary redundant recording scheme) permit the FR-900 family to record up to 10 megabits per second per channel of serial NRZ digital data at very low error rates. If the digital data source is synchronized to the timing reference of the recorder this reference can be used as an error-free data clock when the data is reproduced. Error rates at 10 megabits per second are less than 1 in 10^8 bits measured on a bit-by-bit basis. Data rates in excess of 10 megabits per second can be handled by multichannel recorders, for example: 20 megabits per second on the two-channel FR-950 or AR-550. In fact, the existing technology of the FR-900 family can be extended to rates up to 20 or 30 megabits per second. The absence of head-switching transients permits recording digital data at high bit rates even during the switching period at these low error rates.

Another important consideration is that more digital data can be recorded on a given amount of tape on a rotary instrumentation recorder than on any other type of magnetic tape recorder. One roll of tape on a standard 10½-inch reel is capable of recording 10 megabits per second for one hour or 3.6×10^{10} bits. Standard longitudinal recorders with 14 tracks on 1-inch tape at 800 bits/inch can record 5×10^8 bits/roll (3600 feet). For an equivalent volume comparison, two 1-inch rolls of 1-inch tape on 10½-inch reels will hold 10^9 bits. One rotary-head recorder tape holds almost 36 times as many bits as two longitudinal recorder tapes.

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