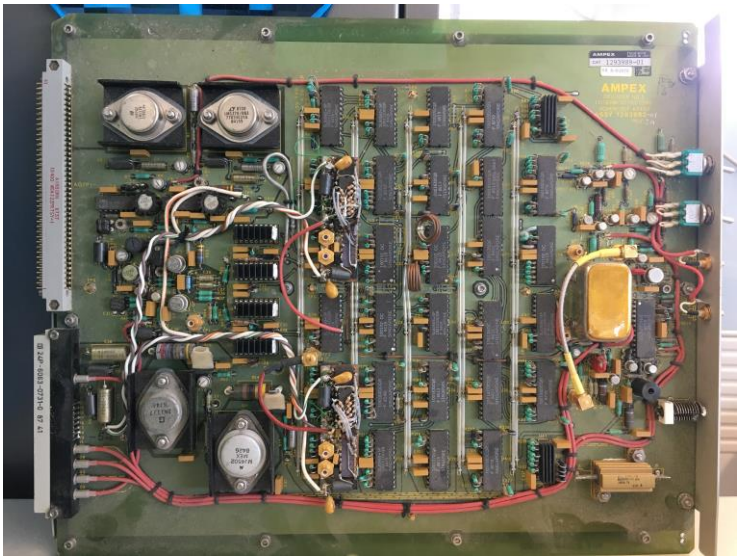
Prototype of first commercial PRML channel

What is it?

The circuit board pictured here is a prototype of the Ampex PRML[1] detector card from 1983. This prototype used 100k ECL logic and operated at the full product data-rate of 117 Mbits/s. It was tested in a head-to-head comparison against the null-zone detection[2] technique and this led to its selection for the DCRS product. David Petersen was the engineer who developed the PRML detector board[3],[4]. Charles Coleman[5] was the designer and lead engineer for the DCRS recorder.



Why is it important?

Ampex was the first company to introduce a PRML (Partial Response Maximum Likelihood) channel in a commercial product. This occurred in 1984. The technology was one of the key innovations in the DCRS (Digital Cassette Recording System) high data-rate transverse-scan instrumentation tape-recorder. DCRS was Ampex' most successful digital product earning some $320 million over its lifetime (solid-state replacements became available in 2003)[6]. Later, in 1990, IBM became the first to deploy PRML technology in hard disk-drives[7].

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[1] https://en.wikipedia.org/wiki/Partial-response_maximum-likelihood

[2] J. Smith, "Error Control in Duobinary Data Systems by Means of Null Zone Detection", IEEE Trans. Comm., Vol 16, No. 6, pp. 825-830, Dec. 1968

[3] C. Coleman et al., "High Data-Rate Magnetic Recording in a Single Channel", JIERE, Vol. 55, No. 6, pp. 229-236, June 1985.

[4] R. Wood, D. Petersen, "Viterbi Detection of Class IV Partial Response on a Magnetic Recording Channel", IEEE Trans. Comm., Vol., COM-34, No. 5, pp. 454-461, May 1986

[5] https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7264820

[6] K. Hallamasek, unpublished written response to and article by H. Kobayashi's article (see following pages)

[7] J. Coker et al., "Implementation of PRML in a rigid disk drive", IEEE Trans. Magn., Vol. 27, No. 6, pp. 4538 -43, Nov. 1991

Letter to editor of IEEE Communications Magazine (unpublished):

March 26th 2009

Dear Dr. Schwarz,

My colleagues and I at Ampex Corporation read with great interest the "History of Communications" article in the March issue of IEEE Communications Magazine. The author, Hisashi Kobayashi, provides an excellent description of the importance of Partial-Response Maximum-Likelihood (PRML) techniques in Magnetic Recording [1]. However, the author does himself a great disservice by not recognizing that he was very much a part of the inspiration behind another success story. Papers by Kobayashi & Tang, Ernest Kretzmer, and the late Adam Lender also very much provided the foundation for the effort at Ampex that led to the first commercialization of PRML. This actually occurred many years before IBM's introduction of PRML in Hard Disk Drives (HDDs). The first PRML product introduced to the market was not an IBM disk drive in 1990, but rather the Ampex DCRS (digital cartridge recording system) in 1984 [2-4].

An early airborne version of the Ampex DCRS.

For two decades, the Ampex DCRS rotary-head tape recorder was the de-facto standard for video and high-data rate instrumentation recording in flight-test and military airborne mission applications. They were deployed on the F15, F16, F17, and F22 fighter aircraft and the SR71, U2, and AWACS reconnaissance and command aircraft. In addition, they served as the main instrumentation recorder on test flights of many commercially flying aircraft. The small size, exceptional bandwidth, and flexibility in data-rate made these machines ideal for recording multiple streams of video, navigation data, radar, and instrumentation data. Many of these machines are still in operation to this day. A variety of models were introduced including a 2-channel 12-head recorder operating at 240 Mb/s. The DCRS was Ampex' most successful digital product, earning roughly $320 million in revenue over this period. Only in 2003 did DCRS recorders start to be gradually replaced with solid-state recorders.

The PRML story began at Ampex in 1979 when John Mallinson assembled a new Advanced Recording Systems Group. This included a bevy of recently-graduated bright young engineers (of which I would humbly like to claim to be one) plus a veteran recording engineer, the late Charles Coleman. Coleman was the winner of the IEEE Reynold B Johnson Information Storage award and received many other accolades. He actually had little formal education but he was without doubt the finest engineer I have ever had the pleasure of working with. When Ampex made the decision to push helical-scan rather than transverse-scan machines for professional digital video recorders, Coleman arrived in the Recording Systems group with his transverse-san recorder (already complete with a threshold PR4 detector) and a plan to crank the single-channel data-rate up to 120 Mb/s!

In parallel with this activity, Ampex was trying to enter the HDD business. Taking note of Coleman's implementation of PR4 and the work of Kobayashi and others on maximum likelihood detection, the team of Ahlgrim, Hallamasek, Petersen, Stenerson, and Wood put together an experimental HDD including a prototype PRML channel and a Reed-Solomon error-correction system all running at 20 Mb/s [5-7].

In 1983 a friendly competition ensued between Coleman, who by then was implementing Smith's null-zone detector [8] and Petersen et al., who were determined to make PRML work at 120 Mbit/s. In the end, the latter prevailed by a very small margin and Coleman graciously accepted PRML as the channel for the DCRS machine. The PRML system occupied two entire 11″ x 13 ½″ cards. The first included an analog integral-derivative equalizer (to form an approximately flat response) before an explicit "$1\text{-}D^2$" coax delay line. Timing and gain were derived from the PR4 error-waveform driven by simple threshold decisions. The second card contained two 'ping-pong' 6-bit A/D convertors, each formed by stacking four 4-bit convertors. The remainder of the card was devoted to 100k ECL logic chips that implemented the twin two-state Viterbi detectors. The entire system operated at 120 Mb/s, a data-rate not achieved by HDDs until 1996).

Ampex may be famously regarded by some as the company that lost the VCR business to Japan. That is arguable. What cannot be disputed, however, is the seminal role that Ampex played in introducing PRML into tape and disk drives.

Sincerely

Kurt Hallamasek, Ph.D.
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[1] H. Kobayashi, "Partial Response Maximum Likelihood Decoding: Capitalizing on the Analogy between Communication and Recording", IEEE Communications Magazine, Vol. 47, No. 3, pp. 14-17, March 2009
[2] C.H. Coleman, D.A. Lindholm, D.A. Petersen, R. Wood, *"High data rate magnetic recording in a single channel"*,. J. IERE, vol. 55, no. 6, pp. 229-236,June 1985 (Charles Babbage Award: Best Paper)
[3] Wood, R.W., *"Magnetic recording systems,"* Proceedings of the IEEE , vol.74, no.11, pp. 1557-1569, Nov. 1986 (invited)
[4] Mallinson, J.C., "Achievements in rotary head magnetic recording," *Proc. IEEE* , vol.78, no.6, pp.1004-1016, Jun 1990
[5] R. Wood, S. Ahlgrim, K. Hallamasek, R. Stenerson, "*An Experimental Eight-inch Disc Drive with One-hundred Megabytes Per Surface*", IEEE Trans. Mag., vol. MAG-20, no. 5, Sept. 1984, pp. 698-702. (invited)
[6] Wood, R.; Petersen, D., *"Viterbi Detection of Class IV Partial Response on a Magnetic Recording Channel,"* IEEE Trans. Comm. , vol.34, no.5, pp. 454-461, May 1986
[7] *"Digital maximum likelihood detector for class IV partial response",* US Patent 4,504,872, D. A. Petersen, March 12, 1985
[8] J. W. Smith, "Error control in duobinary systems by means of null zone detection," IEEE Trans. Comm., vol. COM-16, pp. 825-830, Dec. 1968