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This Week's Citation Classic

Lender A. Correlative level coding for binary-data transmission. *IEEE Spectrum* 3:104-15, 1966. [GTE Lenkurt, Inc., San Carlos, CA]

A new approach to digital data transmission, termed duobinary and correlative, substantially increases speed over any band-limited media owing to correlation between signal states. Specific codes are used with or without carrier modulation. In the error-detection process, it has been found that with this type of system it is unnecessary to introduce redundant digits into the original data stream. [The *SCI*® indicates that this paper has been cited over 45 times since 1966.]

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"Throughout my career I was fascinated by the idea of achieving digital transmission speeds over and above the Nyquist rate, well known to communication theorists and practitioners since 1924. The principal obstacle to achieving higher transmission speeds was the ubiquitous *intersymbol interference,* termed IS I in technical literature. One morning in 1962 while shaving, it occurred to me that instead of fighting ISI one should perhaps join it to attain highest transmission rate. Possibly enhancing ISI and decoding the composite signal could speed up transmission rate. My first experiments with digital FM were highly successful. Indeed, with a rather small signal-to-noise ratio penalty the equivalent of *two binary channels rather than one was transmitted.* I termed the new technique *duobinary* where 'duo' stands for *two* binary channels. While working out the theoretical aspects of the new invention, I noticed clear and distinctive patterns. This led to the invention of error detection without redundant bits. Next, duobinary was generalized to broader correlative techniques. The term correlative was coined to indicate correlation between pulses.

"My first manuscript[1] was submitted in 1962 to AIEE (predecessor of IEEE), and presented at the AIEE winter general meeting in New York in January 1963. While on the plane flying to this meeting, I met one of my professors from Columbia University, a prominent scientist. He had always been friendly to me and casually asked, 'What are you doing nowadays, Adam?' I replied, 'Oh, I just invented a black box such that if your input consists of two frequencies, the resulting output has three frequencies.' This was a rather oversimplified description of the duobinary technique. My dear professor felt uneasy, and whispered softly, 'Can we change the subject, Adam?' We never discussed it again until I received a warm and congratulatory letter a few months later from my good friend, the professor.

"One of the most important and widely cited papers is the tutorial manuscript which is this *Citation Classic.* A well-written and more up-to-date exposition of the duobinary and correlative techniques appears in two recently published textbooks.[2,3]

"Today the duobinary techniques are widely applied in the US and throughout the world! While just about all current applications are in digital communications such as data transmission, digital radio, and PCM cable transmission, new possibilities are being explored. Recently, the duobinary technique has been applied to fiber optics[4] and to high density disk recording with excellent results.[5]

"In recognition of my contributions I was elected IEEE Fellow and have served as editor-in-chief of *IEEE Transactions on Communications* since January 1,1978. I have 29 US patents and many in foreign countries. I am listed in *Who's Who in the West, Leaders in Electronics,* and *Who's Who in Engineering."*

1. **Lender A.** The duobinary technique for high-speed data transmission. *IEEE Trans. Commun. Electron.* 82:214-18, 1963.
2. ..... Correlative (partial response) techniques and applications to digital radio systems. (Feher K, ed.) *Digital communications—microwave applications.* Englewood Cliffs, NJ: Prentice-Hall, 1981. p. 144-82.
3. **Schwartz M.** *Information transmission, modulation and noise.* New York: McGraw-Hill, 1980. p. 189-200.
4. **O'Mahony M J.** Duobinary transmission with p-i-n F.E.T. optical receivers. *Electron. Lett.* 16:752-3, 1980.
5. **Price R, Craig J** W, Melbye H E & **Perahia A.** An experimental, multilevel, high density disk recording system. *IEEE Trans. Magn.* **Mag-14:**315-17, 1978.