# Article 1

Name

Company

## INTRODUCTION TO COMMERCIALIZATION OF PACKET SWITCHING

*The following article provides a fast-moving, exciting account of the early days of commercial packet switching in the 1970s, focusing on X.25 and, in particular, on Datapac, the X.25-based Canadian packet switching network. It follows an earlier article in this Column on packet switching in the United Kingdom. We hope to publish additional papers on the history of packet switching from other countries as well.*

*We are so used to the Internet and its amazing suite of ever growing applications that we may tend to forget that in the 1970s and well into the 1980s, common carriers and computer manufacturers worked together in a concerted effort to introduce data packet switching capability worldwide. This effort required the rapid development of an international standard, X.25. This standard, once introduced, led to quick deployment of multiple data networks in many countries, helping lay the groundwork for the Internet. The Canadian Datapac network, in particular, was the first network to fully implement the X.25 suite.*

*Tony Rybczynski, the author of the article, was a key figure in these developments. He describes both the technical and political discussions involved in expediting the introduction of the standard and data networks using it. All readers of this magazine will, I feel, gain considerably in reading this article.*

*—Mischa Schwartz*

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# COMMERCIALIZATION OF PACKET SWITCHING (1975–1985): A CANADIAN PERSPECTIVE

TONY RYBCZYNSKI

### CONTEXT

In the 1970s packet networking research was vibrant around the world. Larry Roberts [1], who many call one of the fathers of the Internet, discussed many of these in his article. I would highlight ARPAnet in the United States, Cigale and the Reseau de Commutations des Paquets (RCP) testbed in France, and work at the U.K. National Physical Laboratory. Most of this work was built on commercial minicomputers of the day (e.g., DEC PDP11s).

A small number of commercial store-and-forward message-based services had been developed, for example, one run for the airlines by the Societé Internationale de Télécommunications Aéronautiques (SITA), and one in Spain operated by Telefonica for interbank networking. There was also Tymnet in the United States, which multiplexed character streams from multiple users in addressed transmission blocks.

Enterprise networking was in its infancy, based on star networks run over leased lines. These were typically mainframe-based with remote job entry (RJE) and IBM 3270-style access, using vendor-specific protocols defined by IBM and the other computer manufacturers (e.g., Digital). General-purpose user access was provided by "dumb" async terminals (e.g., VT100) via low-speed modems over the public switched telephone network (PSTN).

At the time, T1/E1 leased lines were very expensive. There were no PCs (the Apple II debuted in 1977, the IBM PC in 1982, and the Apple MacIntosh in 1984!). Commercial LAN deployment would only start in the 1980s. IP was a research tool.

In 1972 Bell Canada, on behalf of the TransCanada Telephone System (TCTS), set up a dedicated engineering, operations, and marketing organization (called the Computer Communications Group, CCG, and referred here to as Bell/CCG) to develop advanced data services. In November 1974 Bell/CCG announced plans to introduce packet switching services by July 1976. In the United States, Telenet had launched proprietary packet network services in 1975 and saw the value of an international standard. The French post, telegram, and telephone agency (PTT) were going down the path of rolling out what became Transpac (announced in 1973), and Euronet on behalf of the European Economic Commission (EEC). The British Post Office was running their Experimental Packet Switching Service, and NTT in Japan was likewise researching packet networking opportunities.

There was one major problem with attempts to commercialize packet switching. Without a global standard, IBM (and the "seven dwarfs," as the other seven smaller computer manufacturers were called) would not have a strong business case to connect to these networks, which in turn heavily impacted the business case for these carriers to launch services.

### THE DRIVE FOR GLOBAL STANDARDS AND SERVICE ALIGNMENT

Bell Canada owned Northern Electric (later called Northern Telecom, Nortel Networks, and Nortel) at the time, and together they owned Bell-Northern Research (BNR). BNR had a packet switching research group and was a strong partner in Bell/CCG's packet project. We saw the advantages of packet switching over circuit switching summarized in Table 1.

Bell/CCG issued a draft packet interface specification proposal called the Standard Network Access Protocol (SNAP). SNAP included three layers on top of the physical layer:

1 The data link control layer
2 The datagram layer
3 The virtual call procedure layer, which included a window-based flow control/error recovery/sequencing/duplicate detection mechanism.

The datagram/virtual call procedure layers had many of the elements of TCP/IP, outlined in a 1974 paper by Cerf and Kahn [2].

The draft proposal was sent to carriers and hundreds of researchers in the preeminent laboratories around the world, and of course to IBM. Our objectives were (1) to kick start the discussion of the business need for a global standard (ultimately called the X.25 family of standards) and alignment of public service development timelines; and (2) to propose the key attributes of the required standard. To that end, Dave Horton, the VP of CCG, and I, as technical prime, took a world tour to start the face-to-face dialog.

The feedback was opinionated and varied. The central discussion was whether datagrams or virtual circuits (VCs) should form the basis of the standard.

### ONE ARCHITECTURE WAS NEEDED: DATAGRAMS OR VIRTUAL CIRCUITS?

We argued that datagrams were the basis of a more robust and flexible networking technology, as all packets are


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| Attribute | Packet switching | Circuit Switching |
| --- | --- | --- |
| Better use of bandwidth | Statistical multiplexing with bandwidth dynamically shared across users/applications | Time division multiplexing dedicated to the user/application |
| Speed conversion | Ability to allow low speed devices to talk to high speed devices | Speed must be the same at both ends |
| Dynamic routing | More options | Per circuit routing only |
| Acceptable delays | While variable, not seen as a major problem if kept small | Low fixed delays |
| Error performance | Built-in error recovery at the data link control level | Dependent on the transmission infrastructure |

**Table 1.** *Packet switching vs. circuit switching.*

| Attribute | Datagram | Virtual Circuit |
| --- | --- | --- |
| Routing | Per packet | VC-based (unless datagram implemented as underlying layer) |
| Flow control | End-to-end function | Network function |
| Sequence preserving | No | Yes |
| Chance of packet duplication | Yes | No |
| Accounting | Per packet | Per VC and optionally per packet |
| Cost | No need for state information in the network | Higher at edge nodes; lower at transit nodes |

**Table 2.** *Summary of datagram vs. virtual circuit attributes.*

routed independently, and there is no need to maintain state information in the network. Re-ordering and duplicate elimination could be handled by endpoints or at the edge of the network. In the future more intelligent endpoints would allow for faster networks. We proposed that datagrams could more effectively support current and future applications, for example, transaction and broadcast applications.

While researchers were supportive of our proposed approach as it aligned with their IP networking research, the response from other carriers was unanimously in favor of VCs. They argued that VC services better fitted their service models, existing applications and user expectations. Their perception was that VC-based networks would be easier to engineer. They were particularly uncomfortable with an architecture that required per-packet accounting in an environment in which packets could be lost or duplicated. Table 2 summarizes the key attributes of Datagrams and VC's.

Technically, they argued that network-based flow control would eliminate a major source of packet loss. For example, without flow control, a mainframe connected by a T1/E1 circuit could send 1500 100-byte packets/s to a 9.6 kb/s device, and the network would quite predictably drop the vast majority of these. Not only would this result in low service levels, but it raised the question of having to collect and reconcile accounting data at both ends (we eventually implemented this).

IBM's reaction to our datagram proposal was twofold. On one hand, they wanted datagrams, to keep as much of the intelligence in the endpoints as possible. On the other, they wanted a frame-based sequence-preserving nonduplicating VC service, which could replace their synchronous data link control (SDLC) layer within their planned System Network Architecture (SNA) (introduced in 1976). It took the industry another 15 years to develop a "simplified X.25" or frame relay that better fit IBM's model.

The conclusion we reached in 1974 was to work toward an accelerated VC-based standard within Study Group VII of the CCITT, the International Consultative Committee on Telephone and Telegraph (formally in response to question 1 point C of that Study Group), and to implement a common packet interface in the public packet networks that had been announced. This was a major challenge since the CCITT at the time had a cumbersome process structured around a four-year cycle. Even though a datagram option was, over time, built into X.25, it was never implemented. That said, it would be another 20 years before public IP networks would become widely available, leveraging TCP for flow control, order preservation, and duplicate elimination.

## IMPORTANT PRINCIPLES ADOPTED FOR X.25

There were three important principles adopted in the development of the X.25 family of standards.

First, the layering principles of the open system interconnection (OSI) model being developed by International Organization for Standardization (ISO) at the time were followed. OSI broke the then common approach of vertically integrated data communications sys-tems. This was a first for CCITT. For example, the X.25 physical layer definition anticipated rapid growth in higher-speed connectivity, while the X.25 data link control layer leveraged the recently defined High Level Data Link Control (HDLC) protocol [3], which had many advantages over various proprietary forms of binary synchronous communications (a.k.a."bisync"). The heart of X.25 was the packet or network layer, where all signaling took place. This principle was implicit in Bell/CCG's original SNAP proposal.

Second, it was agreed to not only define the interface between the network and user devices, but a **common end-to-end service definition**, making it easier for IBM *et al.* to leverage packet services globally [4]. For example, a lot of work went into standardizing the end-to-end behavior of packet network flow control. More specifically, the X.25 standard defined a windowing mechanism (similar to that used by TCP) whereby flow control could be exerted by the user or the network. The heart of a common end-to-end definition was allowing the user to specify the maximum number of packets in transit across the network, one option being the local X.25 window having end-to-end significance. We were one of the first to implement this scheme, greatly facilitated by our internal datagram and TCP-like architecture.

Thirdly, it was agreed to introduce the notion of a **packet assembler disassembler** or PAD to allow service providers to extend the value of their networks to non-X.25 devices. The adopted architecture included a PAD-to-mainframe protocol that rode above the network layer (following OSI principles). While the CCITT defined one set of standards (labeled X.3, X.28, and X.29) to allow support for asynchronous devices connected over leased lines or over circuit-switched connections, we saw opportunities for a number of PAD services, including one for IBM 3270 devices for which we developed a common spec with Telenet and Tymnet.

## ACCELERATED STANDARDS DEVELOPMENT

Up until the early '70s, telecommunications standards had traditionally been set and implemented in largely government run public networks, but only once the technology had reached a certain level of maturity. Thus, for over 100 years the International Telecommunication Union (since 1947, a specialized agency under the United Nations) and the Comité Consultatif International Téléphonique et Télégraphique, CCITT (later the ITU — Telecommunication Standardization Sector), had been the focal point of telecommunications standards. The primary objective of the CCITT was the development of international agreements (called Recommendations) to be implemented by member countries.

In contrast, computer technology had historically operated in a highly competitive environment. Computer communications and packet switching brought these two industries closer than ever before, while at the same time non-governmental organizations (e.g., Bell/CCG, Telenet) along with national PTTs (e.g., French PTT, the British Post Office) emerged as prime movers behind public packet networks [5]. Furthermore, ISO, along with national/regional organizations such as the American National Standards Institute (ANSI) and European Computer Manufacturers Association (ECMA), were major stakeholders, representing the computer industry.

As mentioned above, we targeted the CCITT as being the most appropriate standards body. There are two major categories of participants in the CCITT:

1 Telecommunications administrations such as PTTs and the Canadian Department of Communications (DoC)

2 Recognized private operating agencies such as CCG/Bell and Telenet (recognized in April 1974)

In addition, industry organizations such as ISO, and international telecommunications organizations such as IATA could participate in an advisory capacity.

The CCITT worked in a four-year study period or cycle, at the beginning of which certain Questions were identified that would be subject to study, and at the end of which only telecommunications administrations voted on the resulting Recommendations (which had to be unanimous). Since 1968 there had been an accelerated provisional approval procedure, but it was rarely used.

In 1974 the challenges to develop a packet standard by 1976 (the end of the then current CCITT cycle) were many. First, Study Group (SG) VII was already halfway through its study period in addressing point C of a general Question on new data services: "Should the packet-mode of operation be provided on public data networks and if so how should it be implemented?" Second, Bell/CCG and Telenet were private carriers and had to work through their national organizations. In fact, both the Canadian Department of Communications (DoC) and the U.S. State Department did not take a pro-packet position due to competitive views of carriers in these countries. Third, packet networking was not the technology of choice of many PTT'=s; for example, Deutsche Bundespost in Germany and NTT in Japan already had firm plans to rollout digital circuit switching services. This complicated the consensus building process required by CCITT SG VII as 22 of 23 points being studied related to circuit switching.

On the positive side, there were a number of opportunities. First, SG VII was led by Vern MacDonald from the Canadian DoC, who was empathetic to the opportunity presented by packet switching. Second, Halvor Bothner-by (who had been involved in an experimental packet network in Norway) was appointed in July 1973 as a Special Rapporteur on packet switching. Third, there was a growing commercially driven set of operators that were determined to roll out interoperable packet services over the next couple of years, and eliminate all obstacles to having IBM *et al.* connect to these services.

At the November 1974 meeting of SG VII, the general sense was that work could begin toward what was to become Recommendation X.25. But time was of the essence. I have already mentioned the international lobbying effort undertaken by Dave Horton and myself to further accelerate the technology, business, and standards convergence of packet networking. If Datapac and partner packet networks were to be launched in 1976–1977, a fairly complete standard would be required as early as 1975!

Work accelerated through a rapid pace of meetings, some official CCITT ones and other informal ones with key stakeholders. In March 1975 we held an informal drafting meeting in Ottawa under the auspices of the CCITT Special Rapporteur on packet switching. These and other proposals were submitted (often through France via Remi Després and his team, the United Kingdom via John Wedlake and his team, or NTT of Japan) to the May 1975 meeting of SG VII in Geneva, which had in

**Figure 1.** *Key movers in the X.25 standard (left to right: Bernard Jamet (France), Masao Cato (Japan), Paul Guineaudeau (France), Claude Martel (Canada), Vern MacDonald (Canada), Remi Després (France), Halvor Bothner-by (Norway), Phil Kelly (United Kingdom), Mr. Ishino (Japan), Tony Rybczynski (Canada), Larry Roberts (United States).*

attendance Dave Horton of Bell/CCG, Philippe Picard who headed the Transpac initiative, and Phil Kelly who headed packet efforts in the United Kingdom. The result was a relatively complete draft definition of a packet mode standard based on VC operation, which, after further editing, was finalized in September 1975. At the time, cut and paste was a scissors and glue process! Much of the final impetus came from the active participation of Larry Roberts, the hands-on CEO of Telenet and previous chief scientist at ARPA.

X.25 was approved by the final meeting of SG VII in March 1976 (Fig. 1 is a photo from this time period), although three Rapporteurs were assigned to address a number of key areas (e.g., internetworking leading to X.75, and user options leading to X.1) even prior to the start of the next Plenary period. Given that the majority of PTTs were still more interested in circuit switching, a key "horse-trading" area was allowing both X.25 and X.21 (the digital circuit switching standard) to receive unanimous approval. Another key factor was that Euronet, an EEC research network primed by France, was also to be based on X.25.

Recommendation X.25 (1976) was a techno-marketing-business success and allowed network operators to roll out X.25 networks, although extensive work, particularly during the next two years, led to a more complete specification in the form of X.25 (1980).

In his 1981 MIT thesis, Laurence Zwiimpfer [6] concluded that the accelerated X.25 standardization process could be deemed a success. In an interview with Louis Pouzin, a noted French researcher at the time, Louis called the X.25 standardization process a "well-engineered political coup." Laurence identified eight lessons from this process. A number of these spoke to the importance of bringing together both business and technical drivers, in what we could have called a "Packet Networking Forum" — a group of key stakeholders working together outside the formal standards process to accelerate the process. The concept of Forums became the norm in the 1980s and 1990s to address, for example, frame relay and asynchronous transfer mode (ATM) opportunities.

In a Bell/CCG survey of 60 computer and terminal manufacturers in 1977 [7], it was determined that 25 were committed to implement X.25, and in fact 16 had already made announcements to this effect. As IBM was not yet among these, Bell/CCG worked with Cambridge Communications Inc (CTX) to develop software for the IBM 3704/3705 front-end processors, making remote devices appear to applications as locally connected. Ken Hayward of BNR made important contributions in this area. In the early 1980s IBM developed native support for X.25 as part of its SNA portfolio [8]. This spurred the acceptance of X.25 by enterprises.

What Bell/CCG kicked off in 1974 not only helped create a multibillion dollar packet industry, but also had a significant impact on how standards can be developed in a more business-driven manner.

## DATAPAC: THE FIRST STANDARD X.25 SERVICE PLATFORM

Datapac was the first public network to fully support the X.25 family of standards. Trials of Datapac were undertaken across four cities in 1976, with numerous papers presented and demonstrations given at the International Conference on Computer Communications (ICCC) in Toronto the same year [9]. Commercial services were launched in 1977.

The Datapac architecture, which persisted through various generations of Northern Telecom packet switches (first SL-10 introduced in 1976, then DPN [1985], then DPN-100 [1988], the Passport 7400 [1992], and Passport 15000 [1995]), included a packet/datagram subnet, a VC layer, and an application/PAD layer. This VC/datagram architecture was also applied to frame relay services, providing a very robust networking infrastructure. The trunk and access physical layer were based on Dataroute [10], the world's first digital private line network. All of the Northern Telecom packet switch technology was developed in Ottawa, Canada, which was also where Bell/CCG was located, making close collaboration a reality.

When launched, each Datapac node could handle 420 access ports up to 9.6 kb/s, 6 trunks up to 56 kb/s, and 200 packets/s. The network could only support 14 nodes. Over the next 10 years, the technology evolved to support a network with 40,000 subscribers across Canada through 180 switches, all managed as a single system.

Some of the more important optional features provided included:

- Closed user groups, effectively delivering virtual private networks
- Hunt groups, allowing mainframes to be connected via multiple links
- Various performance options, including flow control parameters, throughput classes, and transit delay, and extended sequence numbering for higher throughput and satellite applications

The Northern Telecom SL-10 (Fig. 2) and successor products used in Datapac supported a broad range of PAD services, most rolling out during the decade following its launch:

- The interactive terminal interface

**Figure 2.** *Northern Telecom SL-10 packet switch, the foundation of the Datapac network.*

for async terminals following the X.3/X.28 and X.29 standard
- The asynchronous polled interface for point-of-sale devices
- The bisynchronous interface for IBM 2780/3780 devices
- The display station protocol for IBM 3270-compatble data entry systems
- The HASP multileaving interface for RJE devices
- The SDLC interface for SNA devices

The Northern Telecom SL-10 was the first purpose-built packet switch to go into commercial service. It had a multiprocessor architecture built around a common memory through which inter-processor data and control packets passed. Queuing and dequeuing of packets were performed by duplicated hardware controllers, with contention among processor modules resolved by a hardware arbitrator.

In 1979 the first X.75 gateway services were established between Datapac and Telenet in the United States. This was extended to other U.S. networks and internationally via Teleglobe Canada. We needed a data network identification code (DNIC), equivalent to a telephone country code, but there were no procedures on how to get one. So I chose 3020 (302 was assigned to Canada), and we sent a notification to the Canadian DoC. Some carriers in the United States hired psychologists to determine the most memorable DNICs for their networks! As an aside, "surfing" became a reality for Canadian users, particularly once Datapac was connected worldwide. For example, Canadian medical researchers could make a local modem call and have access to the National Library of Medicine in Washington, DC. The latter had bibliographic records of over 2200 medical journals with access to 600 subscribing libraries, and was delivered through System Development Corporation's (SDC) Search Service [11]. Search services combined with packet networks were a precursor of today's Internet and World Wide Web.

The management of Datapac, a truly distributed multiprocessor architecture, was an ongoing focus of Bell/CCG. Bell/CCG worked closely with Northern Telecom and developers in BNR to evolve the administration and control in line with its needs as the subscriber base grew. The centralized network administration system provided network-wide service management capabilities, software distribution, data collection, report generation, and statistical analysis. The network control system provided network monitoring and control, and alarm management, all transported over a separate virtual private network. In addition, a family of network engineering tools assisted in capacity planning for a new and dynamic environment.

The latest published plan from Bell Canada is to decommission the network in December 2009 after over 30 years of customer service. At its peak, Datapac supported 50,000 devices. The dominant application in its final years was for point-of-sale (dev)ices, which are being migrated as an IP VPN POS service on Bell's IP/multiprotocol label switching (MPLS) networks [12].

## IMPLICATIONS OF X.2.5 COMMERCIALIZATION

Some of the implications of the commercialization of X.25 packet switching services are:
- Packet switching technology was established as a viable technology, setting the stage for the ultimate commercialization of IP networking. Evolution continued in the X.25 domain with higher speeds and feeds and switching capacity and scalability, leading to the introduction of frame relay and ATM.
- Carriers around the world embraced packet switching and started offering services following the success of packet services offered by Bell/CCG, France Telecom, Telefonica, Telenet, and NTT (Table 3). Datapac grew to be one of the biggest public packet networks in the world.
- Enterprises likewise embraced packet networking, including early adoptors such as Societé Generale de Banque in Belgium (1979) and the U.S. Federal Reserve System (1980).
- Multiple vendors entered the packet switching arena including Northern Telecom, Telenet (later GTE), Alcate,l and many others, which generated billions of dollars (U.S.) of revenues for these vendors. Northern Telecom's early entry ultimately established it as the number 1 vendor in this space over several years (e.g., 21 percent market share in 1990 according to Dataquest), and included building some of the largest packet networks during the 1980s. For example, the SITA network supported 120,000 terminals and printers; served 460 airlines across 31,000 offices in 187 countries; and processed 36 billion data transactions and messages each year.

- Packet standards continued to evolve in CCITT including X.75 for packet network interconnection, and various performance and related standards.
- The standards-making process evolved toward a more agile and market-responsive process.

## ACKNOWLEDGMENTS

The author would like to thank David Jeanes for reviewing this article. He would also like to thank many national and international collaborators who helped make it happen. He would personally acknowledge the contributions of Vern MacDonald of CCITT; David Horton, Don Weir, and Carl Strahlendorf of Datapac; David Jeanes, Dave Twyver, Peter Cashin, Ron Prince, and Claude Martel of BNR; Larry Roberts and Barry Wessler of Telenet; Hal Folts of U.S. NCS; Philippe Picard, Remi Després, and Bernard Jamet of Transpac; Phil Kelly, John Wedlake, and Chris Broomfield of the BPO; Masao Kato and Mr. Nakamura of NTT; and Luis Lavandera from Spain.

| Country | Date of service | Network |
|---|---|---|
| Belgium | 1979 experimental; 1980 planned service | |
| Canada | 1976 experimental; 1977 public service<br>1978 public service | TCTS's Datapac<br>CNCPT's Infoswitch |
| Denmark | 1980 planned service | Datapak |
| Germany | 1979 planned limited service | Datex P |
| France | 1978 public service | Transpac |
| Italy | After 1980 | Itapac |
| Japan | 1977 experimental;<br>1979 planned service | DDX<br>DDX-P |
| Netherlands | 1980 planned service | Datanet-1 |
| Norway | 1980 planned service | Datapak |
| Spain | 1973 public service (pre-standard) | RETD |
| Sweden | After 1980 planned service | Telepak |
| Switzerland | 1979 planned service | Telepac |
| United Kingdom | 1977 experimental (pre-standard)<br>1979 planned service | EPSS<br>PSS |
| United States | 1975 public service<br>1969 private network; 1976 public service<br>1978 public service | Telenet<br>Tymnet<br>Compac |

**Table 3.** *1978 view of public packet switched data services [13].*

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## BIOGRAPHY

TONY RYBCZYNSKI [SM] is retired from Nortel, where he was director, Strategic Enterprise Technologies reporting to the CTO. He has over 37 years' experience in various forms of packet switching. In the 1970s he helped Bell/CCG pioneer the commercialization of X.25 packet switching (and in fact co-authored the spec). In the 1980s at Nortel R&D Laboratories (BNR) and later in Nortel, he drove the introduction of frame relay product capabilities, and was instrumental in the definition of Nortel's ATM and IP portfolio. Over the last 10 years, he participated in a large number of strategic initiatives leveraging IP networking and Unified Communications applications. He has written over 200 trade articles and wrote a column in *IP Telephony* magazine for over a decade. He is a graduate of McGill (B.Eng EE) and the University of Alberta (M.Sc-EE), and is a co-author of a protocol reference book (*Computer Network Architecture and Protocols*, Plenum Press) and a contributor to the *ATM for Dummies* book.

Article 2

# ARMSTRONG'S INVENTION OF NOISE-SUPPRESSING FM

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## INTRODUCTION

Edwin H. Armstrong is well known as the inventor of wide-deviation or wideband FM. His patent on this invention was granted December 26, 1933, followed soon thereafter by demonstrations of his system before engineers, papers on the subject of wideband frequency modulation (FM) and its noise-suppression property, and eventually, of course, after World War II, widespread acceptance of FM by the radio industry and the public at large. The years in between were devoted to a bitter court fight between Armstrong and RCA, leading eventually to Armstrong's tragic suicide in 1954. This is well documented in the book by Lessing devoted to Armstrong's life [1]. What is not clear is precisely how and when Armstrong had the intuitive leap, his Eureka! moment, that led to this truly momentous invention. Armstrong was notorious for leaving very little documentation on his inventions. Lessing does note that Armstrong was fully occupied with his FM work, carrying out thousands of experiments, from 1928 to 1933, but no attempt to further narrow this interval of time down or discuss how he came to develop the wide-deviation FM concept is offered [1]. We try, in this brief note, using documentation available in the Armstrong papers housed at Columbia University, to come to grips with these questions.

Edwin H. Armstrong had been experimenting for years in his laboratory at Columbia University with various methods of reducing static in radio reception [1, 2].[1] By 1927 he thought he had come up with a solution, based on many experimental studies with radio teletype transmission carried out in his laboratory. His proposal was to "cancel" static noise, thinking that atmospheric disturbances in a "crash or burst of static" are highly correlated at closely adjacent frequency bands. His paper describing the technique and including results of some of his experiments was published in the 1928 *Proceedings of the IRE* [3] and was promptly (and properly) critiqued by John R. Carson of AT&T Bell Laboratories in a paper appearing six months later in the same journal [4]. Carson, in replying to Armstrong's paper, showed, using a simple single-sinusoidal model to represent random noise (static), that noise cannot be canceled out. In setting up this model for random noise and carrying out the analysis, Carson relied on pioneering work on modeling and analyzing noise in communication systems he had been carrying out for some years before. Carson did, however, make a regrettable and now famous comment in this paper. In replying to Armstrong's error in thinking noise can be cancelled, Carson stated unequivocally

*"Static, like the poor, will always be with us."*

Armstrong was to demolish this unfortunate comment by Carson just a few years later with his invention of noise-reducing wide-deviation/wideband FM.

## ARMSTRONG'S PATENT ON WIDEBAND FM

Armstrong's U.S. patent on his wideband FM invention, which he had submitted for patenting January 24, 1933, was granted December 26, 1933 with number 1,941,069.[2] The patent carried the simple title *Radiosignaling*. It was one of four FM patents granted to Armstrong that same day. It was the only one dealing with noise suppression, however. The others dealt with such issues as improved means of generating FM (now called the Armstrong system), the use of a limiter in FM, and FM as a way to reduce signal fading. The other patents had application dates ranging from May 18, 1927 to the same date as '069 of January 24, 1933. Armstrong, while working over the years on finding a means to reduce noise, had been heavily involved with the design of FM systems as well. Much of this work on FM systems was carried out in conjunction with RCA engineers, in his capacity as a consultant to RCA [5]. Correspondence between RCA engineers and managers over the years he worked with them indicates that Armstrong worked closely with RCA personnel in perfecting his FM systems, and provided demonstrations for them at his Columbia laboratories [5, 6]. But these demonstrations were, until he was granted the '069 patent, of narrowband FM systems only.

The wideband FM patent '069 is quite specific on the noise suppression property of wide-deviation FM, indicating that this is the essence of the invention. The patent begins with the words "This invention relates to a method of increasing the distance of transmission which may be covered in radio signaling with very short waves. It is well known that waves of the order of ten meters or lower are limited in the distance of transmission by tube noise alone as the amount of static in that part of the spectrum is negligible." So it is clear he knows that this method of transmission will reduce tube noise,

*Note: This paper first appeared, in somewhat modified form, in* Antenna, Newsletter of the Mercurians, *Special Interest Group on Communications, Society for the History of Technology, vol. 20, no. 1, Oct. 2007.*

[1] *Armstrong himself refers to these years of experiments in the report referenced in [2]. In this 1933 report to Michael Pupin, the first such report rendered "during the 19 years… of the laboratory," as Armstrong himself noted, Armstrong comments that, in spring 1924, "I resumed work on the old problem of the elimination of atmospheric disturbances making some progress toward its solution, despite the widespread belief it was insoluble. Some of this work was [presented] in October 1927 before the IRE. Since that time I have been practically continuously engaged on the same problem… " The work referred to as presented at the 1927 IRE conference was published the next year in* Proceedings of the IRE *[3].*

[2] *The term* wideband *used here refers to the* transmission *bandwidth. Armstrong himself, as will be seen shortly, referred explicitly to the system as "wide-swing" or "wide- deviation" FM. In such a system the frequency swing is large compared to the audio bandwidth, resulting in a much wider bandwidth than would be the case for narrowband FM or AM. There has been some confusion with terminology in the literature, some authors referring, incorrectly, to such a system as "high-fidelity" FM. The fidelity of a communications system is based on its* audio *bandwidth. Wide-deviation FM with low audio bandwidth would be a low-fidelity system, whereas, conversely, an AM system with a wide enough audio bandwidth would be classified as a high-fidelity system. Wide-deviation FM, with its corresponding wide transmission bandwidth, produces noise suppression only. High-fidelity FM requires a wide-enough audio bandwidth as well. It is clear, as seen below, that Armstrong was quite aware of the distinction. In the patent claims for his invention, he simply specifies the variation in frequency should be "substantially greater in extent than the frequency range of good audibility."*

"due mainly to the irregularities of the electron emission from the filaments of the vacuum tubes" (i.e., mainly shot noise), but, in the jargon of the day, encompassing thermal noise as well. He does not seem to be sure of its effect on static, however; hence the constraint to operate at higher frequencies at which it was thought at the time that static would be much lower. He then describes the specific invention as follows: *"I have discovered that by imparting greater swing to the frequency of the transmitted wave than can exist in the disturbances due to tube irregularities and providing means for selecting these large swings of frequency which are at the same time substantially not responsive to the lesser swings due to the tube disturbances or to the variations in amplitude due to these disturbances, that a very great improvement in transmission can be produced."*

Much work had been carried out in the 1920s on studying noise appearing in vacuum tubes. Early studies had focused on so-called shot noise, due to the discrete and random emission of the electrons giving rise to the current in vacuum tubes. Studies by J. B. Johnson of Bell Laboratories had, however, recognized the fundamental nature of thermal noise as well. This type of noise was due to resistive effects in circuitry as well as so-called radiation noise introduced at a receiver antenna. The presence of these two types of noise was recognized by the telephone engineering community. Both types of noise were referred to as *fluctuation noise*. Articles appearing in a number of technical publications at the time described experiments and measurements made to understand shot-noise phenomena, for example, in great detail. The radio engineering literature, however, did not appear to reflect this activity on fluctuation noise. The focus in that literature had been on external static (i.e., atmospheric disturbances). It was not until 1930 that papers on shot and thermal noise began to appear in the radio literature. It is clear from patent '069, however, that Armstrong, at the time of the patent application in January 1933, was well aware of the properties of tube or fluctuation noise. He writes of the "irregularities of the electron emission from the filaments of the vacuum tubes." He notes the radio frequency noise current as a result "consists of irregular variations in amplitude." The patent further notes that "the limit of reception is… determined by tube noise or the disturbances which arise usually in the first tube in the receiving system," this "interference manifest[ing] itself as a steady hiss in the telephones or receiver," and exhibiting "a continuous spectrum of substantially constant amplitude…." These properties of random or fluctuation noise are precisely those described in the work in the 1920s of Carson and other investigators. The only ambiguity appearing in the patent appears to be on the differentiation made between the properties of static and fluctuation (tube) noise.

Armstrong's invention of wide-deviation/wideband FM and its ability to suppress noise, once announced, was well received by the engineering community. Very soon after being awarded patent '069, Armstrong demonstrated his wide-deviation FM system for the first time to RCA engineers [5, 7], with impressive results. (The Sadenwater letter and memo in [7] are based on Sadenwater's recollections. Beers' report, specifically recommending the construction of "two receivers for field tests to determine the merits of the Armstrong FM system," notes, on p. 33, that "the results obtained by the [early 1934] demonstration were so impressive that it was decided to investigate the merits of this system….") Armstrong's later demonstration of his system before an IRE audience on November 5, 1935, and its very positive impact on the engineers attending, has been well documented [1]. The demonstration accompanied a formal paper presented at the meeting, which was later published as Armstrong's now-classic paper "A Method of Reducing Disturbances in Radio Signaling by a System of Frequency Modulation" [8]. What is particularly remarkable about this paper is that Armstrong was able to analytically demonstrate the noise reduction effect of wide-deviation FM, given a carrier-to-noise threshold had been exceeded, using a vector approach. Soon thereafter, M. G. Crosby of RCA, who had worked for years on FM systems, published a more mathematical paper on the noise suppression effect of FM [9], followed by papers by Hans Roder of GE [10] as well as Carson and Thornton C. Fry of Bell Labs [11]. Other papers by various investigators soon followed. It is of interest to note that through the years, even to this day, papers by various investigators have continued to be published using different techniques to explain the wide-deviation FM noise suppression property. Armstrong had created quite a cottage industry on explanations for this property of wide-deviation FM! (The reception of FM signals in the presence of noise is a highly nonlinear process, involving, for example, the required use of a limiter. Analysis thus does not lend itself to a tidy mathematical approach,)

## WHEN AND HOW DID HE ARRIVE AT THE WIDEBAND CONCEPT?

The questions now remain, when specifically, and how, did Armstrong actually come up with the concept that widening the deviation ratio results in noise reduction? These questions are difficult to answer and may, in fact, never be answered exactly. The problem is that Armstrong never kept notes of his conceptions and the experiments based on them. All that is available are system and circuit diagrams, usually prepared for purposes of proving dates of inventions. Using the existing documentation, it does appear possible to this author, however, to establish a reasonable approximate Eureka! date for the conception of the invention. The date turns out, in this author's estimation, to be *September 1931*, fully 16 months before the patent application was made.

On what basis is this date of the invention of wide-deviation/wideband FM as a means of reducing noise made? The Armstrong papers (AP) housed in the Columbia University Rare Book Library contain much documentation concerning his conflict with RCA on his FM inventions, including the litigation he commenced against RCA in July 1948. (It was this protracted litigation that was to end with a despondent Armstrong taking his life January 31, 1954 [1, 12].) In particular, a memo prepared for the litigation, labeled "WideSwing Patent, Information obtained by questioning Armstrong" and dated Dec. 17, 1948 [13], states, in part, "First tried multiplier in receiver to raise mid-frequency and swing from 35 kc [kHz] ± 5 kc to 140 kc ± 20 kc. No improvement because noise multiplied. Then tried multiplier at transmitter to multiply mid-frequency and swing without multiplying noise. At 140 kc ± 15 or 20 kc first found reduction in tube noise. Six months to be sure of this. *First written description March 30, 1932…*" [Emphasis added.] (The "multiplier at transmitter" term refers to the use of what is now called the Armstrong method of generating FM.) So, if Armstrong's recollection almost 17 years after the events leading up to the wideband FM invention is assumed accurate, the invention must have been conceived six months prior to March 30, 1932, or in September 1931. Unfortunately, the written description to which reference is made has not been located. But there is some corroborating information: There does exist a hand-drawn sketch by Armstrong made July 21, 1932 and labeled "Demonstration of Reduction of Tube Noise by FM at 7.5 meters" [14]. (This wavelength corresponds to a transmission frequency of 40 MHz.) In addition, on August 23, 1932, a month after this sketch was made, Armstrong prepared a detailed memo [15] to his patent attorneys Moses and Nolte very similar in wording and content to the wideband patent '069 submitted to the patent office five months later. Some additional corroborating facts: Armstrong had demonstrated his (narrowband) FM system using the Armstrong method of FM generation at his Columbia laboratory to RCA personnel on June 25, 1931 [16]. The RCA engineers found his system, which incorporated a limiter in the receiver , as well as balanced detection (the latter scheme presumably carried over from his earlier work on noise cancellation), provided "a much more favorable impression of the possibilities of FM than… at Riverhead [the RCA site]" [16]. This was presumably due to Armstrong's superior electronics and design, including the limiter and balanced detection. Two months later, on August 26, 1931, in a memo from one RCA engineer to another [17], the comment is made that FM does not seem as promising as phase modulation for short-wave experiments. It does note, however, that where FM can be used, the receiver characteristics cause balancing of a large part of the noise, *"particularly from the lower audio frequencies."* [Emphasis added] It is to be noted that with lower audio frequencies used (i.e., reduced audio bandwidth), the ratio of frequency deviation to audio bandwidth increases. This effectively causes the system to behave like a wide-deviation one. Could Armstrong have gotten the idea of using wide-deviation FM to suppress noise from these experiments? Note that these experiments occurred just prior to the suggested September 1931 Eureka! date.

## SUMMARY

Using the information referenced above, the process involved in Armstrong's conception of the noise-suppression property of wide-deviation FM might be summarized as follows:

1 He worked for years to try to reduce atmospheric noise, static, being picked up by radio receivers.
2 Experiments he had carried out on signals transmitted on closely-spaced carrier frequencies convinced him that noise arising at these frequencies could be cancelled out. These experiments were the basis of his 1928 IRE paper, quickly answered in the negative by John R. Carson of Bell Labs.
3 Roughly at the same time he worked on (narrowband) FM, serving as a consultant to RCA, coming up with improved FM systems.
4 In June 1931 he demonstrated a narrowband FM system incorporating both a limiter and balanced detection to RCA engineers that appeared to provide some noise improvement compared to their own FM systems.
5 An August 1931 note from one RCA engineer to another [17], referring to Armstrong's system, notes that the receiver characteristics do provide balancing of a large part of the noise, particularly at the lower audio frequencies. The presumption might then be made that Armstrong, using this observation, came up with the idea of purposely widening the FM frequency deviation.
6 September 1931: This is the presumed date of Armstrong's conception and invention of wide-deviation/wideband FM.
7 Six months of work to verify the noise reduction property of wideband FM. Reference is made, years later, to a March 30, 1932 written description of this work. This written description has not been found, however.
8. July 21, 1932: Armstrong made a hand-drawn sketch referring specifically to the noise reduction property of (wideband) FM.
9 August 29, 1932: He wrote a memo to his lawyers containing essentially the same wording as his wideband FM patent.
10 January 24, 1933: Application to patent office for Armstrong's wideband FM invention.

## REFERENCES


[1] L. Lessing, *Man of High Fidelity*, J. B. Lippincott, 1956; Bantam Paperback, 1969.
[2] Report from E. H. Armstrong to M. Pupin, Apr. 3, 1933, Box 115, Armstrong papers, Rare Book Library, Columbia Univ.. These papers are hereinafter referenced as AP.
[3] E. H. Armstrong, "Methods of Reducing the Effect of Atmospheric Disturbances," *Proc. IRE*, vol. 16, no. 1, Jan. 1928, pp. 15–26.
[4] J. R. Carson, "Reduction of Atmospherics," *Proc. IRE*, vol. 16, no. 7, July 1928, pp. 966–75.
[5] G. L. Frost, *The Evolution of Frequency Modulation Radio, 1902–1940*, Ph. D. dissertation, Univ. of NC, Chapel Hill, 2004.
[6] See, for example, letter from C. W. Hansell

to J. W. Conklin, both of RCA, June 27, 1931, Box 160, AP, which describes a demonstration by Armstrong June 25, two days earlier, in which Armstrong's equipment in New York provided "a much more favorable impression of the possibilities of FM than… at Riverhead [the RCA receiver site]." Note that this demonstration used narrowband FM equipment.

[7] G. L. Beers, Report TR-251, Armstrong FM Receivers, Feb. 6, 1935, RCA Manufacturing; letter from Harry Sadenwater, RCA Victor, to Throckmorton, Mar. 16, 1938; memo from Sadenwater to Frank Wozencraft, Mar. 15, 1940, all in Box 159, AP.

[8] E. H. Armstrong, "A Method of Reducing Disturbances in Radio Signaling by a System of Frequency Modulation," *Proc. IRE*, vol. 24, no. 5, May 1936, pp. 689–740.

[9] M. G. Crosby, "Frequency Modulation Noise Characteristics," *Proc. IRE*, vol. 25, no. 4, Apr. 1937, pp. 472–514.

[10] H. Roder, "Noise in Frequency Modulation," *Electronics*, May 1937, pp. 22–25, 60–64.

[11] J. R. Carson and T. C. Fry, "Variable Frequency Electrical Circuit Theory with Application to the Theory of Frequency Modulation," *Bell Sys. Tech. J.*, vol. 16, Oct 1937, pp. 513–40.

[12] T. Lewis, *Empire of the Air, The Men Who Made Radio*, HarperCollins, 1991.

[13] Typed memo, "Wideswing Patent, Dec. 17, 1948, Information obtained by questioning Armstrong," p. 2; Box 160, AP, Note: It is not clear who prepared this memo, but the person being quoted is clearly Armstrong.

[14] Box 159, AP; reproduced in [5, p. 220].

[15] Memo to Moses and Holte, Aug. 23, 1932, Box 245, AP. Note: The title "Specification" appears on page 3 of this memo. Each page is signed by S. Nolte and someone else, perhaps another lawyer. There is no accompanying information of any kind, however.

[16] Letter, C. W. Hansell to J. W. Conklin, RD-1105, RCA, June 27, 1931, Box 160, AP.

[17] C. W. Hansell to R. R. Beal, Aug. 26, 1931, folder labeled "Notes from Forta's original examination," Box 160, AP. [These notes appear to have been prepared during the Armstrong-RCA litigation.]

## BIOGRAPHY

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