Project X---The Beginning of the Digital Transmission Age

There is an oft repeated saying that "Necessity is the mother of invention." This was certainly true of the independent invention of Pulse Code Modulation by the Bell Telephone Laboratories.

In the summer and fall of 1940 the crucial Battle of Britain was in its early stages. During this period, the United States government and other people became increasingly concerned about the degree of privacy offered by different communication systems. During this time of urgency, very highly placed government officials, both American and British, were wont to use the Trans-Atlantic radio for highly confidential discussions with the assumption that it was more secure than it really was. While it was good for normal forms of eavesdropping, it was not difficult for an expert with sophisticated techniques to undo the scrambling.

One group primarily concerned with this problem was the division of NDRC charged with military communication problems. Dr. O.E. Buckley, soon to be President of Bell Labs, was a member of this group along with R.K. Potter as an alternate. Dr. Buckley was strongly in favor of Bell Labs working on the problem, and Mr. Potter was assigned the job of coordinating the work. Dr. Buckley suggested that the code name "Project X" be assigned to it, hence the name X System.

It became one of the most closely guarded projects of World War II and for thirty years after. It resulted in the first speech enciphering and transmission system which by its nature could not possibly be deciphered by other than its intended receiver. While this aspect was very important, historically it was even more important as the starting point of the digital transmission age that has followed.

In the first few days there was much "brainstorming" by a few people in the high echelons of Bell Labs. There was no lack of ideas. A later search of the Patent Department uncovered some 80 patents, but those systems all suffered the same problem as the Trans-Atlantic radio system; they could be solved by an expert skilled in the art.

One of the groups, which was shortly made aware of the problem, was the one working on the vocoder. In those days, as now, telephone people were always trying to get more voice channels on a circuit. The vocoder, based on the syllabic nature of speech, was one of these attempts. It tore the speech signal apart resulting in a number of very low frequency signals, and then the voice was reconstructed at the receiving end. These signals were in the telegraph range and resulted in a theoretical compression range of about 10:1. By itself it was a privacy system in that the signals could not be understood, but it fell in the category of the other systems in that it could be easily undone. However, it was the low frequency nature of the signals that was attractive to the researchers..

One must remember that it was an analog and vacuum tube world at that time. An important prior example of a perfect enciphering system was the Vernam Telegraph system invented in World War I where a random key was added and subtracted in such a way that the signal transmitted was also a random stream of characters. This suggested that the vocoder signals might be treated in a somewhat similar manner. An initial trial using on-off telegraph type signals (a quasi binary arrangement) for each of the eleven

vocoder channels resulted in a speech that was badly mutilated. It then became apparent that more discrete levels were necessary in each channel. An experiment was then arranged to use up to ten levels, a final choice being six for reasonable quality. However, there developed a "fly in the ointment."

One of the vocoder channels defines the pitch of person's voice, and this channel was very sensitive, requiring about thirty levels. The use of many more channels would negate the possibility of using the frequency-shift telegraph system, which had been successfully used over the short wave radio system, the only means available over the Atlantic. The suggestion then arose of subtracting out the nearest lower level, multiplying the error signal by six, and treating it as another channel; thus, we obtained thirty six levels with two channels. It was called a Vernier channel, a rather obvious comparison to other such arrangements for scaling. It then became apparent that this was a very general process, an n-ary coding arrangement. If we had used a factor of two instead of six, it would have become a binary system. This then was the way PCM was independently invented at Bell Labs.

As it turned out, it was very lucky that this form of PCM had been arrived at in such a manner and didn't have the binary arrangement so commonly used today. It would have steered the researchers in the wrong direction. Later attempts to use the binary approach on this type of system were not very successful.

At this point in time, there did exist two patents on binary transmission, but they were unknown to workers on the X System. One early patent by P.M. Rainey of Western Electric (part of AT&T) was applied to a form of facsimile transmission; the second was by A.H. Reeves filed in England. As far as is known, neither had ever been implemented. The latter, however, did enter into follow-up work on the X System as discussed later.

This six level system (roughly equivalent to 1500 B.P.S.) was close to optimum for using the frequency-shift telegraph system over the Trans-Atlantic short wave radio and over normal telephone links. It operated over the Trans-Atlantic with very few errors, working up to about the same point that it would be unusable for normal voice transmission. As a matter of fact, it has been stated that this system was tested successfully in a connection from North Africa to the U.S., across the continental U.S., and thence to Australia. Incidentally, the nickname "Green Hornet" for the system was given to it by telephone people in Long Line offices where well marked "untouchable" trunk circuits appeared. They could monitor the distinctive tones that sounded like a theme tone of a popular radio show called “The Green Hornet”. The Signal Corps people called it SigSaly. The Signal Corps set up what became known as the 805th Signal Service Company to handle the system. This company was a rather unusual one in that it contained almost as many officers as it did enlisted men, and nearly all the enlisted men were technical sergeants. Practically all the personnel had previously worked in the Bell System.

The desirability of the multi-level arrangement for regular channels is exemplified even today where data modems translate from binary 2 level, to 4, or 8, or more levels to obtain maximum rates. The first modem actually took its cue from the X System and

used FM. While FM was good for use on the multi-path transmission of the Trans-Atlantic radio, on the more stable standard telephone circuit, phase modulation was more useful.

When the first X System was being installed in Great Britain, several knowledgeable people from Bell Labs were sent to discuss communication problems with their people. H.S. Black (of negative feedback fame), one of these, came in contact with A.H. Reeves and learned of his coding patent filed in 1938 (issued in U.S. in 1942). On his return, he started work on a binary arrangement to be used directly on the speech wave and for use as a short distance secret radio system for the military.

As the processes of quantizing, coding, and transmission of the X System developed, considerable interest and enthusiasm arose. It was a new area to think about, creating considerable discussion and speculation about its many facets. The ability to regenerate the signal in the face of noise and distortion with the different possible combinations of quantizing raised some intriguing questions. The relation of the signal-to-noise ratio to the probability of reproducing the signal was brought into sharp focus.

At this point there was serious consideration as how to best apply the process to the telephone system. There was the experience of Black's application of the binary form to the military system with its large bandwidth requirements. Another proposal was to use a "tertiary" system (n=3) which would have required less bandwidth and have had a more balanced wave, a problem encountered later in using the binary on some types of transmission systems. A recent proposal for using this form of system has labeled its units as "trits." The binary, of course, has been ideal for fiberoptic systems.

During the vacuum tube era, PCM Systems were just too large and complicated to be "proven in," not to mention the large bandwidth required for high quality speech. With the advent of the transistor the situation changed. It was still difficult to prove it in over the usual long distance telephone because of bandwidth requirements. Its first useful application was on local circuits and then on switching, which is still one of its more important uses. It was with the advent of fiberoptic transmission that digital transmission has finally found a home.

The X System was huge. It had over a 1000 vacuum tubes and some predicted it would never stay in operation. Surprisingly, it gave very little trouble in maintenance. In the final stages of the war, a "Junior X" was developed that reduced some thirty bays to six and could be put in a van, but it was never used. When transistors came along, it, except for the key, was reduced to two 8 inch panels, the whole system occupying a filing cabinet.

Following the war a rather unusual situation took place. The Bell Labs was primarily interested in its possible application to the telephone system. While the government was mainly interested in the secrecy aspect, the military still had some installations of the X system (SigSaly) in operation. A government agency, NSA, was formed that took over further work of the Signal Corps. About 30 patents that covered the X System were placed in SECRET files and not released to the public until about 1970. By that time, Digital transmission was "old hat." Work on secrecy systems was continued by the government. Because of its initial involvement and expertise, Bell Labs

was involved in some of this work. It is interesting to note that one end product of the government's line of work was the ARPA System and thence, finally, the Internet. Because of the work of Black and the two open patents, Bell Labs was not hindered in further work on its application to the telephone system.

While this narrative has been directed at the course of events that led to the origination and development of PCM, it has not intended to overlook the many other important developments associated with it. It was a whole new field in electronics. It has been stated that there were at least five historic firsts leading to thirty patents: the development of the key, quantizers, the regenerators, synchronizing systems, and transmission modems.

Several anecdotes about its use are worthy of note. One of the more interesting was that, at first, General Eisenhower, for some reason, was not about to use it. The Captain in charge of the Pentagon installation had the brilliant idea of inviting Mamie in to talk to General Eisenhower in North Africa. The captain didn't realize that the pitch channel of the vocoder was designed around men's voices and could break up on some women's voices. Apparently, he got away with it. One of the great thrills for the people working on the system was when a picture of Churchill's underground headquarters in London was published in Life magazine. It showed the distinctive telephone handset that had to be used with the vocoder. A connection to the "X System" also existed at the White House, but there is not much information about Roosevelt's usage of it. (Members of his staff apparently did use it.) There is a story (second hand) of a high ranking General whose office was near that of the "X System," in the Pentagon, but the general did not have the "need to know" clearance required to enter the carefully guarded room. Apparently, the general became so frustrated at not being able to find out what was in the room that one day, in passing the armed guard, he grabbed the gun. Realizing the probably consequences of what he had done, he quickly restored it to the guard. Towards the end of WWII, one system was unloaded in the surf at Port Moresby. It was restored, placed on a barge and followed McArthur on his approach to Japan. The Bell Laboratories was cited by him for its contribution. The X System had at times linked 5 continents, the first Internet.

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