ARTHUR C. KELLER

An Interview Conducted by

Julian Tebo

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INTERVIEW: Arthur C. Keller
INTERVIEWER: Julian D. Tebo
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Tebo: This is a recording of an interview with Mr. Arthur C. Keller, on March 13, 1973, to obtain information about his experiences working for Bell Telephone Laboratories. Mr. Keller, one of the first things we would like to know is how you happened to go to Bell Telephone Laboratories and how you got started in the work there?

Keller: That goes back a long time of course, but actually this was before I had any formal college education. I saw an ad in the paper that the Western Electric Company on 463 West Street was looking for laboratory assistants. So I applied and was taken on. My first assignment was in telephone instruments, that is, transmitters and receivers, and I was a laboratory assistant at the time.

Tebo: What was the date?

Keller: This was about 1918. The telephone instruments were tested by people speaking into them and judging the quality as compared with standards, things like that. It was a pretty boring job but at the same time I was able to pass the entrance examination to Cooper Union, where I continued until I got a degree in 1923. I applied to Yale University in 1923 to become registered as a student for a master's degree. It turned out that nobody from Cooper Union had ever been to Yale before, so I had to bring with me some information on Cooper Union which had been in existence since 1863, but Yale didn't have any of that information. In the correspondence I indicated that I was still working at the Western Electric Company. So they arranged to see me on a Sunday morning, and I went up to see Dean Warren, who was the dean of the Engineering School. I was accepted, so I went up to Yale. Yale has a ruling that you can't get a masters degree in less than two years. However, I was able to finish the work in one year and they insisted upon my staying for the summer but I did get a master's degree with honors in 1925. Cooper Union has an arrangement whereby you can apply for an engineering degree that is an EE rather than a BS, on the basis of your experience. I applied for that and got it in 1926. In the meantime I went back to Bell Laboratories and registered for graduate work in physics for a PhD at Columbia University. I carried this on until about 1930.

One of the inspiring people I worked with was Henry Harrison, a product inventor. Before he retired, he had more than 100 United States patents. One of the important things he did was to recognize the importance of the mechanical analogy of electrical circuits. Now that was known before, but he tied it in with a vast amount of work that Bell Systems had done in electrical transmission theory. He applied that first to a telephone transmitter with its carbon grains, and looked upon it as a transmission system with distributed constants and masses and so on. I mention that because the next important phase of my career had to do with recording and reproducing sound. Again, I worked for Henry Harrison. He began to apply this analogy to the problems there and this eventually led to what became known as "Hi Fi" recording and reproducing. Although in the 1925-1927 period it wasn't called that, he applied it not only to the recorder itself which became a so-called "revoline" recorder. He also applied it to the acoustic phonograph which became the Victor Ultraphonic acoustic phonograph, and it was designed on the basis of these analogies. Now all this experience gave me an opportunity to do a number of other things. For one thing, I was asked with Halsey Federick to write the article in Petter's Handbook on recording and reproducing sound and including mechanical, optical and magnetic recording. Later, in 1950, and again in 1956, I was asked to write the article on the gramophone in the Encyclopedia Britannica. That was interesting because of all the things that I have done that was the only one that ever impressed my daughter

Perhaps the most crucial thing I'll talk about here is the importance of measurements. That doesn’t sound very exciting when you put it that way. What I mean is, it's important in research and development to stress measurements, particularly new and different measurements, because these often lead to interesting things. I can give you two examples of this. In a recording there are two general systems. The lateral system is the old-fashioned recording. Later, with the Bell Laboratories, we picked up vertical recording. In that connection I was interested in measuring the amplitudes and velocities of the stylus as it passed over a vertically modulated groove. In order to do this, I recognized that with frequencies up to like ten thousand cycles, elasticity gets into mechanical systems and makes it very difficult to reproduce high frequencies. As a result of trying to do a measurement job, I fixed up a very tiny coil and sat it on top of the stylus to track the groove and make a little moving coil. This gave me a chance to practically eliminate any compliance between the stylus and the measuring element, mainly the moving coil. I was able to measure precisely what was recorded on the disk record. The only difficulty with this was that the electrical output was pretty small. I soon realized that since amplification at that point became relatively inexpensive, I really had invented not only a good measuring instrument but I had also invented a rather superior wide range phonograph reproducer. It was good until something like 15,000 cycles, which was unheard of at that time. So here was a case of trying to do a measurement job and winding up with an invention that was patented not only in this country but in twenty foreign countries as well.

The other example of the importance of measurement came very late in the work on sound recording at the Bell Laboratories, and this had to do with the study of distortion. In analyzing the distortion from disk records, the simple harmonics of tones recorded on the record were measured in both low frequencies and high frequencies. These were found to be fairly reasonable. However, we found that the cross-modulation between low frequencies and high frequencies--that is the sudden difference in tones--turned out to be far more severe and damaging than the simple harmonics of cellular frequencies. So I decided to separate the high frequencies from the low frequencies and recorded two bands on a record in which the high-frequency band was on the outside of the record and the low-frequency band on the inside of the record. The reason was that the wavelengths of higher frequencies are of course much shorter and so putting them on the outside of the record gave you a better chance to track them properly. Having taken the sound, broken it into two bands, recorded it and then put it back together electrically, it represented a very considerable improvement in the quality of disk recording.

What bothered me was that you would only get perhaps half as much recording time because you now have two bands instead of one. It then occurred to me whether it would be possible to have vertical and lateral recording--to have the high frequencies recorded with one form and the low frequencies with the other and then put them back together. So, I asked Rafius, who was then working for me, to try to build a recorder which would do this, which would simultaneously follow vertical and lateral recording signals. He did, and it was really quite successful, thanks to his mechanical ingenuity. We then proceeded to record the high frequencies and low frequencies with the different modes of recording and put them together and we got an astonishing improvement in the quality of the sound. We were doing a measurement job, to measure distortion. At this point it occurred to me that if we could have a wide band on each of these two lows of recording we really could have stereophonic disk with a single stylus. In other words you are recording two channels with a single stylus. So we did this and sure enough the results were really quite striking from the point of stereo effects.

The patent was applied for and I realized because of the measurement that there was a slight difference in quality between the vertical and the lateral recording. So It was obvious that it you wanted to have identical quality from both channels, instead of recording vertically and laterally for the two modes, you ought to have them both at 45 degrees to the surface of the record but normal to each other. The patent also covers that and that later became the present system of stereo recording. This actually got me the N.A. Berliner Award from the Audio Society in 1962. The patent, I think, was in 1938 or 1939. That was a pretty bad time to invent anything that required twice as much equipment. It was the bottom of the Depression; people had trouble buying one large speaker and one amplifier, let alone the two loudspeakers needed for stereo. Bendix and RCA and others came out to hear this, but it was during the Depression and nothing really happened that I know of. Later on in England, looking forward to the day when something like this would be available, they were recording things stereophonically on magnetic tape. Much later, I think in the 1940s, a very good friend of mine, John Frain, who was with Westrix out in California, called me and said they had been working on a very confidential project that recorded stereophonic sound on a disk record. They had done it successfully only to find out when they applied for a patent that Bell Laboratories already had such a patent in my name. So the stereo disk record was not only invented but reinvented.

By that time the seventeen years had run out so it was free for anybody to use, and that is the system which is now used. If you are interested, I might talk about a couple of other patent problems that had to do with the sound recording business. I think the first patent that was ever applied for in my name was a loudspeaker patent, a cone tag loudspeaker with a very softly mounted edge of the cone. It was applied for, and must have taken ten years before it was issued. I had lost interest in it because I was doing other things, but I had a call one day from the patent attorney and he said to me, "What would you say if I told you that any loudspeaker mounted in a cabinet was covered by your patent?" I didn't know exactly what to say because that wasn't what I was trying to do. I was trying to have an improved loudspeaker. Well the way patent things work, that patent kept going in the patent office and it was amended and amended and finally they had this broad claim in there which covered every loudspeaker in a box. However, I don't think it would have been valid if it were tested in court. Another interesting thing that came of the recording experience was that in recording on disk, it was usually a cut, a groove with some sort of a sharp stylus, and it was necessary to regulate the depth of the cut. This was done by having adjacent to the cutting stylus a round jewel bell of some sort, usually made of sapphire. This was adjustable so that the cut could be two or three or five mills deep. I was unhappy with this because it left a mark on the record. This preceded the cutting stylus, so it marred the surface just before it was cut. I was concerned that this would change the character of the surface and might introduce some kind of noise or unwanted distortion. In order to get around this I decided to float the cutting recorder on a cushion of air, by blowing down into a tube with the flames on the end of it. I had seen in the physics books an experiment where you take a spool and blow against it and hold a piece of paper against it. This principle worked extremely well; it maintained a very stable and small separation between the flames riding over the moving disk that was being cut, and it was an extremely stable condition. We tried to analyze this mathematically and started out with the assumption given in the physics books explaining this spool experiment, and this was completely wrong. If you follow that explanation, the separation would keep increasing until the thing flew. So we kind of drew a mathematical analysis on this. It turned out to be rather difficult, and I sent one of the fellows working with me, Harold Henning, up to the library--he couldn't find anything. He finally found something in the New York Public Library. It seems that a German soldier just before World War I had started to study this problem. He was working for his doctor's degree and he didn't quite finish the work. Apparently he said he was going off to war and after the war would come back and finish it, but there is no further reference to him. I imagined he was killed, but he did give us a clue about what to look for, and the answer was that the viscosity of air was neglected in the simple textbook explanation. When you put the viscosity of air into the mathematical equations, you come out with a solution where you have opposing forces that give you this stable solution. That led to several patents. Several years later I applied this to the transportation of magnetic recording tape around curved surfaces. In affect you had a frictionless pulley by blowing air through small openings out against the tape, and that is now used in practically all computers by IBM and various other organizations. So here is something that grow out of disk recording and has become quite important. I guess this is basically the Bernoulli Effect that you read about. It is Bernoulli's Principle, but the simple explanations that are given are just incorrect. It is kind of shocking to find that the ordinary textbooks were wrong and that we have been believing this all these years because no one really got into it very deeply and tried to explain it properly.

Tebo: Mr. Keller, can you tell us something about the measurements that make you sure of their validity?

Keller: That is a very good question. I think you have to be as quantitative as possible. I am reminded of an incident where people were judging the quality of recording. This is a good illustration of how you can get fooled if your measurements are not done properly. An improved recorder was being tested, and one of my colleagues (who will remain nameless) decided to determine how much of an improvement this was by getting all of the people he could in the room to listen to the old recording and the new recording. He played all of the records he could find, and what he came out with was not surprising to me: there wasn't any difference. If you take enough inexperienced people and you take too many records where it doesn't make any difference anyway, you can come to the conclusion that there isn't any difference. As a matter of fact, there was a big difference. If you had selected the skilled listeners and if you had selected records to bring out the difference, it would have been obvious. In this case my colleague incorrectly decided there was no difference, so you do have to be careful in taking measurements, preferably on a quantitative basis rather than a subjective basis.

Tebo: Was there any connection between your work and the history of sound pictures?

Keller: Yes, indeed. As a matter of fact I wrote the history of sound pictures for the Bell Laboratories some time back. While all this recording stuff was going on it was also applied to sound pictures-- talking movies, as it was then called. Some of the people who were heavily involved with this were J.P. Maxfield and S.S.A. Watkins.

Tebo: You had two things to consider: the vitaphone, which was the synchronous disk recording with the films and the movie tone, which was the sound directly on the film.

Keller: I have to correct that. The movie tone was a trade name by the Fox Corporation. The proper term, technically, for that is sound on film, as compared to sound on disk. Bell Laboratories worked with both of these things. The sound on disk work was being done by people like Maxfield, Watkins, Harrison and myself. The sound on film work was being done by I.B. Krandal and E.Z. Witte. The Bell Laboratories worked on both systems and both systems were put into use. The vitaphone, which was a Warner Brothers project, went in for the sound on disk, whereas the Fox people went in for what they called "movie tone", which was sound on film. There were two systems there, it was a variable area and a variable density system and both of these became important.

Tebo: In the vitaphone work, I believe, S.S.A. Watkins was the principal factor?

Keller: Yes. Watkins was very much involved, the principal person under J.P. Maxfield who carried on the work as applied to talking movies, using the recorders Harris and I had worked with, using the reproducers we'd worked with. As a matter of fact, you see, the Bell System then proceeded to license people like Victor, Columbia Phonograph and others. In the movie business, it licensed Fox, Warner Brothers, Paramount and others, everybody but RKO. Part of the deal with Warner Brothers was that Watkins would go with Warner Brothers to act as their chief advisor and chief engineer, I suppose.

Tebo: In the case of the sound on film, I recall a magnet for that which would vibrate a wire in the light path to record the sound. Was that part of Fox's scheme? I would like for you to tell us something about the troubles that are known as the "fly wheel patent suit."

Keller: I'll get into the "fly wheel patent suit" but I must answer your question. There were two systems. There was a carousel which would bury the intensity of light. This was a system that Fox started out with, whereas the Bell system used a vibrating ribbon, which gave either variable density or variable area. It was that system that Bell developed that later on became the standard. The carousel fell by the way because of various limitations. The fly wheel situation started in a very peculiar way. By the way, the Fox side of this story is all recorded in a book by Upton Sinclair called William Fox. William Fox was rather a slippery businessman, as it turned out. I don't think this is slanderous because he was put in jail later on. In any case, when the sound pictures first became important, enormous investments were required by all of the movie companies in studio equipment, but particularly in theater equipment. In connection with the Fox company the Bell System loaned William Fox and his company something like 15 million dollars. That was a large sum, so they asked to have some people put on the board of directors. William Fox still had an important part of the company, but as things worked out, he wasn't contributing very much. I am not sure what the financial arrangements were, but he soon found himself outside of his own company because he was unable to meet certain financial applications. He was pretty annoyed about all of this but looking back at the history of it I think it was because of his lack of understanding of the financial arrangements. When he was pretty much out of the company, about the only thing he took with him were the triurgan [?] patents. These were patents invented by three German inventors but issued in this country which took care of any kind of a soundtrack stabilized by the use of a fly wheel, so it was called a "fly wheel patent."

Tebo: Was the film held to constant motion by a fly wheel?

Keller: Yes. That is exactly it. In order to give proper sound for pitch of music you had to have a very uniform speed. In the case of sound on film, you had to have some sort of a fly wheel to give it uniform speed. These patents that were issued to the three German inventors and now owned by William Fox were so broad they covered not only the sound on film fly wheel, but any other fly wheel for any other kind of sound recording and flooding disk recording. It all started when the Fox attorneys served papers on a theater in Pennsylvania. The theater they served the papers on did not have Western Electric equipment, but happened to have GE equipment or something else. Everybody realized that the damages, which were claimed to be something like three hundred million dollars, would be largely payable by the Bell System rather than by GE or RCA. The suit started in the United States District Court in Scranton, in 1932. That case was lost, but the judge himself was under a cloud. I remember the Scranton newspaper the first day we got there; on the one hand it said something about technical experts invading Scranton for this big patent suit under Judge Johnson and over on the other hand it said, Judge Johnson probably would be indicted for some other action of his.

Tebo: May I interrupt just a second? You said the suit was lost. Was it lost by Fox or by the Bell System?

Keller: It was lost by the Bell System. In other words, Judge Johnson ruled that the patents were indeed valid. So it went to the Court of Appeals in Philadelphia, which is a three judge panel, and it was lost again. Of the three hundred million dollars, about a hundred million had to do with damages already done, and the other two hundred million or so had to do with infringement on the future. So Bell Laboratories got very busy in developing means to avoid the use of fly wheels. This was done by a kind of two-motor system which was installed in theaters around New York. It was a kind of a hedge against losing the case in the Supreme Court in Washington. It did go to the Supreme Court, but there it was reversed and ruled in favor of the Bell System.

Tebo: Your experience in sound recording and sound reproduction seems to have had a bearing on the work that you did during the war on sonar. I think it would now be appropriate to turn to some of the work that you did there. The use of ADP crystals in place of quartz crystals and so forth, perhaps you could tell us something about that?

Keller: Yes. That was all started about 1940. At that time I reported to Fran Ryan. He was like the department head, I think. He came from AT&T, but later on went back to AT&T and I later took over his job. We developed four major systems for the Navy (QBF, QJA, QJB, QDA) and a whole variety of special development projects for the NDRC. Let me mention an amusing comment. These things are mounted in destroyers and other boats, and they require equipment that can be put into the water or retracted. In a destroyer for example, this requires fairly heavy equipment, so you have to have mechanical equipment that weighs a ton or more to be rigid enough to do this. There were people in the sonar business before the Bell System was asked to get into it by the Navy, notably the submarine signal company in Boston. They were very helpful and made available experience that they had, particularly in connection with this so-called retracting gear, which had large pillars of malleable iron. This has elongation requirements and all the other requirements. But the elongation requirement is the one that comes to mind, because when the special occasion required an elongation requirement, we measured it. We found that the material we were getting from the malleable iron foundries didn't come anywhere near meeting the requirements that were in the Navy specifications. We tried various foundries; none of them even came near it. Finally we decided to measure some of the parts the submarine signal company had been providing the Navy, and they didn't meet the requirements either. So we went back to the Navy and asked for an exception. They were very annoyed that the great Bell System was trying to pass off some kind of second-rated equipment on the Navy. Well, it turned out that nobody had ever met that elongation requirement, so they finally had to change it.

Getting back to the crystals, there was an ammonium dihydrogen phosphate crystal, which people at the Bell Laboratories were familiar with, and they knew a good deal about it. The Brush people in Cleveland called it the "PN crystal", but the Navy didn't like that. Some of my writings referred to it as the ADP crystal, ammonium dihydron phosphate, and that later on was accepted. ADP crystals can be used both for emitting sound and receiving sound and have very good sensitivity. All of these four major systems that I have mentioned were installed by the Navy and gave a very good account of themselves during the war.

Tebo: As I recall, the first system you developed was the QBF. That had a projector on which were mounted the crystals but transmitted around 25 kilocycles.

Keller: That's right.

Tebo: Then you made a larger one for greater distances that went down to 8,000 kilocycles. The QDA was what we call the "swordarm projector", which could be arranged at an angle from the vertical to almost the horizontal with respect to the hull of the ship. What frequency did that operate on? Did we go back to 25, 28?

Keller: That was the same frequency. Actually it was a depth recorder or a depth instrument, the others were range instruments, so they were used in combination with one another. But the frequencies were in the same order.

Tebo: And all of these used the ADP?

Keller: All of them used the ADP crystals and they were very successful. A kind of unfortunate thing happened there, actually. The Brush people had done the original work on the ADP crystal, and the Navy had decided before any of this had become useful equipment that the Brush people would manufacture ADP crystals for the Bureau of Ordnance in the Navy. The Bell System, the Western Electric manufacture, would be for the Bureau of Ships. Western Electric was to manufacture the ADP crystals, but it turned out that the ordnance work never did require very many crystals, whereas the Bureau of Ships work that Western Electric and we were involved with required enormous numbers of crystals. So we actually subcontracted work to the Brush people to provide ADP crystals for our devices, which was kind of a strange twist.

Tebo: The ADP gave you greater change in dimensions for both transmitting and receiving than the quartz crystals did. How did they compare with the magnetic striction type of transducer?

Keller: Some of the earlier work done in sonar, which is an echo ranging system, was done with quartz crystals and magnetic devices. The magnetic devices had the limitation of having a fairly narrow frequency band. That isn't too bad if you are sending a signal frequency, but if you attempt to use the same equipment for listening, you've got some problems. Sonar equipment is used not only for echo ranging to determine the range of a distant submerged object, but is also used in the listening position to pick up propeller noises or any other strange noise in the water. It is in this connection that the magneto striction type falls far short of the lighter frequency band you get with the crystal device.

Tebo: There is another point too: the Doppler Effect to tell you whether your target is coming toward you or going away from you.

Keller: For listening, again, the crystal type when it is broad band, is much better.

INT: When you returned to peacetime activities, they included such things as the wire spring relay, crossbar switches, the card translator and several other devices. Could you recall something about that?

Keller: Yes. That was a very interesting period. That all began about 1946 and continued until I retired from Bell Laboratories in 1966. One of the first things I can mention is the card translator. This was probably the most complicated electromechanical equipment that the Bell System had ever designed. It was primarily the design by Alain Hampton, but in addition to Hampton there were many other people that were involved. I guess you were involved.

Tebo: Yes. Eddie Jimp came to me and asked if I could design magnets to lift and pull down magnetic cards for the translator.

Keller: The card translator, incidentally is a means of automatically directing long distance telephone calls. It was really the first commercial use of transistors. It had something like 120 photo transistors and 120 point contact transistor amplifiers backing up the photo transistors.

Tebo: The photo transistors were invented by John Shive.

Keller: That's right. Notice I said the amplifiers are point contact. These things, twenty years later, were still working perfectly satisfactorily. It is fair to ask how can this be, because point contact transistors were known to be unreliable, particularly in the presence of moisture and so on. There are two lessons about this. One: A great deal of circuit margin was deliberately built into these things; they were not expected to operate at more than about half of their capability. The other thing was really kind of an accident: These things were all put into a cabinet, which ran pretty warm, so they never had a chance to have moisture accumulate on that surface. Thus they operate satisfactorily, although everyone else gave them up as hopeless after a while. For a long time they were the only transistors the Western Electric Company had in production because of this being a commercial advocation which continued to require equipment.

Another project which started about that time was the wire spring relay, which was a new general-purpose relay code card operated with coplanar springs. That sounds a little technical, but it is a different kind of a relay which set the pattern for others that came along later. That development was successful enough that the Western Electric Company is manufacturing about forty million of these each year at the present time. I am happy to say that it also got me the first prize in 1954 from the AIEE communications division. Getting back to measurements, would you like me to say a word about high-speed photography?

Tebo: Yes.

Keller: High-speed photography is used in following mechanical motions because you take it at a high speed and then reproduce in a normal speed so you really have slow-motion action. This was used extensively in relays and switches that we were involved in, and as a result of this, in 1952 I had the high honor to be asked to give the first keynote address at the International Symposium on High-Speed Photography. This has since been a regular feature of the Society of Motion Picture and Television Engineers. The Telstar relay might be interesting in this connection. In the 1960s, when the Telstar Satellite was put into operation, it had something like a dozen miniature relays which we designed. They gave a very good account of themselves, as far as I know, although at one point Telstar had quit momentarily. It was thought the relays had suffered some sort of malfunction. But it turned out to be somewhere else in the circuit. So relays can be pretty reliable.

Tebo: There was another point in connection with the wire spring relays and that was the method of making connections to them. This brought on the wire wrapping tool. That is used almost universally, now, for wire terminals.

Keller: That was a by-product of the wire spring relay development. When the wire spring relays were first put into production, the wire was wrapped and then scattered around the terminals. As a result of work done by people like Molina and Herman Molosh at the Bell Laboratories we were able to satisfy ourselves that a good solderless wrap connection could be made. I remember very well when this came up. M.J. Kelly was then president of the Bell Laboratories. He said, "Look. I hope you know what you are doing because if this solderless wrap connection doesn't work, you won't have one mistake but a hundred million mistakes on your hands. You better be sure you know what you are doing." That was very sobering, having your boss tell you that, and we did extensive statistical analyses on the thing before we finally released it for production. Presently it is used by IBM in computers, and used by all of the telephone manufactories around the world--Japan, England, Germany and elsewhere. I suppose that there are probably a billion connections made that way each year. That was a by-product of the wire spring relay.

Tebo: When the Western Electric Company introduced the wire wrapping scheme, they soldered it as well until they felt sure they could do away with the solder.

Keller: That's right. When I wrote the paper in 1952, I indicated the possibility, but at that point we did not have the requirements worked out for the long life wrap connection which we finally adopted a long time after. Would you be interested in hearing the story about the trip to Sweden?

Tebo: Yes. I think that would be very good.

Keller: The crossbar switches were invented by a Bell System engineer by the name of J.N. Reynolds. The patent was issued in his name. It was a revolutionary design, as the name implies, of a crossbar-type contact actuation--a coordinate switch, in fact. The Swedish people used it for small unattended rural exchanges of a hundred lines or less to replace the step-by-step switch they had been using. The Bell System, on the other hand, had conceived a whole new system of common control in which the crossbar switch was the basic switching network element apparatus.

Tebo: Was the common control system first developed for the panel machine switching systems?

Keller: Quite right. It was first developed for other systems, but what the Bell System was trying to do was to use the crossbar switch as the central switching network, as the basic unit rather than the traveling contact that the panel system used. It took a long time to develop the control system based on the crossbar switch. In the meantime the Swedish people had actually gotten the crossbar switch into production before the Bell System, but they misinterpreted this. This was brought out by comments made by Dr. Sterky, the head of the PTT in Stockholm, Sweden, when he asked to have some of their experience reported in Bell System publications. His interpretation of what had happened was not in keeping with what the facts were, so we were never able to agree to have published their view of what had happened. They were of the opinion that the Bell System had neglected the crossbar switch. Actually, a more complicated development had caused the Bell System to get into production after the Swedish people did.

Tebo: We have talked about the phototransistor and the point contact transistor amplifier, first used in the card translator. You were probably familiar with a number of other uses of the transistors. Could you tell us something about those?

Keller: I remember one particular application that turned out to be quite successful. This had to do with the military application under development after World War II. These were not point contact transistors, and there was a fair amount of trouble with them. As a result I was in constant touch with Jack Morton and Bill Shockley out in Murray Hill. I was in New York. I remember one day Bill Shockley called me up and said that he needed a lathe that cost about a thousand dollars. He didn't have any capital money. Did I have any? I found that I had some money I could spare. I had to buy it and send it up to him for his use. I will come back to this in a minute.

We continued to have trouble with this military application, which was being done for the Bureau of Standards. Finally, the people working on it under me were kind of stumped. Jack Morton and his people didn't seem to understand as much as we hoped they would. I finally called Bill Shockley and said, "Bill I would like to come out and tell you about the troubles that we are having with transistors." He said, "I am not interested." Now, that was a bit of a shock to me because Bill Shockley, I guess sometime later, was one of the three people who got the Nobel Prize for the transistor. And so I said, "Bill, it seems to me, that if I told you about some of our troubles you would understand transistors even better than you do now." He said, "I am not interested." I kept at this and kept getting the same answer. Finally I had to get back to the lathe I bought. I said, "Look. I don't like to bring this up, but I contributed some of my capital money, which I could have used for something else, to help you out. I think at least you owe me an explanation." And he said, "Well, I guess that's right." His reason: "If I listen to all of your troubles that you are having with transistors and all the other troubles Bell Laboratories are having with transistors I wouldn't have time to dream up new forms of transistors." I thought this was spoken like a research physicist. Bill is quite a character but, I don't know, if you have a top-grade theoretical physicist like Shockley who is also a member of the American Society of Magicians, I guess you can expect almost anything.

Tebo: You should have talked to Walter Brattain.

Keller: I talked to Walter Brattain, but he took a definite approach to all these things. He is a different kind of a person altogether.

I mentioned the Bureau of Standards. At the time that military project was under way, which was an ordnance device, there were two divisions of the Bureau of Standards having to do with military equipment. We finally licked this problem, which was a circuit problem. The transistors would burn out, and we finally found out what to do about that. The demonstration was arranged at Blossom Point to have the final demonstration with the Army brass and the Bureau of Standards and the Bell Laboratories people. I invited Jack Morton and some of his people and at the last moment decided to invite Bill Shockley. I was sure he wouldn't come. So I called him up and much to my surprise, he said, "Sure. Where do I go? Where do I meet you?" He came along and we had a very successful demonstration. This was below Washington, you get there by car after you get to the Washington Railroad Station. Coming back to the train that night in the car, everybody showed up but Bill Shockley, and we were kind of worried about him. But just before the train took off, Bill showed up with a couple of bottles of champagne to celebrate the successful demonstration. He may have not been interested in our troubles, but was sure glad to celebrate the successful demonstration.

I bring up the Bureau of Standards because some years later, M.J. Kelly, who was then the president of the Bell Laboratories, was asked to investigate the Bureau of

Standards to see whether it was set up and being operated in the national interest. He was the chairman of the committee. This was in 1953, I think, and he appointed me as the consultant to examine two sections of the Bureau of Standards, which were sections working on military equipment. All I can say is that while they had been doing a good job it was decided that the military work should be separated from the rest of the Bureau of Standards work. I believe it is now all under a new organization called "The Diamond Ordinance Fuse Laboratory" or something of that sort.

Tebo: You had a lot of experience with sealed contacts, the variant switches and miniature relays. Perhaps you could tell us something about those.

Keller: All of that has a very interesting beginning. After World War II, Elway Buckley, who was then the president of the Bell Laboratories, called me into his office one day and said he was interested in being sure that we had some kind of a new program to develop better and smaller relays. He asked me to get some inventive people together and come to his office to discuss this thing. Two of the people who were present were Henry Harrison and Walter Elwood. He gave them the same instructions, namely that we needed smaller and better relays for telephone switching systems. After a long time the work that Henry Harrison started turned out to be the wire spring relay, which is the workhorse relay of the Bell System now. Walter Elwood, having heard the same instructions, invented the glass sealed contact called the dry read relay and this has become the basis for the electronic switching system network. These people had the same instructions and came out with two very different but both extremely useful devices, the seal contact being a glass enclosed, magnetically operated contact. Later on, the seal contact was used into a form of a ferine which is a combination of a magnetic latching type material with a sealed contact. It is the cross point for the latest electronic switching systems, and this is what Elwood really started.

Tebo: This has been a lengthy interview and I certainly appreciate the information you have given me. Perhaps now in conclusion you might to care say a few words that could be used for engineers in the future.

Keller: Well, I will do what I can. I have had a very interesting career. I have had awards, honors from the Bureau of Ships, the Bureau of Ordinance, and from the AIEE and the Berliner Award. I was elected to the board of directors of a couple of companies. I really have had an interesting career. When I retired I talked to the people that I worked with closely, my staff you might say. I told them I thought the Bell Laboratories was a great place to work, particularly to advance in technological matters. I felt as a director, which I was when I retired, it was important to keep in touch with the outside world, to be sure that everybody was up to date. The reputation that our people had was enviable and it takes a bit of doing to maintain that reputation. Some of the thoughts that I passed on to my staff had to do with people, really. To do our best job, the better we should know our people, their strong points and limitations, and we all have these. It doesn't mean that they all have to be good companions; we were not hired at the Bell Laboratories to be good companions, but to do a technical job.

At all levels of the organization, we have to keep up to date technically and most important to stay ahead of outside competition, which arises from all directions these days. But to do the best technical job, which is the thing we spend most of our time on, we have to bring out the best in the people that work with us and to help them develop. You don't have to love them all, but you do have to respect them, and to work effectively with people you should let them know where they stand. For example, when you tell a person about his raise, tell him about his strengths and also his limitations; it may be easier to talk to him only about the good things, but in my opinion you should also give him the total picture. There is nothing worse than a man going along with his work, thinking all is well when his limitations could be improved if he knew about them. To work with people in this labor requires judgment, which is really the most precious of all human attributes. It is often easier to be expedient rather than to discuss uncomfortable matters with people. My experience is that whenever you do the expedient thing you will be sorry at some later date. Now I have rambled on here and there are unfinished technical problems that I could have spoken about, but I think maybe I have said enough as it is.