A Selected History of Magnetic Recording

by Friedrich Engel and Peter Hammar; additional editing by Richard L. Hess

The Premiere of the Magnetophon Audio Tape Recorder in Berlin, 1935

> *The Magnetophon machine created a great deal of interest at the exhibition. The dealers recognized the fact that this machine was the "hit" of the show, something we heard as well. They realized the many important applications of the machine, including its use as a dictation and news-gathering device, as well as the perfect replacement for phonograph records. Many inquiries about the delivery of 25 or 50 machines at a time were heard. Many people indicated their desire to see variations of the Magnetophon: combined with a telephone; an auxiliary unit for a radio; pre-recorded music and entertainment tapes; a special version to create artificial reverb for open-air concerts; feedback control for indoor performances with sound reinforcement; a device for "speed telephoning", that is, recording a speech at normal speed, playing it back over the phone at a higher speed with the recorder on the other end of the line also working at the increased speed, and then playing back the tape at a normal speed.*

These were the words of Friedrich Matthias of BASF, the company that produced the first-ever coated magnetic recording tape. He was reporting on 4 September 1935 to BASF (then called I.G. Farben, Ludwigshafen works) headquarters about the introduction at the German Radio Exhibition of the AEG Magnetophon audio magnetic tape recorder and BASF tape. The machine was one of the main attractions at the AEG booth . Even this formal report reflects the enormous excitement that the new audio recording technology generated at its first public demonstration. After only two-and-a-half years of development, a promising new product family was ready, thanks to the cooperation of two large companies, AEG and BASF. An AEG team in Berlin had designed and built the Magnetophon hardware, consisting of the tape transport, the magnetic heads, the electronics, and the loudspeakers, while a BASF team in Ludwigshafen had done the research and development leading to the production of the first mass-produced magnetic tape. By 1940, when the quality of the magnetic recording process had increased significantly, tape was firmly established for the next six decades as a universal recording method.

The Development and First Implementation of Magnetic Recording

In 1935, magnetic sound recording was by no means a new technology. Much had already been developed in the previous 60 years. Realizing the imperfections of the Edison cylinder phonograph introduced in 1877, a 38-year-old American named Oberlin Smith in the summer of 1878 sketched out the fundamentals of magnetic recording and performed some basic experiments. Smith represented the quintessential 19th Century inventor, an engineer with a wide technical background. He primarily made his living manufacturing forges, machine tools, and metal presses in Bridgeton, New Jersey. Smith's favorite proposal for magnetic recording suggested the use of a cotton thread interspersed with short, thin steel wire pieces run at a constant speed through the core of an electro-magnetized spool of wire. Smith did not take out a patent on the process because he could not create a working model of his idea, presumably absorbed by the increasing demands of his business. Ten years after sketching out his theoretical proposals on magnetic recording, Smith published his findings in the 8 September 1888 issue of the American technical journal, *The Electrical World*, under the title*, "Some Possible Forms of Phonograph".* Although the article created almost no interest in magnetic recording in the new industry of recorded home entertainment, Smith's position as a magnetic recording pioneer was assured.

In 1896, the Danish electrical engineer Valdemar Poulsen designed the first working magnetic recording device, which he called the "Telegraphone". The wire recorder, patented in 1898, was enthusiastically received at the Paris World Exhibition of 1900. Following that success, Poulsen developed important variations of his magnetic recording design. Besides wire wrapped on spools, the inventor built steel-tape recorders, and even a coated steel disc recording device for short dictation, whose basic function resembled the Winchester hard disk recorders widely used in computers 80 years later.

In practice, the Poulsen magnetic recorders could not succeed because of their lack of electronics. Poulsen introduced his machines before the invention of the vacuum tube;, so that the lack of amplification on playback, as well as good microphones, doomed the machines to commercial failure. The mechanical gramophone continued to reign supreme in audio recording. Suitable amplifiers did not arrive in Europe

until the introduction of tube amplifiers by the Austrian Robert von Lieben. Von Lieben's patent of December 1910 suggests its possible use with magnetic audio recording. In America in 1913, "Audion" tube inventorLee DeForest also wrote about the application of his audio amplifier to the Telegraphone wire recorder. At the end of the 1920s, the German chemist Curt Stille introduced a steel-tape machine for use in production and distribution of the newly introduced technology of movies with sound, "talking pictures". A film producer named Ludwig Blattner acquired the rights to the steel-tape recorder, which he renamed the "Blattnerphone". Blattner later sold the invention to the British company Marconi, which, in 1935, built for the British Broadcasting Corporation (BBC) its own, definitive version of the steel recorder: 3 millimeters (mm) wide, 50 micrometer (µm) thick steel tape, running at a speed of 1.5 meters per second. The machine could record for 30 minutes on a 9 kilogram, 60 centimeter-diameter reel. Similar machines remained in use at the BBC until 1954.

In Berlin, Germany, electrical engineer Semi J. Begun designed comparable steel-tape recorders for the C. Lorenz Company, the Stahlton-Bandmaschine or "Steel Sound Machine", which was put into service at the German national broadcasting company, the Reichs-Rundfunkgesellschaft (RRG), in the mid-1930s for test purposes. Begun had much experience in the construction of magnetic dictation machines, including his 1931 "Dailygraph", a device featuring recording wire contained in a cassette.

Steel tape was not only heavy and clumsy to handle—if not properly threaded and tensioned, the spool would explode like a watch spring flying apart—but also was difficult to edit, theoretically one of the main advantages of the linear magnetic medium. A steel tape could only be edited using solder or welding material. After the tape was red-hot, the edit point lost its magnetic flux, meaning the sound dropped out at every edit. Steel tape that met constant specifications was difficult to manufacture. The impracticality of wire and steel-tape recording seemed to assure that wax, lacquer, and acetate transcription discs (78 rpm records) would remain the mainstay of the professional and consumer audio recording industries for some time to come.

Magnetic Recording Using Paper, Iron Oxide Powder, and Glue

As so often happens in the development of technology, progress came from the work of people who were outsiders to the mainstream of the industry. Practical magnetic tape recording originated with an Austrian inventor living in Dresden, Germany, named Fritz Pfleumer. In the 1920s, sales of cigarettes boomed, and the manufacturers wanted a cheap alternative to the expensive gold leaf band that decorated the tips of the most expensive cigarette brands. An expert in special paper and related processes for industrial uses, Pfleumer succeeded in creating a process for striping a cheap gold-colored bronze band on the cigarette paper. Pfleumer was interested in the magnetic recording process, and reasoned that he could use his cigarette-paper manufacturing process to create a magnetizable paper recording tape that would replace expensive and impractical wire and steel.

The inventor glued pulverized iron particles onto a 16 millimeter-wide strip of paper, creating the first magnetic tape. He also built the first tape recorder in the modern sense. For his discovery, Pfleumer received German patent DE 500 900 on 31 January 1928, titled "Lautschriftträger" (sound record carrier) and, amongst others, British patent GB 333,154, "Improvements in or relating to Sound Records", on February 5, 1929. The audio tape recorder produced poor quality sound that nonetheless offered great promise. The paper tape tore readily, but could also easily be repaired with glue instead of the welding method of steel and wire. In his promotion of the invention, Pfleumer pointed out that editing and assembling the edited pieces of his recording tape were as easy as handling movie film, a well-established technology.

Realizing that he needed help developing his invention into a commercial product, Pfleumer determinedly approached several companies. The German electronics group AEG—German General Electric—showed the greatest interest and signed a contract with Pfleumer. In 1931, AEG had set up a development laboratory in their cable factory on the Oberspree River in the Berlin suburb of Oberschoeneweide. Under the direction of Theo Volk, AEG technicians assembled their first prototype paper-tape recorder and began experimenting with methods of manufacturing the tape.

The AEG engineers quickly found they were better at designing electronics and tape transports than they were at experimenting with the chemical processes of iron powder, glues, and coating methods. So they contacted the logical people to help them with the job, the BASF division in Ludwigshafen of the giant chemical combine I.G. Farbenindustrie. The chairman of the AEG board of directors, Hermann Buecher, had taken a personal interest in the tape recording project, and contacted the managing director of BASF, Wilhelm Gaus. The two made a "gentlemen's agreement", later formalized in a written contract, that AEG would build the machines and BASF would make the tape, with their development teams cooperating closely.

The BASF chemists decided that a product they had been manufacturing on a large scale for years, carbonyl iron used in high-frequency coils for telephone transmission and radio applications, would be a suitable magnetizable material with which to coat the tape. Realising that paper was a poor choice as a base film for the new product, the team of chemists also worked on finding a better base on which the magnetic material could be coated. By early 1934,

the team's experiments were pointing in the right direction: they coated a 30 µm thick cellulose acetate base film with 20 µm of carbonyl iron powder mixed with more cellulose acetate to bond chemically with the base film—thus creating a genuine coated tape.

In June, 1934, AEG and BASF had decided to call their "magnetic phonograph" machine and tape "Magnetophon". The Ludwigshafen chemists produced 5000 meters of tape for the introduction of a newly developed machine at the 1934 Berlin Radio Exhibition. However, shortly before the show, AEG encountered technical problems—bad hum from the interaction from the machine's motor and electronics—and cancelled the machine's debut. They also found the tape broke quite easily. It was "back to the drawing board" for both AEG engineers and BASF chemists.

The Definitive Version of Magnetic Tape Recording

The joint development team decided they would show the improved Magnetophon at the Radio Exhibition in Berlin in 1935. The intervening time was put to good use. AEG built a completely new tape transport system, which set the pattern for the modern tape recorder, in respect of the placement of its reels, heads, and tape path, as well as its three-motor design, the best for tape handling. The same transport and electronics were offered in a portable case as well as the basis of an office dictation system in an oak cabinet, the model "ferngesteuerte Truhe" or "remote-controlled cabinet" model. The 6.5 millimeter-wide tape ran past the heads at a speed of one meter per second. The tape length had been extended to 1,500 meters, giving a playing time of around 25 min.

Both these versions in 1935 were called simply "Magnetophon", without addition. Designations like "Magnetophon K 3" came only in about 1937, and apparently the former models were belatedly renamed as Magnetophon K 1, Magnetophon K 2, Magnetophon T1 and Magnetophon T 2.

By the spring of 1935, BASF chemists moved their "Magnetophon Tape Type C" from development to production when they put four experimental coating machines into operation. Test recordings of music and speech made on 27 April 1935 show the progress they had made in their formulations. For the Berlin Exhibition scheduled a few months later, the chemists produced 50,000 meters of Type C tape.

Effective playback and recording heads form the basis for the quality of any analog tape recorder / reproducer. The man who became the AEG Magnetophon chief engineer late in 1935, Eduard Schueller, had developed a "ring head" to replace the pointed magnetic heads designed for steel tape recorders. The older sharpened-head design tore paper and plastic tape, while the smooth face of the new ring head was perfect for use with the BASF acetate tape. Schueller's ring head, the basis for all future magnetic recording heads, was patented on 24 December 1933 (DE 660 337), and was truly a Christmas present for the future of magnetic recording.

The AEG Magnetophon and Magnetophon Type C tape were a sensation at the Berlin exhibition in August, 1935. People were amazed to be able to hear their voices an instant after being recorded. The product roll-out was overshadowed, however, by a fatal fire midway through the show that destroyed the hall in which the prototype machine and tape were being demonstrated. The AEG team across town worked day and night and produced two further machines that were shown only two days later during the final days of the exhibition in a makeshift booth.

The enthusiastic report about the Magnetophon at the Berlin show written by the 39-year old Friedrich Matthias of BASF (see above), combined with the dedication of the 33-year old Eduard Schueller and his AEG team to replace the burned-up prototypes before the show ended, demonstrated the high value that they and others placed on the invention. After only two-and-a-half years of cooperative development work by AEG and BASF, the promising system was ready. The price was attractive: the recorder cost 1350 Reichsmarks, and an hour of tape cost 36 Reichsmarks, about a seventh of the price of steel tape for the competing Lorenz "Steel Tape Sound" machine. By comparison, a trained technician earned about 250 Reichsmarks per month. Clearly, the recording technology was beyond the means of most consumers and was aimed at the professional audio and government markets.

Despite the relatively high cost of the AEG machine and its BASF/I.G. Farben tape, the sales outlook of the new recording medium in various markets looked bright. BASF geared up to make tape in volume. By the summer of 1936, the Ludwigshafen team had bought a modified a photopaper manufacturing machine from the Koebig company in Dresden with which they could produce a long sheet of cellulose acetate base film and then immediately coat that base with magnetizable iron particles mixed with a "binder"—a kind of glue. The production machine consisted of a narrow cabinet containing a continuous 28 meter-long, about 65 centimeter-wide copper belt. Liquid cellulose acetate was spread onto the belt to create a 60 cm-wide "web" or sheet of cellulose acetate base film. Then the newly made base film web was run through the air another 12 meters to dry it.

In the final step of the tape-making process, the treated sheet of cellulose acetate was coated with a liquid mixture of acetone, cellulose acetate, and carbonyl iron. After about 26 meters , the finished tape was dry enough to leave the support of the copper belt and be wound into a wide spool of finished bulk tape, ready for slitting into individual Magnetophon tapes, each 6.5 mm wide. The tape base film was 30 µm thick, with a 20 µm coating, close to the specifications of modern professional audio tape. In the mid-1930s, the speed of the tape manufacturing machines was limited to only three meters per minute.

For a run of 1000 meters of tape, the process required six hours, from which 84 tapes with a playing time of 16 minutes (at 1 m/s tape speed) each could be made. (Latest magnetic tape manufacturing process yielded over 1,000 meters per minute.)

In the summer of 1936, the BASF chemists replaced carbonyl iron with magnetite as the tape's magnetizable component. This type of iron oxide, Fe_3O_4, offered a higher coercivity and greater remanence, meaning higher quality audio recordings. Instead of light gray, the Magnetophon tapes were now black.

The first formal test of the new "Magnetophon Type C" tape product came on 19 November 1936, when BASF technicians recorded a concert by Sir Thomas Beecham and the London Philharmonic Orchestra in the "*Feierabendhaus*", the employees' auditorium on the factory grounds. Unfortunately, the poor-quality DC-bias electronics still produced recordings not as good as the competing wax transcription discs used by recording companies and radio stations in Germany.

The State of the Art of Tape Recording by 1936

With his pioneering Telegraphone, Poulsen had added a DC current to the signal—a process called "biasing"—to attempt to reduce distortion and noise in the recording. Biasing "pre-magnetizes" the magnetic medium to reproduce more precisely the magnetic flux from the recording head. Poulsen's DC-bias designs did not work well; all wire, steel tape, and early paper and plastic tape recorders used DC bias and made noisy, distorted recordings with limited frequency response. By 1936, even after much research at AEG and BASF, little had changed in record bias designs. Even the 1936 version of the Magnetophon with its DC-biasing circuit produced a distorted signal with a frequency range of 50 Hz to 5 kHz, and a dynamic range of less than 40 dB.

Engineers knew there had to be a way to improve the performance of the new technology. The answer was AC record bias, i.e., a high-frequency alternating bias current oscillating thousands of times a second sent to the record head at the same time as the audio signal to be recorded. Ironically, in 1934, BASF physicist Erwin Lehrer had experimented with AC bias while testing magnetic materials, but was unable to make the process work well. AEG Magnetophon engineer Eduard Schueller also unsuccessfully tested AC bias, apparently having been not correctly informed about Lehrer's work. Another six years passed before Walter Weber of the Reichs-Rundfunkgesellschaft, the German broadcasting service, in 1940 made the definitive step towards truly "high fidelity" recordings. If the Magnetophon had had AC bias as early as 1935, who knows what the machine's quality would have been?

Comparing the specifications of the Magnetophon of 1936 with today's analog audio tape recorders reveals the difficulties faced by the first tape makers and machine builders in their new world of magnetic recording. For chemists and electronic engineers, creating a tape recorder and its tape meant a step-by-step exploration of magnetism, mechanics and motion theory, and advanced audio electronics. The teams had to explore basic scientific and technical theories that we take for granted today in the design and manufacture of magnetic recorders and tape. In the 1930s, measurement of the hysteresis loop of magnetic materials, a common practice today that takes under a minute, took one to two hours. Lack of efficient measuring equipment presented one of the first obstacles, solved by BASF physicists Erwin Lehrer and Friedrich Bergmann. They and their associates developed measuring devices to establish objective electronic, magnetic, and mechanical quality parameters, which they often first had to define. Their work offered alternatives to purely subjective listening tests.

At the end of the 1930s, tube amplifier desigers started to use "negative feedback" in order to reduce distortion caused by all-too-simple circuits. Initially, the advantage of this feedback procedure was not understood. The negative feedback meant reducing the gain, but resulted in better audio quality. AEG engineers incorporated the technique into the Magnetophon's amplifier design.

After AEG had built only ten to fifteen Magnetophon models of the 1935 version, which ran tape at one meter per second, the company introduced an improved model in 1936, most of them with the slower speed of 77 centimeters per second, offering a playing time of 22 minutes using a 1,000 m roll (the 1,500 m rolls apparently had overstressed the initial tape transport system). Planned or by chance, the new speed was almost exactly half the 1.5 meters-per-second speed of the still-competitive steel-tape magnetic recorders. Around 100 machines of the 1936 model and the successor, now named "Magnetophon K 3", were built in the next two years. AEG introduced in 1938 its first commercially successful tape recorder, the Magnetophon K 4, with its modern amplifiers and modular magnetic head stack. The K 4 was the best of the DC-bias machines. All of the 1935 to K 8 types (1948) consisted of three units: tape transport (motor and head assembly), separate amplifier, and a loudspeaker, each contained in its own portable case.

The German radio service, the Reichs-Rundfunkgesellschaft (RRG), in one of the earliest known examples of "electronic news gathering" (ENG), tested magnetic recording in the field in 1934 with the Lorenz steel-tape machine in the streets and trains of Hamburg. But In 1938, the RRG declared the Magnetophon to be one of its future recording devices. They recognized the cost and performance advantages of magnetic tape—including the ability to record uninterruptedly for 20 minutes—over their current recording standard, the wax transcription disc, which could record for only four or five minutes, but at a higher quality level. At first, the RRG used DC-bias Magnetophons for non-critical recordings such as speeches and interviews. The director of the RRG

electronics development laboratory, Hans-Joachim von Braunmuehl, was optimistic that the Magnetophon could be improved enough to record music, so he put RRG engineer Walter Weber to work perfecting the new tape technology. The RRG magnetic tape lab operated independently of the AEG Magnetophon R&D operation across town.

The first implementation in German radio stations was the R 22, based on the AEG Magnetophon K 4 tape transport, but with special amplifiers developed by RRG engineers. The RRG realized the importance of the new Magnetophon for ENG operations, and, working with AEG, helped develop the Magnetophon R 23 in 1939, a compact, battery-powered portable deck—still with the inferior-sounding DC-bias record circuit.

The German military in the 1930s naturally adopted any technology that would advance its cause, and found many uses for magnetic recording. The Army "Propaganda Corps" and other departments used portable recorders in a variety of field applications. The military versions of the AEG recorders were called "Tonschreiber" or "sound writer". R-23s and other models were modified and dubbed "Tonschreiber Dora" or just "Tonschreiber d". Other models appeared at the same time, including the Tonschreiber Caesar ("C"). In fact, Caesar came in two versions: the recording device, technically very simple, was a tiny, spring-driven machine, the most portable magnetic recorder yet created. The playback unit, of about the same size, had an electric motor and tube amplifiers. The most interesting and technically advanced pre-war Tonschreiber was Berta ("Tonschreiber b"), a transportable deck and amplifier with variable recording speeds from 9 cm/s to 120 cm/s. In addition to the normal head stack, the field recorder featured an additional four-gap spinning head assembly for playback at variable speeds without a change in pitch, in other words, it was used to expand speech or decode telegraphic or morse messages.

By 1939, BASF researchers had advanced the state of the art of tape quality far beyond its 1936 debut. Probably the most important progress came that summer with the introduction of gamma ferric oxide tape, γ-Fe_2O_3, with red iron oxide particles, a formula dating back to a 1935 BASF patent that proved so effective that it was not until thirty years later, in 1971 with chromium dioxide tape, that anything fundamentally better would replace it. Tape formulas in Germany, Japan, and the United States in the 1940s, '50s, and '60s, were evolutionary improvements on this BASF patent. The γ-Fe_2O_3 magnetic particles were considerably smaller than the original Fe_3O_4 formulation, which resisted erasing by the permanent magnet erase heads then in use. With DC-bias Magnetophons, the new tape achieved a signal-to-noise ratio of little more than 40 dB and a frequency response remaining 50 Hz to 5 kHz, still unacceptable for "broadcast quality".

Using the same name between 1935 and 1943—the last year of its production—, Magnetophon tape Type C contained no fewer than three magnetic formulations:

- up to the summer of 1936: carbonyl iron (light-gray, metallic pure iron)
- from the middle of 1936 to the summer of 1939: Fe_3O_4 (black, cubicular iron oxide)
- from the autumn of 1939 to 1943: γ-Fe_2O_3

Gamma-type red, cubicular oxide; needle-shaped variations were developed at the beginning of the 1950s using the same formula.

Throughout the development of these magnetic materials, the base film remained the same—cellulose acetate, after which BASF named the product "Magnetophon Tape Type C". Although polyvinyl chloride (PVC) and later, polyester (Mylar) base films eventually replaced cellulose acetate, the technology lasted well into the 1960s. Type C tape had advantages in manufacturing. Acetone used in the process was cheap and plentiful, and the cellulose acetate was used in all three parts of the tape: base film, magnetic coating, and binder, resulting in a cost-effective and straightforward manufacturing process. One can understand why acetate tape was produced well into the 1950s in Germany and into the 1960s in America.

Acetate tape had its weaknesses—it broke easily and was sensitive to humidity. The product had a clear advantage over its plastic successors: it broke cleanly and did not stretch. When acetate broke, the recording engineer could easily splice the tape back together with no audible break in the sound.

The Great Quality Leap—AC-bias Recording

Joining AEG and BASF in 1938, the Reichs-Rundfunkgesellschaft (RRG) became the third branch of the Magnetophon R&D effort. Starting in 1940, the RRG successfully applied AC-bias to the new recording technology. RRG engineer Walter Weber discovered the AC-bias application through a combination of systematic research and a bit of luck. Weber was not the first to apply AC bias to magnetic recording, although he evidently had no knowledge of the earlier work. The engineer's success was due to his ability to recognize immediately the practical value of his discovery and to use it to improve the Magnetophon's recording quality.

Weber had been experimenting with phase-cancellation circuits in an attempt to reduce the distortion and noise of DC-bias recordings. An amplifier in a test set-up went into oscillation, accidentally creating an AC-bias current in the record circuit. It took some systematic engineering detective work before Weber found what had happened and could recreate the phenomenon. AC bias for the magnetic tape recorder was born! Rumor had it that the AEG engineers on the other side of town were happy that the RRG engineer had solved the problem with AC bias, although they were a little annoyed that they had not thought of

it themselves. Weber's supervisor, H.J. von Braunmuehl, worked with AEG to establish patents and licensing of AC bias for the Magnetophon. The most important of the resulting patents, DE 743 411, was published 24 December 1943, exactly ten years after Eduard Schueller took out his ring-head patent.

The Magnetophon now had the best audio quality of any recording technology in the world, far better than the old DC-bias tape recording, but also better than the current commercial competitors to Magnetophon tape: optical sound on film; shellac, the Philips-Miller system and wax discs; and steel tape and wire. The superiority of the new "high fidelity" magnetic recording process was clearly demonstrated in Berlin on 10 June 1941 in an AEG-RRG demonstration publicly reported by the local press: *"A fantastic experience in electrical sound recording...a total revolution in sound recording...."* No wonder the journalists were impressed: for the first time in history, a sound recording had achieved 60 dB dynamic range and a frequency response of 50 Hz to 10 kHz (figures based on weighting filters and tolerances of the day).

AEG/RRG researchers soon added stereo recording to their 1940 high-fidelity Magnetophon triumph. As early as 1942, they had made test recordings using three condenser microphones made by the famous Berlin company Georg Neumann and a stereo version of the AEG / RRG R 22a studio deck.

While engineers had made progress in its electronics, the "hi-fi" Magnetophon based on the K 4 left room for improvement in tape handling, wow, and flutter. The breakthrough was the Magnetophon model K 7, the first tape deck with synchronous motors. Test versions were introduced in the spring of 1943. Subsequently, for the first time, even stereophonic "acoustically accurate" sound reproduction was demonstrated to the public, using the latest loudspeakers developed by RRG engineer Hans Eckmiller. Since this was before the era of stereophonic radio broadcasting, all of these recordings went to the radio archives labelled "for archival purposes only". The stereo version of the Magnetophon never made it into regular production, and war-time pressures and post-war chaos ended serious stereo experimentation until the late 1940s.

The German film industry took an immediate interest in the new high-quality sound recording method. A German Cine Color film system had recently been introduced, but the optical sound-on-film suffered from the new color emulsions, which did not reproduce optical sound as well as black-and-white film. In 1941, engineer Karl Schwartz of Klangfilm GmbH in Berlin received patent number DE 969 763 for his solution to the fundamental problem of synchronizing film-camera and film-projector transports: the use of perforated magnetic tape—oxide coated on clear film stock. Unfortunately, few details of Schwartz's invention are known, although the German film manufacturer Agfa did show a strong interest in the invention and performed some experiments dating back to late 1941, including trial production runs.

Further Wartime Developments

On July 29, 1943, the BASF Magnetophon tape plant in Ludwigshafen was completely destroyed by a non-war-related, accidental explosion of a tank car. The disaster wiped out all tape-manufacturing machinery in the factory, including the only coating machine for Magnetophon Type C tape, installed in 1936. To meet RRG tape needs as well as wartime military tape consumption required quick improvisation and an alternative manufacturing site. With a world war raging around them and their factory destroyed, with no hope of rebuilding the plant or replacing mixing and coating machinery at Ludwigshafen because of scarce resources, the tape makers found they had three possible solutions to the problem:

1. Plant Relocation: The photographic film maker Agfa in Wolfen, Germany, a fellow member of the I.G. Farben chemical combine, in 1941 had already begun manufacturing test runs of the Type C formula developed in Ludwigshafen. By the end of February, 1943, the Agfa chemists had sent four 50- to 70-meter-long samples to BASF for analysis. After the Ludwigshafen explosion a few months later, lots of the BASF oxide, which Ludwigshafen could still produce in volume, as well as magnetic tape production know-how were sent to Agfa in Wolfen. It took another few months, until well into 1944, before the new Agfa plant was operational and producing Type C tape. The operation was the beginning of Agfa's commercial tape production. After the war, the Wolfen plant, located in the future "German Democratic Republic" or East Germany, became a state film and tape factory called "Orwo". In 1948, tape experts from Wolfen built a new Agfa tape factory in Leverkusen, near Cologne, which was moved to Munich in the 1970s, and finally merged with BASF AG to form BASF Magnetics GmbH in 1991. Its successor, EMTEC Magnetics GmbH, went out of business in 2004. In 2006, RMGI in The Netherlands began producing some BASF/EMTEC tape types on equipment purchased from the EMTEC bankruptcy auctions.

2. New Base Material: The second option available to continue tape manufacturing was a change in base material, from cellulose acetate to a new plastic, polyvinyl chloride or PVC, which had been developed and manufactured since the end of the 1930s at the Ludwigshafen plant. As early as 1938, BASF researcher Heinrich Jacqué, inventor of the tensilized PVC foil had suggested putting the oxide directly into the PVC mixture and rolling the result by means of a calendering machine into 50 µm-thick homogeneous tape webs, ready for slitting. The process totally eliminated the need for tape coating and oxide binding to the base film.

Considering the likelihood of the tape manufacturing plant could be destroyed by an air raid, Jacqué had been ordered to revive his homogeneous tape experiments in 1942. When rebuilding the destroyed coating machinery proved to be impossible (at least, digging through the ruins of the old tape plant yielded two old slitting machines that could be refurbished),

he had to speed up his developments, resulting in the delivery of “Magnetophon Tape Type L” in October 1943 using an available calendering machine. The “L” stood for “Luvitherm”, I.G. Farben’s trade name for the PVC manufacturing process. The BASF, Agfa, and AEG people were pleasantly surprised to discover that the new Type L tape performed far better than the old Type C product, with an amazing 10 dB improvement in signal-to-noise ratio. The downside was that the tape’s sensitivity also decreased by 10 dB, (a special handicap for tube amplifiers), because the oxide particles mixed into the base film were more dispersed, with some particles physically farther from the magnetic heads than with coated tape.

3. Modern PVC Coated Tape: In 1942, BASF chemist Rudolf Robl was given the job of finding a way to coat iron oxide onto the new PVC Luvitherm base film instead onto the somewhat brittle cellulose-acetate base. He had to develop a new coating process that differed from the manufacture of the original Type C tape. Acetone, the solvent used to make Type C tape, dissolves PVC too well, so Robl had to find a more suitable solvent. Coincidentally, BASF had begun producing THF, tetrahydrofuran, which Robl discovered he could use as a solvent in the PVC coating process.

Unlike the manufacture of Type C tape, in which the base film and coating occurred in one long process, Robl had to coat pre-manufactured webs of PVC “Luvitherm” base film. The long webs of PVC were difficult to handle during the coating process. Robl’s solutions to materials handling formed the basis for tape manufacturing methods still in use today. The PVC base film had to be pre-treated to improve the handling of the wide plastic web of tape as it made its way through the coating machinery, as well as to allow the oxide-binder to adhere to its surface. Robl mixed titanium dioxide into the base film to improve tape handling and to help the end-user more easily distinguish the back and front of the tape. (Backcoating the reverse side of the tape is, by the way, an invention of Rudolf Robl and Erich Merkel of November, 1955, see patent DE 1 101 000.) He called his new tape “Type LG”; “L” for Luvitherm and “G” for the German word “Guss” for “cast” or “coated”. Type LG is thoroughly modern magnetic tape: a plastic base film with a γ-Fe_2O_3 oxide coating.

By the end of 1943, Robl was ready to go into production with the new Type LG tape. The BASF explosion that summer had eliminated Ludwigshafen as a manufacturing site, with many resources diverted to the Agfa plant at Wolfen to produce Type L tape. Ludwigshafen could, however, still deliver iron oxide (and did so in 50-liter milk cans). They set up their man Robl in late 1944 in a truck garage in Aschbach in the Odenwald, about 50 kilometers east of Ludwigshafen. Starting in February, 1945, Robl and his five employees produced 1600 kilometers of Type LG tape per month.

AEG and BASF co-founded “Magnetophon GmbH” or Magnetophon Company in 1942 in Berlin. One of the two corporate officers was Friedrich Matthias. In the summer of 1944, he moved the management operation to Waldmichelbach in the Odenwald, two kilometers from Aschbach, where Robl later on was making Type LG tape. Waldmichelbach would be the tape-slitting and packaging center, where the wide rolls of manufactured tape were slit into 6.5 mm-wide tape, wound onto hubs, packaged, and sent to end users. One can easily imagine the (post-) wartime transportation and logistical problems that Matthias faced. Magnetic tape was going through the most hazardous phase of its history.

In early 1945, because of the Allied air raids on Ludwigshafen, the BASF tape calendering machine was moved to Gendorf in Upper Bavaria. In 1948, on demand of the US government, the Wald-Michelbach plant and the Aschbach coating machine were relocated to Gendorf in Upper Bavaria. Early in 1949, Friedrich Matthias, formerly of Magnetophon GmbH, set up a complete tape manufacturing plant in Gendorf, producing tape with the brand name “Genoton”. The plant operated until 1956, when it was closed and some of its personnel were transferred back to BASF in Ludwigshafen. Matthias died in 1956 near Gendorf.

A year after the end of the war, in 1946, the BASF crew began to rebuild their tape-making facility in Ludwigshafen. About 30 employees battled hunger and difficult circumstances to set up a tape plant in a makeshift building. The team’s biggest problem was to find enough PVC base film: the calendering machine in Gendorf could not be transferred back to Ludwigshafen, since Gendorf lay in the post-war American zone of occupation, while Ludwigshafen was located in the French zone. Immediate post-war Allied politics impeded intra-German trade across zones of occupation. Even the machinery in nearby Aschbach, also in the American zone, was not available to the BASF team, so they had to overcome post-war shortages by scrounging parts to rebuild the tape plant in Ludwigshafen.

The beginning of the 1950s saw the appearance in Germany of the first consumer tape recorders. Private consumption of tape was on the upswing, although the largest consumers of German-made magnetic tape were still the German and Allied Forces radio stations. Consumers needed tape that would play at speeds slower than 19 centimeters per second with acceptable quality. To meet the need, BASF developed a tape with increased sensitivity, Type LGH, the “H” standing for “hochempfindlich” or “high sensitivity”. With increasing sales of home recording decks, the consumer tape market rapidly eclipsed the professional tape segment in size.

Magnetic Tape Recording Worldwide

Practical magnetic recording, started by the Danish engineer Valdemar Poulsen in 1898 with his Telegraphone wire recorder, was about 40 years old at the

start of World War II, well after the Germans had adopted tape as their future professional recording standard. However, the technology was still in its infancy in the United States. Although DC-bias tape recording was known in the U.S.—AEG marketers had shown a K 3 machine to their colleagues at International General Electric Company in Schenectady, New York in 1937, with no result—magnetics had been largely ignored in America.

To a limited extent during World War II, the U.S. military used AC-bias wire recorders designed by Marvin Camras of the Armour Research Institute and S. J. Begun of the Brush Development Co., but strangely, no one on the U.S. side seemed to have heard of the high-fidelity German Magnetophon studio tape machine. The German technology was certainly no secret, having been featured in articles in popular German publications throughout the war, including the June, 1941, reviews in Berlin newspapers of the first public demonstration of the high-fidelity AC-bias machine. America did not enter the war until six months later, and was still maintaining a diplomatic station in Berlin—evidently staffed with people who did not care about recording technology! Even after the war ended, American and British occupation troops in Germany did little to exploit the technology, although their wartime and post-war intelligence missions included filing detailed official reports (named FIAT, BIOS, CIOS) on all aspects of German technical advances.

It took the initiative of a U.S. Army Signal Corps officer, Major John T. ("Jack") Mullin, to help get the advanced German recording technology to America. While working on radar and other electronics in England before the Allied invasion of Europe, Mullin occasionally listened to German classical music broadcasts from the RRG. An avid audiophile, he noticed the "live" quality of the continuous nocturnal broadcasts and assumed the Germans were using some sort of advanced recording apparatus for high-fidelity reproduction of sound. While based in Paris during and shortly after the war, Mullin led a team of engineers evaluating captured German equipment. The group became acquainted with the AEG K 4 and Tonschreiber DC-bias tape machines, as well as Magnetophon Type C and Type L tapes, but they still had not heard about the AC-bias studio decks in use throughout German radio. The Allies' mysterious ignorance of high-fidelity German tape recording was continuing!

The war ended in Europe on 8 May, 1945, and two months later Mullin visited Bad Nauheim, a "branch" radio station of Radio Frankfurt, and saw the AC-bias AEG/RRG Magnetophon studio machines in use. By that time, the entire RRG broadcasting apparatus had been turned over to the Allied occupation forces for transmissions in their languages, as well as programs for the German populace. Under Allied military supervision, the German technicians at the stations continued their normal routine of using tape recording throughout their broadcast day.

Mullin was so impressed by the audio performance of the AC-bias studio decks that he collected information on them, including schematic drawings and specifications, and immediately returned to his headquarters in Paris to file full reports to his Army superiors on the technology. Following strict U.S. Army protocol, he also obtained for his own use the parts for two K 4 Magnetophon transports to ship home to San Francisco, California. In Germany, the post office ran the telephone service. During the war, the "Reichspost" had used many K 4s like Mullin's machines as eavesdropping recorders to monitor domestic and diplomatic telephone calls. Mullin took only mechanical components—especially head stacks—as well as many reels of tape, material he knew he could not find in the States. An accomplished electrical engineer, Mullin knew he could recreate using American tubes the entire electronic assemblies for a successful tape recorder, also replacing the 220 V reel motors with 117 V types and exchanging the German asynchronous capstan motor to an US 60 Hz synchronous type. He also accumulated 50 reels of tape, mostly Type L, which remained the only professional tape in America until 1947, when 3M and others began making limited batches of coated tape that closely resembled Type LG: a gamma ferric oxide (γ-Fe_2O_3) formula.

Working with his partner Bill Palmer of W. A. Palmer Films in San Francisco in 1946, Mullin built two Magnetophons with American electronics. U.S. broadcasters and entertainment stars, including the ABC Radio Network and Bing Crosby, soon heard about the machine, as did a tiny electronics manufacturer in San Carlos, California, named Ampex Corporation. Ampex wanted to be the first in the U.S. to build professional tape recorders. With help from Jack Mullin and Bill Palmer, the little company succeeded.

Ironically, the American entry into tape recording—and the country's immediate dominance in the shattered post-war world economy—meant that the tape width and recording speed specifications established by the joint AEG-BASF team ten years earlier were changed forever. When Mullin and Palmer measured the tape width of 6.5 mm, they decided to assign a nominal width of a quarter inch, or 6.35 mm. The tape speed of 77 centimeters per second became 30 inches per second, nominally 76.2 cm/second. The differences were so negligible that the English measurements became the dominant world standard, even in Germany. The quarter-inch tape and 30 ips speed also became the standard measure on which most future audio, video, and data tape formats were based, from the audio "Compact Cassette" to two-inch audio multitrack and "quad" video tape.

Starting in 1948, dozens of American companies joined the race to build the best or the cheapest or the largest or the smallest professional and consumer tape recorders. 3M's "Scotch 111" audio tape brand became the world sales leader. The Americans made rapid progress in their research in and development of magnetic recording technology. BASF accepted the fact that 3M had made certain technical advances

in tape manufacturing by naming their 1953 consumer tape series “Magnetophon Tape Type LGS”. Only industry insiders knew the “S” designation meant “Scotch-compatible”, indicating the technical compatibility of Type LGS with the new 3M formulation being used on many consumer tape decks of the time.

Cellulose acetate tape such as Scotch 111, whose base film was almost identical to Type C tape, was widely used in America until well into the 1960s, when it was replaced with polyester. American broadcasters who used acetate tape for decades and who hear the story of the birth of German tape are surprised to learn that a plastic-based PVC tape was in use in Germany as early as 1943.

From its rebirth in America, magnetic recording spread rapidly around the world in radio broadcasting, consumer sales, professional and military data recording, including computers, and the motion picture industry. Since the post-war Allied Commission had invalidated most German patents and therefore the rights to royalties on their pre-war and wartime inventions, AEG, BASF, and Agfa received no immediate benefit from the tremendous worldwide growth of their inventions. Patents filed after the war by the German companies and by European newcomers such as Studer/Revox and Kudelski in Switzerland and EMI in Britain later re-established Europe as a place of magnetic recording innovation. Japanese companies also began to play an increasingly important role in post-war magnetics, especially video recording, with Sony Corporation’s entry into the field in the late 1940s, followed by Matsushita (Panasonic), Toshiba, and others.

The birth of the Magnetophon in Germany and the quick adoption of the technology in America led directly to the rapid and important advancements in videotape recording. While working for Bing Crosby, Jack Mullin invented the first prototype magnetic television recorder in 1950 using one-inch-wide tape with fixed heads. Ampex in 1956 introduced the world’s first practical videotape recorder, the VR-1000, which used two-inch tape and spinning heads. The machine used 3M’s new Scotch 179 video tape. Originally, the video technology was designed to time-delay programs to bridge the three-hour time difference between the U.S. East and West coasts. But almost immediately, magnetic video recording revolutionized the production methods in television studios worldwide.

Magnetic Recording— A Recording Medium with a Future

All of today’s video recorders and tapes are direct descendants of that first Ampex machine and 3M tape, which are, in turn, the offspring of the first AEG Magnetophon and BASF tape—as are all data tape recorders, computer floppy and hard disks, and the billions of consumer audio “Compact Cassettes” and cassette decks around the world. The decision of AEG and BASF/I.G. Farben in the 1930s to build high-quality audio recorders and tape—despite the worldwide economic depression—and the decision of the RRG to make the technology its recording standard, showed tremendous foresight. The success of tape recording, especially in the face of the total destruction of a world war and its grim aftermath, demonstrated the great engineering talent and sheer determination of all of the hardware and tape development teams working on the Magnetophon project.

Since about 1980, a wide variety of tape formats have been introduced, although as of 2006, many of these are also becoming obsolete. Tape is still used in video, especially for field acquisition.

Far from obsolete, linear tape technology lends itself to future uses where digital access time plays a less important role than storage and archive capability, for example in data archival storage. Tape’s incredible packing density will lead to innovative, cost-effective applications for storing vast amounts of data, continuing its success as a reliable archival medium. Magnetic tape will accompany us well into the 21st century.

About the authors

Friedrich Engel worked for more than two decades with the Application Engineering Department of BASF Magnetics GmbH, Ludwigshafen. His special interest in magnetic tape recording history led to some papers on selected subjects (Oberlin Smith and Walter Weber), of which this one is a preliminary version of a complete presentation of the story of magnetic sound recording.

Peter Hammar also has a strong interest in the history of entertainment technology. As a magnetic tape historian, he created and ran for many years the Ampex Museum of Magnetic Recording, in Redwood City, California. Hammar also did additional research and the English translation for this paper.

Conversions from the Metric to the English Measurement System

All figures are approximate
Official abbreviations:
millimeter ⇒ mm;
centimeter ⇒ cm;
meter ⇒ m;
kilometer ⇒ km;
meter per second ⇒ m/s;
centimeter per second ⇒ cm/s;
kilogramm ⇒ kg

page 2, At the end of the 1920s ...:
3 mm ⇒ 1/8 inch; 50 µm ⇒ 2 mil,
1.5 m/s ⇒ 5 feet/second;
9 kg ⇒ 18 pound; 60 cm ⇒ 23 ½ inch
The inventor glued ...:
16 mm ⇒ 2/3 inch
The BASF chemists decided ...:
30 µm ⇒ 1.2 mil; 20 µm ⇒ 0.8 mil (1 mil ⇒ 25.4 µm)

page 3, The enthusiastic report ..:
1350 Reichsmarks ⇒ 320 US$ (1935!)
Despite the relatively high cost ...:
28 m ⇒ 92 feet; 70 cm ⇒ 27 ½ inches;
65 cm ⇒ 25 ½ inches; 12 m ⇒ 39.3 feet;
In the final step of the tape-making...:
26 m ⇒ 85.1 feet;
6.5 mm ⇒ ¼ inch (exactly 0.256 inch);
30 µm ⇒ 1.2 mil; 20 µm ⇒ 0.8 mil;
400 m/min ⇒ 1300 feet/min

page 4, After AEG had built ...:
77 cm/s ⇒ 30.315 inches per second;
1.5 m/s ⇒ 59.06 inch/s
The German military ...:
9 cm/s ⇒ 3 ½ inches per second;
120 cm/s ⇒ 47. 2 inches per second

page 6, Plant Relocation ...:
50 m ⇒ 164 feet; 70 m ⇒ 230 feet

page 7, By the end of 1943 ...:
50 liter ⇒ roughly 12 gallons;
50 km ⇒ 31 miles; 1600 km ⇒ 1000 miles
AEG and BASF co-founded ...:
6.5 mm ⇒ ¼ inch (exactly 0.256 inch);
360 km ⇒ 225 mi
The beginning of the 1950s ...:
19 cm/s ⇒ 7 ½ inch per second

Sunday, 27. August 2006