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The Complete Handbook of Magnetic Recording

An all-in-one guidebook on modern magnetic recording theory, practice, applications, and maintenance!

by Finn Jorgensen

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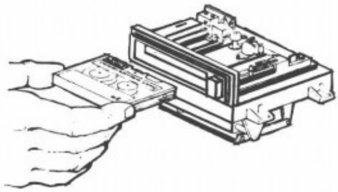


Preface

The *Complete Handbook of Magnetic Recording* is a textbook in Know-How and a reference that covers all aspects of magnetic recording. It is written for the technically inclined person working in the field and for the equipment user who wants to acquire an in-depth knowledge of magnetic recording and storage.

A brief history is presented in Chapter 1, followed by an introduction to recording equipment in Chapter 2. The book then falls into three main areas.

FUNDAMENTALS

The presentation of magnetism is novel in that it builds up the reader's understanding without popular explanations or gross simplifications. Rigorous mathematics have been left out and formulas are only included where they assist in understanding or in summarizing certain laws.

The four chapters cover fundamental and technical magnetization, the theory of recording and playback theory. This section is comparable to a photographers basic course in lights and optics, which gives him the foundation for understanding lenses and films; their magnetic counterparts are covered in depth in the following section.

HEADS, TAPES AND DISKS

Two chapters on magnetic heads and tapes cover virtually all aspects of theory, materials, fabrication and performance. A large number of references has been included so the interested readers can probe into subjects that are of particular interest for him.

Chapter 7 on magnetic heads is quite detailed. This was done to make the reader aware of the many parameters that have effect upon the final head performance. This should allow the designer and end-user to better evaluate and specify magnetic heads.

EQUIPMENT AND APPLICATION

The magnetic recording industry really took off in the 70's and is growing at an unprecedented pace. The acceptance of Philips' audio cassette around 1970 allowed tape recording to establish itself into a large percentage of homes and automobiles.

Then the computer business adopted the cassette and added the floppy disks, in addition to the established rigid disk files. This market is expanding at a rapid pace. And quite recently, in the late 70's, the home video recorder market opened up.

The last part therefore is devoted to a detail analysis of the recording theories, followed by a step-by-step analysis of equipment configurations and performances. Chapter 9 is devoted to direct digital recording. Chapter 10 is devoted to AC-bias recording. It is recommended that specialized readers study both chapters; interdisciplinary knowledge is the best breeding ground for innovation.

The limitations on signal accuracy in AC-bias recording are analyzed in chapter 11. The quality improving methods of Frequency Modulation recording (FM) and High Density Digital Recording (HDDR) are outlined in chapter 12. This chapter also includes several references on applications.

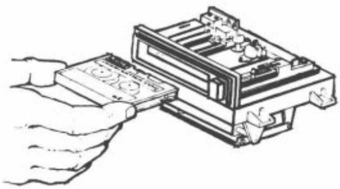
Optimum recording performance is only achieved when several practical rules are adhered to. These rules are discussed in chapter 13. The book concludes with Chapter 14 on maintenance and equipment troubleshooting.

The technical units in the book are MKS. The reader will notice a lack of consistency since the author in several places gave in to overwhelming common usage, such as Gauss rather than Wb/m^2 and Oersted instead of A/m. The net effect should hopefully minimize confusion and mistakes.

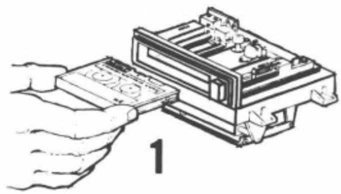
Several friends deserve thanks for their advice and help during the early preparation of the manuscript: Eric D. Daniel of Memorex Corporation, Cdmr. Steve S. Jauregui of the U. S. Naval Postgraduate School in Monterey, Len Johnson (formerly with Bell & Howell) and John McKnight of Magnetic Reference Laboratories.

And a sincere *Thank You* goes to the many students of my first courses in Magnetic Recording, where we used the manuscript of this book. Their comments and critique helped shape the entire volume, and my son Morten was of invaluable help in all final editing.

Finn Jorgensen



Contents



1

A Colorful History

The history of inventions and the developments of magnetic recording is a very human and fascinating story. It has all the facets of a true cloak-and-dagger tale. It is a story of the many hopes and dreams of men who met the challenges to not only create saleable products, but to advance the welfare of their fellow man as well.

We are indebted to them for their contributions to scientific advancement and better living conditions. All of us are now *in touch* with magnetic recording including television, homevideo, computers and best of all—music. This book would be incomplete without highlighting the history of magnetism, and one of its many aspects—magnetic recording.

EARLY HISTORY

Our recording technology is founded on magnetism and on electromagnetic induction. The earliest description of magnetism is obscure, but a mineral called magnetite, having the composition of Fe_3O_4, was known centuries before the birth of Christ. It would attract iron, and would also magnetize a piece of iron if it was rubbed against it.

The sailor's compass could be made from a properly shaped piece of magnetite, free to turn about a pivot. It would turn in the north-south direction and was named *lodestone*, which means "waystone" or "leading stone"—pointing the way. Another legend concerning the use of a lodestone depicts its use in defense (Fig. 1-1).

The first scientific study of magnetism was made by the Englishman William Gilbert, who published a classic book, *On the Magnet*. All his experiments had to be carried out using iron or steel samples that were rubbed with a lodestone.

Fig. 1-1. A typical legend about the lodestone, first permanent magnet known to man.

The great break-through came in 1820 when the Dane Hans Christian Oersted discovered that an electric current produces a magnetic field (Fig. 1-2). This very important discovery shortly led Ampere to the finding that two currents also have a mutual magnetic effect. And in 1831 Faraday discovered that a magnetic field conversely generates an electric voltage (Fig. 1-2).

THE TELEGRAPHONE

While Oersted had enjoyed triumphal progress, this did not quite happen for his countryman Valdemar Poulsen. His invention of the Telegraphone in August 1898 has indeed today spread into every home in the Western world, but the progress was by leaps and bounds and with numerous setbacks. During certain periods technology was lacking (wire, tape, ac-bias) and at other times manipulating business interests or national interest seemed to hold back universal progress.

Poulsen was received with great enthusiasm at the World Fair in Paris in 1900, where the Telegraphone won a Grand Prix. He described his invention as the outcome of a simple experiment where he stroked out a line along an iron plate and found that iron filings would gather along the line. The next experiment involved a strung-out piano wire and a primitive electromagnet connected to a microphone. Poulsen moved the electromagnet along the wire as he spoke into the microphone, and by later connecting the wires from the magnet to the telephone receiver he heard his voice reproduced, (Fig. 1-2). The electromagnet could be either single pole or double pole, as shown, and he later advised how the two poles should be offset to produce a longitudinal magnetization rather than perpendicular. Finally, Poulsen is also credited with applying a dc-current for improvement of the recording (see Chapter 5, dc-bias).

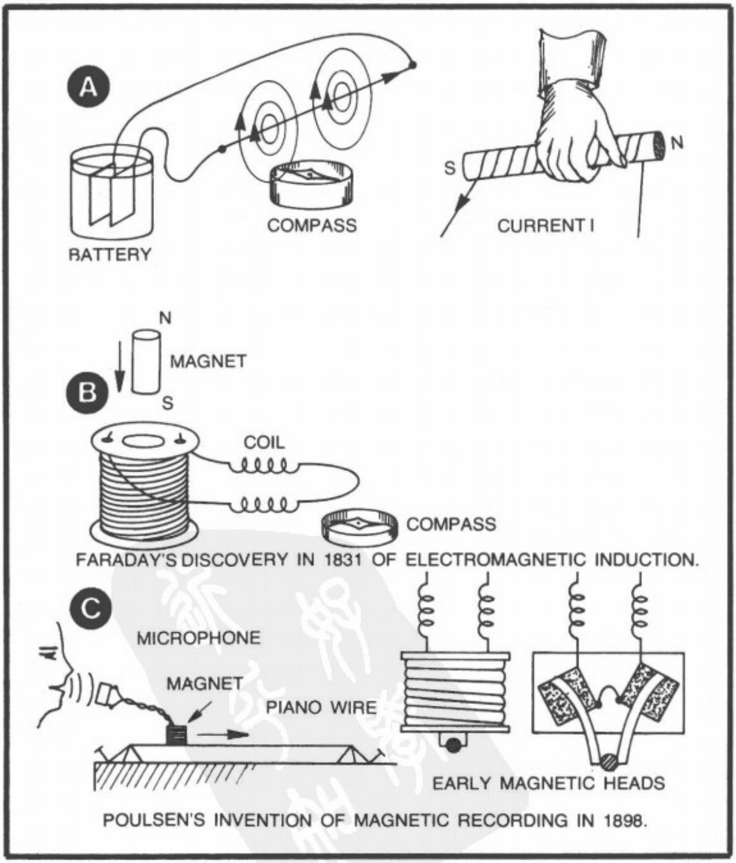


Fig. 1-2. Important electro-magnetic discoveries (A). Oersted's discovery of electromagnetism in 1820, and an early drawing showing the right-hand rule, (B). Faraday's discovery in 1831 of electromagnetic induction, (C). Poulsen's invention of magnetic recording in 1898.

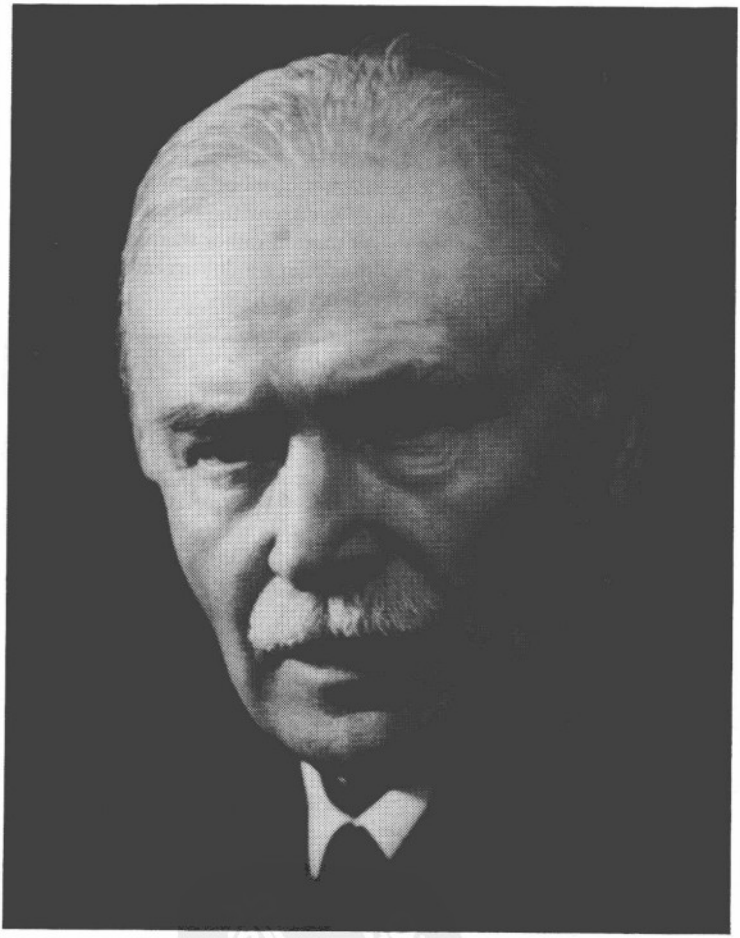


Fig. 1-3. Valdemar Poulsen, Danish inventer (1869-1942).

In 1902 Poulsen made another invention, described in his paper *System for Producing Continuous Electric Oscillations* (Fig. 1-3). This was a high power oscillator operating at 50,000 Hz (cycles per second, cps) which broke the way for worldwide wireless telegraphy and telephony (Fig. 1-4). This work soon absorbed all of Poulsen's time, and it is, in retrospect, a shame that just a little fraction of this 50,000 Hz oscillation did not stray over to the Telegraphone. Poulsen could then have added ac-bias to his patents!

The first decades in the twentieth century were tumultuous for the Telegraphone. Numerous companies were formed, and many varieties of the recorder promoted. There were dictating machines, message repeat-

ers, telephone answering machines, small disks w
and so on. But there was no technology to imprc
time. The invention and the associated ideas were clearly too early. So the companies struggled and either lost money or changed hands. Accusations were voiced against the American Telegraphone Company. People wondered if the president of the company paid to suppress production which the phonograph and the telephone companies feared? Or worse, was he or others in a pact with the Germans, who successfully used telegraphones onboard their submarines in World War II. The Germans had made message recordings at normal speed and then transmitted them backwards, at higher speed.

THE MAGNETOPHONE

Whatever the cause, leadership in magnetic recording went to the Germans. In the 20's they manufactured and sold recorders with steel tape and in 1928 a patent was filed for coating iron particles on a strip of paper as a recording medium.

In 1935 the German Magnetophone was exhibited in Berlin and made a hit because it used plastic tape instead of steel. But no more was heard of it until 1943.

At that time the U.S. Army Signal Corps, stationed in England, was puzzled over sometimes hearing radio broadcasts of operas and music during the middle of the night (noting no record scratches and other such deficiencies) and then hearing Hitler speaking from different parts of Germany almost within the hour.

The answer was found in 1945 in Frankfurt by one of their officers, John Mullin. He found in a radio station several A.E.G Magnetophones, all

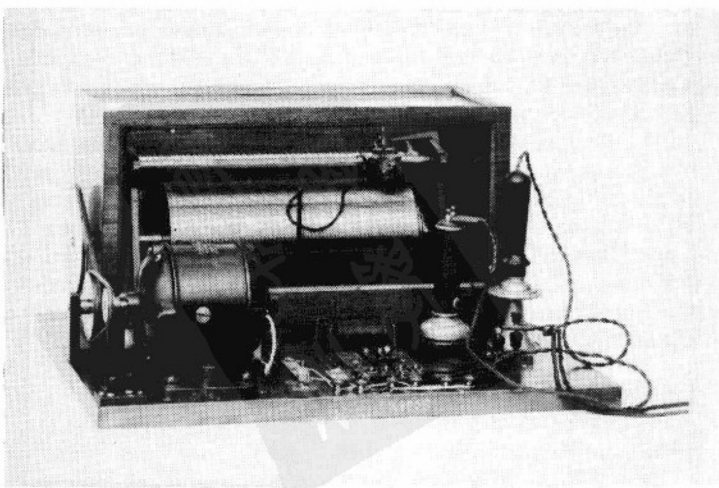


Fig. 1-4. Valdemar Poulsen's telegraphone, 1900.

equipped with ¼″ plastic tape, some of which later would serve for the Bing Crosby radio shows.

The sound quality was far better than any other machine in these days, and a close examination revealed that the Germans used high-frequency ac-bias. Chapter 5 will explain how it works—but it is today universally used in recorders. History will have it that W.L. Carlson and G.W. Carpenter of the U.S. Navy discovered and patented ac-bias in 1927, but it was obviously not used to any extent. The Magnetophone ac-bias patent was in 1946 granted in Germany (retroactive to 1940) to H.J. von Braunmuhl and Dr. W. Weber.

AFTER WORLD WAR II

The next three decades bring us through a rapid growth period with innovations, products, people, and companies too numerous to list in a few pages. The Minnesota Mining & Manufacturing Co. (3M Co.) finished their first oxide tapes in 1947, under Dr. W. Wetzel. Ampex, founded by Alexander M. Poniatoff, started delivering audio recorders in 1948; Mincom, a division of 3M Co., pushed the state-of-the-art in instrumentation recorders, and demonstrated television recording in 1951, followed by RCA in 1953.

Other early pioneers were Dr. Marvin Camras of Illinois Institute of Research (then Armour Research), Otto Kornei of Brush/Clevite, and S.J. Begun, who wrote the first book on magnetic recording. The result was an industry that flourished with a large selection of sound tape and sound film recorders.

The breakthrough in television came from Ampex where in 1955 Charles Ginsburg and Ray Dolby (father of today's Dolby System) unveiled the rotating head video recorder (the readers of this book are aware of the perfection this technique has achieved today). Instrumentation recording jumped ahead in 1961 when Wayne Johnson at Mincom conceived a tape drive virtually free of timing errors (low-TDE).

Industry standards were always needed to provide interchangeability of recorded tapes. Audio tapes experienced rapid developments from full track recorded tapes to 2, 4, and 8 track on ¼″ tape, and now 4 tracks on 0.150″ wide tape in cassettes. Such transitions could not have happened in an orderly fashion if it were not for the cooperative work of manufacturers and standard committees. There are today about 20 different standard groups and of these the following played a key role in the past 35 years of developments:

ANSI—American National Standards Institute
CCIR—International Radio Consultative Committee
IRIG—Interrange Instrumentation Group
NAB—National Association of Broadcasters
SMPTE—Society of Motion Picture and Television Engineers.

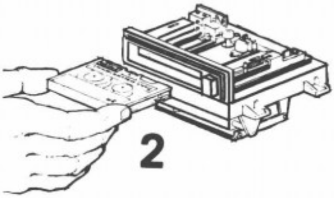
The most difficult standards to reach agreement on were those for the equalization of the recorder response. Thus, there are still several standards today for essentially the same thing (see Chapter 10).

And the next generation of recorders are already on their way, using digital encoding of the data, music or video. Studio recorders are now available that reproduce music without noise and flutter (see Chapter 12). They employ analog-to-digital converters, and the signal is recorded in its digital form. It is doubtful that this technique will be employed in home tape recorders due to its large consumption of tape. It is much more likely that the digital technique will be applied in disk recordings with prerecorded music or movies.

Magnetic recording is enjoying a steady growth in the field of computer storage. The pace setting leader in this field is IBM who since the 50's have introduced techniques that have become industry standards. The most interesting device is the *Diskette*, an 8″ or 5¼″ round disk for storage of digital data. It was introduced by IBM in 1970 as a time saving peripheral device with s storage capacity of a few hundred kilobytes. This number fits the requirements of a large number of small business and large home computers. The Diskette, or ***Floppy***, market is therefore enjoying a fast growth with about one million disk drives manufactured in 1979.

An entire book could be written about the evolution of the magnetic recording industry, its people and the chain of developments. It would be most interesting reading. And this chapter is well concluded with a saying an old friend of mine has about us in the industry:

"It is not really a business—it's a Way of Life."



Introduction To Modern Recording Equipment

Magnetic recording has come to play a major role in our modern society. Speech, music, measurement data, bookkeeping, computations, and live pictures are currently recorded, stored, and replayed on magnetic tapes or disks.

The success of magnetic recording is found in its convenience of use, low cost, and reusability of the media. It is quite paradoxical, however, that many tapes are recorded only once. When the voice of a family member or a distant friend is heard, or a favorite music number finally recorded, one is quite hesitant to erase it. This also applies in the recording of scientific data where the tapes normally are stored in libraries.

The *principles of magnetic recording* are based on the physics of magnetism, a phenomenon which relates to certain materials,; magnetization of these occurs when they are placed in a magnetic field. If the material is in the group of so-called "hard" magnetic materials, it will hold its magnetization after it has been moved away from the exciting field.

Figure 2-1 is a simplified diagram of a sound recorder. An incoming sound wave is picked up by a microphone (1) and amplified (2) into a recording current, I_r (3), which flows through the winding in the record head. The record head has a "soft" magnetic core (so magnetization is not retained) with an air gap in front. The current, I_r, produces magnetic field lines that diverge from the air gap (4) and penetrate the tape, moving past the record head from the supply reel (5). The tape itself is a plastic ribbon coated with a "hard" magnetic material which retains its magnetization after it has passed through the field from the record head gap.

The tape passes over the playback head which, like the record head, is a ring core with a front gap. The magnetic field lines (flux) from the

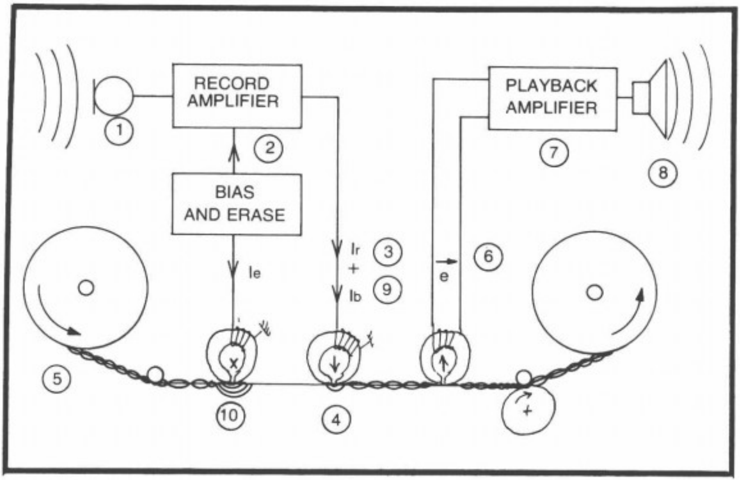


Fig. 2-1. Block diagram of a sound recorder.

recorded tape permeate the core and produce an induced voltage, e (6), across the winding. This voltage, after suitable amplification (7), reproduces the original sound through a speaker (8).

This fundamental record and playback process is limited by a poor fidelity in music and data recording. It is used only in *computer* applications, where the criteria for performance is the presence or absence of a signal. In *high-fidelity* music recordings and in *instrumentation* recordings, an additional *bias* current, I_b (9), is added to the record current flowing through the record head winding. The bias is a high frequency current that provides a great improvement in recording fidelity and a simultaneous reduction of background noise.

Figure 2-1 also illustrates the components that are found in all recorders:

- *Magnetic heads* for recording (write) and playback (read); these functions may be served by a combination record/play (write/read) head.
- A magnetic head for erasure of any signal previously recorded on the tape. This erase head is an optional feature that mainly is used in audio and television recorders. Old information is in computer recorders generally over-written by a strong recording field. Instrumentation tapes are bulk degaussed.
- A *transport mechanism* for moving the media (tape or disk) past the magnetic heads at a uniform speed. Reeling mechanisms or motors are required for providing smooth supply and takeup of tape.
- *Record and playback amplifiers* for processing of signals to and from the magnetic heads.
- *Control logic circuitry* for start, stop and fast winding of tape.

- *Power supply assemblies* for the transport motors, solenoids and relays, and for the amplifiers and control logic.

The *media* is currently not just ¼″ sound recording tape but are tapes in various grades and widths, magnetic stripes on film and cards, rigid disks and flexible disks ("floppies").

Each recorder application and its media configuration dictate how that recorder is configured. Anyone familiar with recording equipment is aware of the large variety of equipment designs.

The matter of selecting, specifying, using or designing a piece of recording equipment will therefore involve tradeoff decisions.

These decisions will be better, and easier to make, if the person involved has a good knowledge of magnetic recording.

It is not possible to provide a survey of various recorders and data storage files within the bounds of a reasonably sized book. So, in this book, there is no detail treatment of conventional amplifier circuits, control logics, power supplies, overall packaging and the many possible operational features.

The main theme is the nature of magnetism, recording (write), playback (read) and the performance of magnetic heads and media, in a variety of applications. Of prime concern is that the playback signal is a faithful reproduction of the input signal of the recorder. The second concern is the achievement of the highest possible packing density on the media which provides the minimum storage volume (length of tape or size/number of disks).

The original (and basic) *audio recorder* is a good example to illustrate the signal record/reproduce process in further detail. (Later chapters will deal with instrumentation, video, film, computer storage, coding and modulation techniques).

FREQUENCY RESPONSE AND NOISE

When the magnetic tape leaves the record head, it has a permanent magnetic record of the sound or data signal, with flux lines extending from the surface (Fig. 2-2). These flux lines pass in sequence through the reproduce-head core and induce a voltage, e, which after amplification reproduces the original signal. The number of flux lines is proportional to the recorded signal strength and their duration is inversely proportional to the recorded frequency. Their duration represents a certain *wavelength* on the tape and can be expressed as:

$$\text{Wavelength } \lambda = \frac{\text{Tape speed v}}{\text{Frequency f}}$$

It is a general practice to run tape at slow speeds to reduce the quantity of tape needed and to design magnetic heads and tapes for good short wavelength performance. If a high-frequency response of 15 kHz is desired, as in the reproduction of high-fidelity music, the wavelength should be as