CRITERIA FOR THE SELECTION OF AUDIO TAPES FOR ANALOG AND DIGITAL RECORDING ACCORDING TO THEIR DROP-OUT CHARACTERISTIC

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ABSTRACT

The paper describes and interpretes some results of drop-out measurements on several recorder types with different signal processing (AC biased and FM), different tape drive and/or loading systems (open reel and cassette) and various tape material technologies (conventional, chromium and metal evaporated tapes). Mechanical and visual control (through an optical and a scanning electron microscope) of the surface of the tested tapes are added. In the field of the analog audio recording the tests were performed on a sophisticated audio drop-out measurement system. That gives the ability to draw a drop-out histogram and a three-dimensional plot of the tested audio recording system showing drop-out occurrence over length and depth of of the drop-out.

In a similar way, for digital audio recording on consumer VTRs, especially on VCR, the full drop-out statistics (of the video signal path) for strongly used and brandnew tapes was measured and plotted for different systems and types of VTRs. In addition an equivalent circuit for a drop-out model on VTRs is given.

These tests offer the ability to provide additional tape selection criteria considering the effect of length, depth and frequency of occurrence of drop-outs to the recorded information (analog and digital audio signals) and, on the other hand, a useful tool to define the end of the life time (with objective limits) for the tape material in use.

1. INTRODUCTION

Modern technologies in manufacturing of audiotapes have considerably reduced recording errors caused by drop-outs. Nevertheless efforts are made to measure, classify and interprete drop-outs to enable the selection of the appropriate tape. High quality audio recording is increasingly performed on the digital region (using rotating head or stationary head machines). Exact knowledge of the drop-out performance of the tape can help to reduce or simplify error correction circuits and minimize redundancy on the tape.

Drop-out characteristics depend widely on various parameters like type of tape (manufacturing technology), area of tape where the measurements are made (e.g. begin or end of a cassette, tracks in the middle or near the rim of the tape), mechanical construction details of the recorders (especially the shape of the head) and long time behaviour of the tape (tapes of different technologies show different wear which results in a variable drop-out frequency of occurrence over abrasion function. The basic theory and the principal definitions of drop-out phenomena are described in appendix A1. The used drop-out measurement-system and the applied routines are shown in appendix A2.

2. TAPE WEAR MECHANISM.

2.1. Principles

For long time aspects the tape quality decreases normally with the time of use. Various parameters contribute to a steady reduction in reliability until a predefined limit is reached where the tape can be considered as worn out.
The parameters include abrasion by the magnetic heads and the tape transportation system of the recorder as well as mechanical and chemical stresses. The higher the head to tape speed, the stronger the tape wear.

2.2. Abrasion phenomena

Magnetic tape recording techniques currently in use require a contact as tight as possible between the tape and the magnetizing head. This results in a constant mechanical interaction and must lead to changes of the surface structure of the 'softer' partner involved. The amount of wear caused by this grinding procedure depends on the material of tape and magnetic head, on the compression and the head to tape speed.

2.2.1 Analog Audio Tape Recorders

Analog audio recording systems consist of a stationary record and playback head and a magnetic tape that is pulled across the magnetic gap of the head with a relatively slow speed. Therefore tape abrasion occurs right at the head/tape area and along the band guiding parts of recorder and cassette or reel. The mechanical interaction of head and tape is strongly determined by the shape of the head and the effectiv angle of wrap (arc of contact) from the tape around the head. Usually a compromise has to be found between the reproduction quality (low short-time amplitude variation and good high frequency performance) and the head wear. Some manufacturers try to avoid these problems by implementing extremely hard ferrite heads with glass passivation for low friction, but the important drawback is a decreased magnetic behaviour of the head. Counter measures against excessive tape abrasion in the magnetic head area are done on the head itself (hyperbolic shape along the contact zone, milled grooves at the tape edges, extensive polishing of the head surface). The tape surface is prepared for very low friction losses with special coating materials that enable smooth gliding.
The band transportation and guiding parts of the recorder are polished to a certain level of granulation. In addition, if a cassette system is used, the tape has to pass some low cost synthetic material provided for wow and flutter reduction and proper winding on the internal core. To keep production costs low

these parts sometimes don't show suitable surface treatment. As a consequence, tape abrasion is strongly influenced by the mechanical performance of recorder and cassette. (Open reel analog audio recorders naturally don't have to deal with cassette problems. Nevertheless, improper adjustment of the transportation system around the reels, or reels of poor quality (excentric alignment) can damage the edge of the tape and result in insufficient reproduction of the tracks near the rim on multitrack recording because of very long drop-outs, audible as level loss especially at high frequencies).

Drop outs found on analog tape recorders are - as far as they are caused by abrasion - a result of microscopic damages evolving from the motion of the tape rectangular to the gap of the magnetic head. So the shape of defects on the tape will be oriented mainly parallel to the transportation direction as grooves of quite different lengths (fig.2.1a) and distributed in a more or less statistical manner all over the width of the tape, usually with increased concentration at the edge of the tape. As can be seen from fig.2.1, some of these grooves and holes are comparable in size with the gap width of magnetic audio heads (a few microns). Therefore it can be assumed that there will be a substantial loss of amplitude of the recorded signal if the number of such drop-outs along the head gap exceeds a certain value. The graph that shows the functional connection between the head to tape distance and the amplitude loss can be found in A1.

2.2.2 Video cassette recorder

In a VCR there are two combined motions that may contribute to tape wear:
First there is the motion of the video heads caused by the rotation of the moving part of the head drum. The tape is wrapped around the head drum with an angle of a little more than 180 degrees up to 330 degrees, and the video head crosses the tape

along the contact area with an angle between 5 and 10 degrees to the tape edge, and a head to tape speed between 3 and 7 m/s (depending on the recording system, s. tab.1). The head to tape speed is much higher than the speed of analog audio recorders. The contact zone of head and tape is much smaller because of the narrow track width, s. tab.1. In contrary to analog audio recording, the physical dimensions of the magnetic video-head is small compared with the tape. The head is intentionally pressed into the tape (10 to 50 microns) and creates a small tape convexity at the location of contact.

Recording scheme (TV standard)	Video-track width	Head to tape speed	tape speed
N T S C			
U-matic	85 um	8.54 m/s	9.53 cm/s
VHS I	58 um	5.81 m/s	3.33 cm/s
VHS II	28.8 um	5.83 m/s	1.67 cm/s
VHS III	19.3 um	5.85 m/s	1.12 cm/s
Betamax I	58.5 um	6.98 m/s	4.00 cm/s
Betamax II	29.2 um	7.00 m/s	2.00 cm/s
Betamax III	19.4 um	7.01 m/s	1.33 cm/s
V 2000	17.9 um	6.10 m/s	2.33 cm/s
Video 8	20.5 um	3.75 m/s	1.44 cm/s
P A L			
VHS	49 um	4.85 m/s	2.34 cm/s
Betamax	32.8 um	5.83 m/s	1.87 cm/s
Video 2000	22.6 um	5.08 m/s	2.44 cm/s
V 2000 2x8 Nor.	17 um	5.08 m/s	2.44 cm/s
V 2000 2x8 LP	11.3 um	5.08 m/s	1.22 cm/s
Video 8	34.4 um	3.14 m/s	2.00 cm/s

Tab. 1 Parameters of typical VCR recording schemes depending on the used TV standard, for NTSC and PAL.

The recorder manufacturer, when determining the position of the head relative to the tape guiding surface of the head drum, usually chooses a compromise between good tape/head contact with rather few drop-outs (at least when using a new tape) and a tolerable wear of the tape.
Recording and playback cause a constant polishing of tape and head surface. This is partly intention, the video heads need a certain amount of cleaning during operation.

The tape transportation system is the second important factor causing abrasion (see fig 2.1b). The tape is pulled over numerous guiding wheels (turning) and axes (fixed) forming several loops with positive and negative curvature, and glides through the guiding groove of the head drum (fig.2.2). These parts are touched over the full width of the tape and passed with relatively slow speed (tab.1). Therefore, the number and distribution of drop-outs caused by the tape transport system during record and playback should be comparable to analog audio tape recording (the tape speed is slower but there are more and larger contact zones). Some of the guiding parts are still in contact with the tape during fast winding mode, depending on the system. In addition, the transition from the record/playback mode to the fast winding mode is performed by removing or adding guiding levers which put the tape to the desired position for the next operation. Both procedures are essentially destructive for the tape surface. Especially the transition was found to be excessively degrading the surface quality. Fig.2.4 shows a three-dimensional plot with the frequency of occurrence of drop-outs as a function of playback time and length of drop-out. The figure applies for drop- outs equal to or deeper than -16 dB and shows a 300 second intervall of a commonly available video tape that was played repeatedly on the same section including rewinding to the start position. A brandnew recorder was used. About 0,3 m of tape is pulled out of the cassette and guided in a loop around the various levers and around the head drum. This part equals a playback time of approx. 12 s.

As can be seen from fig.2.4, the first and the last few seconds of the plotted 300 s intervall show an increasing amount of drop-outs. This is a result of repeated playback and rewind mode with a mechanical transition between two different configurations of the transportation system. This damage of the tape can be detected by the drop-out counter after just a few (5 to 10) changes of the mode and becomes visible (i.e. the built in drop-out compensation circuits of the recorder fail to replace the destroyed lines) after 10 to 20 transitions. All depths of drop-outs are affected, as shown in fig.2.3 to fig.2.6. The drastically increased number of dropouts can be considered as a worst case. Nevertheless, for digital audio recording using PCM converters and VTR all contemplations about optimal coding (error correction, redundancy a.s.o.) must be based on it.

2.3. Tape coating

Tape manufacturing has substantially changed over the last decade. Not only the magnetic parameters were improved by using new materials, also mechanical factors like smoothness of the surface, stability of the carrier material against stretching and temperature influences show significant better values. Fig.2.7 to 2.9 are photos made on a scanning electron microscope and show the surface of three different audio tapes. Tape A (fig.2.7) was manufactured in the early seventies. The granulation is comparatively high, the size of the largest objects ('hills' and 'valleys') is obviously in the magnitude of a few microns, which is exactly the wavelength of the highest audio frequencies on the tape. Tape B stems from the late seventies and offers already visible improvements (fig.2.8). The basic structure is much finer than on tape A, though there are some holes left which probably are a result of excessive use of the tape. The holes are oriented in one preferred direction. It can be assumed that it is the transportation direction of the tape. Fig.2.9 (tape C) is quite similar to fig.2.8 but granulation and holes are further reduced. The tape was manufactured in 1983. Still there are some grooves left caused by the transport system.

Though it is surely not only the surface quality that determines the drop-out rate, there is at least a certain influence to it. Fig.2.10 to 2.12 show three-dimensional plots for tape A,B and C. The improvements concerning drop-outs can easily be seen. The average reduction by a factor of about ten is obvious though the logarithmic scale compresses the difference.

The scanning electron microscope had a magnification of about 8000, the equivalent length of 1 micron can be found in the center of the bottom of the picture.

Fig.2.13, 2.14 and 2.15 (tape A,B and C) give an example of a mechanical sampling of the surface, performed by a mechanical profilometer. Naturally, the resolution of the instrument is limited by the stylus tip radius similar to the magnetic pickup of a turntable. Nevertheless, significant differences in surface granulation (as long as the size of the structures exceeds the diameter of the stylus tip) can be detected. The velocity of the stylus was 1 mm/min, the speed of the pen was 10 cm/min, and the vertical resolution was 0.2 micron/div.

The results are in good conformity with the SEM-photos fig.2.7, 2.8 and 2.9, with the restriction that the stylus couldn't completely make out the difference between the tapes B and C because the stylus tip radius is much larger than the average granulation.

Fig.2.16, 2.17 and 2.18 show again tape A,B and C but, in contrary to fig 2.13 to 2.15 (which show the surface as a cross section rectangular to the tape transport direction), the movement of the needle was parallel to the tape transport. A slight increase of roughness can be observed. This seems to be somewhat surprising. One would rather expect more variations rectangular to the direction of tape transport when the measuring stylus crosses the grooves caused by abrasion.

APPENDIX

A1. DROP-OUT THEORY

A1.1 Drop-out definition

A drop-out is normally defined as a signal level loss (compared to the undistorted signal level) of the reproduced signal. The definitions differ according to the application field. The (subjective) dop-out annoyance depends on the depth, duration and repetition rate of the drop-out. Especially the IEC drop-out definition requires a significant momentary reduction of the reproduced signal level (IEV 806-05-64). This definition causes a very coarse drop-out classification raster for the consideration of a tape according to its drop-out behavior. In general drop-outs can be classified in permanent and temporary drop-outs.

A permanent drop-out is a fixed located damage or impurity of the magnetic layer of the tape. A permanent drop-out can be a consequence of the manufacturing process (coating process), improper handling of the tape (bending, cutting or splicing) and mechanical damaging caused by the tape transportation system (e.g. tape loading mechanism at consumer VCRs). A permanent drop-out can be considered as irreversible. A repair of the tape can only be realized by removing the tape area with the drop-out (cutting and splicing the tape). This kind of drop-out can be detected by the incoming test of a tape.

A temporary drop-out is primarely defined by the variable tape to head contact caused by dust particle, finger prints, longitudinal tape oscillations and other defects resulting in an additional head to tape spacing. A temporary drop-out can occur during the recording process as well as during the playback process. It will change its magnitude of signal level loss and its location on the tape by each recording and playback process.

The typical three-dimensional plot of a permanent drop-out of a strongly used VCR tape is shown in fig. A1.1. The plot shows a relatively high "ground floor" of drop-outs, caused by the large number of run-throughs of the tape. Fig. A1.2 shows the same area of the tape, but 30 run-throughs later, in addition the reference level is 4 dB lower. The tape transport mechanism was always started at the same tape position (within a time tolerance of less than 1 s corresponding to a local tolerance of less than 1 cm in the tape transport direction). One can observe that the number of occurences of the area without the permanent drop-out increases. At the location of contact of the tape with the loading mechanism, additional permanent drop-outs will occur (caused by mechanical stresses and damages by the tape guiding system), easily observable by the increase of longer dropouts around the 50 s time mark in fig. A1.3.

The test signal for the measurement of drop-out statistics is normally a sinewave (used at both recording principles: AC biased- for audio recording and FM-recording for VTR) with constant signal level. The detection of the drop-out includes, according to the drop-out definition, a specified (or greater than specified) level loss, normally measured in dB (drop-out depth), during a specified time (dropout duration). The number of occurences of the drop-out (its inverse value defines the repetition rate) depends on the measuring time period.

The reference level for the detection of drop-outs at the playback process is normally the average value of the reproduced signal. This includes also the possibility of the occurence of a drop-in, caused by a playback voltage higher than the nominal (average) value of the tape (e.g. caused by an excessive concentration of magnetic particles in the active layer, or a better than average head to tape contact within a limited area of the tape).

For both recording principles there exists a different sensitivity on the influence of drop-out for the audibility /B14,B20,C10, C11,K17,S20/ or the visibility /B15,H15,M9,M25,S21,S60,W12/ of the drop-out in the reproduced signal.

The recording of video signals follows the time multiplex structure (pixel by pixel and line by line but with interlacing) of the picture scanning defined by the television standard.

The signal path of a video tape recorder (VTR) is optimized to record and playback a picture signal. This type of signal (the picture information) includes a lot of redundancy, because it is relatively insensitive to drop-out phenomena caused by the magnetic recording channel. The drop-out compensation for video signals is relatively simple: replacing the distorted line by the previous one.

If a digital audio signal is recorded as a pseudo video signal, (as commonly used with PCM adaptors) one must bear in mind that the signal structure of the audio signal (with respect to its redundancy) is completely different from a video signal. The error correcting code must be adapted to the drop-out distribution and the internal drop-out compensator of the VTR should be deactivated not to disturb the error correcting mechanism of the code.

The difference between a studio VTR and a consumer VTR (VCR) is found primarely in the video bandwidth (the resolution of a consumer VTR is lower), in the time base error (the time structure of the consumer VTR playback signal includes - in the worst case - a timing error, related to the vertical sync pulse, of approximately 50 to 100 us), in the editing features (the editing of a video signal can only be done elèctronically, with only a few editing modes using a consumer VTR) and in the tolerances and the MTBF of the mechanical parts.

For longitudinal digital audio recording serious drop-out problems are existing, too /T10,S28,V8,B19,C13,H21,M9,S19,04/. Mainly the parameters of the error correcting code must be defined by the drop-out statistics of the combination of tape and transportation system.

A1.2 The playback process

Nearly all drop-out theories base on the signal level of the playback process /P26,M21,H21,A7,A8,E5/. The reproduced signal level can be written with a few simplifications (eg neglecting inhomogenities inside of the magnetic layer) according to /W10, V7,D12,M9,H22/ with GF as gap-function, DF as distance- function and TF as thickness-function:

$$U_{pb} = U_o \cdot GF \cdot DF \cdot TF \qquad (A1.1)$$

$$GF = \frac{\sin (gw/\lambda_{eff})}{gw/\lambda_{eff}} \qquad (A1.2)$$

$$DF = \exp(- d/\lambda_{eff}) \qquad (A1.3)$$

$$TF = 1 - \exp(- a/\lambda_{eff}) \qquad (A1.4)$$

In these equations 'gw' represents the effective gap width, 'λ_{eff}' the wavelength on the storage medium, 'd' the distance between the tape and the head surface and 'a' the thickness of the magnetic layer.

This set of equations can applied for drop-out phenomena. But (A1.3) is only valid, if d covers the full width of the track under test. If not the full width of the track is lifte , another model (the tent model in its original version /K17,S19/, or in its modified version /A8,S17/) must be used.

The distance-function DF according to (A1.3) is shown in fig. A1.4. According to the results of /P26/ for the AC biased recording, for short wavelengths the distance-function DF (A1.3), for long wavelengths of the recorded signal the thickness-function TF (A1.4) is the dominating term for the drop-out influence on the reproduced signal.

The typical signal shape of a sinusoidal signal with the influence of a drop-out is shown in fig. A1.5.

Based on the distance-function, the dominant drop-out mechanism for video recording on consumer VTRs, a relatively simple equivalent circuit can be given for drop-out influence on digital audio signals recorded as pseudo video signals. The bits of the audio data word are concentrated to blocks of data. Within the recording path this signal is converted (caused by the frequency modulation) to a FSK signal. Normally a FSK signal will not be disturbed by a loss of its amplitude, as long as its internal demodulator can detect the zero crossing of the signal. But the consumer VTR uses only the first sideband of the FM, this causes a strong influence of AM on the FM path. A drop out becomes frequency dependent and in the equivalent circuit it is a capacitor with a frequency dependent value.

A2. DROP-OUT MEASURING INSTRUMENTS

Two different drop-out test instruments were used. Their test procedures differ slightly and are described in the following.

A2.1 Audio drop-out counter

The audio drop-out counter used for the test procedures was a microprocessor controlled measurement system (a prototype, based on previous work /P35, S17/), designed at the Technical University in Vienna, Institut fuer Allgemeine Elektrotechnik und Elektronik.

The test procedure is quite simple, especially if a recorder with separate record and playback head is available, otherwise two runs are necessary, the first for the recording-, the second for the playback-process. The measurement system avoids time errors caused by wow and flutter phenomena.

A sine test signal with a frequency preferably in the upper part of the audio frequency spectrum is recorded and immediately controlled through the playback head which is connected to the dropout test instrument. The measuring period is set as a multiple of one period of the test signal (from 1000 up to 20 million cycles), to eliminate the wow and flutter influence on the number of recorded signal periods. This influence is negligible if a very large number of signal periods is evaluated, but this measurement method is advantageous if (to obtain a short measurement time) only a few thousand of periods are used.

The test procedure is completed either when the measuring intervall is over, or when an overflow occurs on one of the counters of the test system. The test results can now be displayed on CRT or printed as a matrix (tab.A2.1) or bar diagram (fig.A2.1), both available in two different configurations. The counted dropouts can either be presented as groups which include all drop-outs of a certain depth and an exactly defined length, or as groups containing drop-outs with equal depth and a length equal to or larger than a defined length. In any case, drop-outs with a defined depth include all 'deeper' ones. All classes of drop-outs are registrated in parallel at the same time. The range of the instrument includes depths from -1dB to -28dB in accordance to the requirements of audio signals, and lengths from 1 to 10^4 cycles of the test frequency. The output of the system can be fe d into a simple personal computer, to obtain (after computing and smoothing) three dimensional plots of the drop-out data (fig. A2.2a), the full drop-out distribution, or both in a single plot (fig. A2.2b).

The coupling of the drop-out length and the frequency of the test signal protects the results from being distorted by wow and flutter of the recorder.

A block diagram of the audio drop-out test instrument is shown in fig.A2.3. The detailed design principle of the classifier stages and the preprocessor can be found in /S17/, the processor is shown in /P35/.

A2.2 Video drop-out counter

The video drop-out counter was a commercially available instrument intended for testing professional video recording equipment at recording or broadcasting studios (Shiba Soku VH01BZ).

It also enables to categorize into width and depth, but can only count drop-outs of two different width simultaneously. The handling is comfortable because the results can immediately be fed into a computer over the GP-IB if the interface card is available, or displayed through a built-in printer. The range for depth and width of the counted drop-outs are adapted for video, therefore the width is registrated between 0.5 and 50 us and the depth between 10 and 24 dB. The measuring time unit can be chosen between 10, 30 or 60 s or randomly by an external pulse generator. A special circuit allows the exact positioning of start and stop of the counting period between the vertical sync pulses. So the counter can be adapted to all recording systems, and errors caused by the spikes during the transition from one video head to the other are avoided.

The drop-out data are feed into a personal computer, similar to the audio measurement system and processed in the same manner.

In addition to the drop-out distribution, the actual position of the drop-out within a television line or the position within a television field can give additional information about the cause of the drop-out. A damage of the magnetic layer, caused by the tape guiding mechanism normally results in a 'valley' parallel to the mechanical edge of the tape. This defect results in signal level losses located in the same area of the tape. The helical recording scheme defines a linear recording of a field (half a frame) line by line. Consequently lines with the same number are found adjacent (separated by the lines of the other interlaced field) to each other on the tape within an area located in a constant distance of the tape-edge. Therefore the sequence of corresponding lines is oriented in the tape transport direction, and if a mechanical damage of the magnetic layer occurs, a relatively limited number of lines in a sequence (from each field nearly the same line-numbers) are destroyed. The result is a distorted area of the TV-screen or the shape of the FM envelope when regarded through a scope (a few adjacent lines display just noise). If the mechanically caused drop-outs are relatively deep, this phenomenon also changes the drop-out statistics giving multiples of the field (vertical deflection) frequency as an additional component to the sum of drop-outs. This gives the ability to detect scratches through a continuous measurement of the short time drop-out statistics of the tape.

For digital audio there are significant consequences for the interleaving process of the error correction code. The digital audio data stream inserted in the television signal is destroyed at the same location of the frame. Interleaving routines must take into account these restrictions and disperse corresponding data structures over the whole frame.

A2.3 Selection criteria

The selection criteria depend on the kind of test: incoming test or a wear test of a tape.
The tapes currently available are normally tested by the manufacturer and must be tested only for the release procedure by the user.

Referring to the described dropout test procedures two simple selection criteria are applicable:
Using the drop-out matrix according to tab. A2.1 three limits in this table can be defined: A maximum depth, a maximum length and an intermediate area between these two limits according to a linear limit (straight line) or to a hyperbolic limit (curve that defines a constant product of length and depth).
Using a three dimensional plot according to fig.2.12, the limits exist as (simplified) linear boundaries within each parameter. These limits are represented in the 3D plot as a pyramid with a triangle base.

All drop-out statistic values (≥ 0) outside of these limits define a tape of inacceptable quality.

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/W12/ Waechter D.: Einrichtung zur Erfassung der Dropout-Stellen auf Video-Magnetbändern. RTM Vol 5 1961 p 295-296

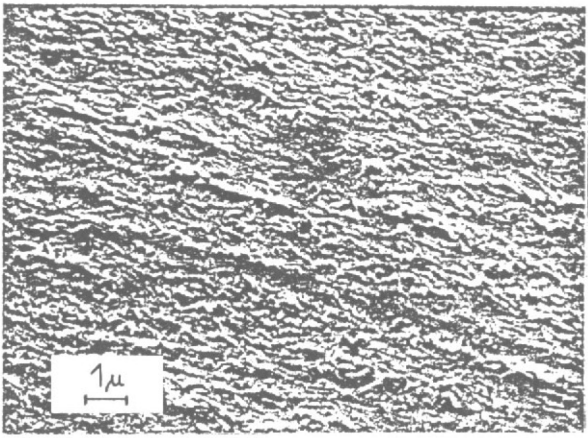

FIG.2.1.A SURFACE OF A MODERATELY USED AUDIO TAPE (MEDIUM QUALITY)

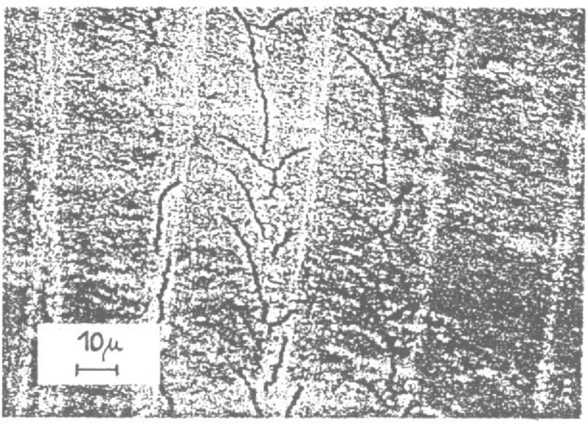

FIG.2.1.B VIDEO HEAD TRACKS CAUSED BY EXCESSIVE USE OF THE TAPE

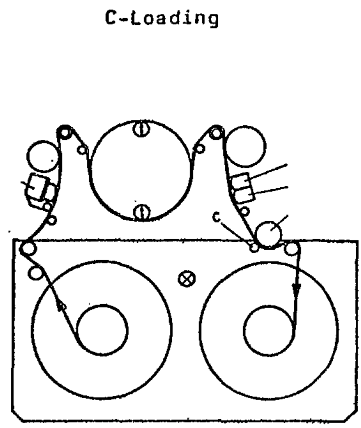

FIG.2.2 TAPE TRANSPORTATION SYSTEM OF A VIDEO CASSETTE RECORDER

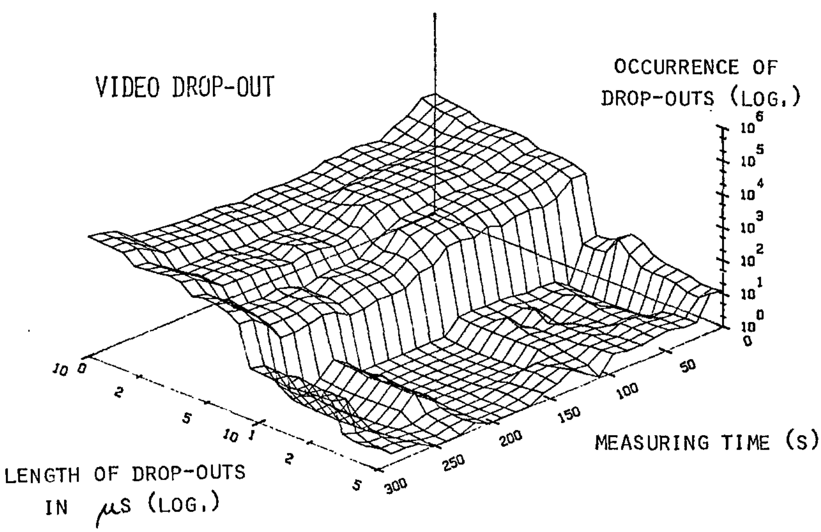

FIG.2.3 3-D PLOT OF DROP-OUTS OVER A 300 SEC INTERVALL (DEPTH ≥ -10DB)

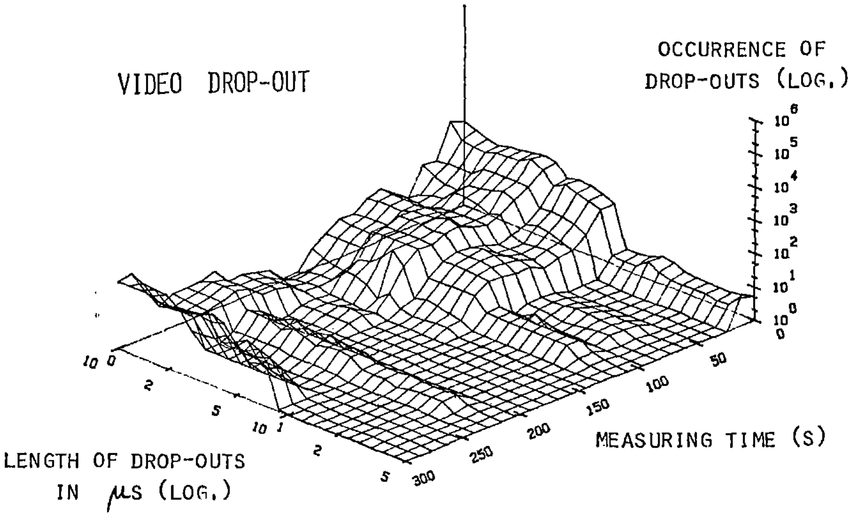

FIG.2.4 3-D PLOT OF DROP-OUTS OVER A 300 SEC INTERVALL (DEPTH ≥ -16DB)

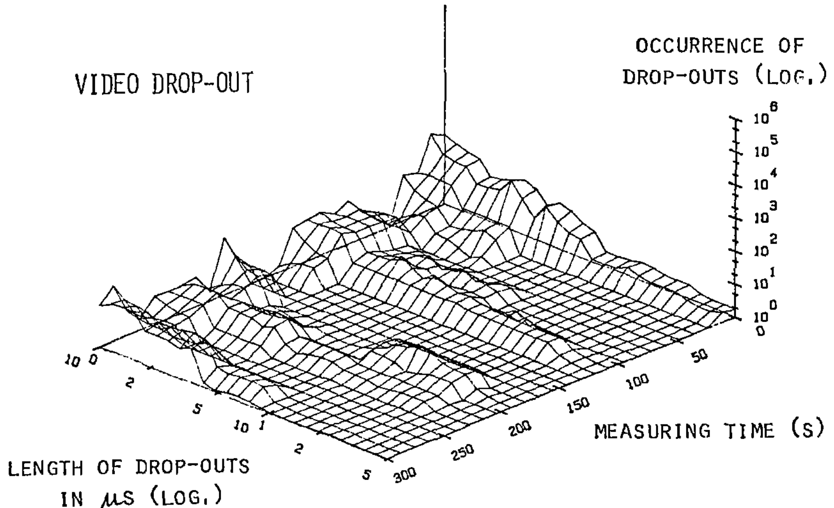

FIG.2.5 3-D PLOT OF DROP-OUTS OVER A 300 SEC INTERVALL (DEPTH ≥ -20DB)

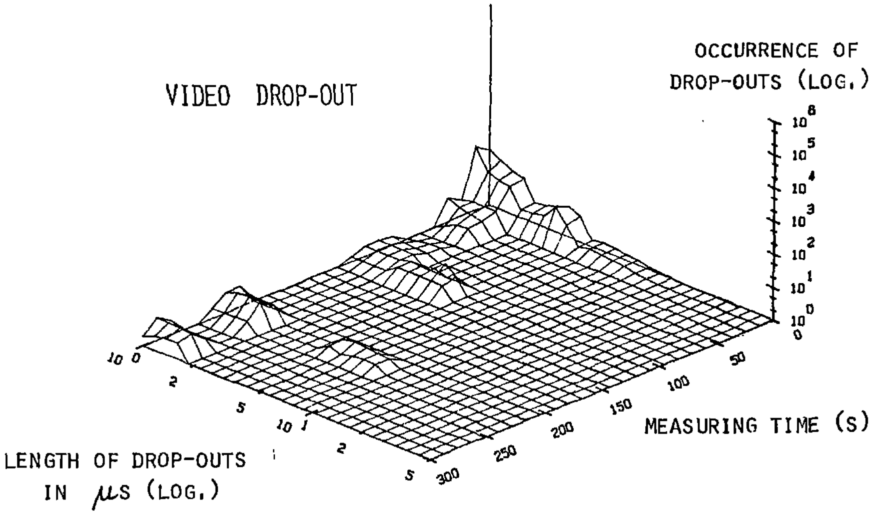

FIG.2.6 3-D PLOT OF DROP-OUTS OVER A 300 SEC INTERVALL (DEPTH ≥ -24DB)

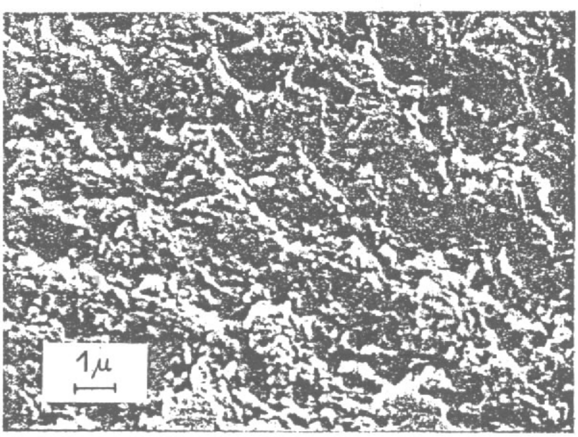

FIG.2.7 SEM PHOTO OF THE SURFACE OF AN AUDIO TAPE (EARLY SEVENTIES)

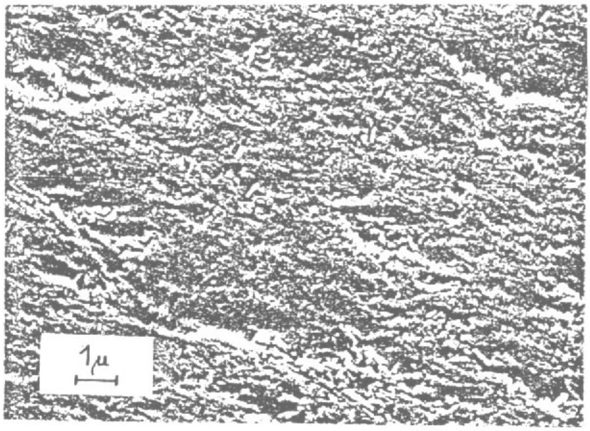

FIG.2.8 SEM PHOTO OF THE SURFACE OF AN AUDIO TAPE (MID-SEVENTIES)

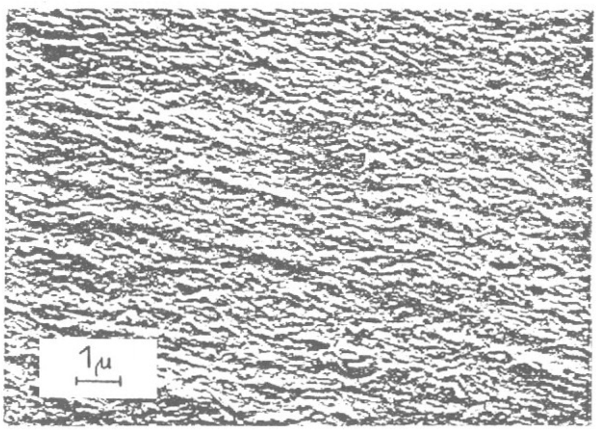

FIG.2.9 SEM PHOTO OF THE SURFACE OF AN AUDIO TAPE (1983)

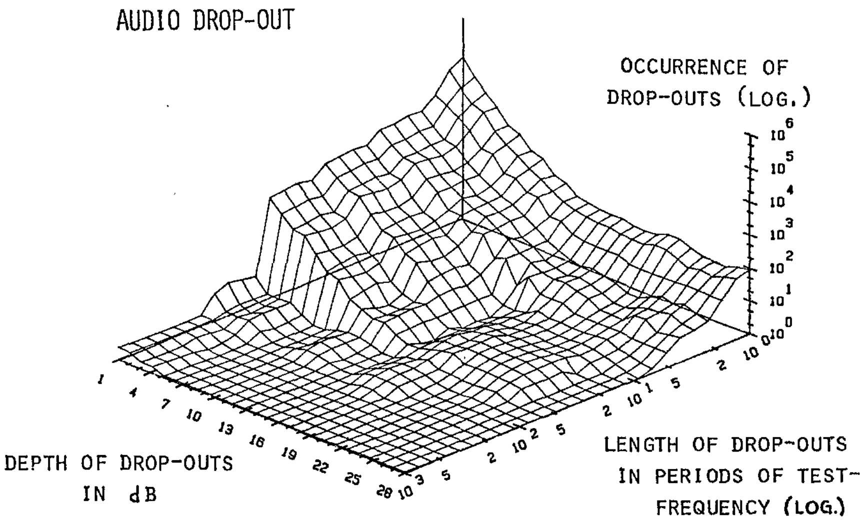

FIG.2.10 3-D PLOT OF DROP-OUTS, TAPE OF FIG.2.7

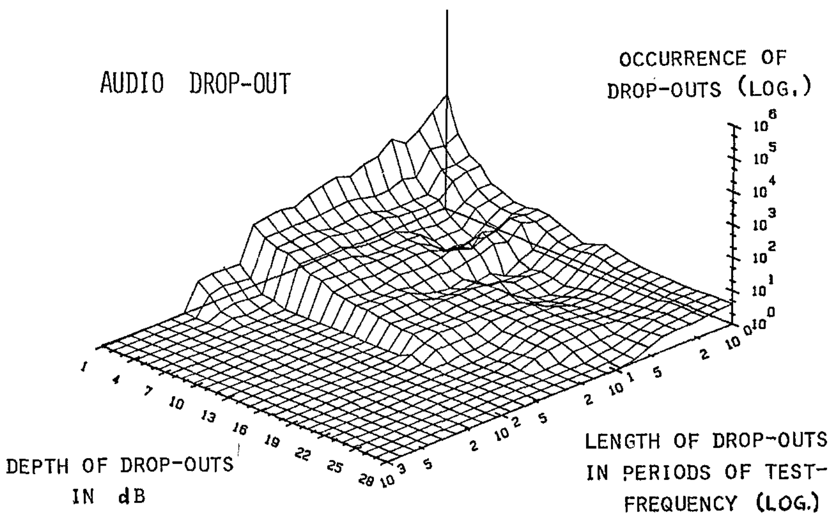

FIG.2.11 3-D PLOT OF DROP-OUTS, TAPE OF FIG.2.8

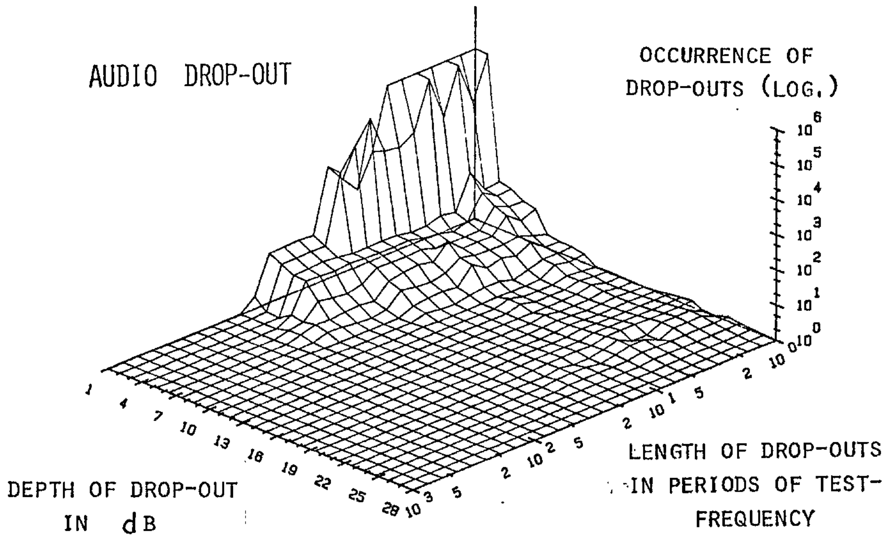

FIG.2.12 3-D PLOT OF DROP-OUTS, TAPE OF FIG.2.9

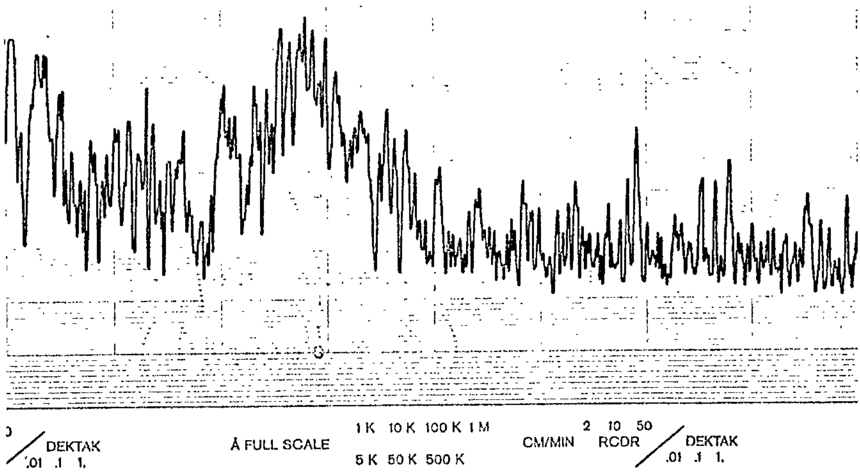

FIG.2.13 PROFIL OF SURFACE, TAPE OF FIG.2.7

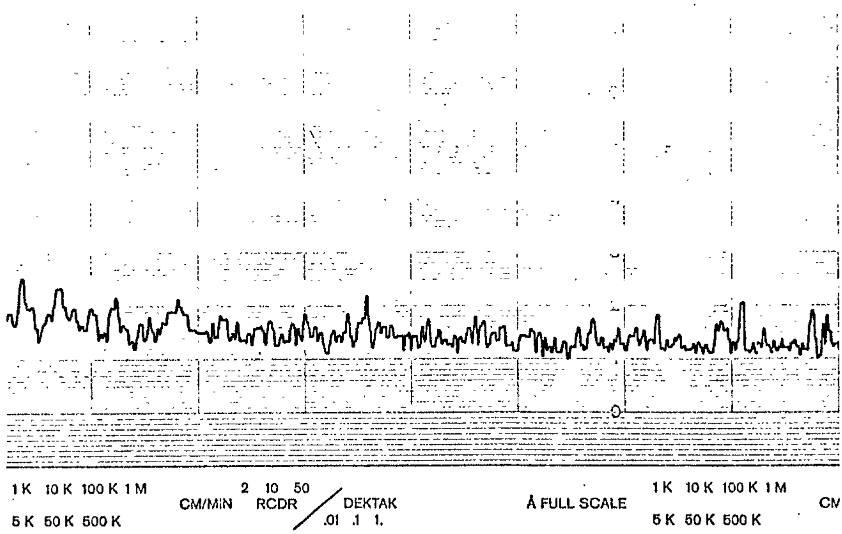

FIG.2.14 PROFIL OF SURFACE, TAPE OF FIG.2.8

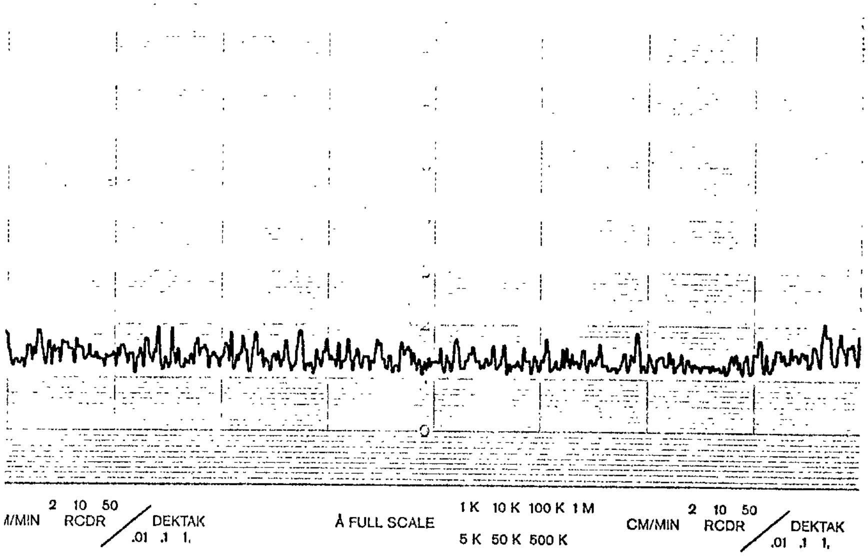

FIG.2.15 PROFIL OF SURFACE, TAPE OF FIG.2.9

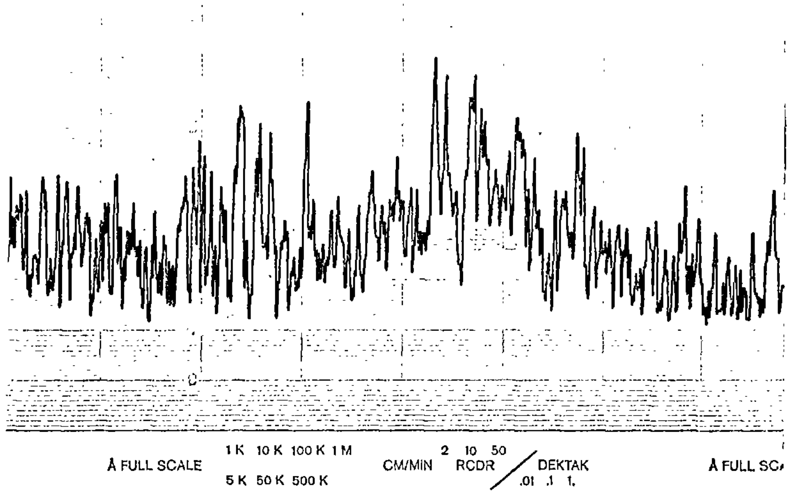

FIG.2.16 PROFIL OF SURFACE, TAPE OF FIG.2.7, DIRECTION OF TRANSPORT

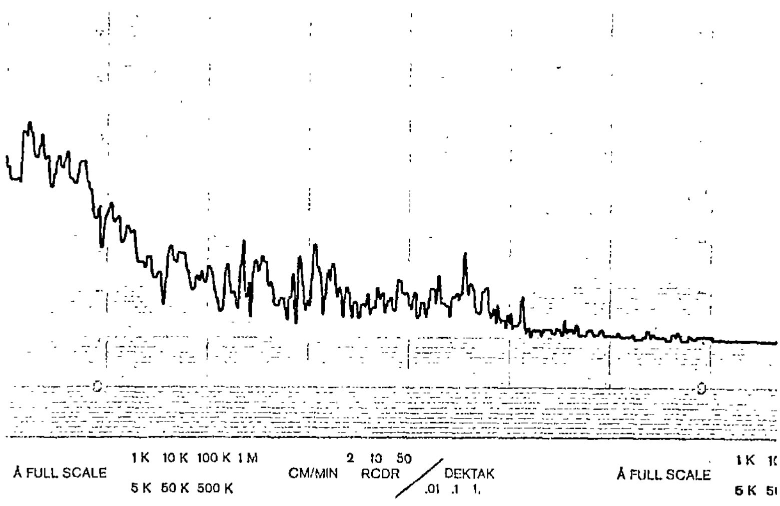

FIG.2.17 PROFIL OF SURFACE, TAPE OF FIG.2.8, DIRECTION OF TRANSPORT

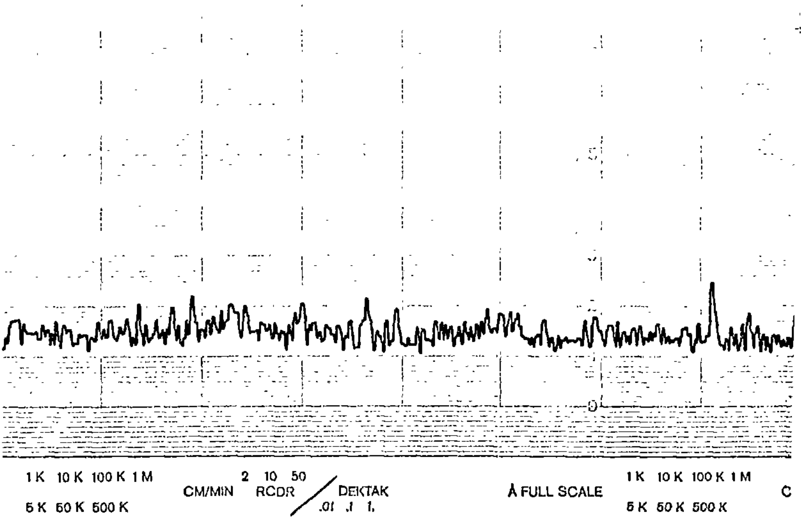

FIG.2.18 PROFIL OF SURFACE, TAPE OF FIG.2.9, DIRECTION OF TRANSPORT

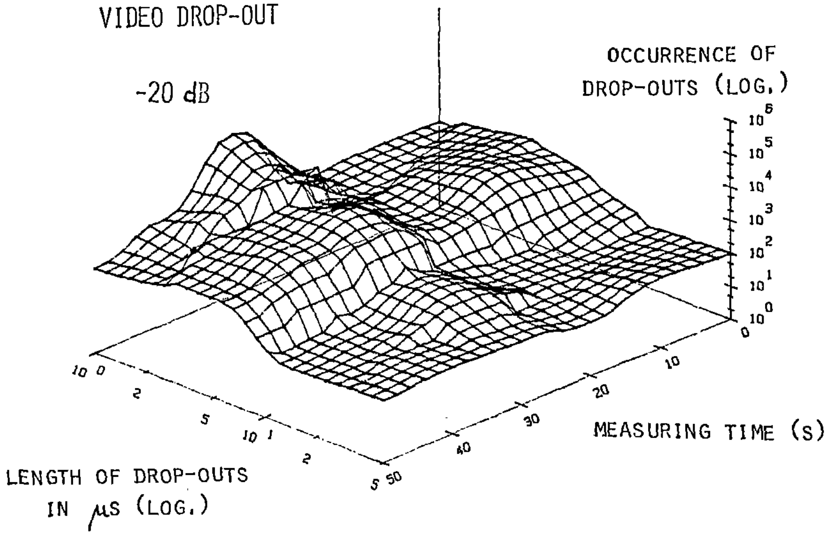

FIG.A1.1 3-D PLOT OF A PERMANENT DROP-OUT (REF.LEVEL: -20 DB)

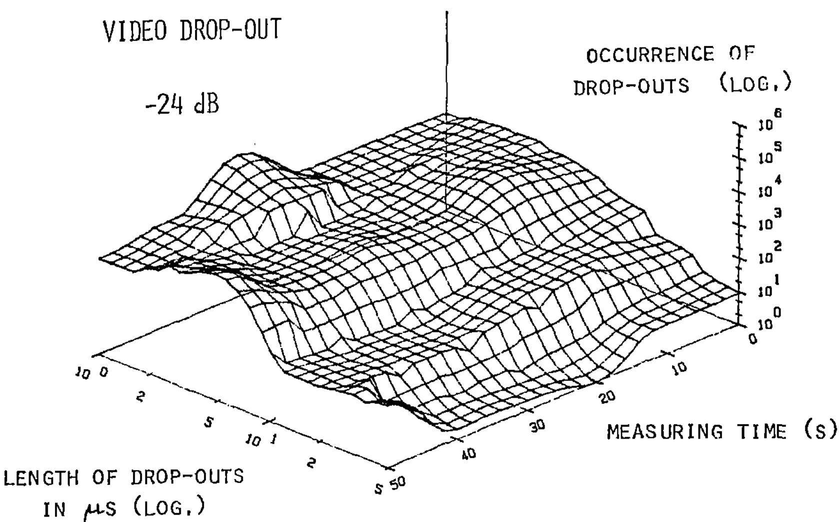

FIG.A1.2 3-D PLOT OF A PERMANENT DROP OUT (REF.LEVEL: -24 DB)

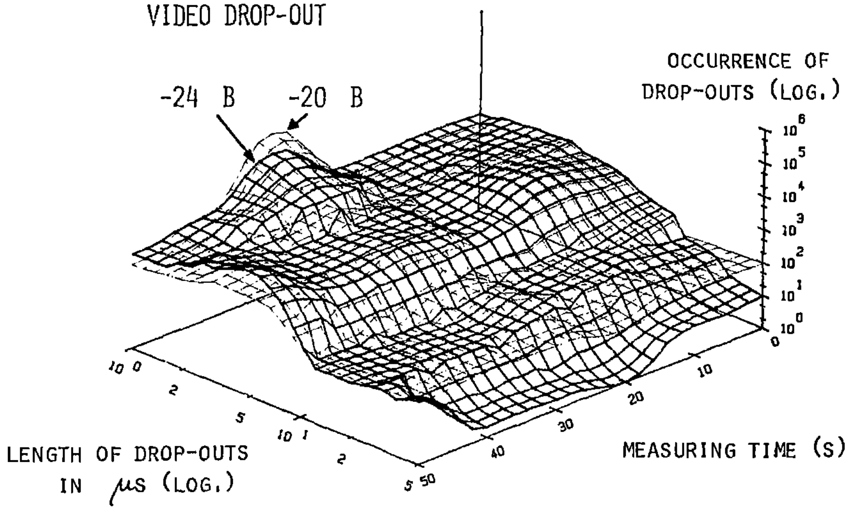

FIG.A1.3 3-D PLOT OF A PERMANENT DROP-OUT (REF. LEVEL: -20 B,-24 B)

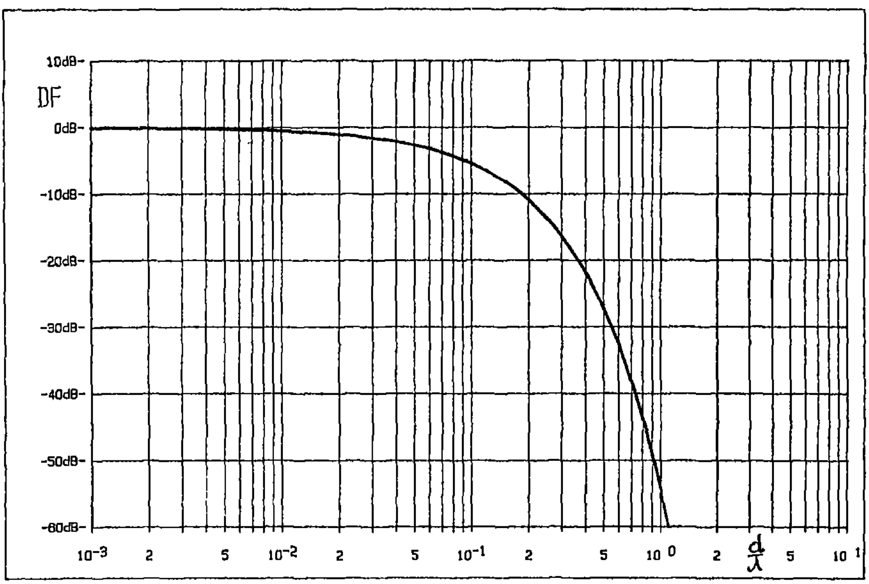

FIG.A1.4 SIGNAL LOSS AS A FUNCTION OF RELATIVE HEAD TO TAPE DISTANCE

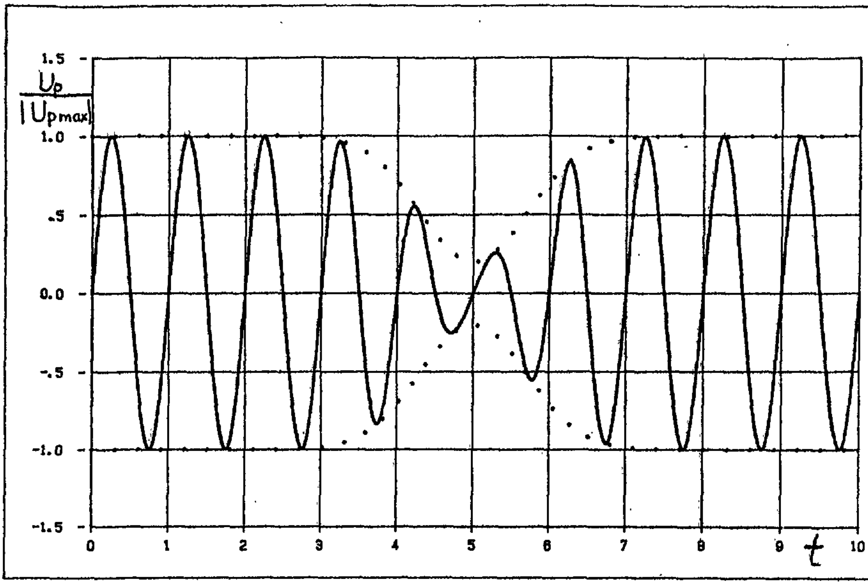

FIG.A1.5 LOSS OF SIGNAL AMPLITUDE CAUSED BY A DROP-OUT

T2
MEASURING TIME:
"4" ~ 1.000.000 C.

DEPTH (dB)

DEPTH (dB)	1	3	10	30	100	300	1000	3000	10.000
-01	3858	1602	744	218	3	0	0	0	0
-02	792	280	273	38	1	0	0	0	0
-03	375	216	139	30	0	0	0	0	0
-04	173	52	18	1	0	0	0	0	0
-06	62	42	32	19	0	0	0	0	0
-08	32	26	22	11	0	0	0	0	0
-10	27	18	12	7	0	0	0	0	0
-12	16	9	8	4	0	0	0	0	0
-14	8	8	8	0	0	0	0	0	0
-16	8	8	8	1	0	0	0	0	0
-21	9	7	6	0	0	0	0	0	0
-28	7	5	1	0	0	0	0	0	0

LENGTH (PERIODS)

TAB.A2.1 TYPICAL PRINT OUT OF AUDIO DROP-OUT COUNTER

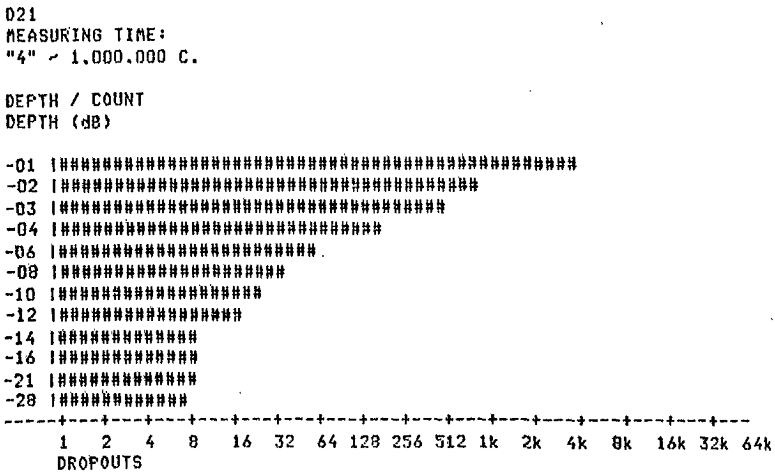

FIG.A2.1 BAR DIAGRAM PRINTED BY AUDIO DROP-OUT COUNTER

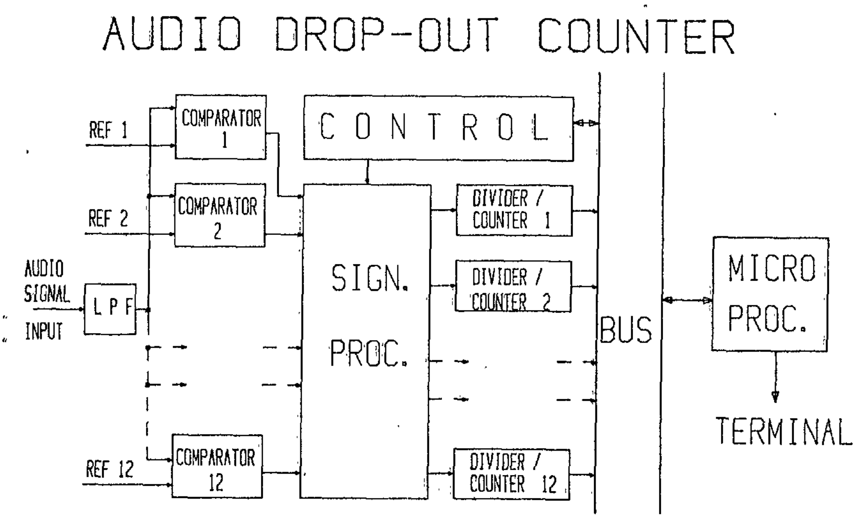

FIG.A2. BLOCK DIAGRAM OF AUDIO DROP-OUT COUNTER

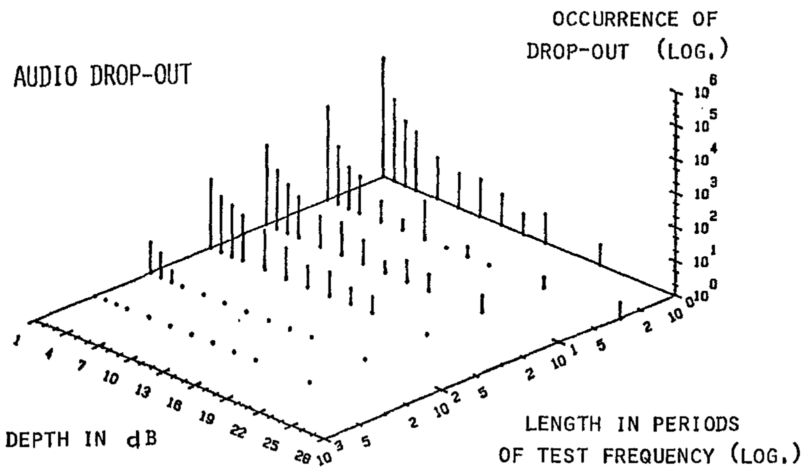

FIG.A2.2A DATA PLOT SHOWING FREQUENCY OF OCCURRENCE OF DROP-OUTS

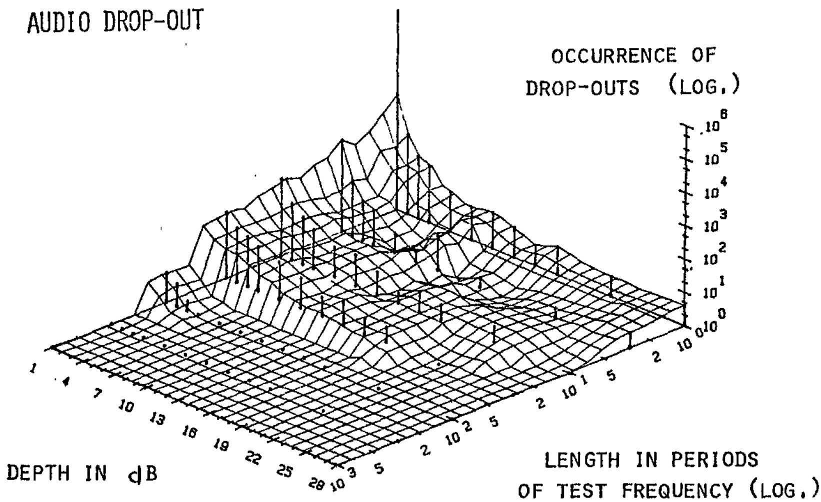

FIG.A2.2B DATA PLOT AND NET OF INTERPOLATION COMBINED