TECHNICAL REPORT

ISO/IEC TR 13841

First edition
1995-07-01

Information technology — Guidance on measurement techniques for 90 mm optical disk cartridges

Technologies de l'information — Lignes directrices pour les techniques de mesurage des cartouches de disque optique de diamètre 90 mm

Reference number
ISO/IEC TR 13841:1995(E)

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Foreword

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In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

The main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/IEC TR 13841, which is a Technical Report of type 3, was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*.

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Information technology - Guidance on measurement techniques for 90 mm optical disk cartridges

1 General

1.1 Scope

This technical report provides Guidance on Measurement Techniques for 90 mm Rewritable/Read-only Optical Disk Cartridges.

1.2 Purpose

This technical report provides guidance on measurement techniques which are not well understood in industry. The basic concept of this report is to aid in the understanding of interchangeability between disks and drives. This report gives guidance and provides some examples of measurement techniques to aid this understanding.

1.3 Reference

ISO/IEC 10090:1992, *Information technology — 90 mm optical disk cartridges, rewritable and read only, for data interchange.*

1.4 Definitions

The definitions of this report are the same as the definitions of ISO/IEC 10090.

2 Measurement environments

2.1 General

This report recommends 3 kinds of measurement environments. Each clause in section 5 may use 1 of 3 measurement environments as specified in this section. Basically, Measurement environment A is used for each clause in section 5 unless noted. Additional environments or conditions are recommended in each clause.

2.2 Measurement environment A

Measurement environment A is the same as the testing environment of ISO/IEC 10090 i.e.

temperature	: 23 °C±2 °C
relative humidity	: 45% to 55%
atmospheric pressure	: 60 kPa to 106 kPa
air cleanliness	: Class 100 000
magnetic field strength	: 32 000 A/m max.

2.3 Measurement environments B

Measurement environments B are used for the highest temperature marginal test

temperature	: 50 °C±2 °C
relative humidity	: Not significant on this environment
atmospheric pressure	: Not significant on this environment
air cleanliness	: Class 100 000
magnetic field strength	: 32 000 A/m max. (unless noted)

2.4 Measurement environments C

Measurement environments C are used for temperature marginal tests. The range of these environments are the same as the operating environment of ISO/IEC 10090.

temperature	: 5°C±2 °C, 23°C±2 °C,50°C±2 °C
relative humidity	: Not significant in this environment
atmospheric pressure	: Not significant in this environment
air cleanliness	: Class 100 000
magnetic field strength	: 32 000 A/m max. (unless noted)

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3 Measurement set up

3.1 General

An optical drive which is used for measuring disks should be calibrated before measuring disks. A typical calibration disk which is suitable for laser power calibration is mentioned in 3.3.

3.2 Measurement accuracy

The measuring equipment should have high reproducibility and repeatability and the recommended performance tolerance ratio (P/T) ;

$$P/T = 6*SD/Tolerance < 0,2$$

where SD is the standard deviation and Tolerance is the upper limit minus the lower limit of the specification.

For example:

In the case of reflectance

$$P/T = 6* SD/(0,29-0,14) < 0,2 \text{ i.e. } SD < 0,005$$

In the case of single ended specifications, the system should be capable of resolving the number of significant digits in the parameter specification.

3.3 Calibration disk

The laser power of the optical drive and/or the measurement equipment on the recording layer can be calibrated from the calibration disk which is provided by the Reliability Center for Electronic Components of Japan (RCJ)

Note - This calibration disk cartridge has been established by RCJ, 1-1-2 Hachiman Higashikurume Tokyo, Japan, and can be ordered under Part number JCM6272 until 2002.

3.4 Measurement area

ISO/IEC 10090 requires disks to satisfy specifications in all the areas of the disk unless noted. (See annex R in ISO/IEC 10090). This report shows the most critical measurement areas in each clause, as follows:

(A) Innermost diameter is critical (R=24mm) for Read power, NBSNR, Signal from headers (I_{vfo} , I_{dmax} /I_{dmin}), Push-pull signal and cross-track signal in ROM area

(B) Correspond to control track data (R=24mm, 30mm, 40mm) Write power, Erase power

(C) Outermost diameter is critical (R=40mm) for Tilt, Axial and radial accelerations,

(D) Outermost and innermost diameters are critical (R=24mm, 40mm) for Reflectance, Imbalance of the MO signal

(E) Inner and outer test zones and control zones. Signal from grooves and headers

3.5 Reference Servo

ISO/IEC 10090 specifies a disk rotational frequency of 30Hz for testing conditions and specifies the transfer functions of the Reference Servo for axial and radial tracking of the recording layer. (See 9.5 and 11.4 of ISO/IEC 10090.)

During the measurement of the signals, the radial tracking error between the focus of the optical beam and the center of a track is made smaller than during the measurement of the radial acceleration. This is achieved by a strong servo as provided in 20.2.4. Therefore the 0,1 μm value of the radial tracking error is increased below the acceleration cross-over frequency and is not changed in the frequency range higher than the acceleration cross-over frequency. There are various strong servos using various phase compensators. If one uses the same type of compensator (C=3) as the reference servo, the 0 cross frequency of this strong servo on the rotational speed of 30 Hz is 1 500 Hz. And this strong servo has an acceleration cross-over frequency of 870 Hz.

For other rotational frequencies, see table 1.

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Table 1. Constants table for the measurement servos

Rot. freq.	0 cross freq. for reference servo (Hz)		Acceleration at low frequency (m/s^2)		Example servo for signals.				Cross over freq. (Hz)
					0 cross freq. (Hz)		Acceleration (m/s^2)		
	Axial	Radial	Axial	Radial	Axial	Radial	Axial	radial	Radial
30 Hz	870	1230	10,0	3,0	870	1500	10,0	3,0	870
40 Hz	**1160**	**1640**	18,0	5,3	1160	2000	18,0	5,3	1160
50 Hz	**1450**	**2050**	28,0	8,3	1450	2500	28,0	8,3	1450
60 Hz	**1740**	**2460**	40,0	12,0	1740	3000	40,0	12,0	1740

Note: The **bold values** are the values calculated for the reference servo.

4 Items for measurement techniques

4.1 General

The following list shows the status of each item. The list classifies these items into 2 groups :

1) guidance on definition and measurement techniques,
2) guidance on measurement techniques.

4.2 List of measurement items

Clause number in ISO/IEC 10090	Title	Status	Clause number
10.4.5	Shutter opening force	(1)	5.1
12.2	Clamping force	(2)	5.2
11.4.9	Tilt	(1)	5.3
11.4.8	Radial and axial acceleration	(2)	5.4
11.5.4	Reflectance	(2)	5.5
12.3	Capture cylinder	(2)	5.6
21	Signals from grooves	(2)	5.7
22	Signals from headers	(2)	5.8
24.2.2	Read power	(1)	5.9
24.3.2/24.4.1	Write power and Erase power	(1)	5.10
25.2	Imbalance of the MO	(2)	5.11
26.2	Narrow-band signal-to-noise ratio	(2)	5.12

5 Measurement techniques

5.1 Shutter opening force

5.1.1 Definition

The shutter opening force is defined as the maximum force including shutter weight and friction between the cartridge and shutter when opening and/or closing the shutter. It is measured as the force in pushing or pulling the shutter parallel to the shutter movement. But the friction force caused by the shutter-opener in the drive mechanism is not included in the definition.

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5.1.2 Measurement procedure

The measurement is done by using a tension gauge as shown in figure 1. This measurement method does not include shutter weight. Therefore, the shutter weight must be added to the result of the measurement. Another method and measurement data are shown in annex H.

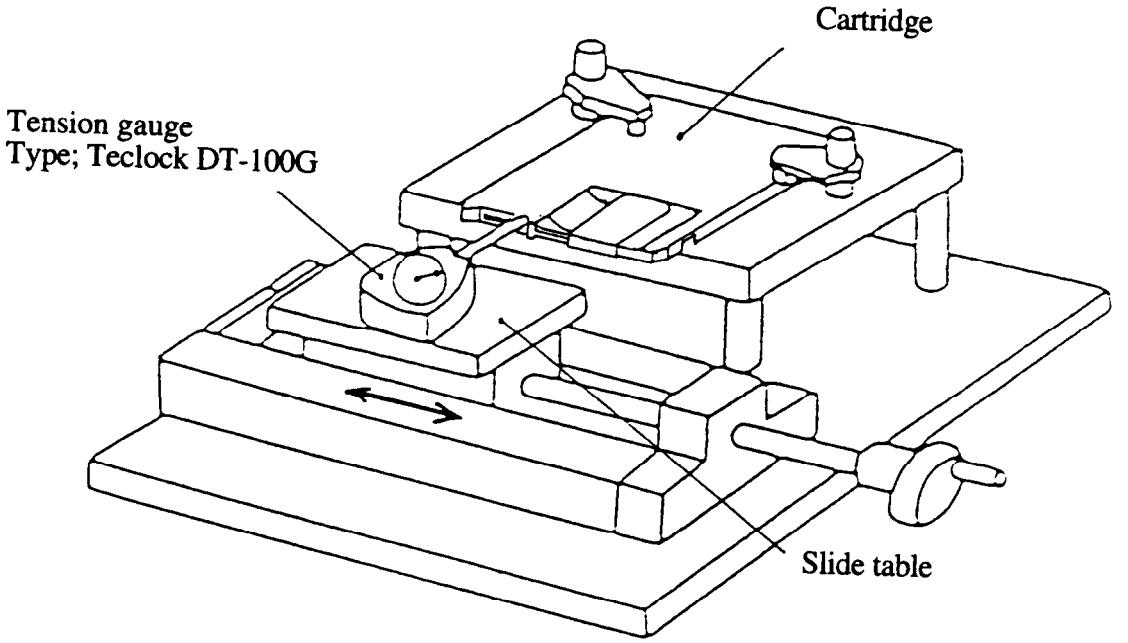

Figure 1 - An example of measurement setup

5.2 Clamping force

5.2.1 Introduction

The maximum allowable force is within a range from clamping a disk without deterioration mechanical characteristics of the disk to unloading the disk by a force of the loading motor or mechanism. The clamping force is checked by the disk with an upper or lower limit of hub which meets the requirement of annex K in ISO/IEC 10090. This item is determined by the drive design.

5.2.2 Measurement procedure

1. Prepare the magnetizable material for a hub which is able to provide the adsorbent force of 4,5 N on the tester in annex K in ISO/IEC 10090.
2. Adhere the material on the non-magnetizable hub with height accuracy of 1,20±0,01 mm including parallelism of the substrate and the material.
3. Clamp the disk on the turntable of the test drive.
4. Measure the clamping force by pulling off the disk.

5.3 Tilt

5.3.1 Introduction

Tilt is defined as the angle between the reference plane of a disk and the entrance surface in the text of the ISO/IEC 10090. The accuracy of the substrate thickness is also considered when the reflectance light is utilized from the recording layer in

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the real measurement. There exist several methods and this report shows following two methods of the measurement. The first method is of the similar method defined in the sentence of the ISO/IEC 10090, that is, to measure the tilt with a parallel light beam directly. The second one is to measure the tilt with a special head utilized over the measurement of the mechanical characteristics.

5.3.2 Measurement method 1

This has been used for long time and the principle of the measurement is depicted in figure 3. When a small He-Ne laser, for example, is used as a light source, the spot size of the measurement is approximately 1 mm. Therefore, this method is mostly close to the sentence defined in ISO/IEC 10090. However, following conditions should be considered in this measurement.

(A)The spot size should be kept in the range of 1 mm when the outermost area is measured.

(B)The error increase depends on the substrate thickness, when the tilt increases.

5.3.3 Measurement method 2

This is a method to measure tilt by the axial deflection values. In order to measure the axial deflection, the position of the objective lens is detected either with a head, which is specially designed within a micro-sensor or by an electric current to the lens actuator. These methods are more convenient for measurement method 1 because the other mechanical characteristics are also measured simultaneously. The method to determine a tilt by the axial deflection is explained in figure 2. Assuming a small square within a few mm^2 as a flat plane, the tilt along the radius (ϕ_r) or along tangential (ϕ_θ) direction is calculated by the axial direction difference of separated two points (A1, B1 or A2, A1) and the distance (l_r or l_θ) respectively.

Tangential tilt angle $\phi_\theta = \tan - 1(\Delta d\theta / l_\theta)$

$= \tan - 1((DA1-DA2)/ l)$

Radial tilt angle $\phi_r = \tan - 1(\Delta dr / l_r)$

$= \tan - 1((DA1-DB1)/ l_r)$

Therefore, compounded solid angle (tilt angle) is,

Tilt angle $|\phi| = SQRT (\phi_\theta^2 + \phi_r^2)$

However, this equation must be used carefully for the following reasons.

(A)Tilt is determined by the axial deflection difference as function of the distance. That is, the shorter the distance of the separated points (l_θ,l_r) is, the more estimated error increases. Oppositely, in the case of the longer distance, the surface roughness disturbs the measurement. Therefore, the measurement conditions must be well considered.

(B)The axial deflection value of 5 μm should correspond to 5 mrad of the specification when tilt is measured every 1 mm pitch. Therefore, the measurement accuracy must be also considered.

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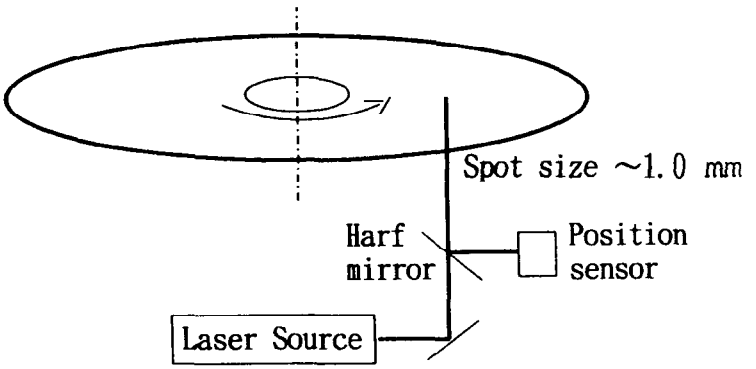

Figure 2 - Direct measuring of tilt (Measurement method 1)

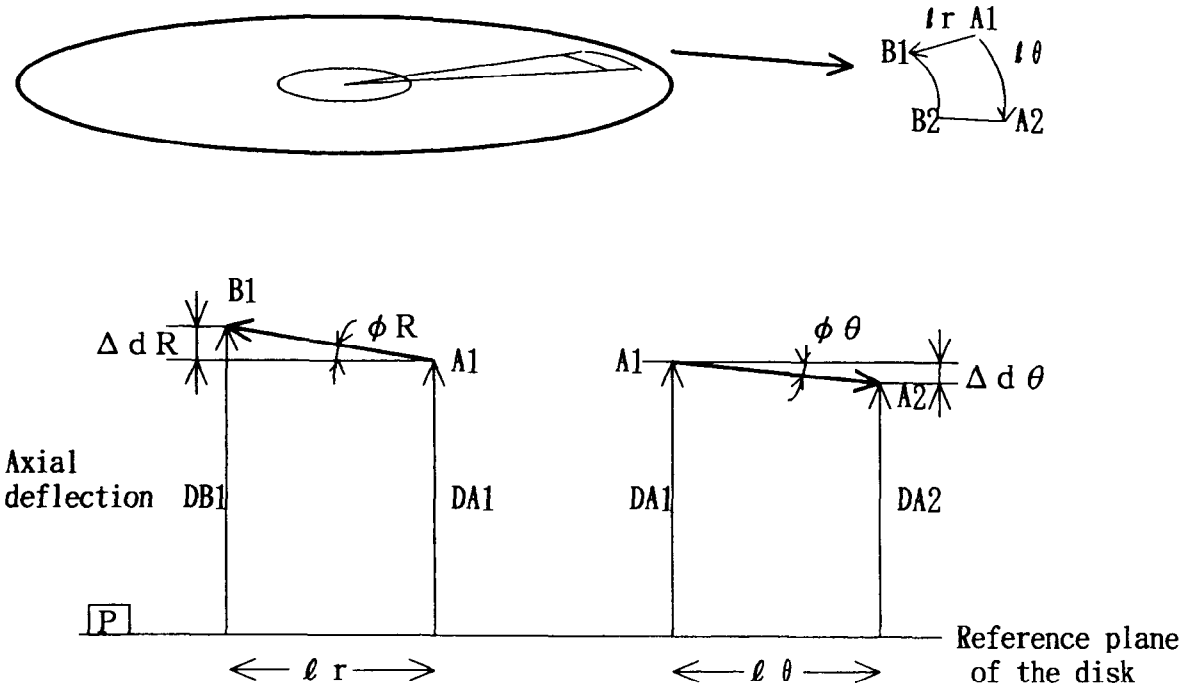

Figure 3 - Measurement tilt calculated by axial deflection (Measurement method 2)

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5.4 Axial and Radial acceleration

5.4.1 Introduction

The ISO/IEC 10090 assumes that a light spot traces tracks on a disk by the use of axial and radial servos. Although this tracing must be accurate to the extent that playback is adequately performed, movement in the axial and radial directions can act as an obstacle to this requirement. At low frequencies, in which the servo responds, the object lens traces disk movement and the servo-loop gain decreases the distance between the track and the light spot by a fraction, which means that the fractual distance shows up in tracing performance. On the other hand, at high frequencies in which the servo does not respond, disk movement itself corresponds to tracking performance. As for typical servo characteristics in an optical disk drive, in the range up to the lead break frequency of the phase compensation filter inside the servo loop, doubling the frequency results in 25% of the loop gain. In the same way, when the disk exhibits sinusoidal motion under the condition that the maximum acceleration is constant, the relationship between the frequency and amplitude is such that doubling the frequency results in 25% increase in amplitude. Thus, because servo gain and disk acceleration are given, tracing characteristics can be estimated at low frequencies (see figures 4 and 5). Accordingly, if we limit ourselves to disk acceleration for low frequencies and disk displacement for high frequencies, track tracing performance of the light spot can be determined to a certain extent. However, the following problems arise if we attempt to make them precise rules. First, the necessity of measuring the two physical quantities of acceleration and displacement independent of the frequency can be complicated, and second, excess movement of the object lens near the zero-cross frequency cannot be accurately ascertained by acceleration and displacement. For example, figure 4 shows that the loop gain at 600 Hz allows the acceleration of 17,5 m/s^2 and that the loop gain at 1000 Hz allows the disk displacement of only 0,8 μm. Taking the above into consideration, ISO/IEC 10090 prescribes a servo deviation specification using a reference servo having fixed characteristics. This is chosen because servo deviation appears directly in tracing performance, and consequently the same physical quantity can be evaluated throughout the entire frequency range.

5.4.2 Measurement system

A measurement system for performing measurements is shown in figure 6 (this figure combines figures C.2 and C.4 of annex C in ISO/IEC 10090). In figure C.2. the output of a non-contact electrostatic capacity sensor is added to the actual servo's error signal and the resultant is input into a filter having the transfer characteristics of the reference servo. For typical non-contact sensors, however, it is not so simple to carry out accurate measurements from low frequencies up to high frequencies. It is generally felt that operation at less than 1 kHz is desirable. As a result, the object lens moves in excess of the disk displacement near the servo's zero-cross frequency, and even if this appears in the error signal, it cannot be compensated by the non-contact sensor's output, and measurement accuracy falls. In figure C.4, the actual servo's transfer function is identified and the servo's error signal is input into a filter whose characteristics represent the multiplication of the inverse of the actual servo's transfer function with the reference servo's transfer function. Here, however, it is generally not easy to measure accurately the servo system transfer characteristics from high frequencies down to low frequencies. In particular, for a leaf-spring type of actuator, resonance frequency due to the spring and the mass of the movable parts of the actuator is several tens of Hz, and characteristics are difficult to identify accurately. Moreover, even for a slide-able type of actuator, the large influence of stick and slip at low frequencies makes it difficult to identify characteristics well. For this reason, using figure C.2 for low frequencies and figure C.4 for high frequencies, a systems proposed in which the output from both of the above can be accurately measured in both the low frequency interval and the high frequency interval independent of frequency. Here, we use well-placed crossover filters having inverse characteristics. These are 1st order filters having cut-off frequencies of 600 Hz. In addition, since object-lens displacement is measured directly in the low frequency interval, the low frequency component of disk displacement stored in memory should be used for feed forward control in the actual servo system. G1 is a sensor-system element transfer function having a band of 100 kHz. G2 and G3 are a servo-loop phase-compensation element and actuator transfer function, respectively, whose characteristics are dependent on the type of equipment used.

5.4.3 Procedure 1: Low-pass measurement system

1a Calibrate non-contact sensor gain

1b Measure error signal gain

Method A (Axial Gain)

* Stop disk.
* Turn axial and radial servos OFF.

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* Coarsely move the disk using a mechanical slow-motion facility and place the disk around the center of the axial error signal e_a .
* Slowly move the disk using a piezo element and search for the center of the axial error signal e_a
* When the difference between the axial S-signals for land and groove becomes large, place radial serve ON.
* Using a piezo element, move the disk ± 1 micron from the center of the error signal and measure the gain at this point.

Method B (Axial Gain)

* Stop disk.
* Turn axial and radial servos ON. While applying an offset voltage to z, detect the object lens motion with an electrostatic capacity non-contact sensor and measure the gain at 1 micron.

Method C (Radial Gain)

* Stop disk.
* Turn axial servo on.
* Apply a chopping wave to the radial actuator to move.
* For the radial error signal e_a obtain a wave form in which the deviation between adjacent periods is within 3%, and treating one period as 1,6 micron, measure the gain at ± 0,1 micron from land centre. Note that by observing the cross-track signal at this time, land and groove can be distinguished.

Method D (Radial Gain)

* Stop disk.
* Turn axial and radial servos on. Whole applying an offset voltage to zero, detect the object lens motion with an electrostatic capacity non-contact sensor and measure the gain at 1 micron.

1c Adjust the variable gain AMP so as to match the error signal gain with that of the non-contact sensor. If method B can be used for gain measurement, it is recommended to input a 100Hz sine wave into z and adjust the variable gain so that signal s_m becomes 0.

1d Implementing a reference-servo simulation filter. In order for the 1/(1+Hs) filter to accurately simulate low-pass characteristics, and analog filter is preferred despite the fact that a digital filter is relatively easy to construct. Figures 7 and 8 show examples of analog filters for axial use and radial use, respectively. Figures 9 and 10 are the simulation results of each filter.

1e Implementing a low-pass filter A 1st order filter which acts as crossover band-limiting filter having a cut-off frequency of 600 Hz is desirable. The cut-off frequency and gain here must be uniform with the high-pass filter of the high-pass measurement system within an accuracy of 3%.

Caution: When performing measurements while the disk is not revolving, deformation of the illuminated part of theplastic disk substrate can be prevented by lowering laser power.

5.4.4 Procedure 2: High-pass Measurement System

2a Sensor-System gain
Adjust the variable-gain AMP as in the low-pass measurement system.

2b Transfer function derivation

* Apply an excitation signal from z and measure the transfer characteristics from z to e_a:
$e_a/z = 1/(1+G_1*G_2*G_3) = 1/(1+H_a)$.
Measurements should be performed in a frequency domain above 200 Hz since the 600 Hz cut-off high-pass filter is employed here for the high-pass measurements.

* Determine the transfer function from the transfer characteristics using the curve-fitting function of an FFT analyzer.

Caution: Considering the wide measurement frequency range, measurement accuracy can be improved by varying the excitation signal amplitude in a step-like fashion for each frequency. During measurement, it is necessary to confirm that each section within the servo loop is not being saturated.

2c Implement the $(1+H_a)/(1+H_s)$ correction filter.

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2d Implement the high-pass filter

A 1st order filter which acts as a cross over band-limiting filter having a cut-off frequency of 600 Hz is desirable. The cut-off frequency and gain must be uniform with the low-pass filter of the low-pass measurement system within an accuracy of 3%.

5.4.5 Procedure 3: Total measurement system

3a Add the output signal of the low-pass measurement system to the output signal of the high-pass measurement system at the same gain. Under these conditions, rotate the test disk, apply the axial and radial servos and observe the e_S output signal.

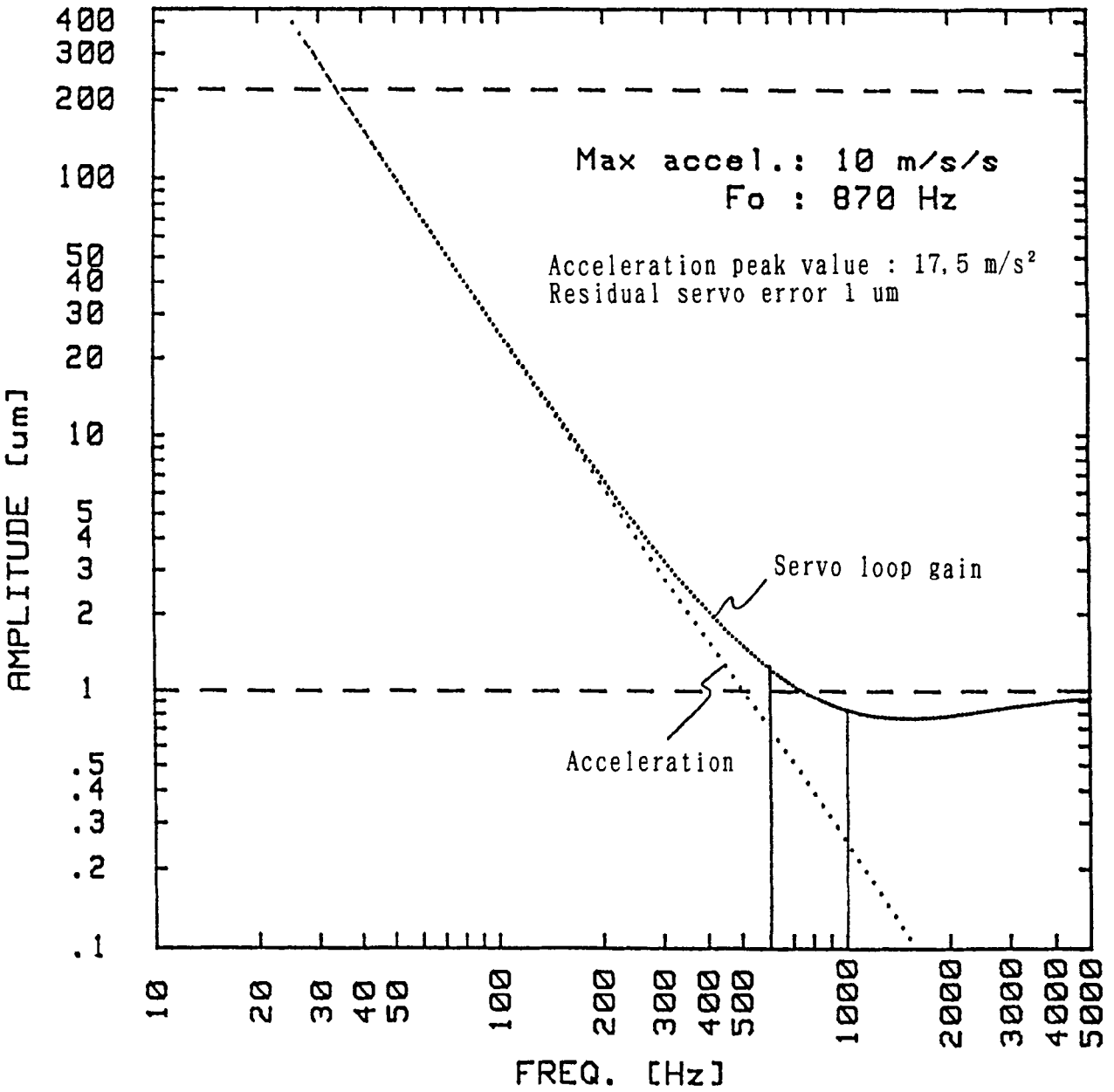

Figure 4 - Ratio between acceleration and servo loop gain

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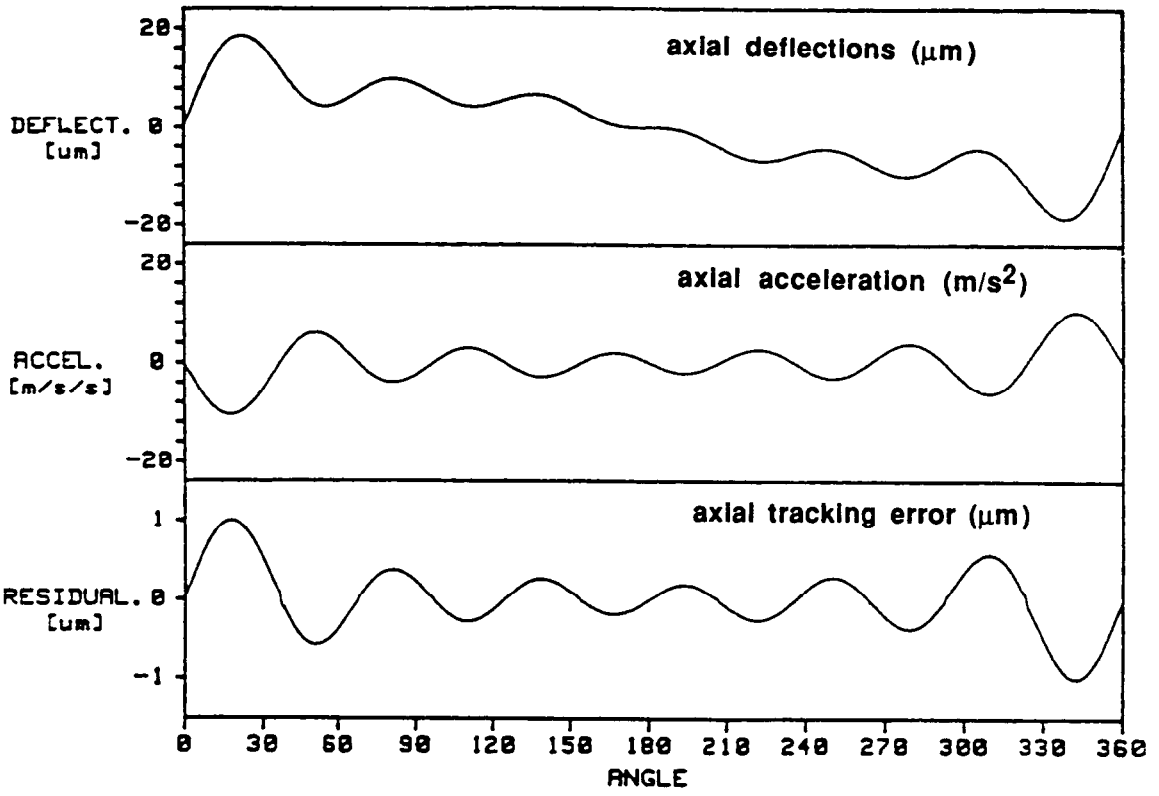
Case A : A disk with only low frequency components of the axial deflection.



Case B : A disk with low and high frequency components of the axial deflection.

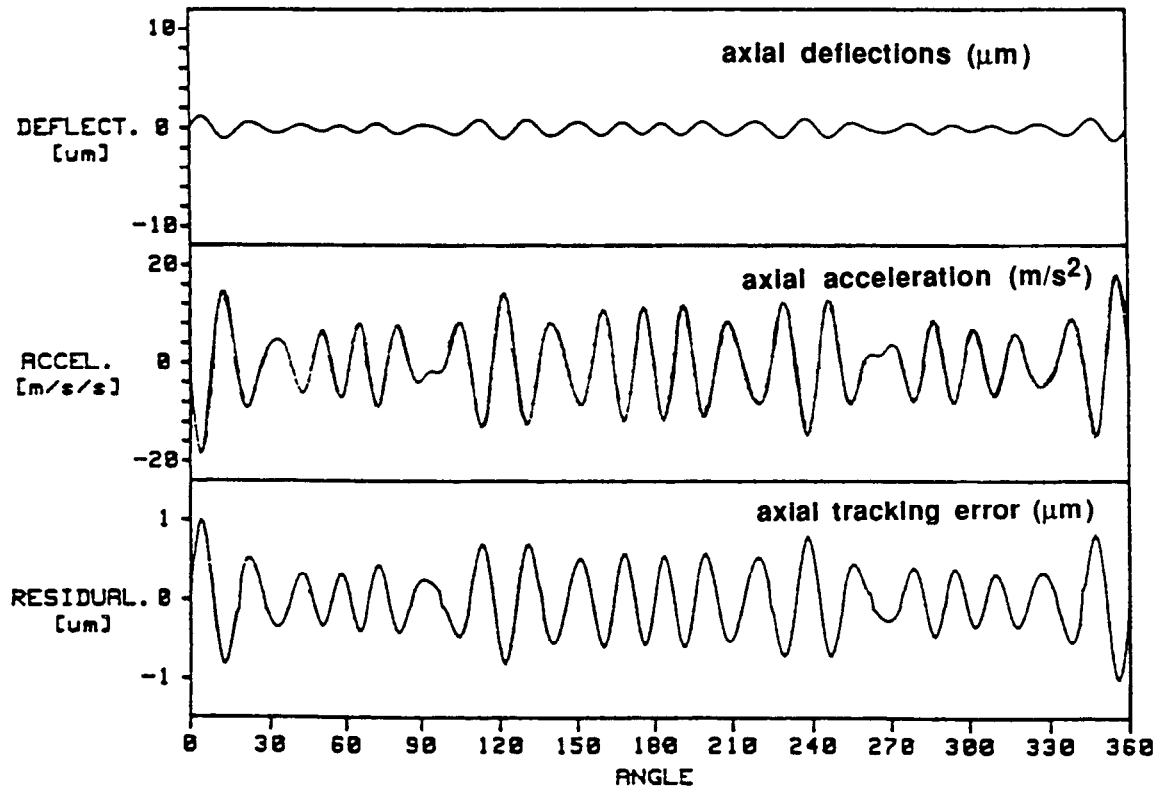


Figure 5 - Simulation of mechanical characteristics of the disk

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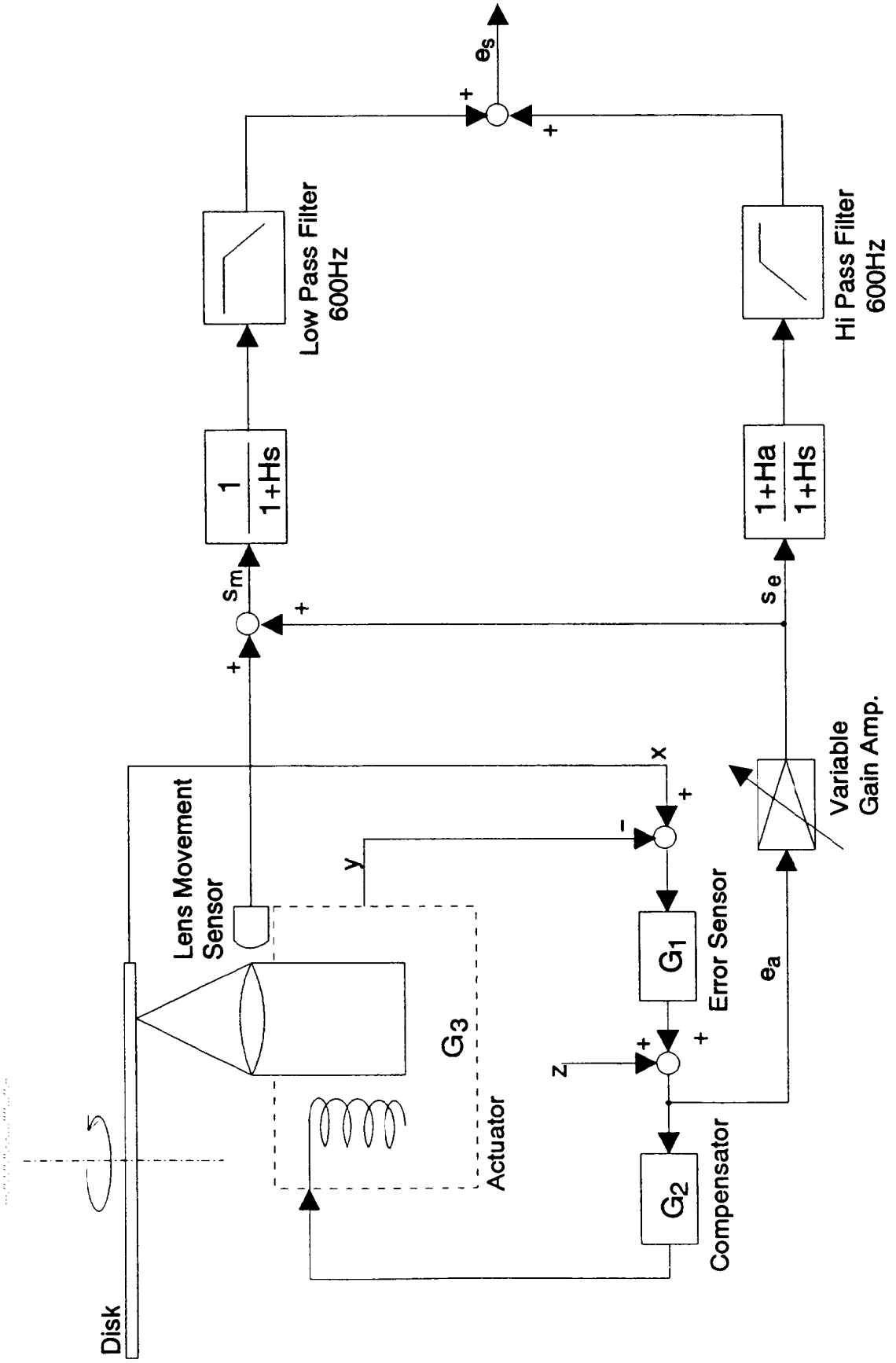

Figure 6 - Measurement system

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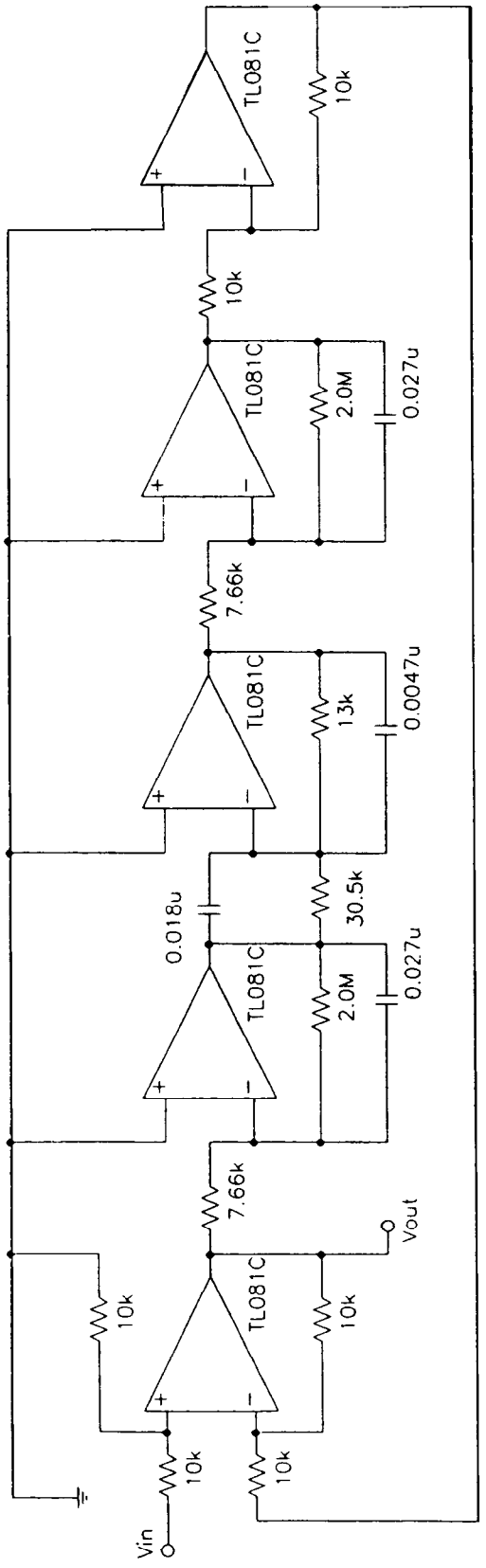

Fig.7 Example of 1/(1+Hs) filter for Axial use

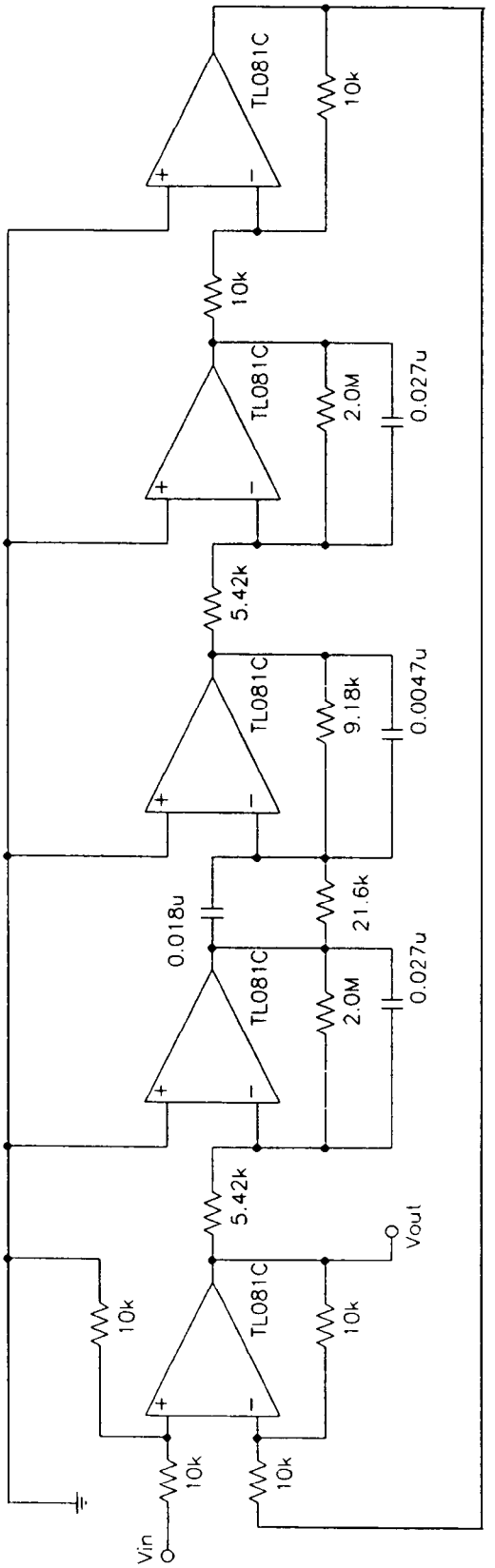

Fig.8 Example of 1/(1+Hs) filter for Radial use

Figures 7, 8 - Examples of $1/(1+H_S)$ filters for axial and radial use

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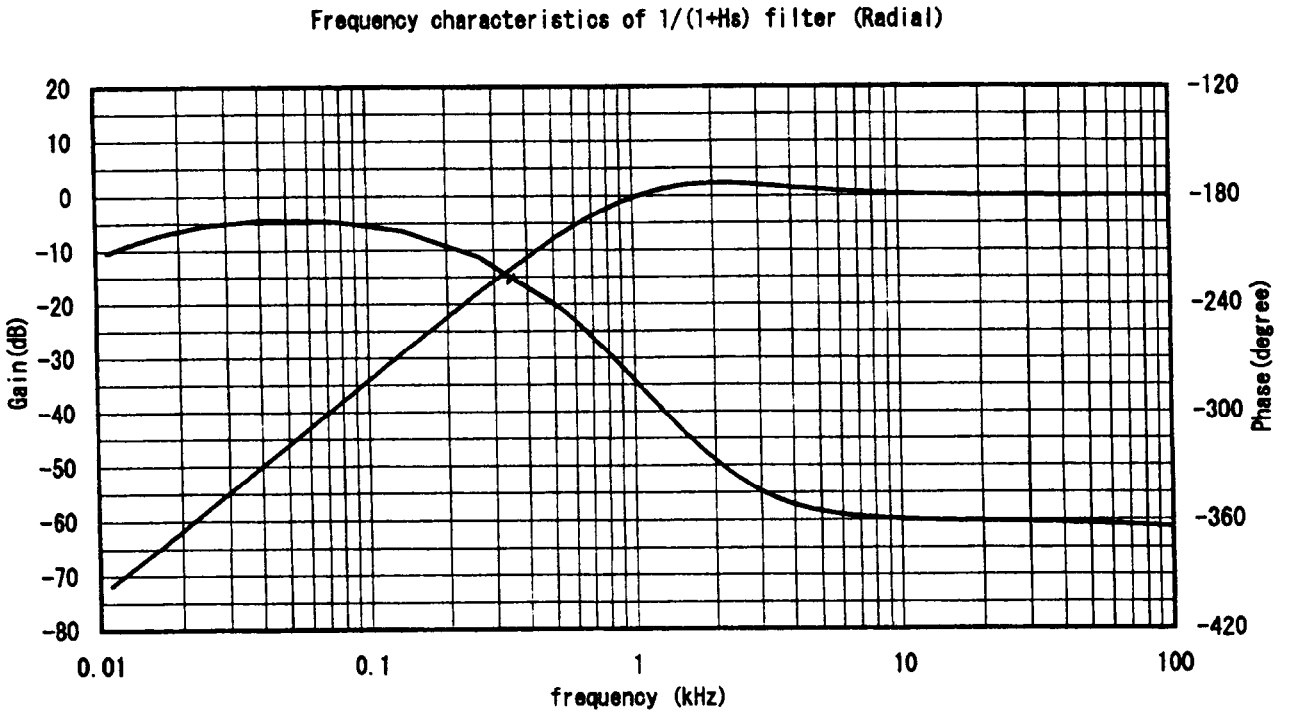

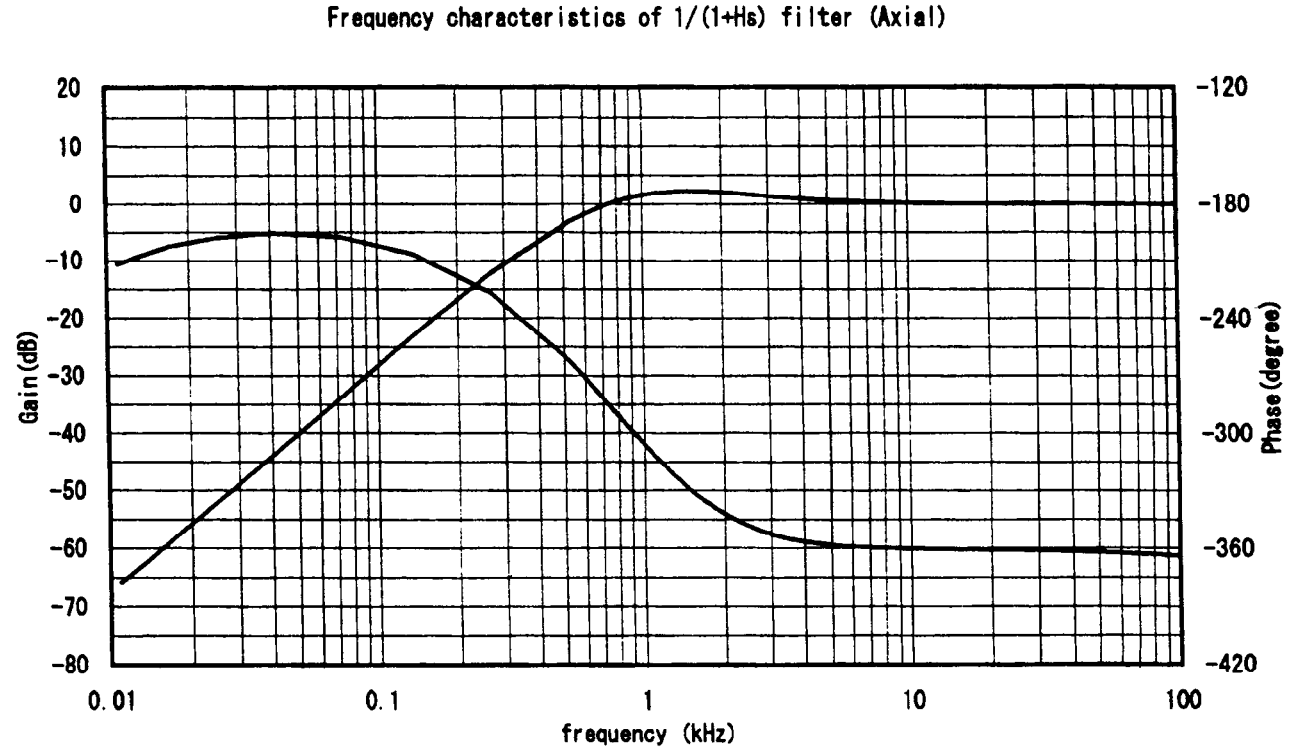

Figures 9, 10 - Frequency characteristics of $1/(1+H_S)$ filters

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5.5 Reflectance

Note: The value of baseline reflectance should exclude the reflectance of disk surface. When the baseline reflectance is measured by Optical pick up i.e. with concentrated beam, the disk surface reflectance is small when the length of light pass of the Optical pick up is very large.

See figure 11.

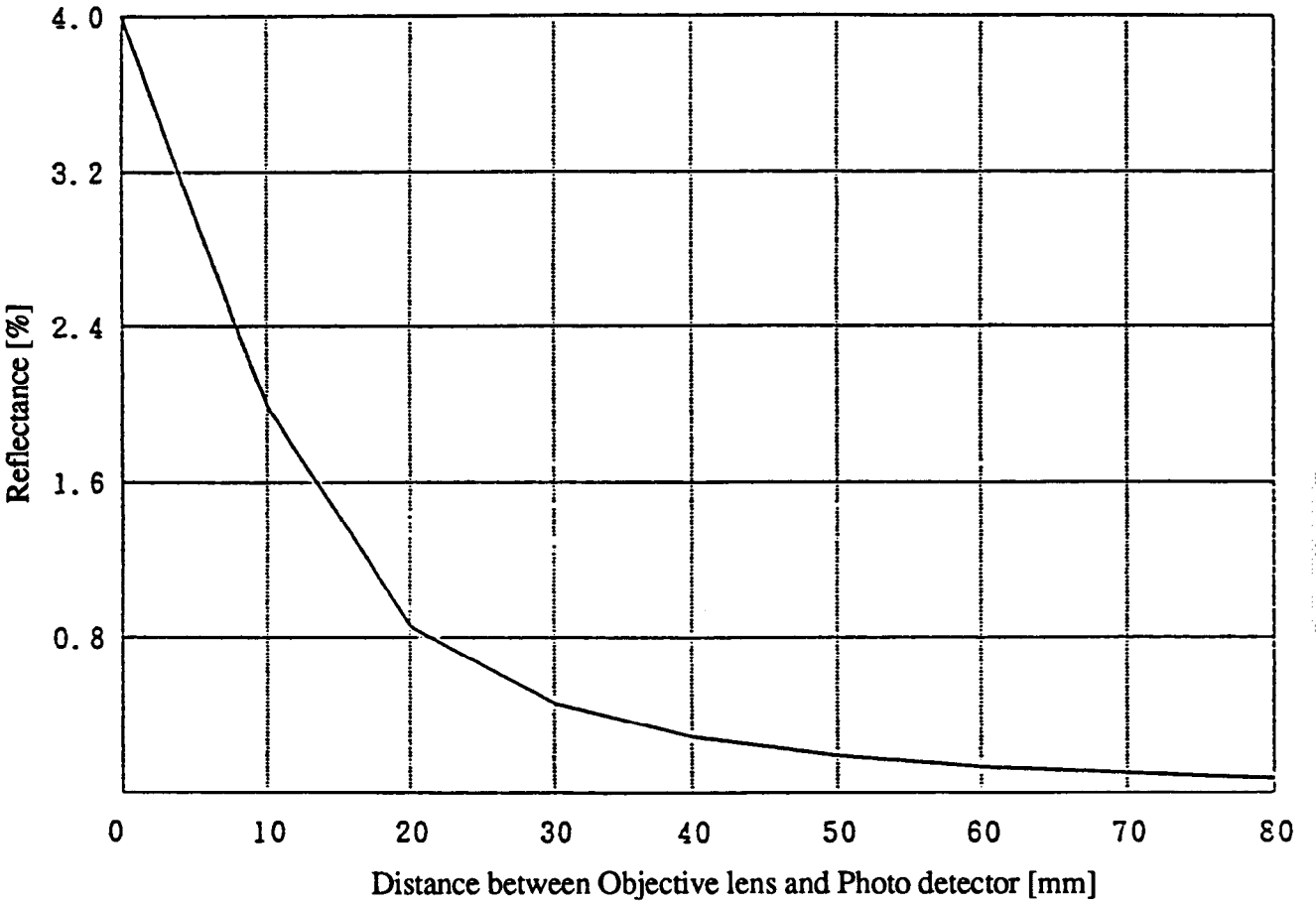

Figure 11 - Reflectance from the disk surface

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5.6 Capture cylinder

Note: Capture Cylinder is a imaginary cylinder of the locus of the center of the hub. The basic concept of Capture Cylinder is not only used for the static but also for the dynamic situation. Especially, when measuring R17, the following issues should be considered.

i. Under operating conditions, the disk should be free from the case with the radial clearances between the disk and the case.
ii. Difference of positions of the centers between the hub and the disk's outer rim.
iii. The tolerances of the dimensions of the cartridge.
(See annex F.)

5.7 Signals from grooves

5.7.1 Measurement equipment

Figure 12 shows the test equipment for the measurements of signals from grooves. LPF means the low pass filter to eliminate the effect of modulation due to embossed marks. Figure 13 shows an example of the circuit, which is a 4th order LPF with cut-off frequency 250kHz and with an attenuation of 48 dB at 1 MHz.

•/• means the dividing circuit to divide the filtered difference signal (I_1-I_2) by the filtered sum signal (I_1+I_2) at real time. The output gives the Divided push-pull signal containing embossed marks, the offset voltage in the input of the dividing circuit should be carefully eliminated to avoid a measurement error. Figure 14 shows an example of an actual dividing circuit.

Connect a probe of an oscilloscope to the arrow to measure the signal denoted after the arrow.

5.7.2 Measurement conditions

1. Use measurement environment A (2.2)
2. Measuring area : See 3.4

5.7.3 Measuring procedure

There are two methods to measure the signals from grooves i.e. (A) track jump method and (B) radial-track-servo-off method. (A) is better because of the ease to avoid the ID interference on the signals and because of the capability to measure in the case of less eccentricity.

A. Track jump method

1. Position the focus beam on the destination track.
2. Connect oscilloscope (digital memory) probes to the $(I_1+I_2)pp$ for Cross-track signal, $(I_1+I_2)_{min}$ for Cross-track minimum signal, $(I_1-I_2)_{pp}$ for Push-pull signal, $(I_1-I_2)/(I_1+I_2)_{pp}$ for Divided push-pull signal or Channel 1 output for On-track signal.
3. Jump to the neighboring track during the recording field period, (not the ID period), of a certain sector using the track jump function.
4. Measure the signal amplitude (for Cross-track signal, Push-pull signal and divided push-pull signal) or the signal level (for Cross-track minimum signal and On-track signal).
5. Repeat the same measurements for the other sectors in a revolution.
6. Check whether the measured maximum and minimum values conform to the Standard.

Note1: The measurements can be done in one revolution by jumping every sector with the direction changed every jump. This is useful as shown in figure 15.

Note2: It is better to measure the reference signal $(I_1+I_2)_a$ of the ungrooved area from ODF in the same sector. When the sum amplifier in the tracking channel has less bandwidth to get the correct ODF level, the ODF level can be compensated using the signal I_0 in Channel 1.

B. Radial-track-servo-off method

1. Position the focus beam at the destination radius.
2. Connect oscilloscope (digital memory) probes to the $(I_1+I_2)pp$ for Cross-track signal, $(I_1+I_2)_{min}$ for Cross track minimum signal, $(I_1-I_2)pp$ for Push-pull signal,$(I_1-I_2)/(I_1+I_2)pp$ for Divided push-pull signal or Ch.1 output for On-track signal.

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3. Store the signal waveforms from grooves obtained when the disk rotates in one turn with the track servo off.
4. Read the signal amplitudes (for Cross-track signal, Push-pull signal and Divided push-pull signal) or the signal levels (for Cross-track minimum signal and On-track signal) from the stored waveforms. For grooved areas without embossed Recording Fields, ID periods should be deleted from the stored signal trains to avoid the ID interference.

Note: The recommended example of the measurement procedure is shown in annex E.

5.8 Signals from headers

5.8.1 General

Signals from headers, I_{vfo} , I_{sm} , I_{hmax} and I_0, may vary along to radius or to tangential direction. Therefore, these signals should be measured for every sector in one track of the measurement area described in 3.4.

5.8.2 Amplitude measurement

(1) Acquisition of header signals
Store the header signal in the digital memory at the rate of about 20ns/sample. It is better to change the delay time from the trigger point to acquire the data according to the measured signal.

(2) Peak or bottom level
The peak and bottom levels of sinusoidal waveforms can be obtained by taking value at the time when the 1st order difference of the input signal is zero.

(3) VFO signal I_{vfo}
The average value VFO_p of all peaks of the sinusoidal waveform in the VFO_1 field and the average value VFO_b of all bottoms are calculated. I_{vfo} (n) = VFO_p - VFO_b. In order to improve the reliability of the measured value of small VFO signals, repeat the measurement of the VFO signals 5 times and average the values.

(4) Sector Mark I_{sm} and ID I_{hmax}
Calculate the I_{sm}(n) and I_{hmax} (n) from the difference with the peak level and the average level of the neighboring bottoms. Put the minimum value of all I_{sm} (n)'s as I_{sm}. Put the maximum value of all I_{hmax} (n) as I_{hmax}

(5) I_0
Acquire 32 times the data and take the average of these to eliminate noise.
Determine the average level of the top ten levels in the Mirror mark field as I_0.

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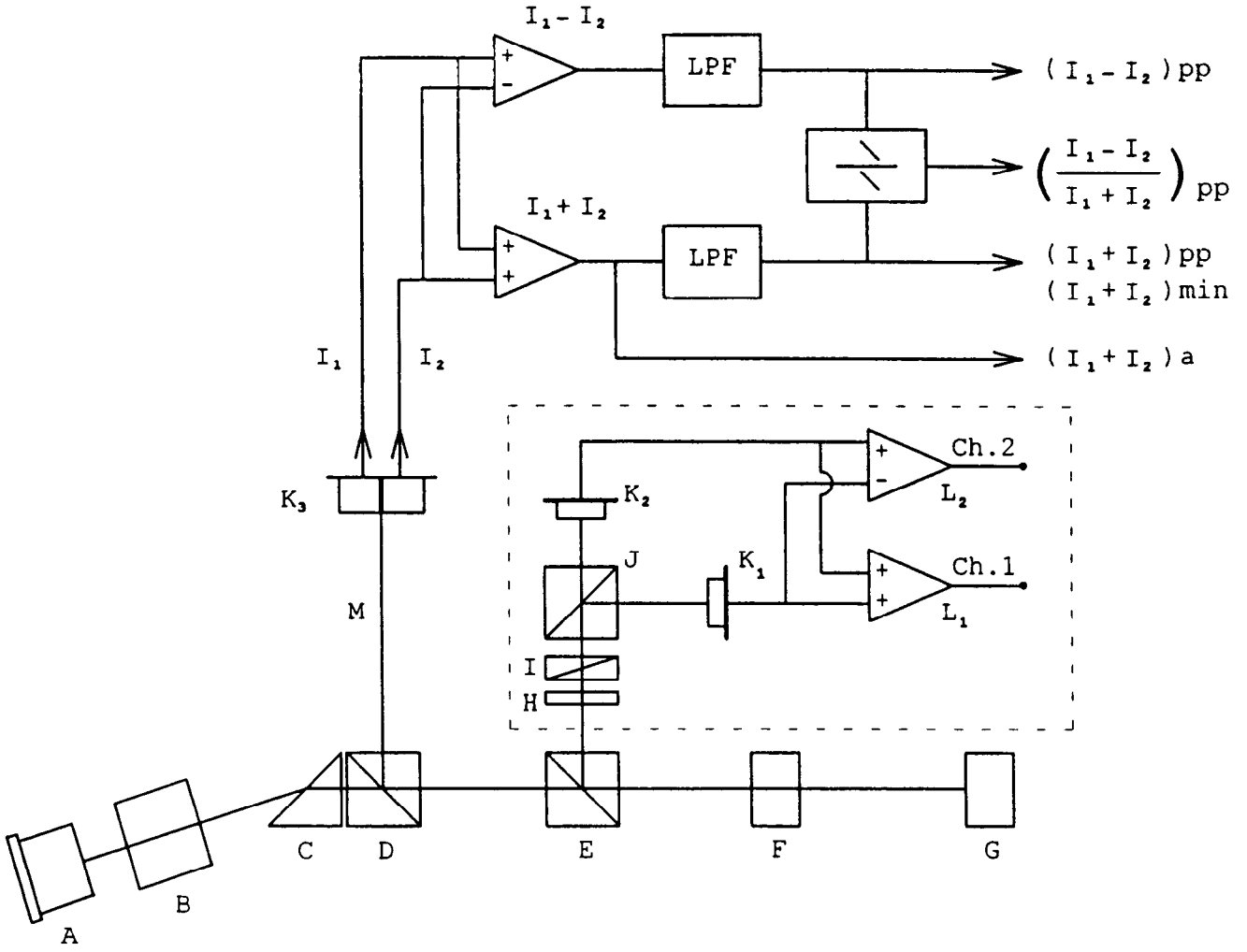

A	Laser diode	G	Optical disk
B	Collimator lens	H	Optional half-wave plate
C	Optional shaping prism	I	Phase retarder
Ch.1	Channel 1	J	Polarizing beam splitter
Ch.2	Channel 2	$K_{1,2}$	Photodiodes for channels 1 and 2
D	Beam splitter	K_3	Split photodiode
E	Polarizing beam splitter	$L_{1,2}$	d.c.-coupled amplifiers
F	Objective lens	M	Tracking channel (see 20.3)

Figure 12 - Optical head and read channel of the tester

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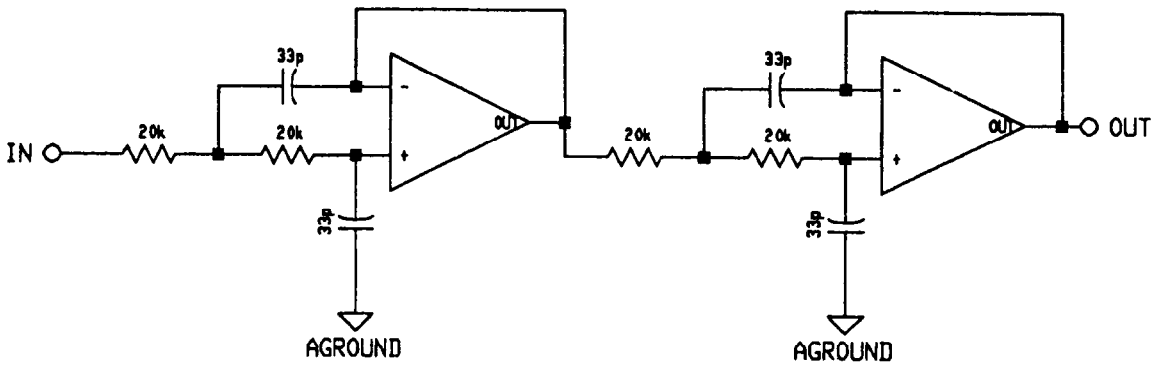

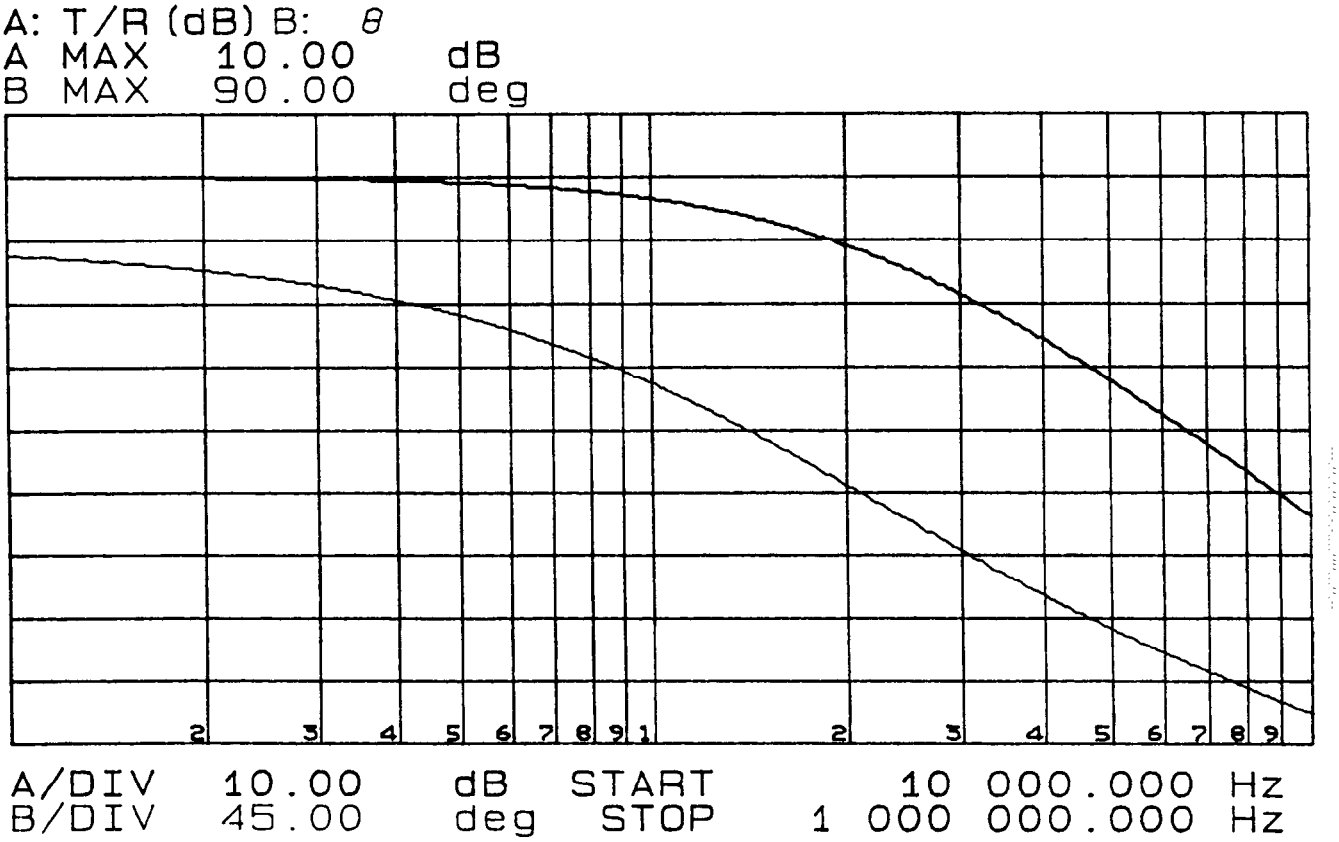

Figure 13 - An example of a Low-pass-filter (LPF)

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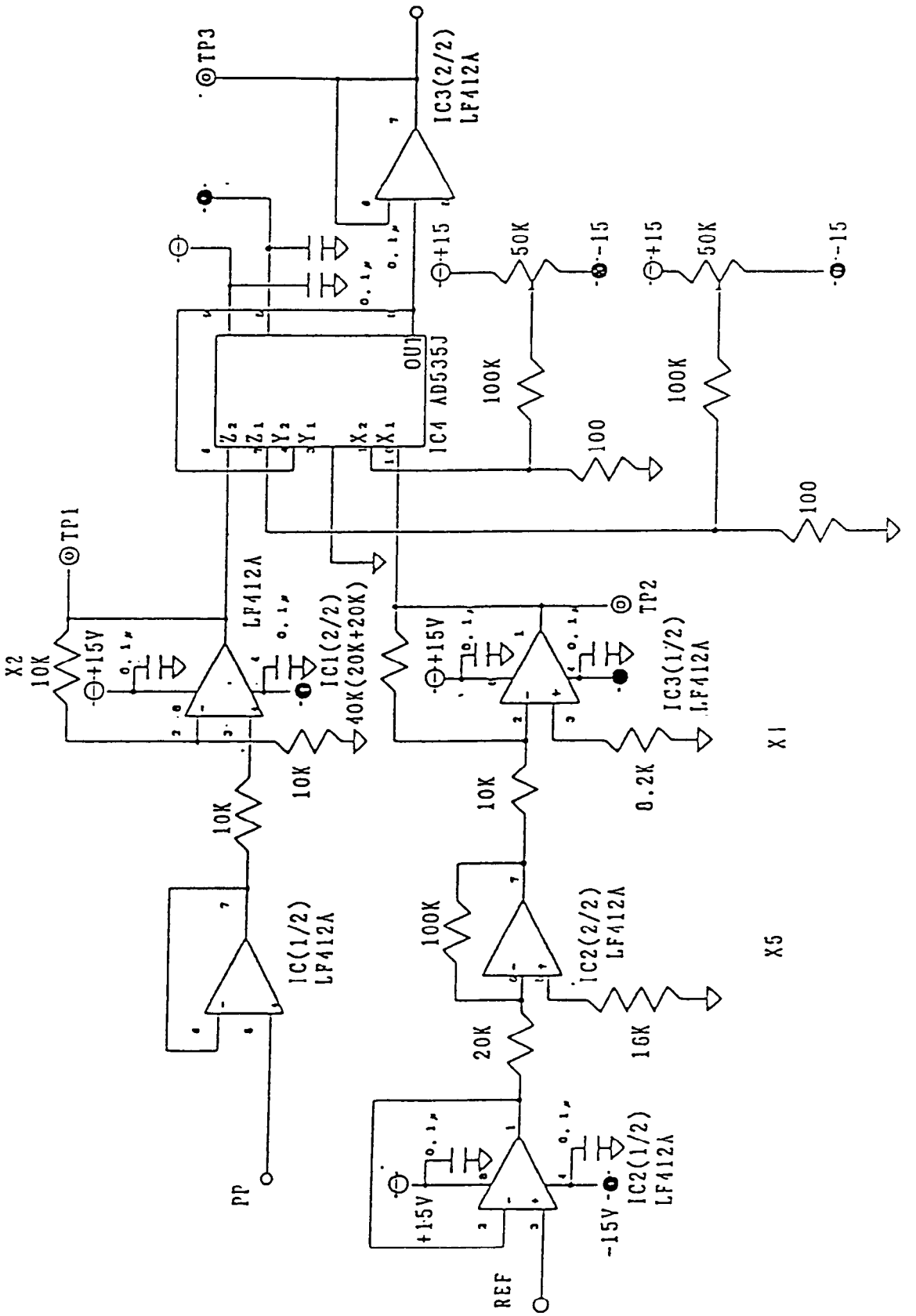

Figure 14 - An example of a dividing circuit

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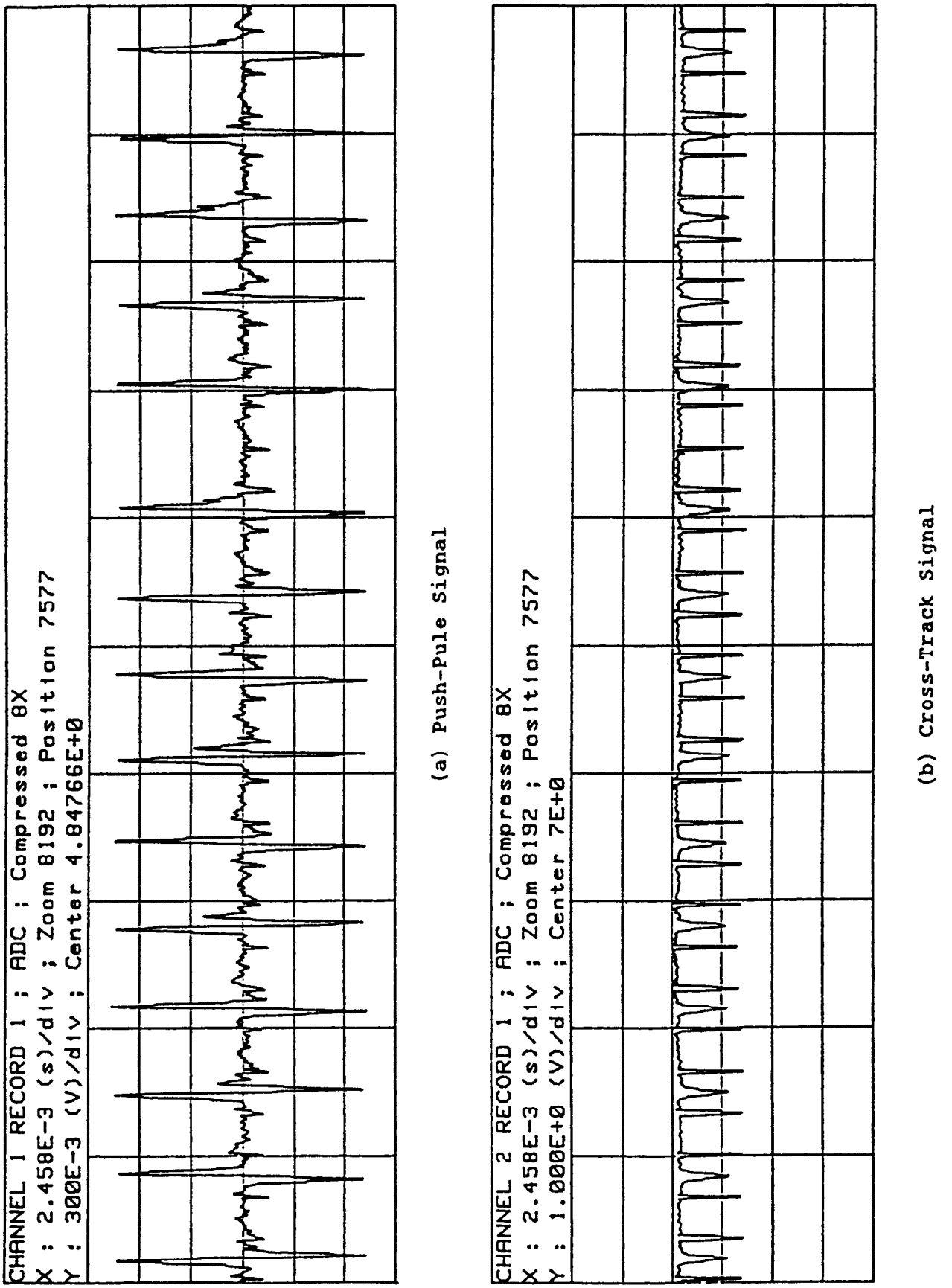

Figure 15 - Typical wave forms measured by the track jump method

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5.9 Read power

5.9.1 Definition

1. The maximum read power is the power which does not damage recorded marks under operating conditions.
2. The minimum read power is the power which gives an NBSNR value larger than 45dB.

5.9.2 Measurement conditions

1. Use measurement condition B (2.3)
2. Measuring area: See clause 3.4
3. Read pass: 10 million passes continuously on one track.

5.9.3 Measuring procedure

1. Erase three adjacent tracks.
2. Write a testing signal on centre track using the writing conditions.
3. Step 1 and 2 may be performed under testing conditions A.
4. Set the disk temperature at 50°C.
5. Set the read power to the maximum power specified in the control tracks.
6. Measure the initial NBSNR
7. Apply a magnetic field of 32 000A/m (Erase direction)
8. Perform 1 million read passes continuously with measuring NBSNR.
9. Extrapolate and estimate the final NBSNR for 10 million passes.

5.9.4 Analysis

1. If the value of NBSNR is not larger than 45dB or the difference of NBSNR values between the initial measurement and the final measurement is larger than 2dB, the disk has not enough read power margin (see figure 16).

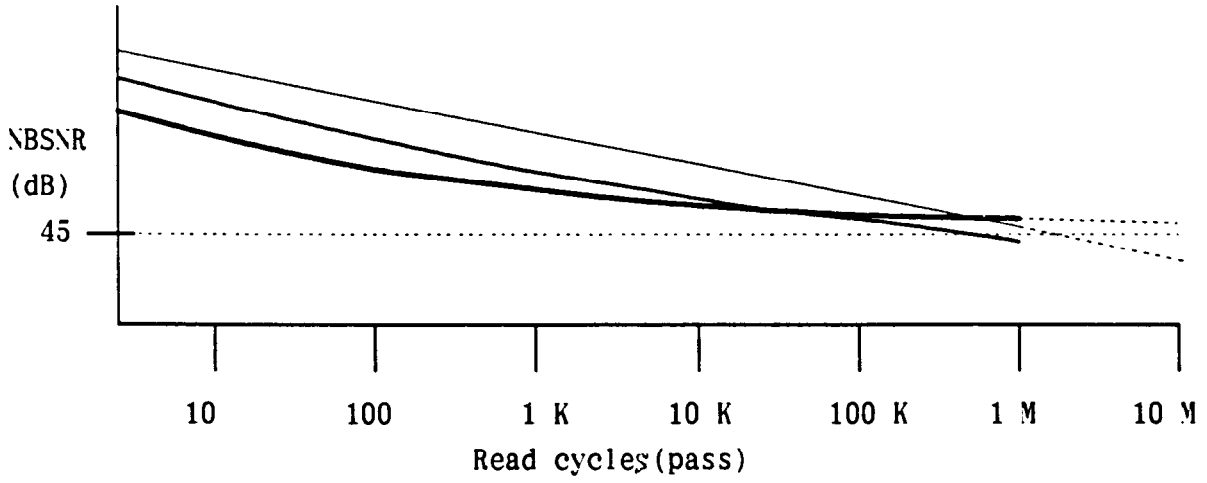

Figure 16 Read stability test

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5.10 Write power and erase power

5.10.1 Definition

The write and erase power specified in the control data is defined as follows;

1) The Narrow Band Signal to Noise Ratio of the MO signal is greater than 45dB,
2) The resolution of the MO signal is no less than 0,40,
3) The disk shall be written many times without damage of the recording layer,
4) The write power and erase power specified in the control data have ± 5 % margin for drives.

5.10.2 Measurement conditions

1. Use measurement environment C (2.3)
2. Measuring area : See 3.4
3. Write and erase cycle : 100 000 passes on one specified track. Less than 10 times/s

5.10.3 Measuring procedure

This test is as follows (Detail flow chart is given in annex A) :

1. Select marginal disks from the write sensitivity point of view from production disks. (See figure 17)
2. Set disk at the temperature of T1(23°C)
3. Measure write power vs NBSNR (see figure 17)
4. Determine write and erase powers tentatively
5. Do write and erase cycling test
6. Measure write power vs NBSNR again
7. Get write power margin at the temperature of T1
8. Set disk at the temperature of T2(50°C)
9. Repeat step 3 to 6
10. Get write power margin at the temperature of T2
11. Calculate preferable write power at the temperature of 23°C
12. See figure 18

5.10.4 Analysis

The typical results of the test described in 5.10.3 are explained in figure 17. The calculation example of the write power range at operating temperature is shown in figure 18.

Assuming that disks with the highest and the lowest power sensitivities within the allowed sensitivity ranges are tested, we get two curves the NBSNR and the Resolution (see figure 17 a.).

Write power range from P_L to $P_{U'}$ is the power for the NBSNR value no less than 45 dB and the Resolution no less than 0,4. This power range can be considered to have the smallest value for the unused disks; however the write power characteristics usually change during use due to effect of laser power radiation. It is recommended to consider this change in characteristics to determine power ranges. Figure 17b shows the possible write power characteristics after 1 000 000 cycles of erase and write. Both the NBSNR curve and the Resolution curve are expected to shift to lower power side. To get the worst write power range, we need to use the lowest power limit P_L obtained after cycle test. This results in the final write power range for the lifetime of the media considering the erase cycling of 1 000 000.

Note: Write power P_L is the write power which gives 45 dB of the disk NBSNR at the initial condition (before the cycling test). Write power $P_{U'}$ is the write power which gives 40% of the MO signal amplitude resolution at the initial condition (before the cycling test). Write power P_U is the write power which gives 40% of the MO signal amplitude resolution at the final condition (after cycling test). The range (a) is the actual write power range of the production media when considering cycling test.

The upper thick solid line (P_U to $0{,}95P_{U50}$) indicates the maximum write laser power which could be limited by the Resolution specified in ISO/IEC 10090. The lower thick solid line (P_L to $1{,}05P_{L50}$) indicates the minimum write laser power which could be limited by the NBSNR. The point C is the middle point of A and B at 50°C and the thin solid line is made beginning from the point C with gradient of 0,03 mW/°C. All thin solid lines and dashed lines have the same gradient of 0,03mW/°C. The point D is on this line at 23°C and it gives P_{23}. This technical report recommends to use P_{23} for the write power values to be recorded in the Control zone. If the lower solid line gradient is more than -0,03mW/°C (steeper in

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the graph), Case 2 can be used. In this case, the point E is the upper solid line at 50°C and the point F is the lower dashed line at 50°C respectively, and the point G is the middle point of E and F. The lower dashed line is made beginning from the point J at 50°C. The point H and D give P_{23} in the same way.

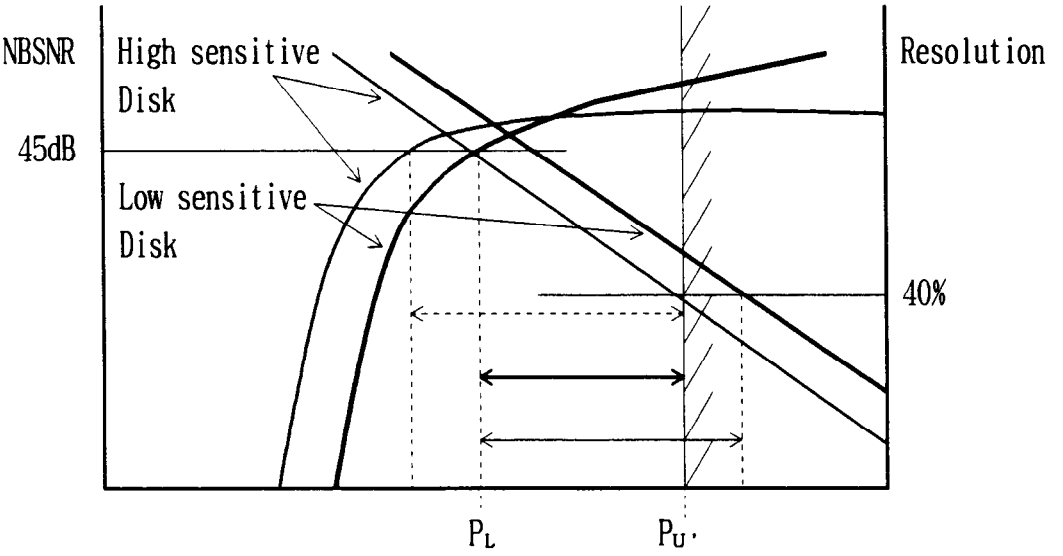

Figure a. Write power characteristics (Initial condition)

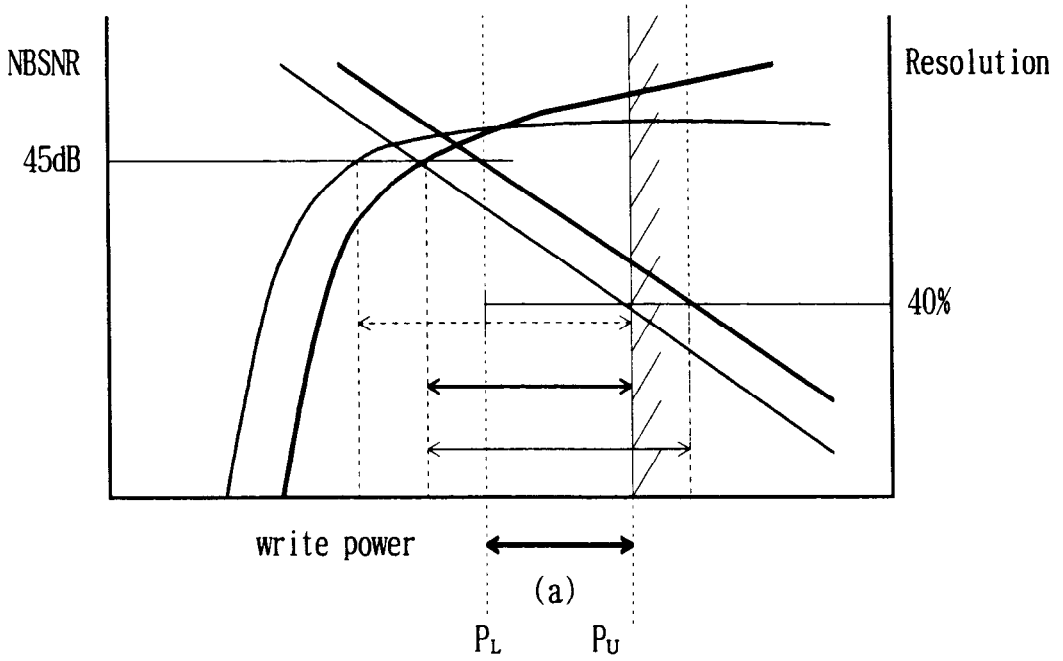

Figure b. Write power characteristics after 100 000 cycle test

Figure 17 - Write power characteristics

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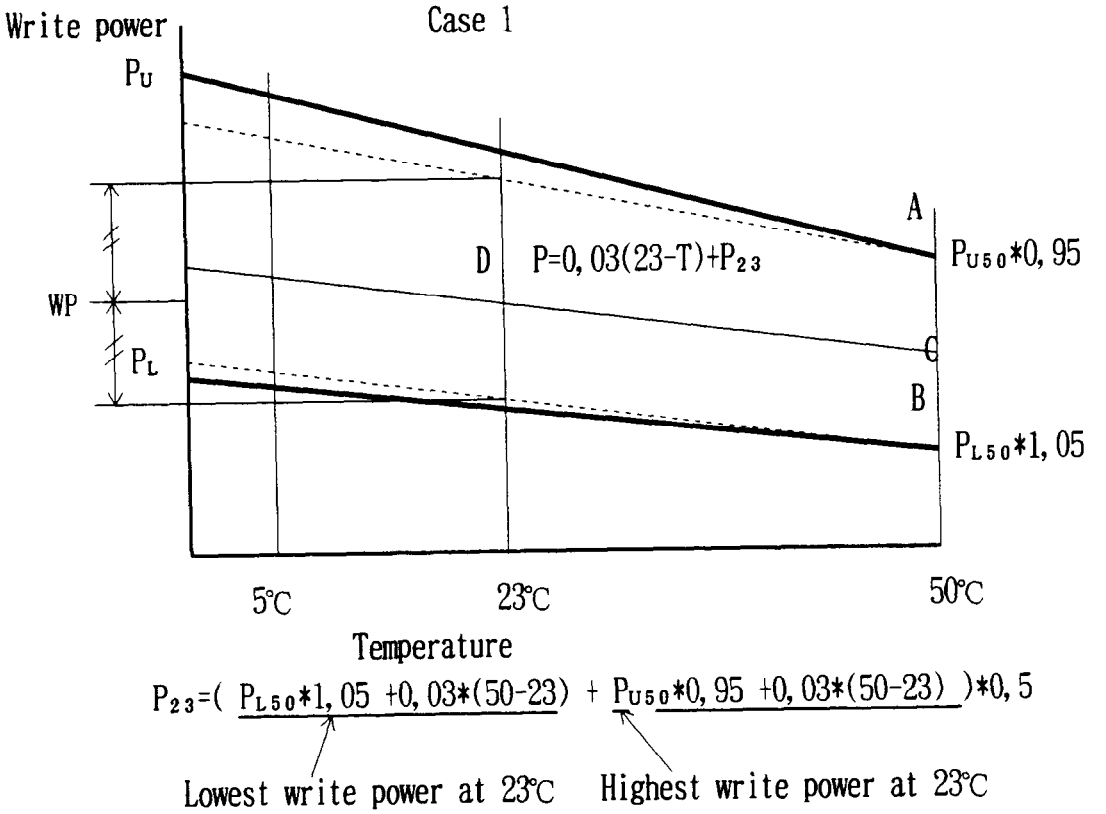

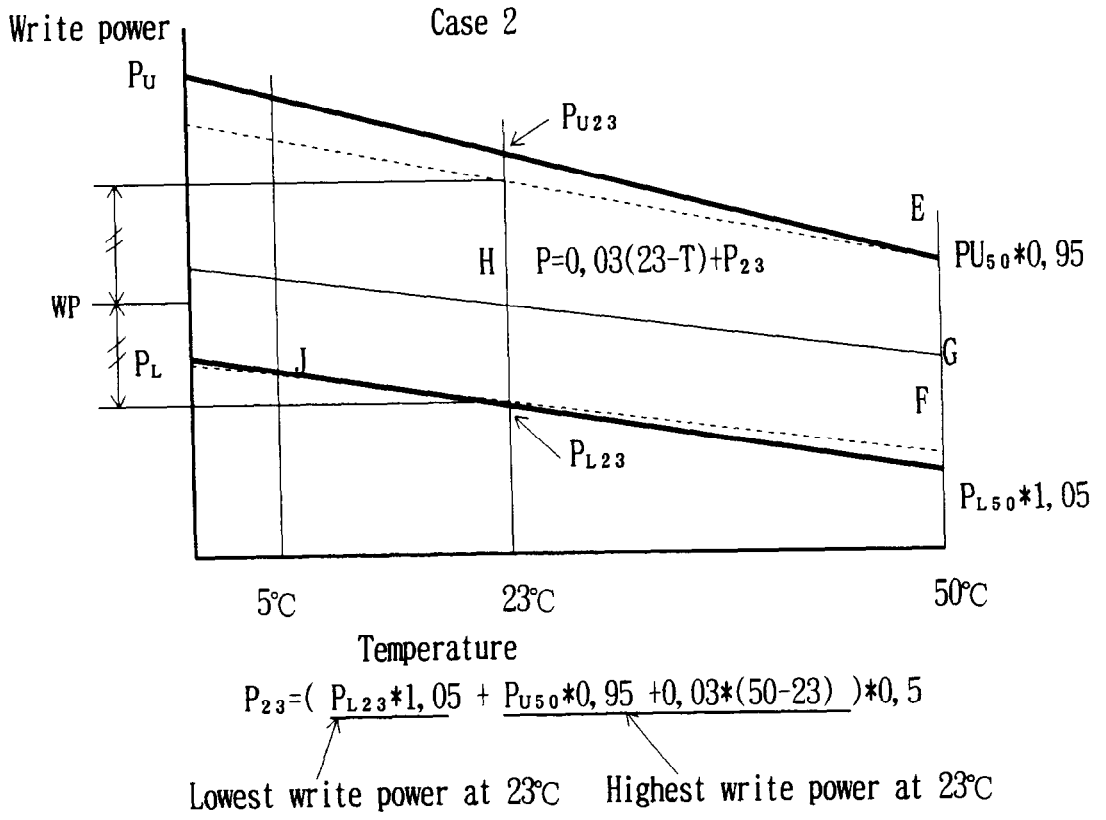

Figure 18 - Write power ranges at the operating temperature

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5.11 Imbalance of the magneto-optical signal

5.11.1 Measurement condition

Use measurement condition C.
Optical Pick-up: the phase difference of Optical Pick-up is 0°±5°

5.11.2 Measuring procedure

Note: If the imbalance is measured when using a low-pass filter, the duty of the written MO marks should be 50%, otherwise the value of imbalance has an unwanted d.c. offset. To avoid this problem, it is useful not to use a low-pass filter but to get a lower and upper envelopes curve. The imbalance of MO is the middle of upper and lower envelopes.

(See figure 19a.)

5.12 Narrow-Band Signal-to-Noise Ratio (NBSNR)

5.12.1 Definition

Accepted Industry Practice.

5.12.2 Measurement conditions

Use measurement environment A and B.
Optical Pick-up: the phase difference of Optical Pick-up is +15° and -15°

5.12.3 Measuring procedure

1. Spectrum analyzer condition

- Decide on the averaging times. It depends on the kind of Spectrum analyzer. The average of more than 100 measurements is enough for measuring the noise level, and the average of a few measurements is enough for measuring the carrier level (see annex B).
- Decide on the measuring noise level frequency. For measuring the point of noise level, the filter characteristics of the spectrum analyzer have to be taken into account. To avoid carrier level energy, at least 200kHz is needed between carrier level point and noise level points (see annex C).
- Get the compensation factor for noise level if needed. Each spectrum analyzer needs a few dB compensation (see annex D).
- Choose gated sweep or non-gated sweep. To avoid the noise from sector header pre-pits, it is useful to use gated sweep; pay attention to its characteristics (see annex D). If one uses a non-gate sweep spectrum analyzer, the noise level is approximately 1 to 2dB higher from the header noise.

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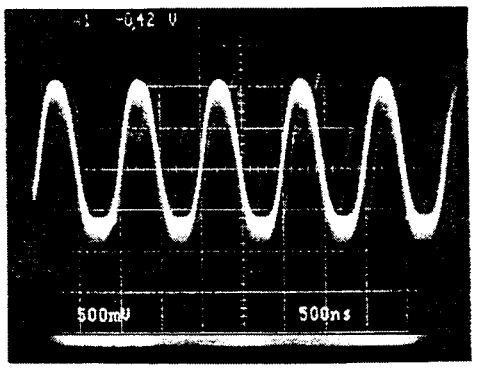
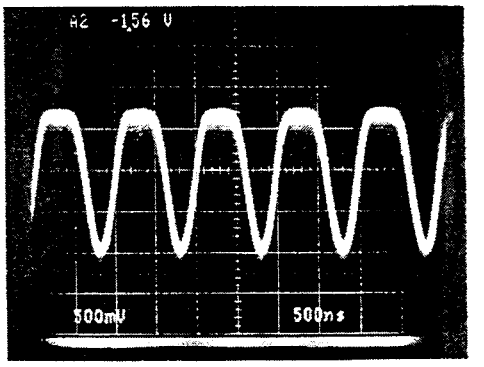
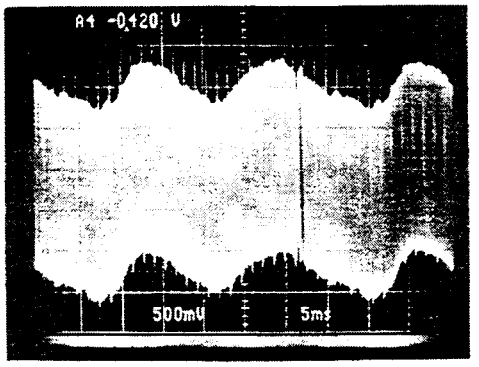
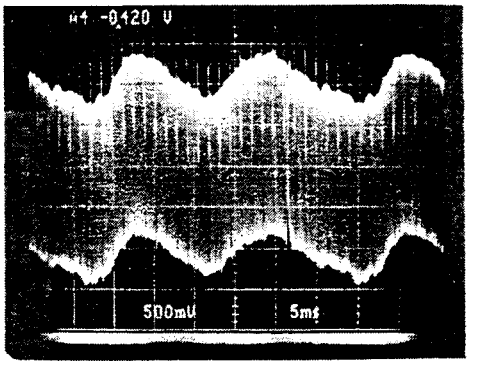




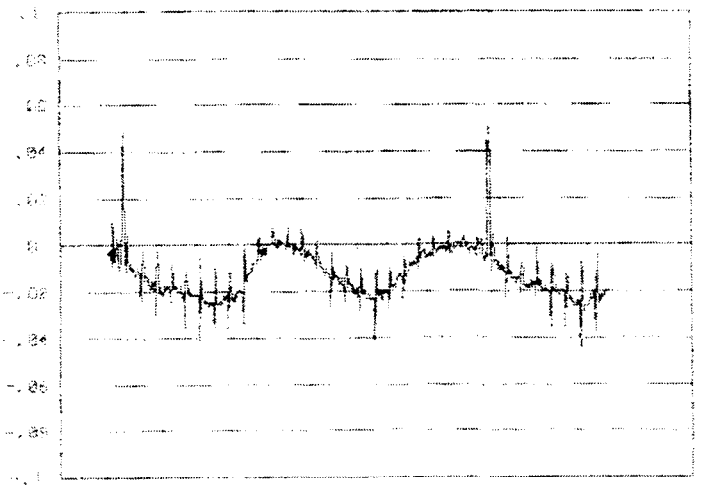


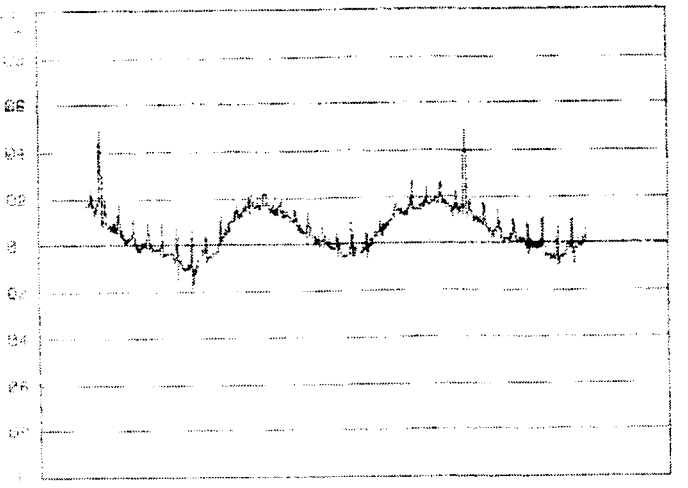


Recording Duty: < 50 %

Recording Duty: > 50 %

a. MO signal without Low-pass filter





Recording Duty : <50%

Recording Duty : >50%

b. MO signal with Low-pass filter

Figure 19 - Imbalance measurement with and/or without low-pass filter

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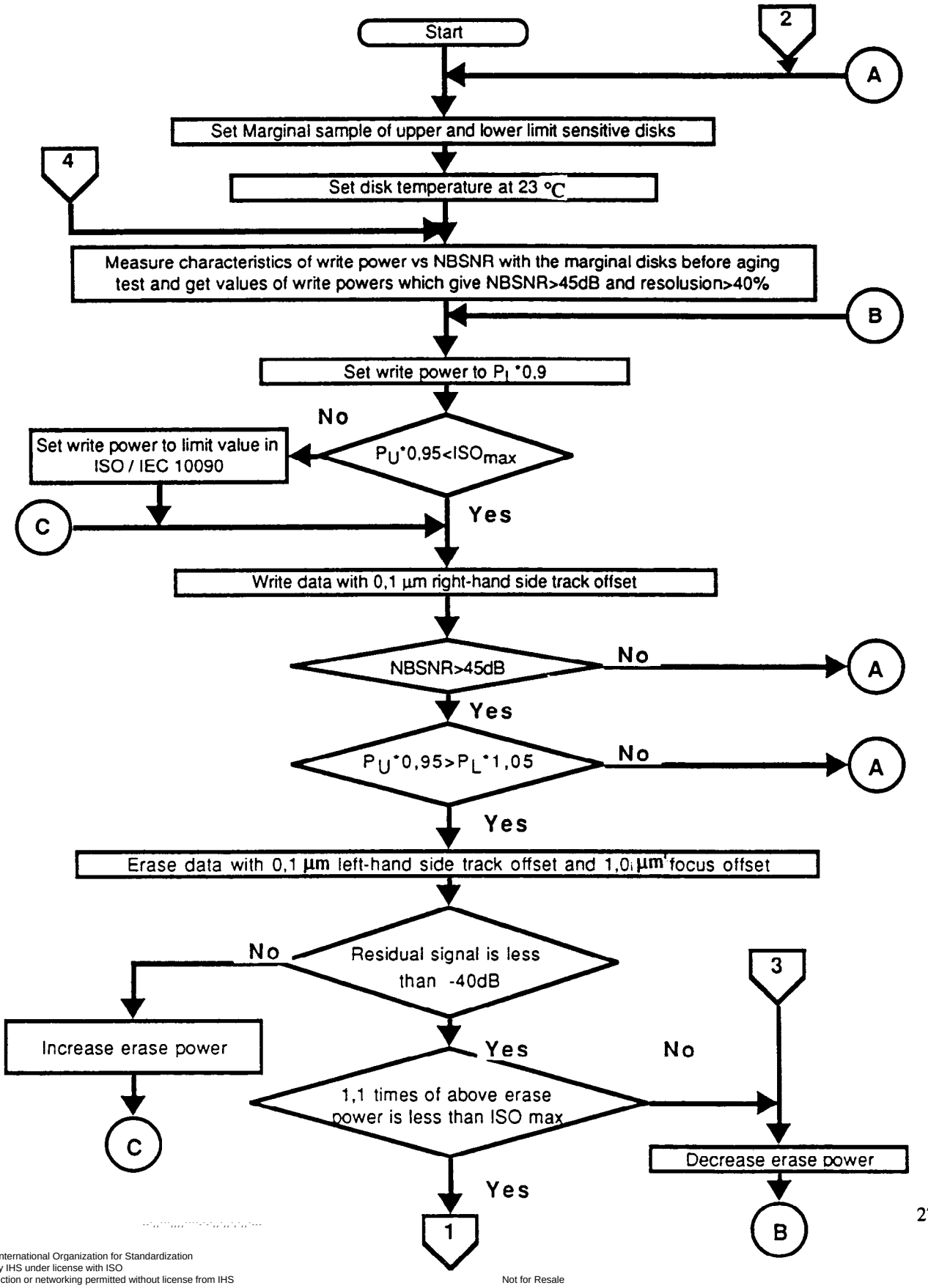
Annex A

The flow chart for determining write power and erase power



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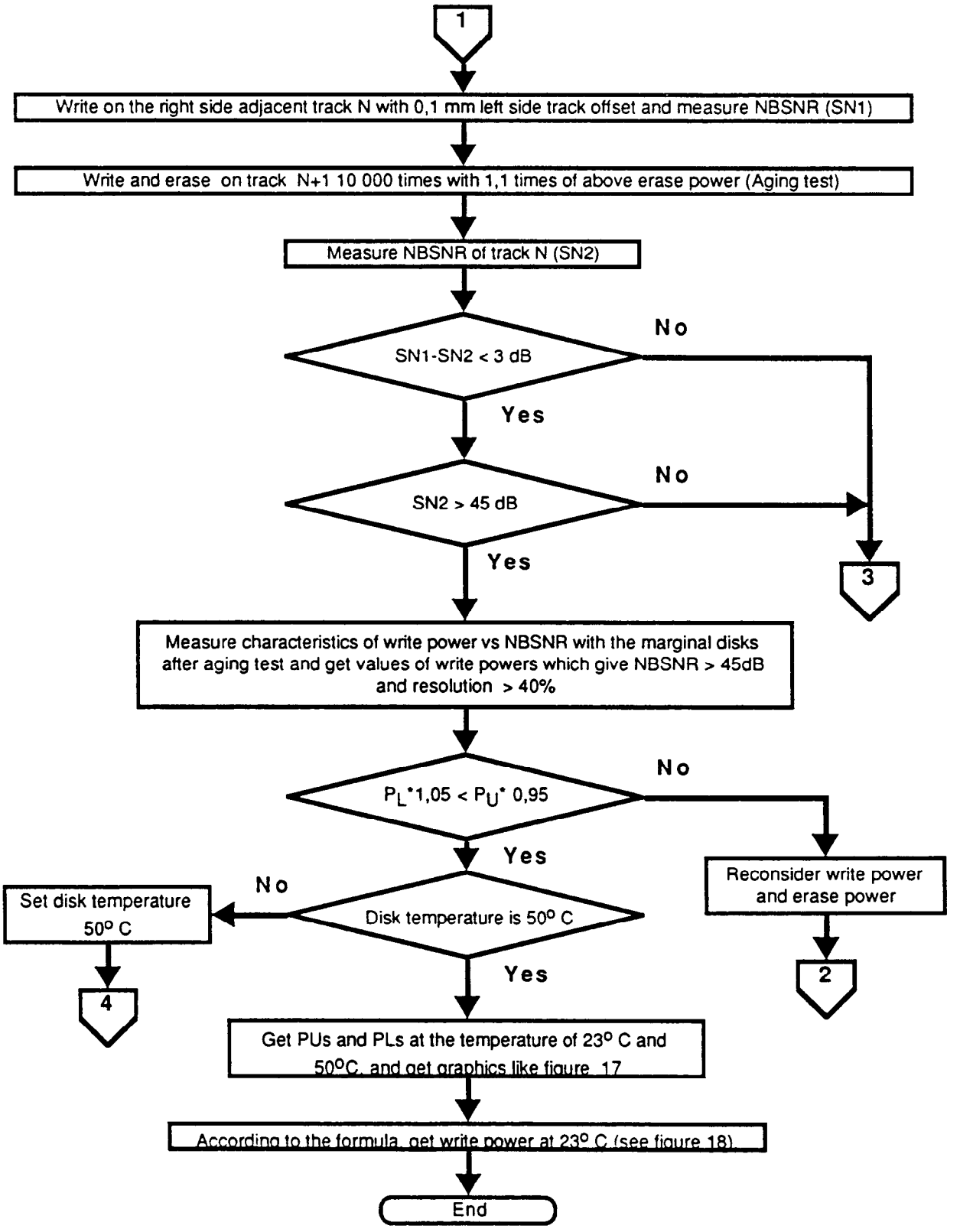

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Annex B

Averaging Times and Spectrum Analyzer Data

When measuring carrier level and noise level with a spectrum analyzer, stable measurement data can be obtained by repeated measurements (averaging times). Although the function of taking the root-mean square after 100 times is built into the spectrum analyzer, here we describe averaging time and reproducibility (stability) with respect to actual measurement data obtained with a typical spectrum analyzer. The spectrum analyzers used here were Hewlett-Packard's HP3585B and HP3589 and Advantests's TR4171. Figure B-1 shows the relationship between measurement averaging times and measurement error for each of these analyzers; the horizontal axis represents averaging times and the vertical axis the data's standard deviation(sigma, when taking 50 measurements). From these figures, we can see that the carrier level measurements for each analyzer sufficiently averages out after only 10 measurements. However, although noise level measurements are different for the various analyzers, 50 to 200 averaging times are needed for each of the three sigma's to fall below 1 dB. The number of averaging times should be selected taking into account the accuracy of the NBSNR measurement.

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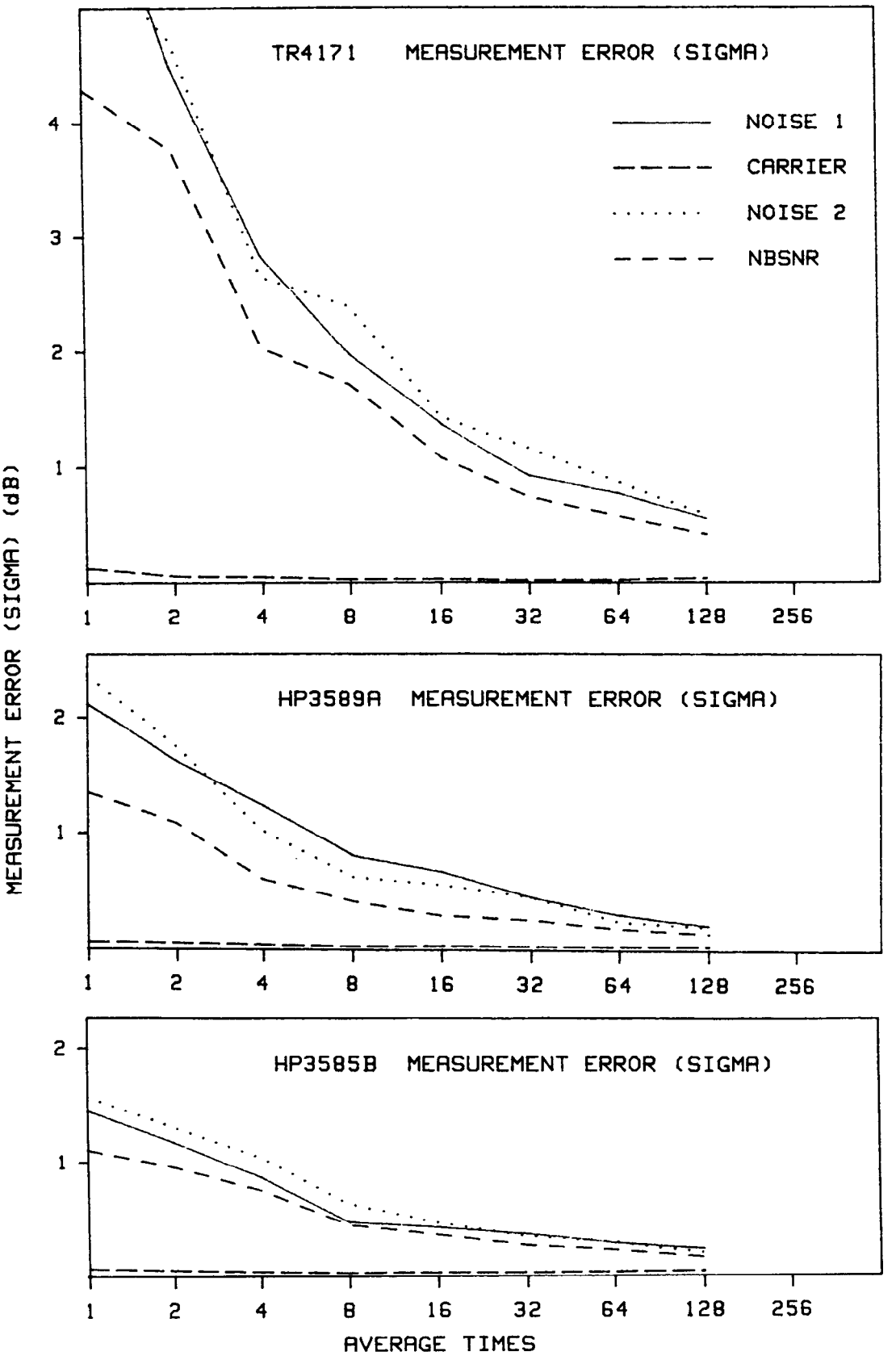

Figure B-1 - The relation between averaging times and measurement error

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Annex C

Measurement Frequency Point for Noise Level

To measure the noise level, a frequency range must be selected so that it has no influence from the carrier. The range over which the carrier level does not have influence depends on the shape factor of the spectrum analyzer's resolution bandwidth(RBW) filter and the phase noise of the local oscillator of the spectrum analyzer.

1. Effect of the resolution bandwidth filter skirt

   Following is an example of the effect by a RBW filter skirt on the noise level measurement when an 11:1(@60dB) shape factor is assumed. Relative to the carrier level, each of the following values is added to the noise level;

   0,5*RBW apart : -3 dB

   0,5*RBW*11 apart : -60 dB

   0,5*RBW*15 apart : -80 dB

   The calculated effect on the NBSNR measurement (for NBSNR 50dB) follows. The resulting values will be read as NBSNR instead of the correct value 50dB.

   0,5*RBW apart : -10*LOG(10exp(-50/10)+10exp(-3/10))=3 dB

   0,5*RBW*11 apart : -10*LOG(10exp(-50/10)+10exp(-60/10))=49,6 dB

   0,5*RBW*15 apart : -10*LOG(10exp(-50/10)+10exp(-80/10))=49,996 dB

   The RBW of 30kHz with the shape factor of 11:1 gives less than 0,4 dB error at 165kHz(11*30kHz/2) apart from the carrier. Less than 0,1 dB error is estimated at 200kHz from the carrier.

   See figure C.2, C.3 and C.4 for more detailed representation of the above.

   The shape factors(RBW 30kHz) of the typical spectrum analyzers are listed below.

   TR4171 11:1

   HP3585A/B 11:1

   HP3588/89A 4,3:1(17kHz BW)

Considering the above values, less than 0,1 dB error is expected at 300kHz apart from the carrier, whatever spectrum analyzer is used.

2. Effect of the phase noise

   Figure C.1 gives the typical/specified phase noise values of the typical spectrum analyzers for 30kHz bandwidth. If the phase noise is 20dB lower than the measured NBSNR value, then the error is about 0,04 dB. Since some spectrum analyzers have the value of -70 dB at several hundreds kHz offset, however, 60dB NBSNR measurement will have 10*LOG(1+10exp(60-70))=0,41 dB error. If the expected NBSNR value is close to 60dB, then a higher offset frequency (e.g. 1MHz) is recommended.

Note: The spectrum analyzer's noise floor could have an effect on the system noise floor measurements if the carrier level is low. It is recommended to check the spectrum analyser's noise floor by disconnecting the input to make sure that the spectrum analyzer's noise is not distorting the NBSNR measurement. The estimated error caused by the spectrum analyzer's noise floor is calculated to be(1+10exp((-NR)/10)) dB, where NR is the ratio (dB) of the input noise and the spectrum analyzer's noise floor.

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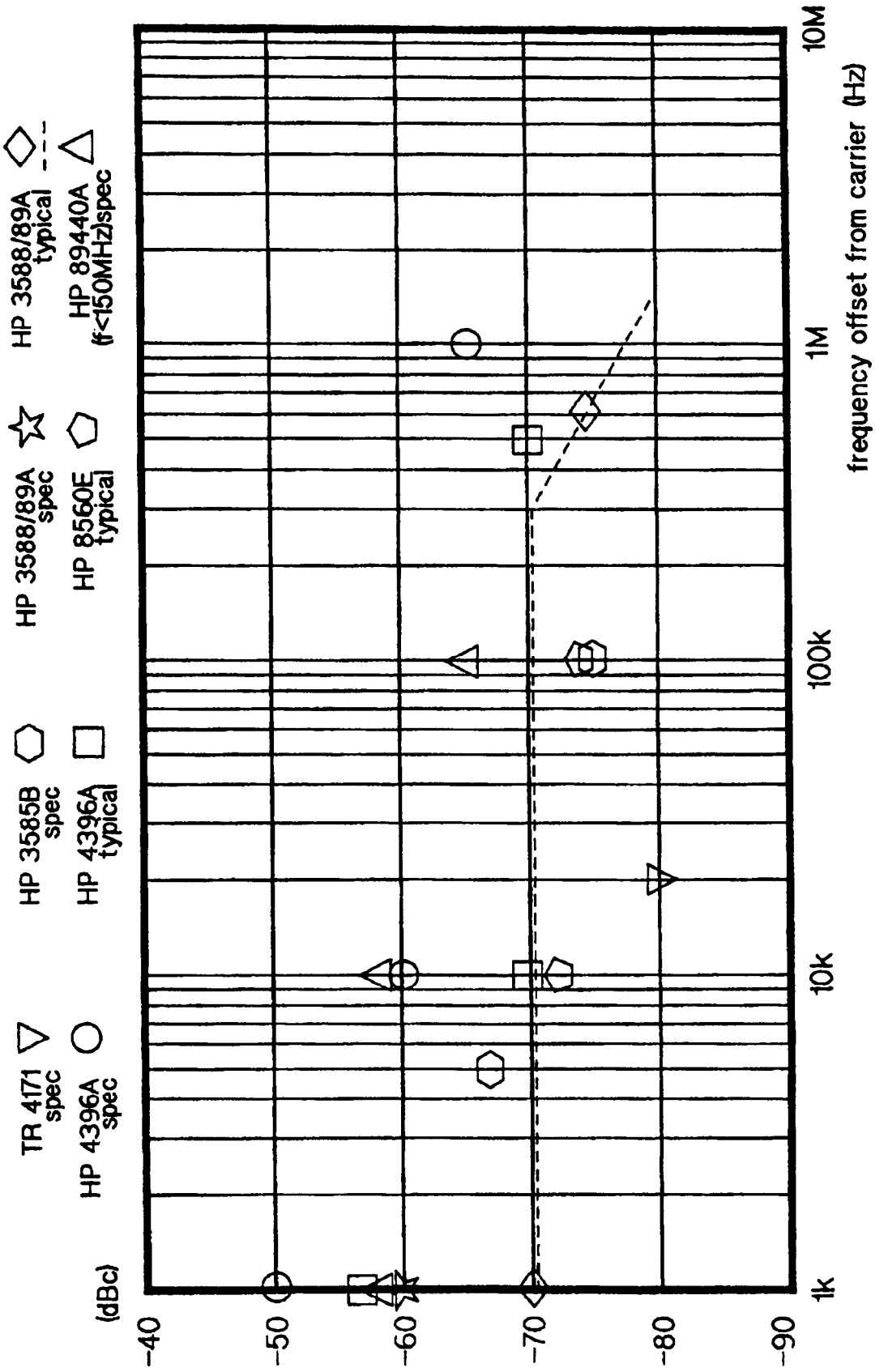

Figure C.1 - Effect of phase noise on close-in NBSNRmeasurements (Normalized to 30KHz Band width)

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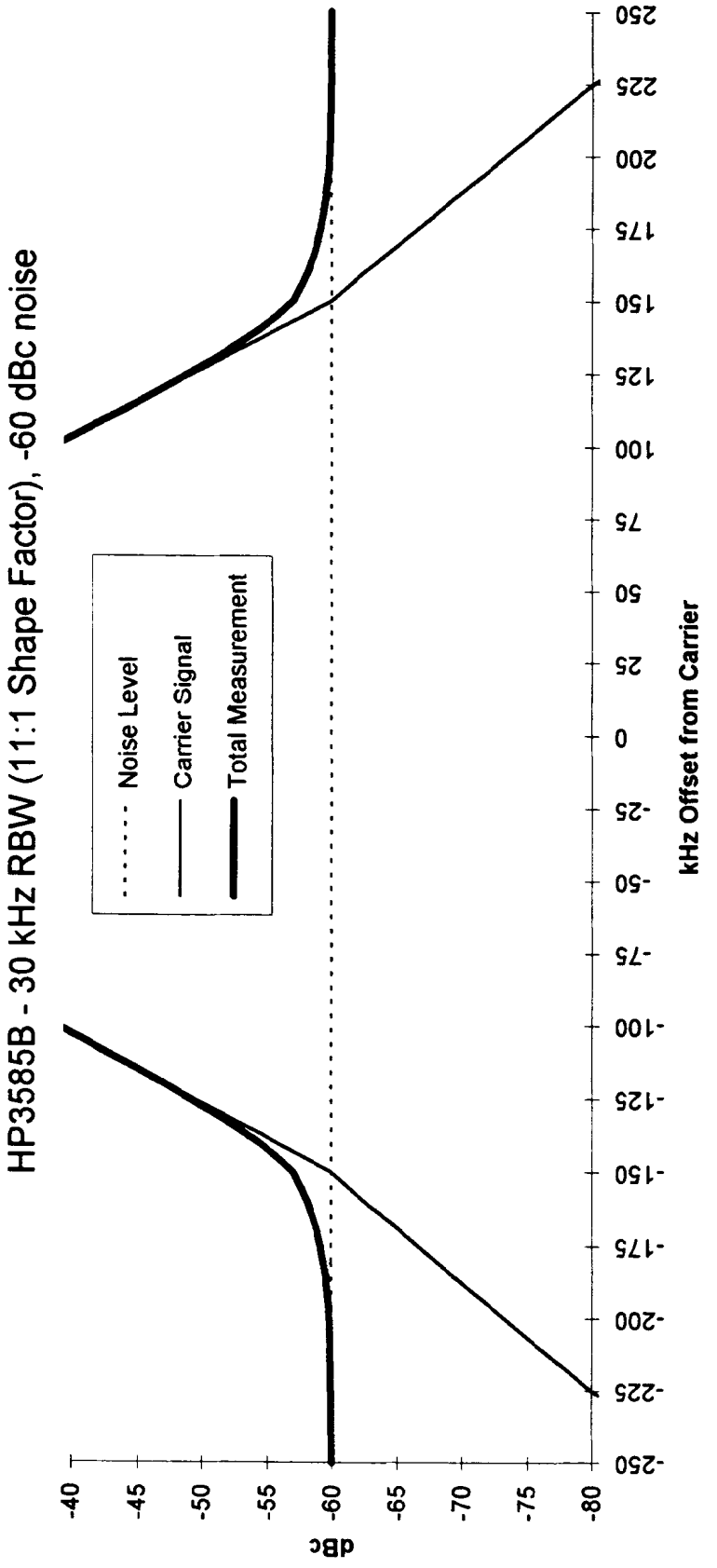

Figure C.2 - Effect of RBW shape factor on close-in NBSNR measurements

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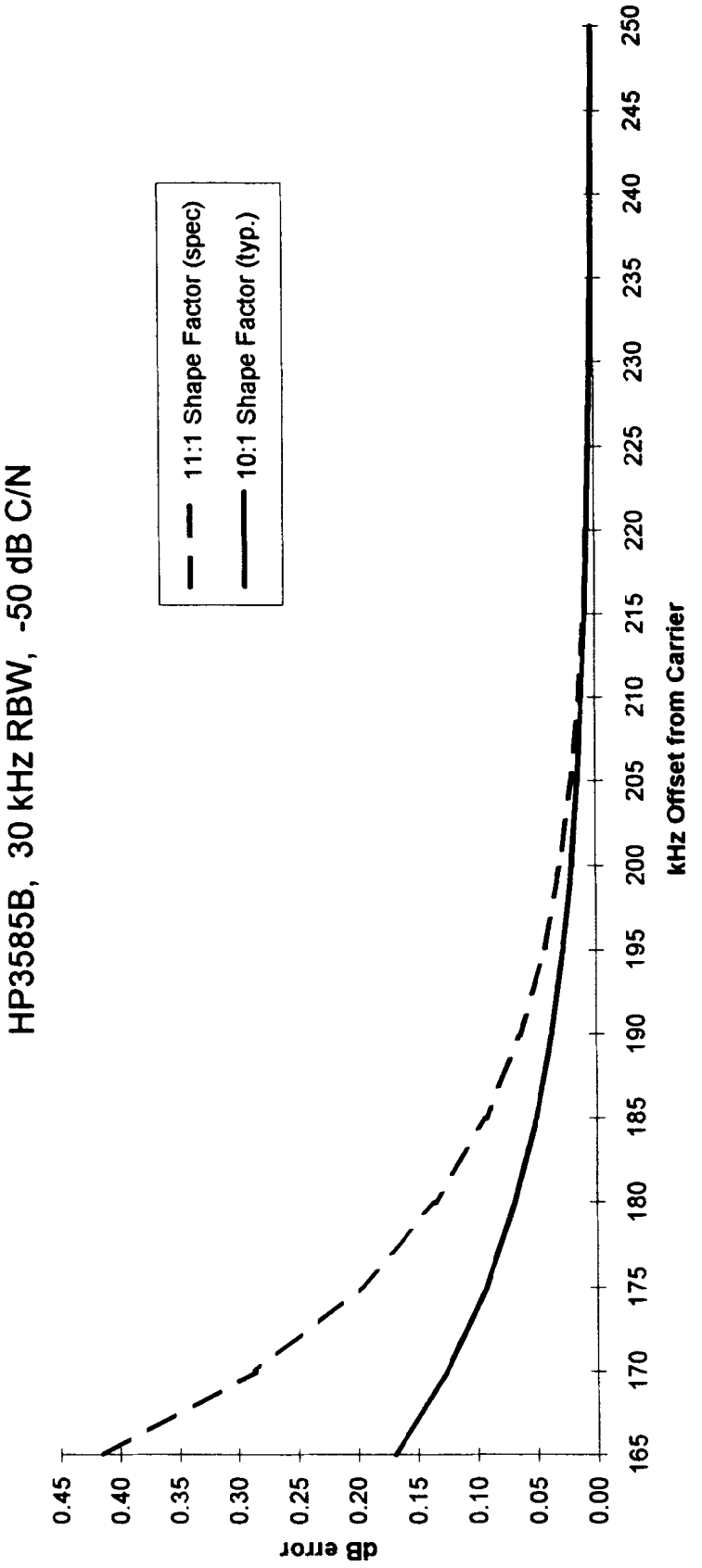

Figure C.3 - Effect of RBW shape factor on close-in NBSNR measurements

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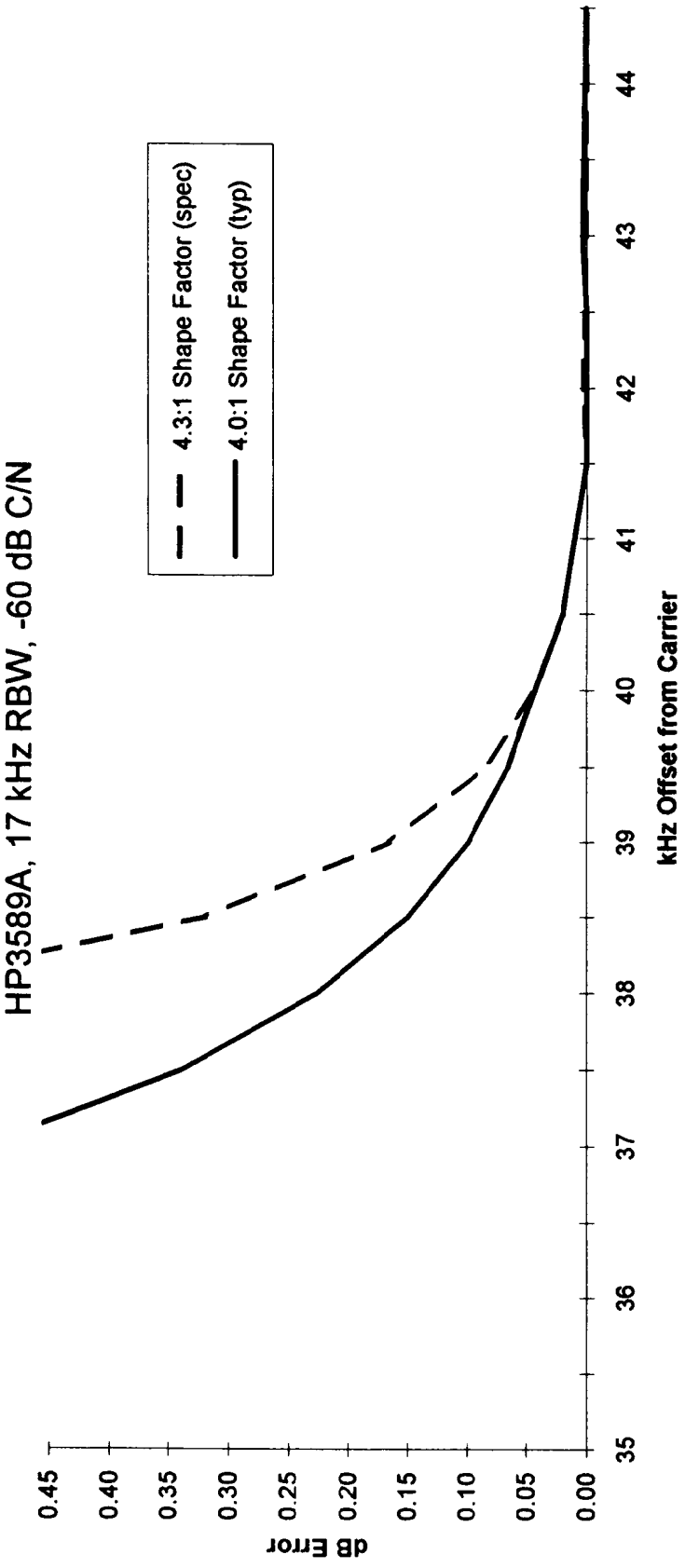

Figure C.4 - Effect of RBW shape factor on close-in NBSNR measurements

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Annex D

Notes on Measuring Noise Level

D.1. Possible error factors on noise measurements

Noise measurements have the following possible error factors.

a) Log IF detection (D.2.1)

b) Equivalent noise bandwidth (ENBW)(D.2.2, D.3.2)

c) Scale fidelity (D.3.1)

d) Peak detection (D.3.3)

a) can be compensated by using table D.1

b) can be compensated by using table D.1 but still has some error corresponding to the band width accuracy

c) can not be compensated and remains as a residual error

d) can be eliminated by using an appropriate setting of a spectrum analyzer

D.2. Noise level compensation.

D.2.1 Log IF detection compensation

Noise level measurement using a spectrum analyzer with log IF detection requires compensation. When the noise is Gaussian, which is mostly the case, the log IF detection causes a measurement error by the factor of 2,51 dB

D.2.2 Equivalent Noise Bandwidth (ENBW) compensation

The ENBW is not necessarily equal to the resolution bandwidth (RBW). Since the noise level does not correspond to RBW but ENBW, compensation is necessary to get the noise level for 30kHz equivalent band width. ENBWs of various spectrum analyzers are given in Table D.1.

D.2.3 Table of compensation factors

Table D.1 gives the compensation factors of the typical spectrum analyzers to get the accurate noise values for 30kHz equivalent noise bandwidth.

Table D.1 Compensation values for NBSNR measurements

	detection	RBW	ENBW	30kHz/ENBW	total
TR4171	LOG(2,51 dB)	30 kHz	36,0 kHz	-0,79 dB	1,72 dB
HP3585A/B	LOG(2,51 dB)	30 kHz	33,3 kHz	-0,45 dB	2,06 dB
HP3588/89A	LINEAR(0 dB)	17 kHz	18,1 kHz	2,19 dB	2,19 dB

The "total" compensation values mean "how much better the noise looks" on the spectrum analyzer's display than it actually is.

For example, if the displayed noise level is -70dBm on the HP3585B, the compensated value will be -70dBm+2,06dB=-67,94 dBm. Or, if the NBSNR appears to be 50dB on the HP3585B, the compensated NBSNR will be 50dB-2,06dB=47.94 dB

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D.2.4 Noise marker measurement

There is another way to get the 30kHz equivalent noise power. That is to use the noise marker. Most of the spectrum analyzers have a noise marker function. It calculates the noise power per Hz including the above compensation. In order to get 30 kHz bandwidth equivalent noise power, 10*LOG(3000)=44,8 dB should be simply added to the marker value.

Note: It should be made sure that there's no spur signal at the noise marker frequency.

D.3. Noise measurement accuracy

Even though the noise level is compensated correctly, the resulting value still has uncertainties as is described below.

D.3.1. Scale fidelity

"Scale fidelity " is the uncertainly (non-linearity) of a relative value of two different data points. For example, if the carrier is read to be -10 dBm and the noise value after compensation is -60 dBm, the difference 50 dB has an error within the specified scale fidelity. If the scale fidelity is specified
to be less than 0,5 dB, the value 50dBc may have an error of ±0,5 dB.

Note: The term "amplitude linearity" is used instead of "scale fidelity" in some spectrum analyzers' data sheets.

D.3.2. ENBW accuracy

The resolution band width usually has ±10% to ±20% accuracy. Since the ENBW is strongly related to the RBW, the ENBW also has the same accuracy. This corresponds to 0,46 to 0,97 dB noise measurement error. Measuring the ENBW of the spectrum analyzer and using the measured value instead of using the value in table 1 will reduce this error.

Note: The HP3588/89A has a digital RBW filter whose bandwidth is so accurate that this error is negligibly small.

D.3.3. Peak detection error

If the relationship among the span, the RBW, the VBW (Video Bandwidth) and the sweep time is not appropriate, a peak detection error occurs and the measured noise level becomes higher than it actually is. In order to make this error small enough, follow the instruction below. The span should be smaller than the number of display points times RBW/4. For example, if the number of display points is 1000, the span should be less than 1000*30kHz/4=7,5 MHz. Sweep time should not be any longer than the "AUTO" sweep time. Also, narrower VBWs give better noise measurements. Reduce the VBW until there is no noise level change. Usually, VBW of less than 100 Hz doesn't give this error. Using the noise marker is another way to avoid this situation.
For more detail, see Annex G "Measuring noise with the HP3585A/B".

D.4. Cautionary notes on Gated sweep

When measuring NBSNR, gated sweep is generally recommended because of the necessity of the exclusion of the pre-pit region. However, the following should be noted regarding gated sweep.

D.4.1. Recommended gate length

For a short gate length, measurements can not be performed correctly due to the RBW filter and VBW filter settling time. Using both the RBW and the VBW wider than 2/tp is recommended so that both of the RBW and VBW filters are settled before the data is taken, where tp is the time length of the available signal.

D.4.2. Internal time delay of a spectrum analyzer

The timing of the gate can be defined arbitrarily by adjusting the gate delay and the gate length. However, it should be noted that the measured data does not necessarily correspond to the information of the input data at the defined gate timing due to the internal delay of the spectrum analyzer.
The internal delay of a spectrum analyzer is estimated to be between 1/RBW and 2/RBW depending on the filter shape. In other words, with 30kHz RBW filter, the spectrum analyzer takes the information of the input signal preceding the given gate by about 33μsec to 66μsec.

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Annex E

Example of measurement procedure of signals from grooves

(Radial-track-servo-off method)

This annex shows an example to measure the amplitude of the signals from grooves using Radial-track-servo-off method.

E.1 Gathering of the signal dataStore the signal wave form A={f{n)}, for example Cross-track signal, when crossing tracks. See figure E.1.(a).

E.2 Detection of ID field interference from the dataID field data may interfere with the gathered signal wave form. Therefore, the interference should be deleted.

1) ID field detection

The ID field has the modulated signal and has higher frequency components than groove related signals. So, the ID field can be easily separated from groove related signals by using the second order difference of the gathered signal train {f(n)}. See figure E.1 (b) and E.1 (c).

First order and second order difference are calculated as follows:

$$\Delta f(n)=f(n+1) - f(n)$$

$$\Delta^2 f(n)=\Delta f(n+1)-\Delta f(n)$$

Time n is set as time n_0, when $|\Delta^2 f(n)|$ is maximum. Calculate the variance of $\Delta^2 f(n)$ in the range (65 μs) correspond to ID period including n_0. Determine the period which has the maximum variance as ID field. All ID fields can be calculated periodically from the last determined ID field.

2) Interpolation of wave form A

Interpolate the wave form A by straight lines for all field periods. The interpolated wave form is named A'. See figure E.1.(e).

E.3 Amplitude calculations

At first, calculate the time train {m} when the wave form A' crosses the average line of the wave form. Groove related signal has a sinusoidal wave form with varying periods when the spot crosses track having eccentricity. The peak or bottom of the wave form positions near the center between m_{i-1} and m_i. Therefore, find the peak f_{maxi} or bottom f_{mini} of the wave form in the range of $[(m_i+m_{i-1})/2 \pm (m_i-m_{i-1})/10]$, excluding ID fields. The amplitude V_i' is usually less at the turning point due to eccentricity when $\Delta T_i(=m_i-m_{i-1})$ changes from + to - or from - to +. Therefore amplitude train $\{V_i'\}$ should be deleted from the train $\{V_i\}$. The maximum and minimum amplitude in the train $\{V_i\}$ excluding $\{V_i'\}$ shall be in conformance with the Standard.

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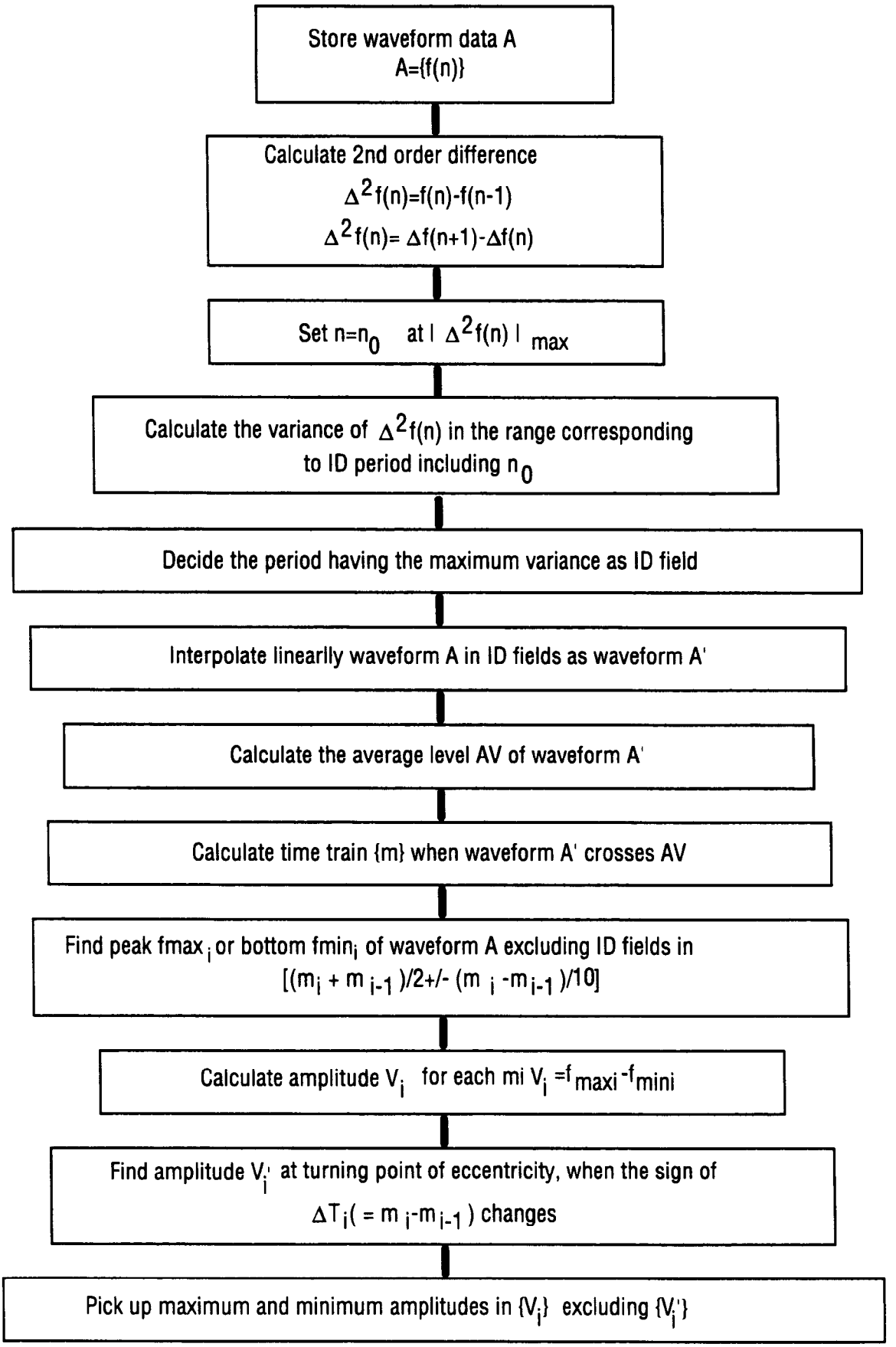

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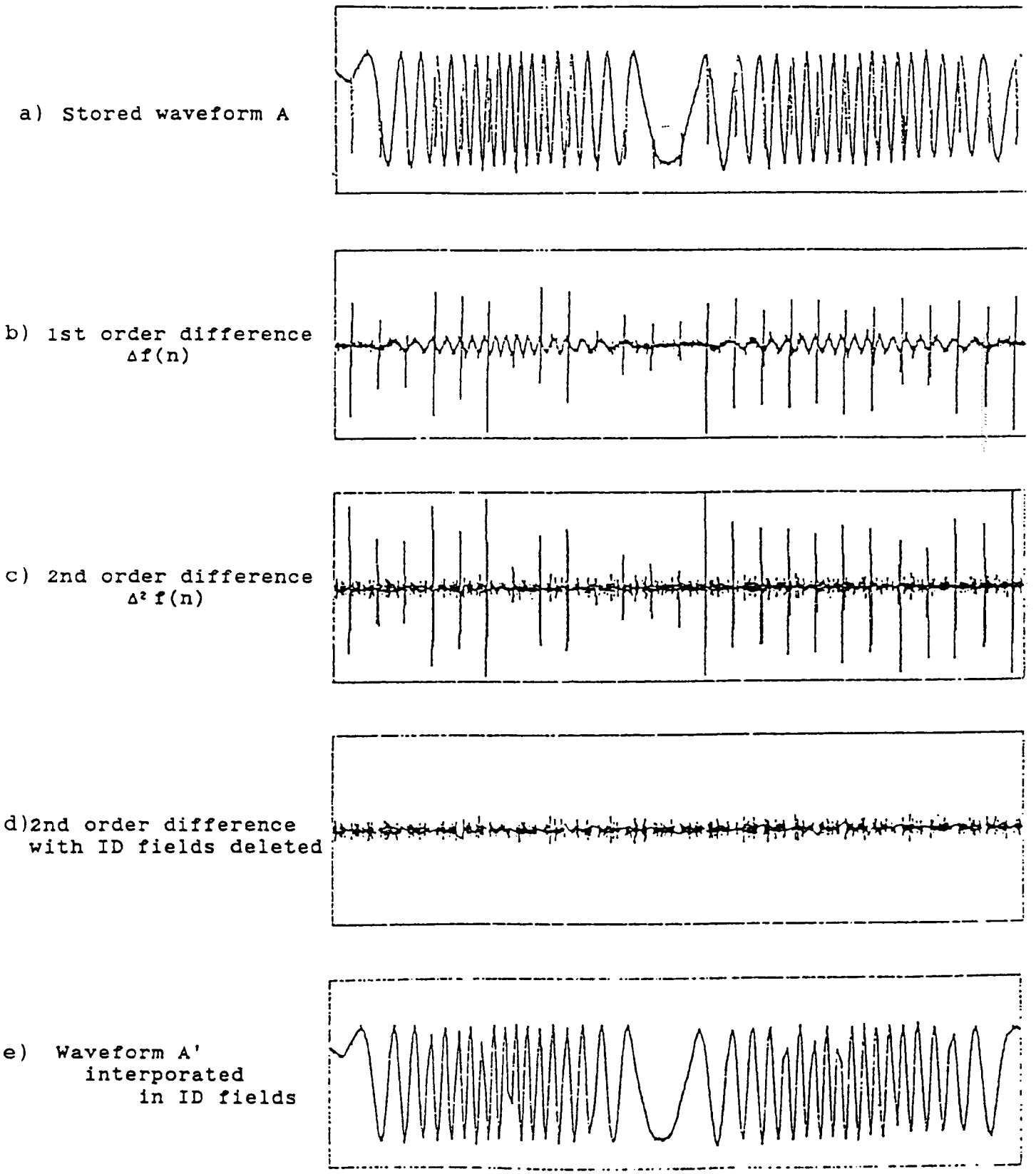

Figure E-1 typical wave form of Cross-track signal.

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Annex F

The Measuring Method of The Capture Cylinder Radius for the Hub

The definitions for the capture cylinder radius is described in the ISO/IEC 10090. However, the definition of the radius of the capture cylinder is complicated, because it is imaginary cylinder which includes many tolerances of the dimensions of case and drive as shown in figure 1. This report explains the measuring and calculation method.

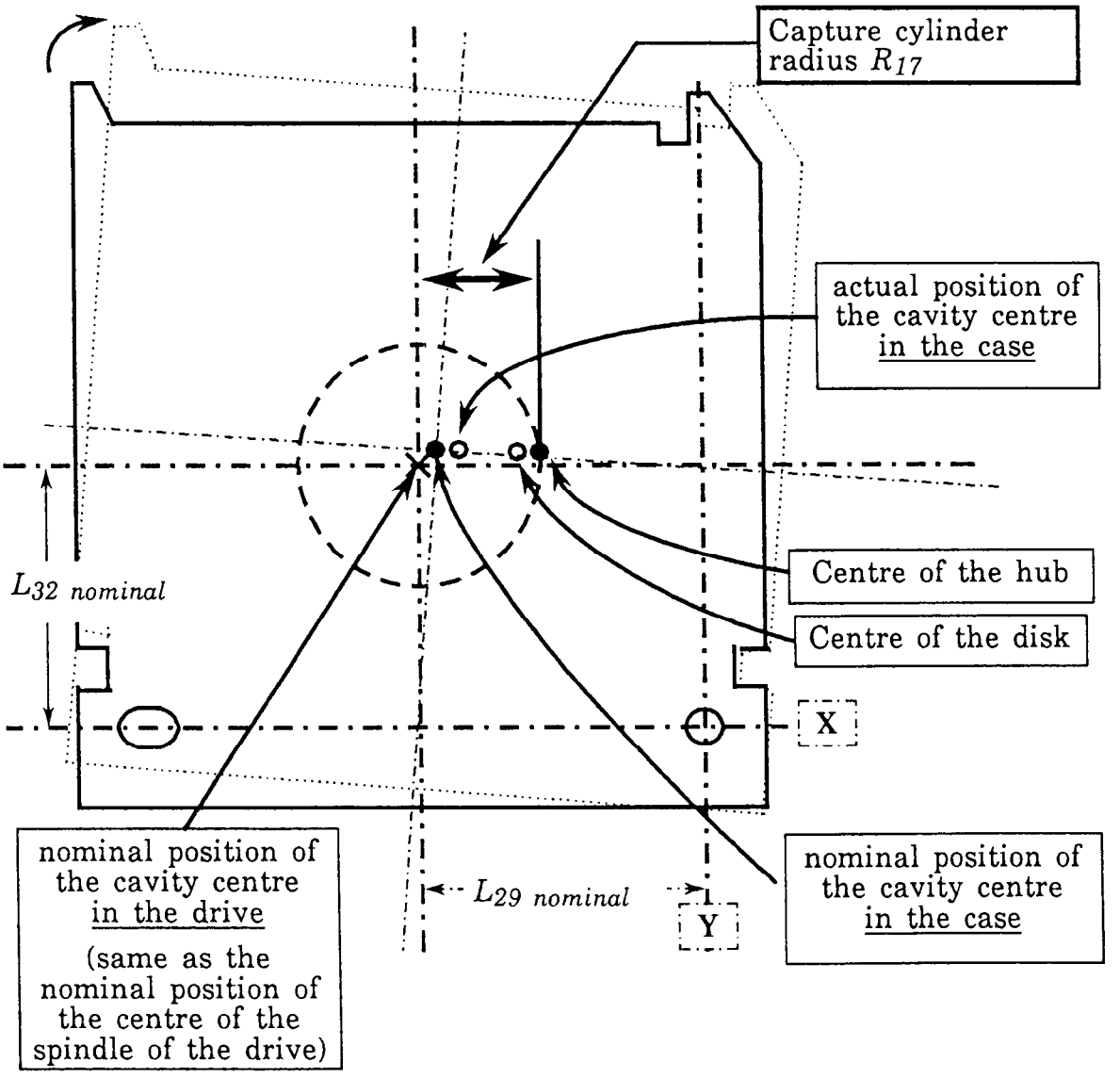

Figure F.1 - The worst case of the capture cylinder radius (R_{17})

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[I] Capture cylinder radius in some cases

(1) Ideal condition (R_0)

In the following ideal conditions, a locus of the centre of the hub draw a cylinder, and its centre is given by the nominal valu of L29 and L32 in the cartridge.

(a) The centre of the spindle of the drive is set to just the same position as the nominal values of L_{29} and L_{32} from the location pin.

(b) The centre of the disk cavity wall of the case is just the same position as the nominal values of L_{29} and L_{32}

(c) The centre of the hole in the hub is just the same position as the centre of the disk (but not necessarily to be the centre of the groove).
In this case, the radius of this cylinder (R_0) is expressed by equation (1).

$$R_0 = \text{Cavity radius} - \text{Disk radius} \quad \cdots\cdots (1)$$

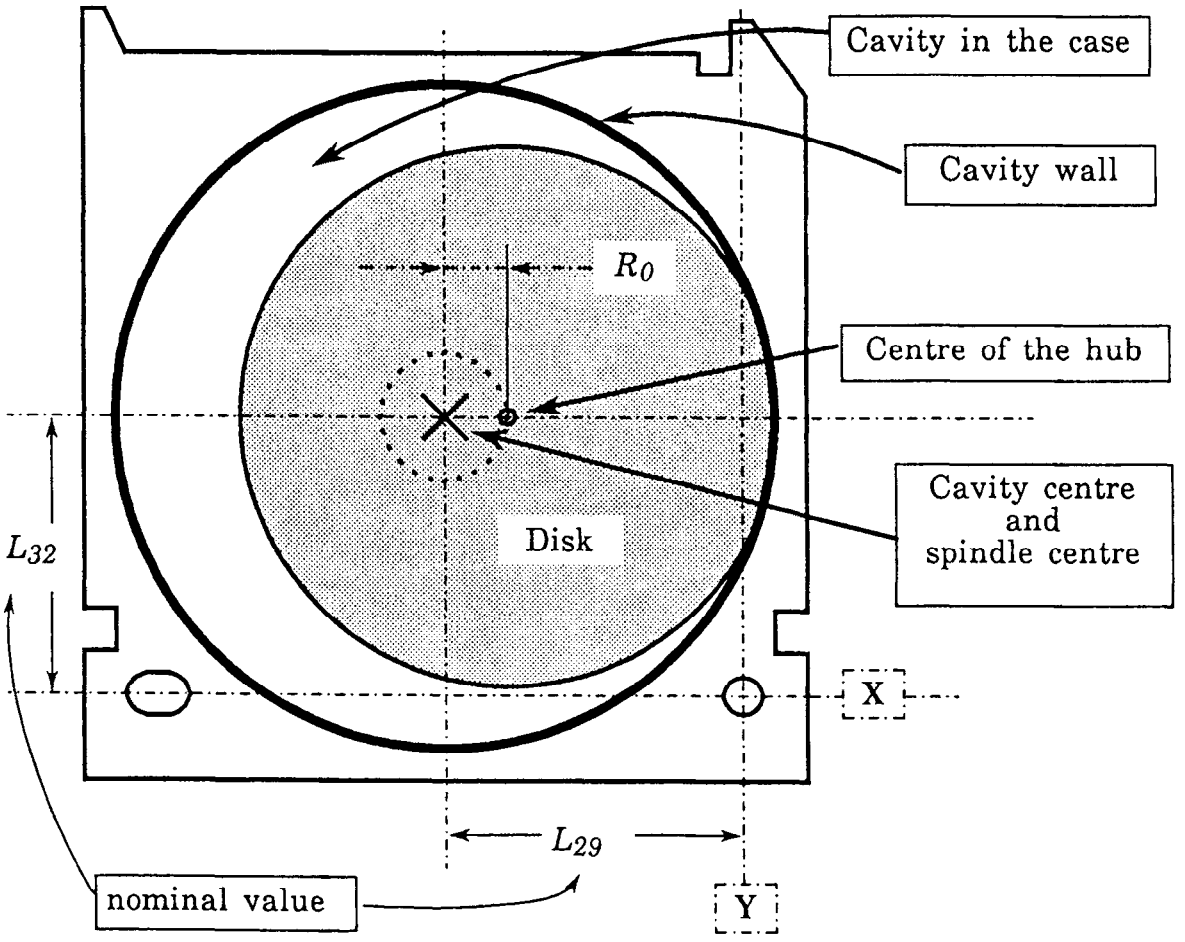

Figure F.2 - Capture cylinder radius (R_0) for the ideal case

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(2) Condition in which the centre position of the hub is deviated from its ideal position.

Usually, the centre of the hub is not located exactly the same location as the centre of the disk. When the centre of the hub is sifted from the centre of the disk with t1 , the capture cylinder radius (Ri) is derived from the equation (2).

$$R_i = R_0 + t_1 \quad \cdots\cdots\cdots (2)$$

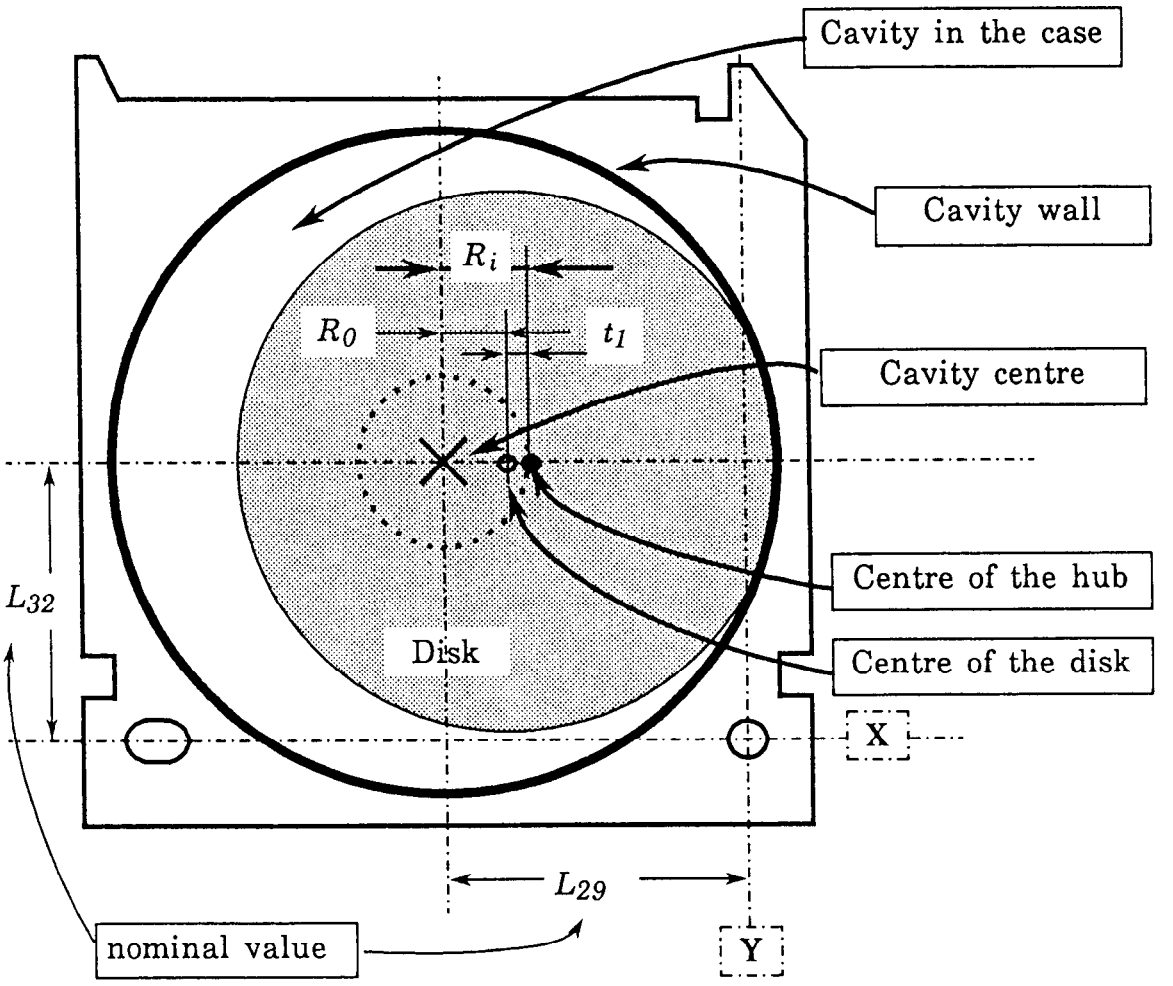

Figure F.3 - Capture cylinder radius (R_i) considering a deviation of the centre of the hub from the centre

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(3) Condition in which the position of the cavity centre ($L29$) is also deviated from its ideal position.

Usually, the cavity centre (L29) of the case is deviated with t2 from its nominal position. The acceptable value of t2 is specified in the ISO/IEC 10090 as a tolerance of L29. When considering both deviations t1 and t2, capture cylinder radius.(R_{ii}) is derived by the equation (3).

$$R_{ii} = R_0 + t_1 + t_2 \quad \cdots\cdots\cdots (3)$$

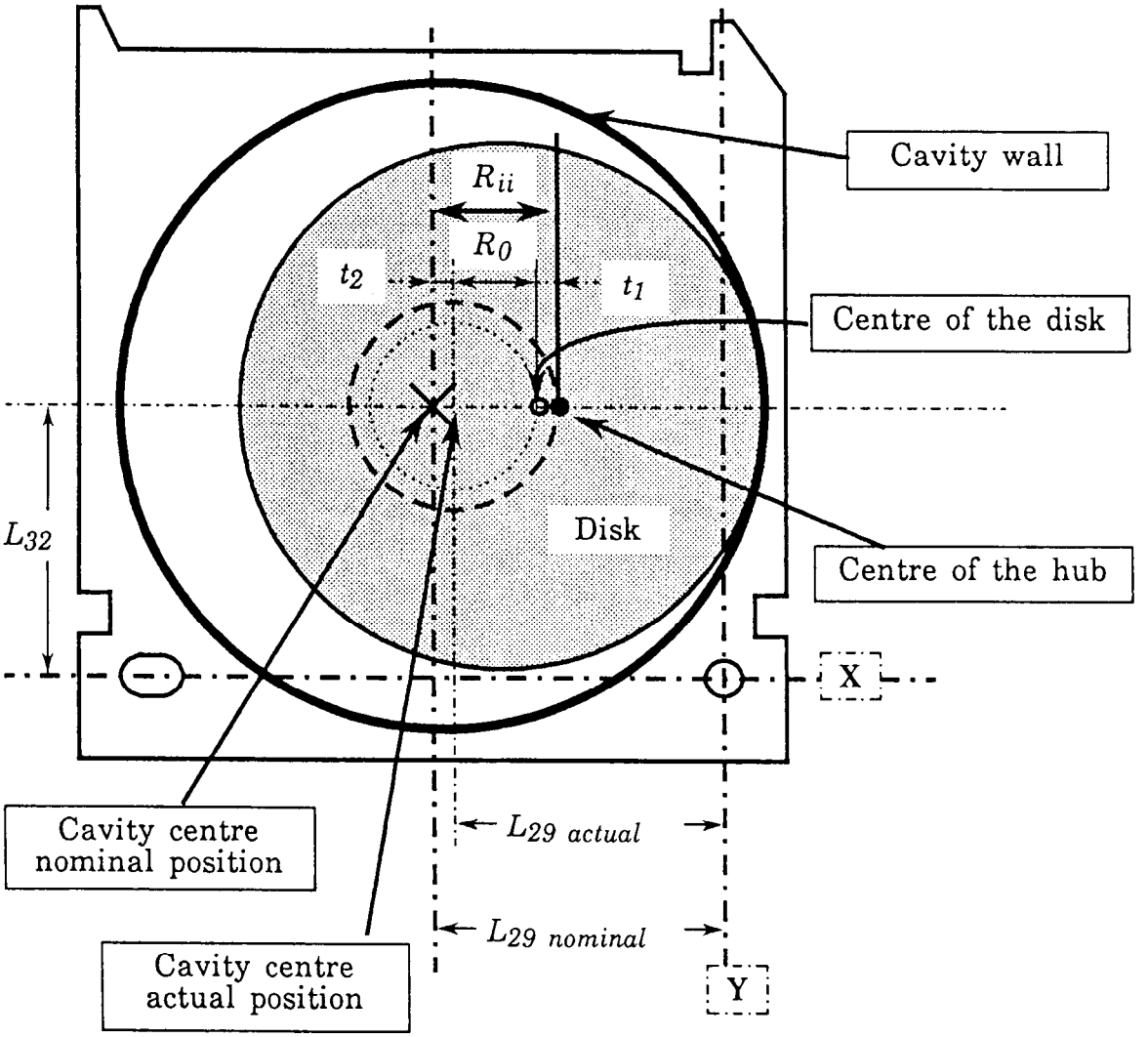

Figure F.4 - Capture cylinder radius (R_{ii}) considering a deviationof the hub centre from the disk and cavity centre

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(4) Condition in which the Rotation of a case in a drive due to a plays of a pins in the location and alignment holes.

If a drive only have a location pin without alignment pin, a cartridge rotate with t3 by a force of the shutter opener as shown in figure 5, and its centre is given by the centre of location pin. Actual drive have both the location and alignment pins, however, location and alignment holes have some play with the corresponding pins.

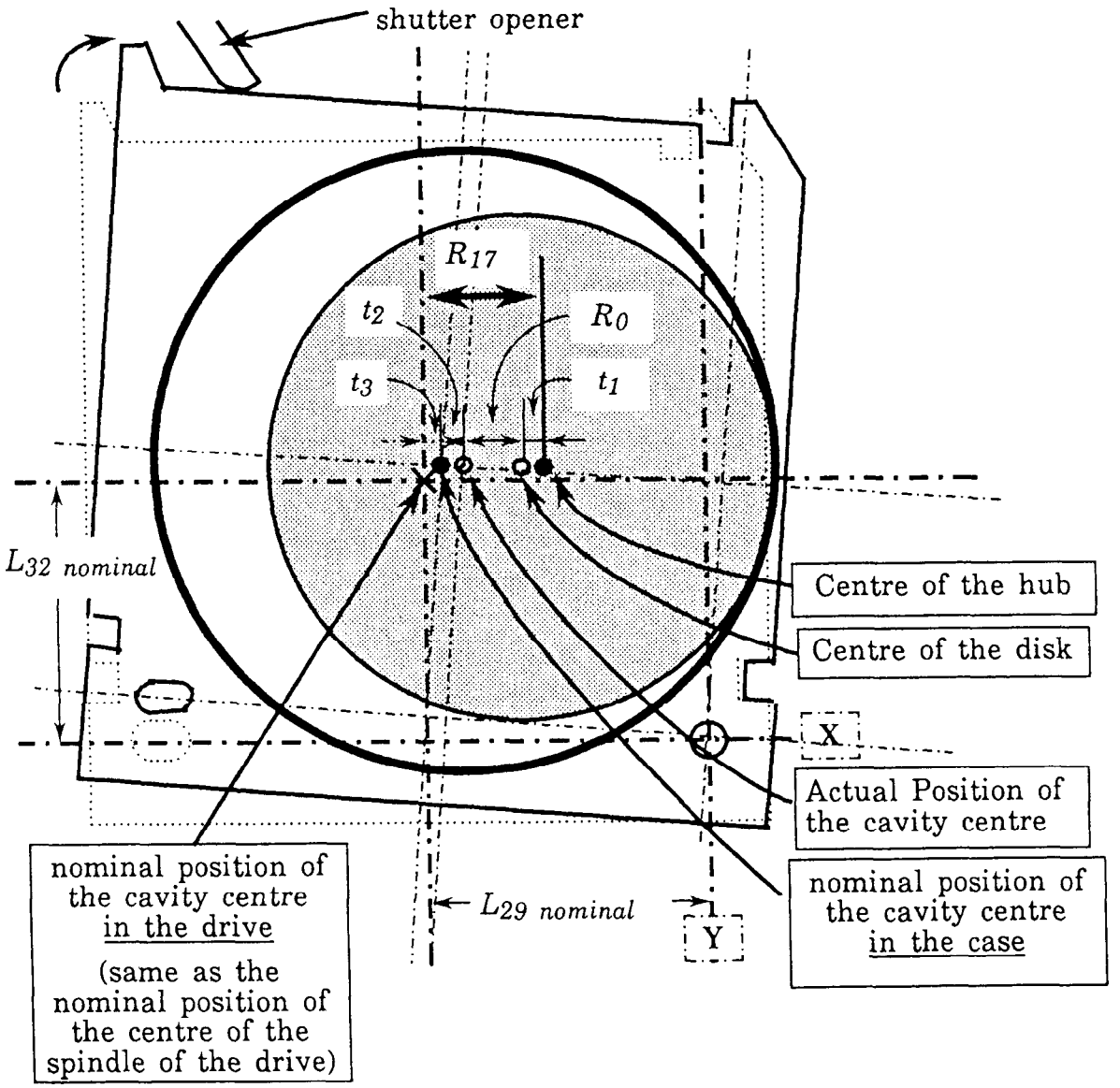

Figure F.5- Capture cylinder radius (R_{17}) considering the rotation of the case by a force of shutter opener.

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In the actual drive, considering all deviations t1, t2 and t3, the maximum length (in the worst case) between the centre of the hub and the nominal position of the cavity centre in the drive is expressed by equation (4), and this value is the radius of the capture cylinder (R17) of a cartridge.

$$R_{17} = R_0 + t_1 + t_2 + t_3 \quad \cdots\cdots\cdots (4)$$

Where, t3 is the deviation of the centre of a case parallel to the X plane in the drive. t3 can be derived by equation (5), (see figure 6).

$$t_3 = L_{32} * t_a / L_{11} + t_l \quad \cdots\cdots\cdots (5)$$

Where, ta and t1 are the clearance between alignment hole and pin and clearance between location hole and pin, respectively.

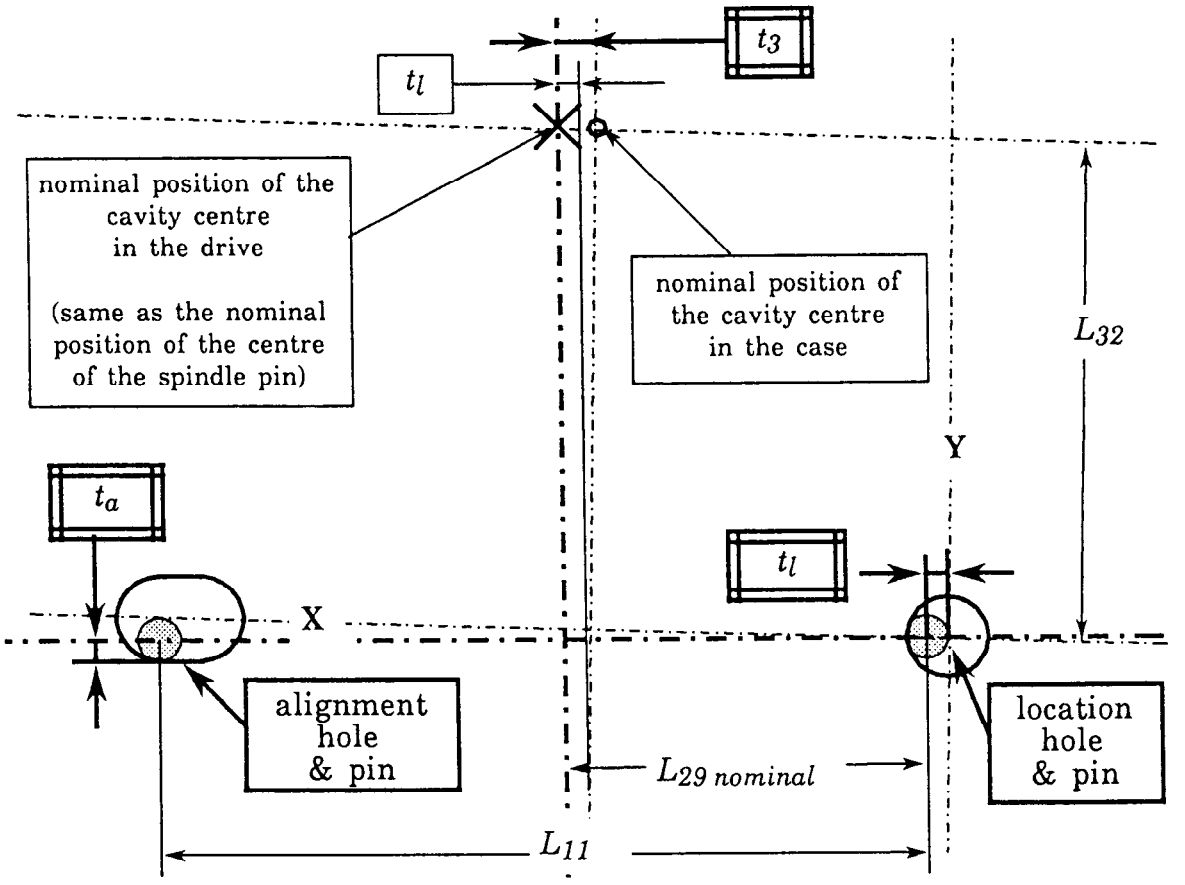

Figure F.6 - Capture cylinder radius (R_{17}) by considering a situation perfectly located and perfectly sized alignment and location pins in the drive".

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[II] Measuring method the capture cylinder radius

As is indicate in the equation (4), the capture cylinder radius ($\mathcal{R}17$) is able to be obtained by the values R_0, t_1, t_2 and t_3 for the cartridge. R_0 in equation (4) is derived by the cavity radius and disk radius as is indicated in equation (1).

The disk radius and its tolerance are specified in the text ISO/IEC 10090, however, the cavity radius of the case is not specify in it.

At first, procedure to obtain the cavity radius is described below.

(1) Radius of a cavity wall of the case

Cavity wall radius should be designed to ensure that a disk dose not touch to the cavity wall in the operating condition in any drive. Therefore, the minimum cavity radius should be designed for the maximum value of the disk diameter with condition of the worst case of a combination of the tolerances, (see figure F.6).

In the worst case, the centres of the cavity of the case (shells), disk, hub and spindle are located as follows.

The centre of the spindle is located parallel to the X plane in the drive from the nominal position with the value of R18. At the operating condition, spindle centre is located at the hub centre. The hub centre is located parallel to the X plane from the centre of the disk with the value of t1. The cavity centre is located parallel to the X plane from the nominal position on the case with the value of t2 . The cavity centre of the case is parallel to the X plane in the drive with the value of t3 by sifting and rotating in the drive. The cavity centres of the upper and lower shells are different parallel to the X plane with the value of t4 each other.
The above conditions are able to describe as the following equation :

(cavity radius)min. > (disk radius)max. + $t_1 + t_2 + t_3 + t_4 + R_{18}$ •••••(6)

Where t_4 it the length between the centres of cavities of the upper and lower shells when case is assembled. Because, the case is usually consisted by the two shells. If the minimum clearance between the disk and the cavity wall was set to t_5;

(cavity radius)min. = (disk radius)max. + $t_1 + t_2 + t_3 + t_4 + R_{18} + t_5$

= 43,0 mm + ($t_1 + t_2 + t_3 + t_4 + R_{18} + t_5$)mm••••••••••(7)

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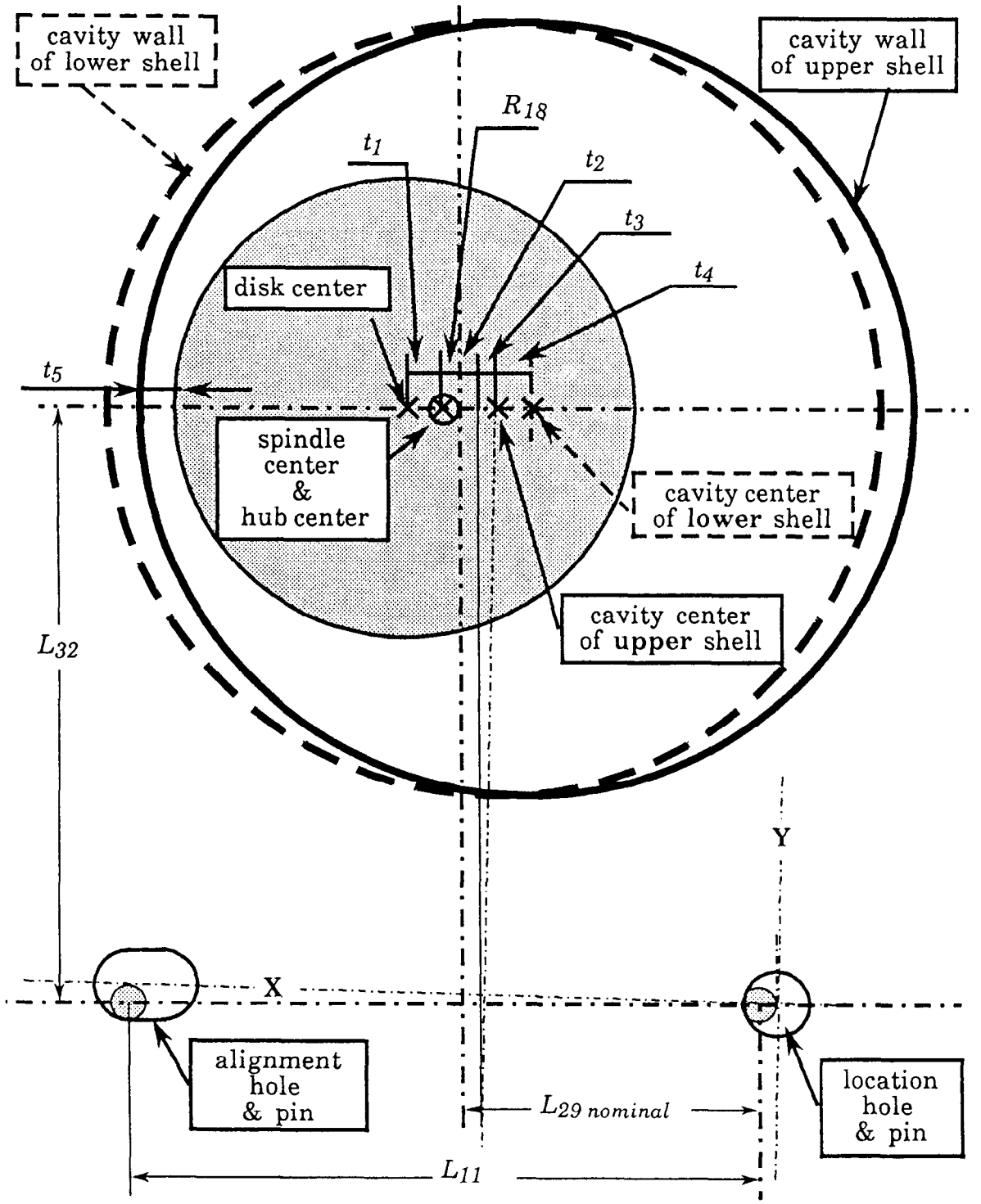

Figure F.7 - Correlation of the disk and the cavity walls of the case in the operating condition

(2) Radius measurement of the maximum value of the capture cylinder (R_{17}) for the disk manufacturers

The radius of the maximum value of the capture cylinder (R_{17} max) is derived by equation (4) and (1) as follows:

$$(R_{17})\text{max.} = (R_0)\text{max.} + t_1 + t_2 + t_3 \quad \cdots\cdots\cdots\cdots\cdots (8)$$

$$(R_0)\text{max.} = (\text{Cavity radius})\text{max.} - (\text{Disk radius})\text{min.} \cdots\cdots\cdots (9)$$

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If the tolerance of the cavity radius was set to t_6;

(cavity radius)max. = (cavity radius)min. + t_6 = (disk radius)max. + ($t_1 + t_2 + t_3 + t_4 + R_{18} + t_5 + t_6$)mm••(10)

On the other hand, the minimum radius of the disk is derived from the tolerance of the diameter of the disk (86,0 mm +0,0 /-0,5 mm)

(disk radius)min. = (disk radius)max. - t_7 = 43,0 - 0,25 = 42,75 mm•••••• (11)

where t_7 is the tolerance of the disk radius.

(R_0)max. = {(disk radius)max. + ($t_1 + t_2 + t_3 + t_4 + R_{18} + t_5 + t_6$)}- {(disk radius)max. - t_7 }

$= t_1 + t_2 + t_3 + t_4 + R_{18} + t_5 + t_6 + t_7$ ••••••••••••(12)

where *R18* is specified in ISO/IEC 10090. Insert equation (12) into the equation (8),

(R_{17})max. = 2 * ($t_1 + t_2 + t_3$) + $t_4 + R_{18} + t_5 + t_6 + t_7$ ••••••••••(13)

This (R_{17})max. is the value for the capture cylinder radius of the cartridges of each manufacturer.

[III] An example of calculation

Tolerances (t_1 ~t_7) vary per manufacturer. An example of calculation of the "radius of the capture cylinder" by use of values in table 1 is indicated below. The values in table 1 are one example, and media manufacturers are able to set the values as required, so far as the specification values in ISO/IEC 10090 are ensured. By the equation (5),

$t_3 = L_{32} * ta / L_{11} + tl$

$= 27,0 * 0,05 / 80,0 + 0,05$

$= 0,067$

$R_{17} = 2 * (t_1 + t_2 + t_3) + t_4 + R_{18} + t_5 + t_6 + t_7$ ••••••••••••(13)

$= 2 * (0,1 + 0,2 + 0,07) + 0,1 + 0,1 + 0,1 + 0,1 + 0,25$

$= 1,39$

$R_{17} < 1,4$ mm (The value specified in ISO/IEC 10090)

Table 1 - The estimated values of the tolerances

	value [mm]	note
t_1	0,1	Estimated value for the concentricity of the disk rim
t_2	0,2	Tolerance of L_{29} (± 0,2 mm)
t_3	0,067	t_a and t_l are 0,05mm in case of pins the diameters of which are 3,500mm
t_4	0,1	Estimated value for assembling the shells of the case.
t_5	0,1	Estimate value for the minimum clearance between the disk and the cavity wall
t_6	0,1	Estimated tolerance value for the cavity radius on the case manufacturing
t_7	0,25	Half of the tolerance of the disk diameter (+ 0,0mm - 0,5mm)
R_{18}	0,1	Disk position in the operating condition (±0,1mm)

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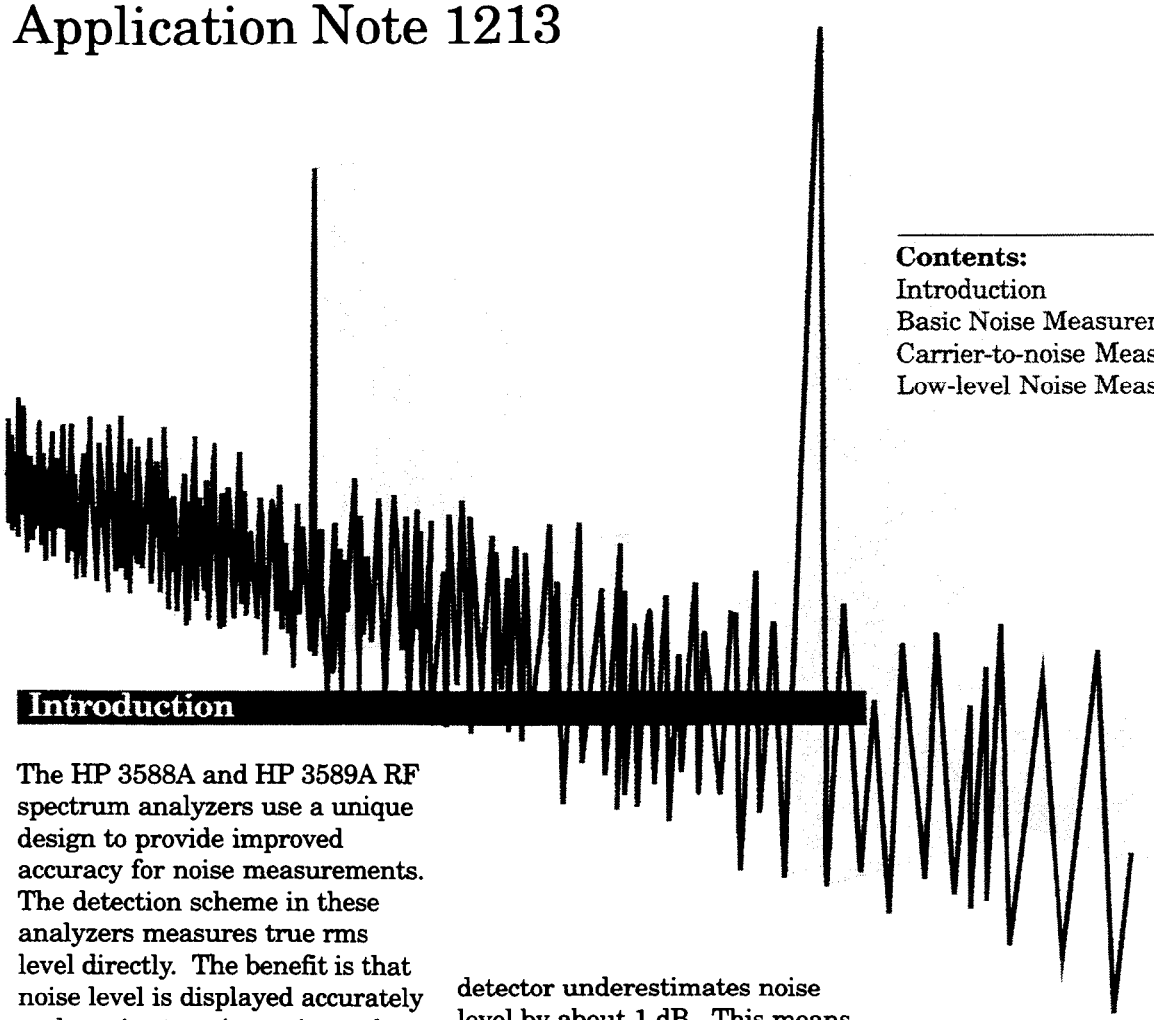
Annex G

Better noise measurement with the HP3585A and HP3589A

Application Note 1213



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Introduction

The HP 3588A and HP 3589A RF spectrum analyzers use a unique design to provide improved accuracy for noise measurements. The detection scheme in these analyzers measures true rms level directly. The benefit is that noise level is displayed accurately and carrier-to-noise ratio can be determined directly from a single measurement. This is different from most RF spectrum analyzers which typically underestimate noise level and therefore require correction factors for noise measurements.

Traditional analyzers use log amplifiers and envelope detection schemes that introduce errors into noise measurements. (See figure 1). The log amp will tend to compress noise level by about 1.45 dB. The standard diode detector underestimates noise level by about 1 dB. This means that displayed noise level will be 2.5 dB too low, giving you the impression there is only about half as much noise power as there really is. This can be misleading in carrier-to-noise measurements, because the carrier level is displayed accurately but the noise level is displayed too low. Therefore, it is a common practice to apply a 2.5 dB correction factor to a noise measurement made with a traditional analyzer.

Even with the use of correction factors, you may not get an accurate noise measurement with a traditional analyzer. The correction factors are based on the assumption that the measured noise has a gaussian distribution. Often, the distribution of the noise being measured is unknown. In contrast, the HP 3588A & HP 3589A spectrum analyzers correctly detect and display the level of all types of noise, as well as CW signals.

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Benefits of Digital Technology

Figure 1 shows the main differences between the HP 3588A & HP 3589A and traditional analyzers. The key to making more accurate noise measurements is the digital technology. In the last IF stage of the analyzer, the analog signal is converted to a digital information stream. As a result, the resolution bandwidth filter (RBW filter) becomes a programmable digital filter and the detector becomes a mathematical algorythm. Both provide benefits.

The digital filters have accurate bandwidths, which reduces uncertainty in noise measurements. Since noise level is always referenced to an equivalent noise bandwidth, or ENBW, it is important to know the precise bandwidth of the filters. Traditional analyzers can have a 20% uncertainty in bandwidth, which translates into noise level uncertainty of up to 1.5 dB. In contrast, the bandwidths of the digital filters are known within 1 %, which translates to a noise level uncertainty of less than .1 dB.

Bandwidth uncertainty directly affects the accuracy of the noise marker, which normalizes the noise level at one point to a 1 Hz bandwidth. Since it divides the measured noise level by the ENBW, any uncertainty in the filter bandwidth translates into an uncertainty in the computed result. Since the digital filters are so precise, the accuracy of the noise marker is improved over traditional designs.

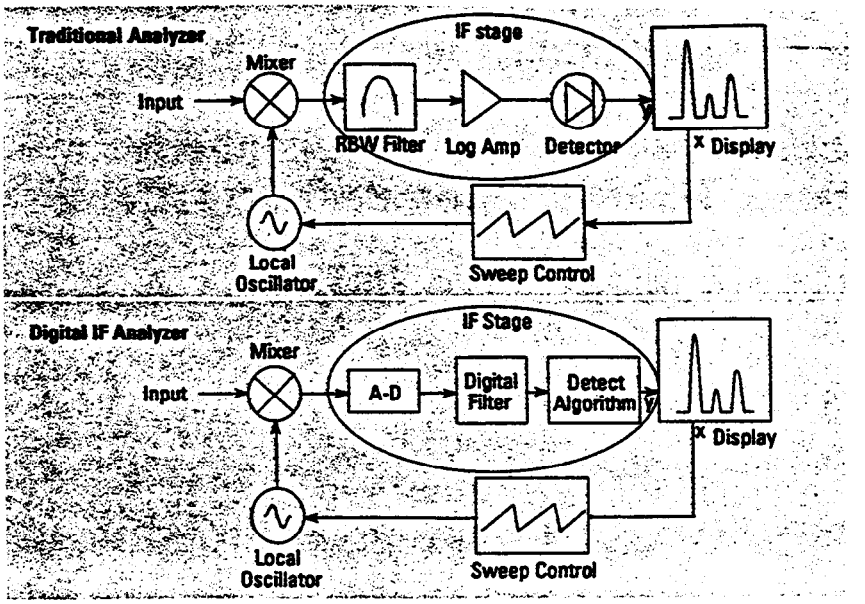

Figure 1: The digital IF analyzer replaces the analog RBW filter with a digital filter that offers more predictable noise bandwidth. The log amplifier and envelope detector are replaced by a digital algorythm that computes average power that provides accurate detection for both CW signals and noise.

In addition to precise bandwidths, the digital filters have an excellent shape factor. Figure 2 compares the shape of the digital filters (shape factor of 5:1) to the analog ones used in traditional analyzers (typically 11:1 shape factor). The excellent shape results in an ENBW that is nearly the same as the resolution bandwidth of the filter, which simplifies some noise measurements. The ENBW is only 1.06 times greater than the resolution bandwidth, as compared to 1.11 or 1.2 in other analyzers.

After the data passes through the digital filter, it goes to the detector stage. With digital processing, it is easy to implement an algorythm that computes true average power, and from that true rms level. As discussed earlier, true rms level detection provides more accurate noise measurements.

This application note describes in detail how to use the HP 3588A and HP 3589A RF spectrum analyzers to make accurate noise measurements. This note also

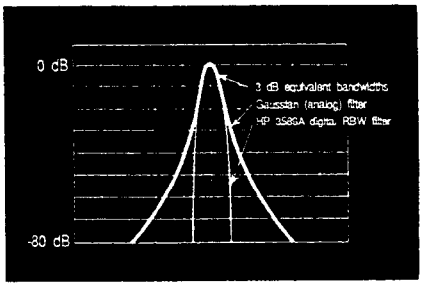

Figure 2: Shape of the digital filters in the HP 3588A is shown by the thin line. The heavy line estimates the shape of analog filters in traditional analyzers.

explains how to compare these measurements to those made on other spectrum analyzers which do not have the same filter bandwidths or detection scheme.

Since the HP 3588A and HP 3589A have identical digital filters and detectors, they will be referred to as the HP 3588/9A in the remainder of this note.

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Overview

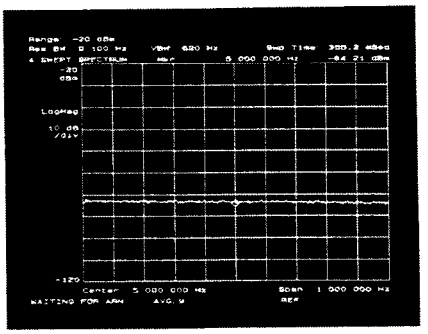
- Analyzer must be in peak (off) display mode.
- Analyzer must have oversweep turned off.
- Correction factors for the detector are not required.
- The noise bandwidth is about 1.06 times the resolution bandwidth.
- The noise marker automatically normalizes results to 1 Hz noise bandwidth.
- The 17 kHz RBW filter produces results that match un-corrected measurements made with the 30 kHz filter in most other analyzers.

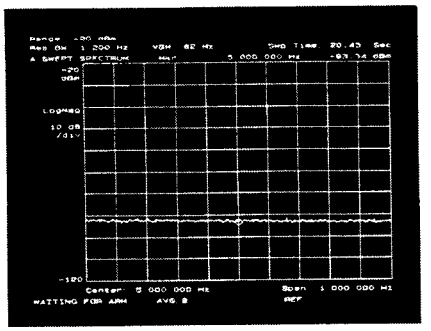
Noise Power and Analyzer Bandwidth

When you use a spectrum analyzer to measure noise, the noise level changes when you change the resolution bandwidth. This is different from measurements of CW signals, whose level stays the same when the resolution bandwidth is changed.

Noise measurements are dependent on bandwidth because noise, by definition, consists of spectral energy distributed continuously over frequency. (Unwanted energy that is isolated to a few discrete frequencies is referred to as distortion). When the resolution bandwidth is increased, the detector in the analyzer is exposed to noise over a wider bandwidth, and measures more total noise. Figures 3A and 3B show how displayed noise level changes when the resolution bandwidth is changed. To allow comparison between different analyzers, noise measurements are often normalized to a 1 Hz bandwidth. Noise power in a 1 Hz bandwidth is called power spectral density

As you can see, noise measurements made in different bandwidths cannot be compared directly. For this reason, noise measurements are often normalized to unity bandwidth (1 Hz). The normalized results, called power spectral density, can be compared directly.





Figures 3A and 3B: Noise power changes proportionaly with bandwidth. In 3A, the marker indicates a level of - 84 dBm in a 9100 Hz bandwidth. In 3B the bandwidth is 7.6 times less which translates to about 9 dB. As expected, the marker in 3B indicates - 93 dBm.

Equivalent Noise Bandwidth (ENBW)

The noise bandwidth is not the same as the resolution bandwidth because the final IF filter in the analyzer does not have a perfect rectangular shape. Figure 4 illustrates how equivalent noise bandwidth (ENBW) is defined. It is the width of a rectangular filter that passes the same noise power as the IF filter in question. Since ENBW is usually not specified, it is computed by multiplying the RBW (resolution bandwidth) by a scale factor that is determined by the filter design:

ENBW = k*RBW

In the case of the HP 3588/9A the "k" factor is about 1.06. Since the digital filters are absolutely predictable, the precise noise bandwidth at each resolution bandwidth setting is known exactly and is displayed in the state table of the analyzer. In addition, the noise bandwidth is available as an operator for math operations so an entire noise trace can be normalized to a 1 Hz bandwidth.

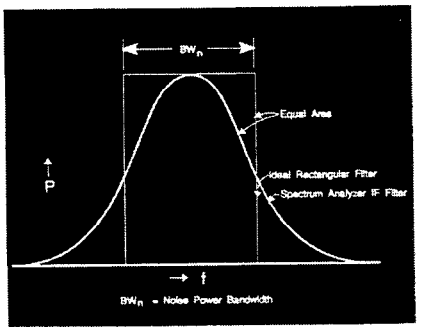


Figure 4: Noise power bandwidth is defined by an ideal filter that has the same area as the actual filter in the analyzer.

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Normalizing to 1 Hz Bandwidth (Power Spectral Density)

To compare two different noise measurements, the noise bandwidths should be the same. If they are not, they should be normalized to unity bandwidth. For random noise, power doubles when bandwidth is doubled. (This is different from impulsive noise, which doubles in voltage when bandwidth is doubled). The bandwidth correction for random noise is computed this way:

correction factor = 10 log (new NBW / measured NBW)

Example: Normalize a 290 Hz RBW measurement to 1 Hz Noise Bandwidth

correction factor = 10 log (1 Hz / 306 Hz) = - 24.9 dB

Note:
306 Hz is the noise bandwidth shown in the HP 3588/9A state table.

This means a noise measurement made in the 290 Hz resolution bandwidth can be normalized to a 1 Hz bandwidth by subtracting 24.9 dB. Normalization to 1 Hz of an entire noise trace can be done with a math operation. (See appendix about the math operation). The noise marker automatically normalizes to a 1 Hz bandwidth.

The Noise Marker

The noise level marker is designed to make a precise noise measurement at the frequency selected by the marker. With the noise level marker turned on, the analyzer sweeps until it reaches the frequency of the marker. Then the analyzer stops sweeping to make several noise measurements at that frequency. These measurements are averaged together to reduce variance. After the averaging is complete,

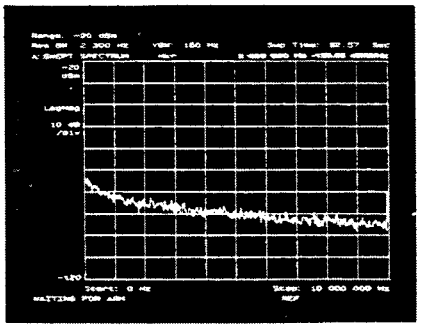

Figure 5: With the noise marker on, the analyzer pauses at the marker frequency to make several noise measurements. These are averaged together and the result is normalized to 1 Hz. The normalized result is expressed in power spectral density which has units of power per unit bandwidth: dBm/Hz.

the result is normalized to a 1 Hz bandwidth and the analyzer continues on its sweep. Figure 5 shows the result of the noise marker.

Normalizing to Measurements Made on Other Analyzers

There are times when you do not want to normalize noise data to a 1 Hz bandwidth. To compare noise measurements from the HP 3588/9A to those made on other analyzers, you must consider two things: the difference in bandwidth and the difference in detectors.

Example:
Normalize 17 kHz on the HP 3588/89A to 30 kHz on the HP 3585A.

Noise Power Bandwidth Correction = 10 log (30 kHz*1.11 / 18.1 kHz) = + 2.65 dB

Notes:
The noise bandwidth of the HP 3585A is 1.11 times greater than the 30 kHz resolution bandwidth.

The 17 kHz resolution bandwidth filter in the HP 3588/9A has a 18.1 kHz noise bandwidth.

The 17 kHz resolution bandwidth filter in the HP 3588/9A sees 2.65 dB less noise power than the 30 kHz filter in the HP 3585A.

To compare the measurements of random noise on two different analyzers, we must also consider the difference between the detector schemes. The HP 3588/9A measures 2.5 dB higher than most other analyzers because it has a true rms detector as opposed to other analyzers which use a scheme that under estimates noise level. (In a traditional analyzer, the envelope detector under estimates noise by 1.05 dB. The log amplifier effectively compresses a noise signal so that the average level is 1.45 dB low. The total is 2.5 dB.) The correction between the two different displays is best expressed this way:

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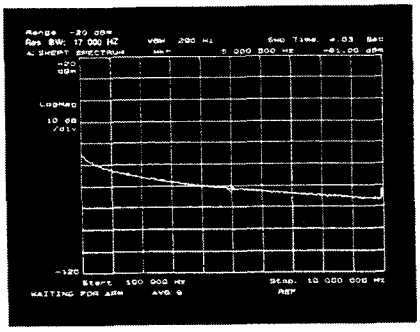
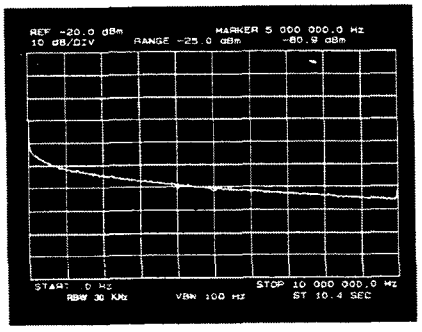
$$\text{Total Correction} = \frac{\text{Traditional analyzer}}{\text{HP 3588/9A}} = \text{Bandwidth factor} + \text{detector factor}$$
$$= +2.65\ \text{dB} + (-2.5\ \text{dB})$$
$$= +.15\ \text{dB}$$

In this case, the bandwidth factor is positive because the 30 kHz bandwidth used on the traditional analyzer sees greater noise power than the 17 kHz bandwidth used in the HP 3588/9A. The detector factor is negative because a traditional analyzer under estimates noise while the HP 3588/9A measures it correctly. This analysis shows the 17 kHz bandwidth of the HP 3588/9A displays almost the same noise level as the 30 kHz bandwidth of a traditional analyzer. The measurements in figures 6A and 6B illustrate this.





Figures 6A and 6B: The 17 kHz filter in the HP 3588A (6A) produces the same result as the 30 kHz filter in traditional analyzers like the HP 3585A (6B).

The 30 kHz bandwidth in traditional analyzers is commonly used for noise measurements, but if the HP 3588/9A had a 30 kHz resolution bandwidth, the displayed noise level would be 2.5 dB higher than with a traditional analyzer. Fortunately, the 17 kHz bandwidth in the HP 3588/9A can be used to produce a measurement that looks about the same as an uncorrected noise measurement made with a traditional analyzer in a 30 kHz bandwidth.

In summary, you must consider 4 things when comparing noise measurements from the HP 3588/9A to other analyzers:

1: Noise measurements made on most other analyzers under estimate noise level by 2.5 dB. The HP 3588/9A has a true rms detector and measures noise level correctly.

2: The HP 3588/9A has unusual resolution bandwidths. It is best to normalize noise measurements to a 1 Hz bandwidth so they can be compared to any other power spectral density display. Remember that the noise marker does the normalization automatically.

3: Many analyzers have a special noise marker to provide accurate and consistent noise measurements normalized to 1 Hz. In the case of the HP 3588/9A, the noise marker only needs to correct for bandwidth. In traditional analyzers, the noise marker corrects for the detector and log amplifier (2.5 dB for guassian random noise) in addition to the bandwidth.

4: Since most noise measurements made in a 30 kHz resolution bandwidth are not corrected for the detector, the 17 kHz resolution bandwidth on the HP 3588/9A can be used to produce a comparable display (within .15 dB, which is better than the accuracy of most noise measurements). Specifically, the narrower bandwidth reduces the noise level by about the same amount that a traditional analyzer underestimates noise level.

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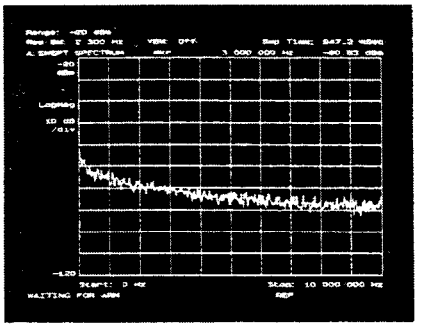
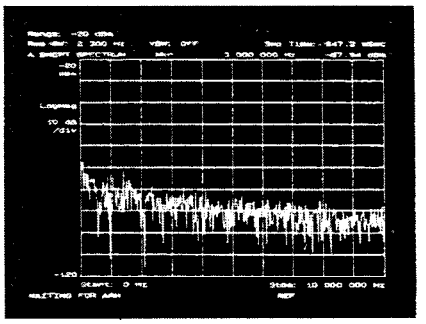
Display Modes for Noise Measurements

Like most modern spectrum analyzers, the HP 3588/9A has a digital display that provides two different display modes: one for CW signals and one for noise. A digital display has the benefit of not flickering like an analog one. Unfortunately, a digital display provides a fixed number of display points. During a slow sweep, the spectrum analyzer can measure at many more frequency points than can be displayed. The display mode determines which of the measured points actually gets displayed.

The peak (on) mode is needed for measuring the amplitudes of CW signals when the resolution bandwidth is very narrow compared with the measurement span. (See figures 9A and 9B). The peak (on) mode is not useful for noise measurements because it will display only peak noise level. This is a problem if you want to use averaging to determine the average noise level.

Therefore, noise measurements require a different display mode that simply samples the detected level at regular frequency intervals. This display mode is called the sample or peak (off) mode. Figure 7A shows a noise measurement with the display mode set to peak (on), which is the default for the analyzer. Notice the variance in the noise seems very low. Figure 7B shows the same measurement with display mode set to peak (off). In this mode, you see true variance of the noise measurement and this allows you to estimate the true average noise level. Video averaging or filtering is then used to reduce the variance and display the true noise level.





Figures 7A and 7B: The peak display mode shows only the peak noise level (7A). This is much higher than the average noise level which is seen in the peak (off) display mode (7B).

Video Filtering and Averaging

Noise is generally random in nature and that is why a single noise measurement has a lot of variance. There are two ways to reduce variance and determine the average noise level: video filtering and video averaging.

The video filtering is a method that effectively integrates the noise level over some period of time. The video filter is a low pass filter that is placed after the detector. As the bandwidth of this filter is reduced, the effective integration time is increased. The analyzer automatically slows down the sweep speed to account for the time constant of the video filter. The slower sweep speed allows the noise at each frequency to be integrated over the time constant of the filter and therefore the noise variance is reduced.

Video averaging is similar in concept. It works by making many sweeps, each at the fastest sweep rate allowed by the resolution bandwidth filter, and then averaging each new measurement with previous ones in an exponential average. Even though each new sweep produces a measurement with a high level of variance, the average converges on the average noise level. The number of measurements in the exponential average can be changed to provide the desired amount of variance reduction.

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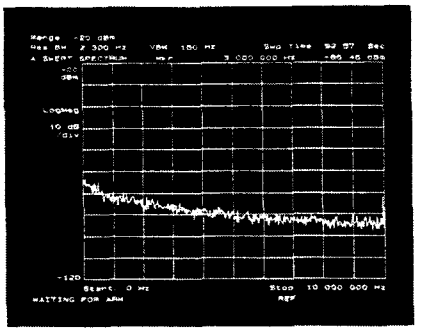

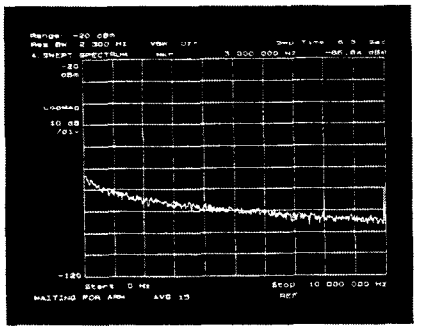

Figures 8A and 8B: Video filtering (8A) and video averaging (8B) are effective ways to reduce the variance of the noise measurement shown in figure 7B.

Video filtering and video averaging work for the same basic reason: total measurement time is increased so that the noise at each frequency is observed for a long time. Extending the observation time (by decreasing the video filter bandwidth or increasing the number of averages) reduces the variance and produces a better estimate of the average noise level. Figures 8A and 8B show the results of video filtering and video averaging.

The HP 3588/9A provides both video filters and video averaging, but video averaging is usually preferred because it permits the fastest sweep speed during averaging, instead of the single slow sweep you get with a video filter. This allows you to see signals that drift during the averaging process.

Remember, the analyzer must be in the peak (off) display mode. Since the HP 3588/9A defaults to the peak (on) display mode, you must switch it manually. (See appendix for key press information).

Oversweep

The HP 3588/9A defaults to a corrected oversweep mode at turn on time. In this mode, the analyzer sweeps four times faster than a traditional analyzer would permit. The measured data is then corrected, but the correction assumes cw signals have been measured. As a result, corrected oversweep introduces error into noise measurements. Therefore, oversweep must be turned off for noise measurements. With oversweep off, the analyzer sweeps slow enough to let the RBW filter respond fully to random nosie and permits an accurate noise measurement.

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Overview

- The offset marker is used for carrier-to-noise measurements.
- The carrier should be measured with peak (on) display mode.
- The noise level must be measured with the peak (off) display mode.
- The noise marker can be used with the offset marker to get a carrier-to-noise measurement normalized to 1 Hz.

The offset marker

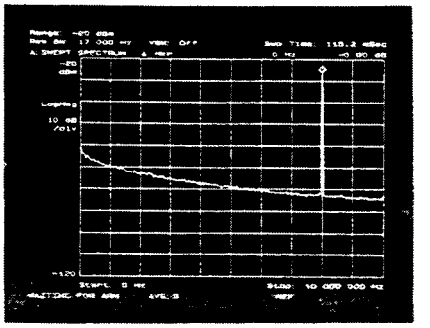
Carrier-to-noise measurements are a simple extension of basic noise measurements. There is one new issue: the level of the carrier must be detected correctly. This usually is not a problem. Figures 10A and B show typical measurements. Notice that the width of the RBW filter is visible. This means that the peak (off) display mode can be used to measure both the carrier level and noise level in the same measurement. To make the carrier-to-noise measurement, move the marker to the carrier peak, reference the offset marker to that level, and then move the marker into the noise. The offset marker will display the difference between the carrier level and the noise level.

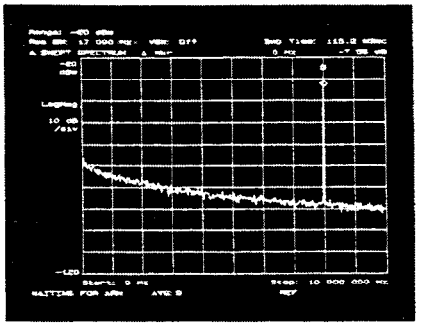
If the width of the RBW filter is very narrow compared to the span, then display modes become an issue in making good measurements. Look at figures 9A,B and C. In this case, the RBW filter is narrower than the spacing of points on the display and therefore the carrier appears as a spike on the display. In this case, peak(on) display mode must be used to measure the carrier level and then the peak(off) display mode must be used to measure the noise level.

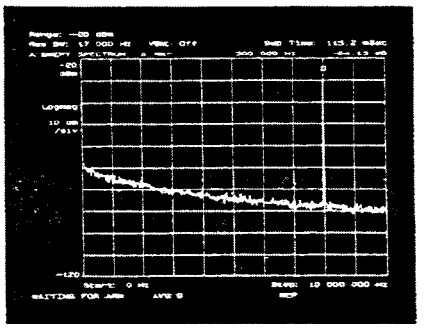
Figure 9A shows a measurement of a carrier and noise. Remember the analyzer defaults to the peak (on) display mode. In this figure, the marker was moved to the carrier peak and then the offset marker was switched on. Since the marker is at the reference point for the offset marker, the offset frequency and amplitude are both zero.

After the offset reference has been set at the carrier peak, the display mode is changed so that the noise level can be measured. Figure 9B shows what can happen to the measured carrier level when the display mode is changed. In this case, the resolution bandwidth is narrower than the spacing of the display points on the analyzer and the peak frequency of the carrier falls at a frequency that is between two display points. Even though the displayed level of the carrier is not correct, the square symbol for the marker reference stays at the correct level.

Figure 9C shows the marker moved 300 kHz away from the carrier and the marker readout shows the carrier to noise ratio. Remember that the measured carrier-to-noise ratio will change if the resolution bandwidth is changed.







Figures 9A, 9B and 9C
The offset marker is used to make carrier-to-noise measurements. 9A shows the marker at the carrier peak and the offset marker referenced to that level. Notice the marker readout shows zero. In 9B the display mode was changed to peak (off) to prepare for measuring the noise level. Notice the displayed carrier level dropped because the resolution bandwidth is narrower than frequency spacing of the points on the display. This is okay since the offset marker reference was set to the true peak. In 9C the marker is moved 300 kHz away from the carrier and the marker readout indicates the carrier-to-noise ratio.

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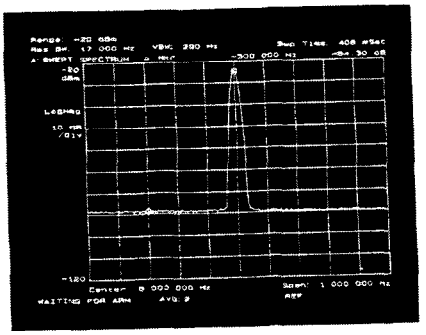
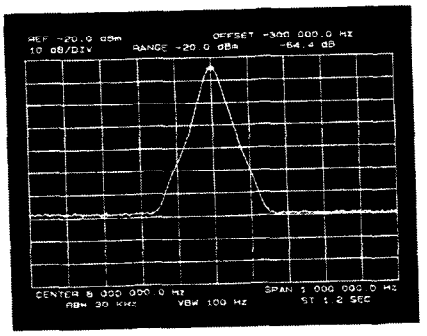
Normalizing to Another Bandwidth

To compare different carrier-to-noise measurements, they must be normalized to the same noise bandwidth. As described earlier, correction factors can be computed to normalize a noise measurement to another bandwidth.





Figures 10A and 10B:The 17 kHz bandwidth on the HP 3588A (10A) produces the same result as an uncorrected measurement made in a 30 kHz bandwidth on a traditional analyzer like the HP 3585A (10B).

Typically, measurements on magnetic storage media are referenced to a 30 kHz resolution bandwidth, and phase noise measurements are normalized to a 1 Hz noise bandwidth. While the HP 3588/9A does not measure directly at these bandwidths, it is designed to make these bandwidth normalizations easy.

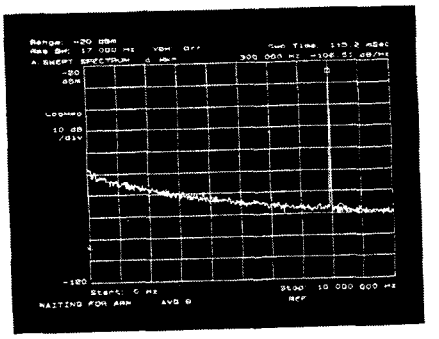
As described earlier, a measurement made with the HP 3588/9A in the 17 kHz bandwidth will provide about the same result as an un-corrected noise measurement made with a traditional analyzer in its 30 kHz bandwidth. See figures 10A and 10B.

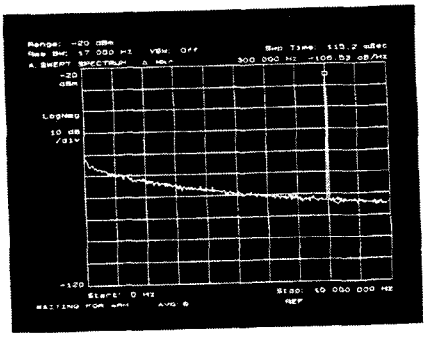
To normalize to a 1 Hz bandwidth, use the noise marker or trace math. (The procedure is described in the appendix).

Using the Noise Marker

Since noise measurements are often normalized to a 1 Hz bandwidth, the noise marker was designed to simplify the carrier to noise measurement. The noise marker works correctly even if the display mode is set to peak (on). This means the noise marker uses the measurement data directly and provides the same result in either display mode. See figures 11A and 11B.

To make a carrier-to-noise measurement, use the analyzer in its default display mode which is peak (on). Reference the offset marker to the carrier peak and then move the offset marker into the noise. Turn on the noise marker. (The procedure is described in the appendix).





Figures 11A and 11B:The noise marker is the most accurate and reliable way to make a noise measurement because the it does not use displayed data. Instead the analyzer pauses at the marker frequency and measures noise directly.

In 11A and 11B, the reference for the offset marker was set with the peak (on) display mode. In 11A, the display mode is changed to peak (off) for the noise measurement. In 11B, the display mode is left at peak (on), but the noise marker still shows the correct result because it does not use the displayed data.

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To make an accurate noise measurement, the measured noise level should be at least 10 dB above the noise floor of the analyzer. If the noise is close to, or below, the sensitivity of the analyzer, a pre-amplifier is needed. The sensitivity of the HP 3588/9A and is specified at -132 dBm in a 1 Hz bandwidth and is typically -140 dBm/Hz.

To determine if you need a pre-amplifier, check the difference between the noise floor of the analyzer and the measured noise. First disconnect any cables from the input and measure the noise floor. Then, measure the noise signal; if it is not 10 dB above the noise floor, a pre-amplifier should be used.

A pre-amplifier must do two things: boost the level of the noise signal and do so without adding too much extra noise. The HP 8447D pre-amplifier fits this requirement and is recommended for use with the HP 3588/9A. It has 25 dB of gain and an 8 dB noise figure.

The sensitivity of a system composed of a pre-amplifier and analyzer is determined by comparing the noise output of the pre-amplifier to the noise floor of the analyzer. Since the noise output of the HP 8447D is less than the noise floor of the analyzer, the system sensitivity is roughly determined by subtracting the gain of the pre-amplifier from the noise floor of the analyzer.

system sensitivity = analyzer noise floor - pre-amp gain
= - 134 dBm - 25 dBm
= - 159 dBm

Note: If your use a differnet pre-amp with greater noise output (gain * noise figure) the system sensitivity will start to be limited by the noise figure of the pre-amp.

Remember that the analyzer does not automatically account for the gain of the pre-amplifier. You must account for it manually, or by using math to change the display scale. With the math feature in the analyzer, you can input the 25 dB scale factor into the analyzer so that the displayed data reads out correctly.

It is important to note that a pre-amplifier does not increase dynamic range. While the sensitivity is increased, the maximum input power is reduced by at least the gain of the pre-amplifier. When measuring high level noise or signals, the pre-amplifier should not be used because it may produce distortion.

For more details on pre-amplifiers and noise figure, refer to Hewlett-Packard Application Note 150.

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The noise marker makes an accurate noise measurement at the marker frequency.

MARKER FCTN
Noise Lvl (on)

To make a noise measurement the display mode must be set to peak (off).

MEAS TYPE
Peak Det (off)

To reduce variance in the measurement, use video averaging or a video filter.

Averaging
AVG/PK HLD
Video Average
Number Averages XX Enter
Video Filter
RES BW
Vid Fltr (on)
Video BW press up or down arrow keys

To make a carrier-to-noise measurement, set the reference of the offset marker at the carrier peak, and then move the marker into the noise. If the resolution bandwidth is less than .5% of the span, the carrier peak must be measured with the display mode in peak (on). If the noise level is measured with the noise marker, then the display mode can be left in peak (on). If the noise level is measured with the standard marker, the display mode must be set to peak (off).

Move marker to peak.

MARKER
Mkr —> Peak

Set the reference of the offset marker.

MARKER
Zero Offset

If you are going to use the standard marker, change the display mode. If you are going to use the noise marker, skip this.

MEAS TYPE
Peak Det (off)

Move the marker into the noise. The offset marker now displays the frequency offset and amplitude difference, which is the carrier-to-noise ratio. If the noise marker is turned on, the carrier-to-noise ratio is normalized to a 1 Hz bandwidth.

An entire noise trace can be normalized to a 1 Hz bandwidth by using the math capabilities in the analyzer.

The math function is defined to be the ratio of the spectrum to the noise bandwidth. The math operators assume all data has units of volts, therefore the bandwidth normalization factor is expressed as the square root of the noise bandwidth.

MATH
Define F1
Spectrum
/
Sqrt(NBW)
Enter

After the math function is defined, it is not displayed until selected.

TRACE DATA
Function(F1-F5)
F1

The reference level may need to be changed. This is done with the softkeys under the SCALE hardkey.

To turn oversweep off.

SWEEP
Oversweep (off)

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Measuring Noise with the HP 3585A/B

This note explains how the HP 3585A/B NOISE LVL marker function computes the power density of random noise. When measuring random noise without using the NOISE LVL function, the information presented in this note can be used to correct the marker amplitude readings.

Swept spectrum analyzers, such as the HP 3585A/B spectrum analyzer, are usually designed to measure the spectral components of deterministic signals quickly and accurately. For this reason, most spectrum analyzers do not measure power directly. They measure the average voltage of the signals within the resolution bandwidth (RBW) and calculate power by assuming the signal in the RBW is a single tone. The HP 3585A/B IF block diagram shown in figure 1 is particularly well suited for accurately measuring the level of signals in the presence of noise. However, the HP 3585A/B, as well as most other spectrum analyzers, is not optimized for measuring noise. Special attention and care must be taken when it is used to measure noise.

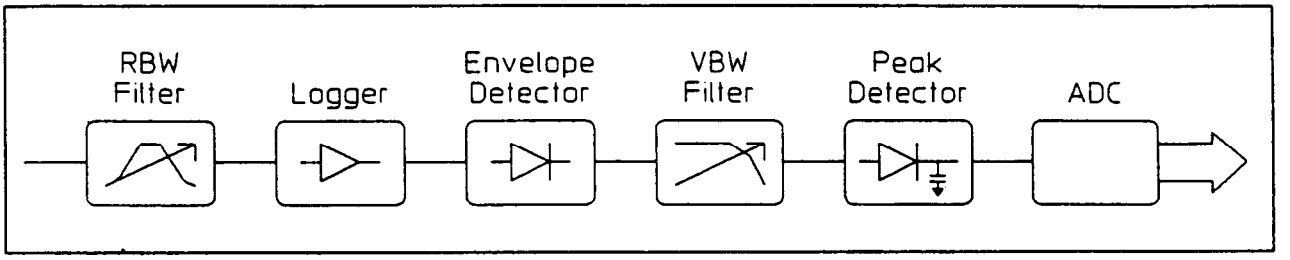

Figure 1. Block Diagram of a Typical Spectrum Analyzer IF

Several factors affect a random noise measurement made by a spectrum analyzer. These factors are:

1. Resolution Bandwidth
2. IF Detector Characteristics
3. Video Detector Characteristics
4. Averaging

When an accurate estimate of the random noise is required, the operator usually spends considerable time and effort calculating the effect each of these factors has on the noise

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measurement. Fortunately, the HP 3585A/B NOISE LVL function corrects for all this automatically. The operator simply sets the marker to the frequency point of interest on the noise and activates the NOISE LVL function. The noise power density reading replaces the marker amplitude in the upper right-hand corner of the display.

In the following sections, each factor affecting the calculation of noise power is considered separately.

Resolution Bandwidth

Random noise can be modeled as an infinite number of frequency components, each contributing an infinitesimal amount of power. Each of these components has random amplitude and phase. This implies that if random noise is measured with an analyzer that has an infinitesimally narrow resolution bandwidth, the measured noise will be zero. On the other extreme, if an analyzer with an infinitely wide bandwidth is used to measure random noise, then the power measured will be infinite. Although these extremes are never encountered, this model illustrates two important principles.

1. The total power measured is directly proportional to the resolution bandwidth of the analyzer.
2. Random noise power at a specific frequency must be expressed as density (e.g. noise power per unit bandwidth).

Usually the noise power is normalized to a 1 Hz bandwidth. If the noise is reasonably flat within the RBW, the noise power density at the frequency of interest is the total noise power measured, divided by the analyzer's noise power bandwidth.

The analyzer's "noise power bandwidth" or "equivalent noise bandwidth" is an ideal rectangular filter bandwidth that has the same power response to flat noise as the analyzer's RBW filter (see figure 2). For the HP 3585A/B, the noise power bandwidth is approximately 1.11 times the RBW setting. For greater accuracy, measure the 3 dB bandwidth of the HP 3585A/B's RBW filter and multiply the result by 1.11.

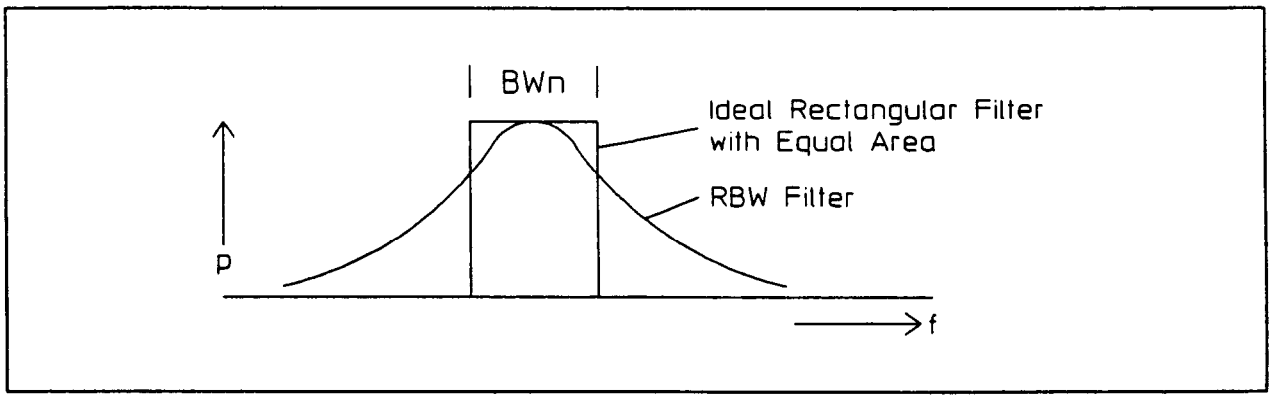

Figure 2. Noise Power Bandwidth

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The HP 3585A/B NOISE LVL function automatically divides the total noise power by the noise power bandwidth of the RBW filter. The result is displayed in units of dBm/Hz. The noise power bandwidth normalization factor, in dB, is given by:

Normalization Factor = 10*LOG(1/(1.11*RBW))

The normalization factors used by the NOISE LVL function are listed in table 1. When the NOISE LVL function is not utilized, add these factors to the marker amplitude to normalize the readings to a 1 Hz bandwidth. To renormalize the result to any desired bandwidth (BWd), simply add a factor of 10*LOG(BWd).

Table 1. RBW Normalization Factor

RBW	Normalization factor
30 kHz	-45.2dB
10 kHz	-40.5dB
3 kHz	-35.2 dB
1 kHz	-30.5 dB
300 Hz	-25.2 dB
100 Hz	-20.5 dB
30 Hz	-15.2 dB
10 Hz	-10.5 dB
3 Hz	-5.2 dB

IF Detector Characteristics

In the block diagram of figure 1, the signal in the IF is shaped by a logging circuit and an envelope detector. The average output of this type of IF detection scheme is not the same for random noise as it is for a sine wave with the same power. If a narrow video bandwidth (VBW) filter is used to average the signal, or if the average is found by computing the mean of many samples of the logged amplitude readings, then the correction factor for random noise measurements is +2.5 dB. If no VBW filtering is used (VBW > RBW) and if the average is found by computing the mean of many samples of the linear voltage amplitude readings, then the correction factor is 12.8% or 1.05 dB. See the appendix of HP Application Note 150-4 (HP publication number 5952-1147) for the derivation of these correction factors.

The HP 3585A/B NOISE LVL function automatically applies the IF detection scheme correction factor to the noise power density readings. When measuring random noise without utilizing the NOISE LVL function, add 2.5 dB to the amplitude readings.

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Video Detector Characteristics

In the HP 3585A/B block diagram, the video signal is peak detected and then sampled by an analog-to-digital converter (ADC). The ADC's 5 kHz sample rate allows 1000 frequency points to be sampled in the minimum sweep time of 0.2 seconds. For greater sweep times, the *effective* ADC sample rate is decreased. When the sweep time is greater than 0.2 seconds, there is more than one ADC sample for each of the 1000 points displayed on the CRT. The HP 3585A/B will display the largest of these samples.

When the HP 3585A/B is sweeping, peak detection ensures that the peak of a signal is always displayed on the CRT. However, if the signal at the input of the peak detector contains significant power at frequencies that are greater than half the effective sample rate, then the signal is undersampled. The combination of peak detecting and undersampling causes the noise level to appear higher than it really is. Figure 3 illustrates the effect of undersampling and peak detecting a random signal. The sample displayed at each grid line represents the peak of the random signal that has occurred since the previous sample. Note how the average of the peak detector samples is biased higher than the average of the random signal.

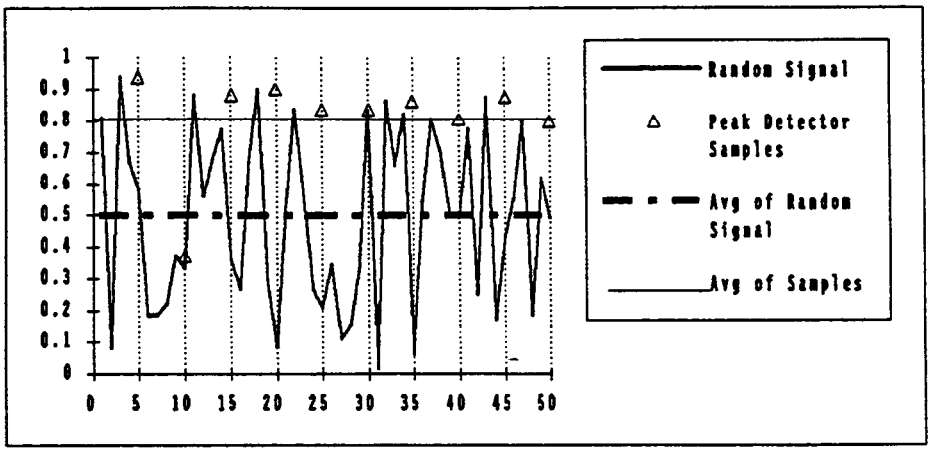

Figure 3. An Undersampled Peak-detected Random Signal.

There are two ways to avoid the noise "bias" caused by undersampling and peak detecting in the HP 3585A/B. The first method is to reduce the VBW to a value that is much less than the RBW. If the VBW is much less than the RBW, then the signal at the output of the VBW filter is a nearly constant level and the peak detector bias is small. When making non-gated noise measurements without utilizing the NOISE LVL function, set the VBW to 1% of the RBW setting or less. This will eliminate the bias caused by the peak detector for any sweep time setting.

The second method is to reduce the VBW/RBW combination so that the signal at the input of the peak detector has a bandwidth that is much less than half the effective sample rate. If the HP 3585A/B is in MANUAL sweep mode, or if the sweep time is 0.2 seconds, then the effective sample rate is 5 kHz. At a 5 kHz sample rate the noise bias is insignificant when either the RBW or

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the VBW is 100 Hz or less. For this reason, the HP 3585A/B NOISE LVL function always uses a manual sweep mode and a VBW of 100 Hz during non-gated noise measurements.

Sweep gating (option 001) is often used to measure interrupted or "burst" signals. For a gated sweep to work correctly, the duration of the signal must be longer than the settling time of the spectrum analyzer. However, the 100 Hz VBW filter causes the settling time of the HP 3585A/B to be too long for most gated sweep measurements. For this reason, during gated measurements the NOISE LVL function automatically sets the video filter to a bandwidth that minimizes the internally generated noise of the analyzer and, at the same time, does not increase the settling time of the HP 3585A/B. Usually this bandwidth is the same VBW the operator has selected.

The actual VBW used during a gated NOISE LVL measurement depends on the RBW and VBW selected by the operator, according to the following table:

Table 2. VBW Used by NOISE LVL Function in Gated Sweeps

Selected RBW	Selected VBW					
	30 kHz	10 kHz	3 kHz	1 kHz	300 Hz	100 Hz
30 kHz	30 kHz	10 kHz	3 kHz	1 kHz	300 Hz	100 Hz
10 kHz	30 kHz	10 kHz	3 kHz	1 kHz	300 Hz	100 Hz
3 kHz	30 kHz	10 kHz	3 kHz	1 kHz	300 Hz	100 Hz
1 kHz	10 kHz	10 kHz	3 kHz	1 kHz	300 Hz	100 Hz
300 Hz	3 kHz	3 kHz	3 kHz	1 kHz	300 Hz	100 Hz
100 Hz	1 kHz	1 kHz	1 kHz	1 kHz	300 Hz	100 Hz
30 Hz	300 Hz	300 Hz	300 Hz	300 Hz	300 Hz	100 Hz
10 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz
3 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz

When the VBW is greater than 100 Hz, the NOISE LVL function automatically corrects for the noise bias caused by peak detecting and undersampling. For gate times greater than 100 microseconds, the correction factors used for each VBW and RBW combination are shown in table 3.

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Table 3. Peak Detector Correction Factors

RBW	VBW					
	30 kHz	10 kHz	3 kHz	1 kHz	300 Hz	100 Hz
30 kHz	-6.2 dB	-4.4 dB	-2.1 dB	-0.8 dB	-0.2 dB	0 dB
10 kHz	-5.8 dB	-4.9 dB	-2.8 dB	-1.2 dB	-0.3 dB	0 dB
3 kHz	-3.7 dB	-3.5 dB	-2.6 dB	-1.4 dB	-0.4 dB	0 dB
1 kHz		-1.7 dB	-1.6 dB	-1.0 dB	-0.4 dB	0 dB
300 Hz			-0.5 dB	-0.4 dB	-0.2 dB	0 dB
100 Hz				-0.1 dB	-0.1 dB	0 dB
30 Hz					0 dB	0 dB
10 Hz						0 dB
3 Hz						0 dB

A gated measurement with a gate time of 100 microseconds is a special case because the peak detection time is shorter than normal. If the External Trigger Mode is TIMED GATE and if the gate time is 100 microseconds, then the correction factors used by the NOISE LVL function for each VBW and RBW combination are shown in table 4.

Table 4. Peak Detector Correction Factors (Gate Time = 100 microseconds)

RBW	VBW					
	30 kHz	10 kHz	3 kHz	1 kHz	300 Hz	100 Hz
30 kHz	-5.1 dB	-3.4 dB	-1.5 dB	-0.5 dB	-0.1 dB	0 dB
10 kHz	-4.4 dB	-3.5 dB	-1.8 dB	-0.7 dB	-0.1 dB	0 dB
3 kHz	-2.2 dB	-2.1 dB	-1.4 dB	-0.6 dB	-0.1 dB	0 dB
1 kHz		-0.8 dB	-0.7 dB	-0.4 dB	-0.1 dB	0 dB
300 Hz			-0.2 dB	-0.1 dB	0 dB	0 dB
100 Hz				0 dB	0 dB	0 dB
30 Hz					0 dB	0 dB
10 Hz						0 dB
3 Hz						0 dB

If the NOISE LVL function is not utilized when measuring random noise, and if the sweep time is 0.2 seconds or if MANUAL mode is used, then correct the amplitude readings by adding the peak detector correction factor found in table 3 or table 4. Use table 3 when correcting non-gated noise measurements.

Averaging

A noise reading is a statistical estimate of the average noise power. In theory, an infinite number of samples must be taken to find the exact average. However, a reasonable number of samples will

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yield results that are accurate enough for practical application. The confidence level in an average is proportional to the square root of the number of samples. Thus, the average of one hundred samples is ten times better than a single sample.

With a spectrum analyzer, averaging can also be accomplished using a video filter. If the VBW is less than the RBW, then the variation in the noise readings will decrease by a factor directly proportional to the square root of the VBW divided by the RBW. A VBW setting that is 100 times narrower than the RBW setting will give effective averaging for most noise measurements.

In non-gated measurements, the HP 3585A/B NOISE LVL function internally selects the 100 Hz VBW during the noise measurement, regardless of the VBW the operator has selected. In addition, 100 independent amplitude samples are used to calculate the average noise power. This ensures an accurate noise level reading.

During gated measurements, the NOISE LVL function automatically sets the video filter to a bandwidth that will minimize the internally generated noise of the analyzer and, at the same time, will not increase the settling time of the HP 3585A/B. Usually this will be the same VBW the operator has selected. When the VBW is greater than 100 Hz, the NOISE LVL function decreases the variation of the noise readings by increasing the number of amplitude samples used to calculate the average noise power.

Using the NOISE LVL Function

The HP 3585A/B NOISE LVL function automatically takes into account all the factors discussed so far. The NOISE LVL function finds the average of at least 100 independent samples of the amplitude at the marker frequency. It then normalizes the noise to a 1 Hz bandwidth and adds a correction factor to compensate for the noise response of the analyzer's IF detection scheme. Finally, if needed, it adds a correction factor for the bias caused by the peak detector.

```
 Average of 100 amplitude readings (dBm)

+ 10*Log(1/(1.11*RBW))
   (RBW normalization factor)

+ 2.5 dB
   (IF detector scheme correction factor)

+ Peak detection correction factor
   (Gated sweep only)
```

```
= Noise power density reading (dBm/Hz)
```

Since the noise reading is normalized to a 1 Hz bandwidth, the reading can be renormalized to any desired bandwidth (BWd) by adding an additional factor of 10*LOG(BWd) to the NOISE LVL reading.

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Use the following guidelines to properly use the NOISE LVL function.

1. Activate the NOISE LVL function only when the signal being measured is random noise.
2. Make sure the VIEW A Trace function is activated.
3. Make sure the DISPL LINE function is deactivated.
4. Make sure the HP 3585A/B is sweeping or in MANUAL mode.
5. Use a RBW that is narrow enough to resolve a reasonably flat portion of the noise spectrum.
6. Make sure the noise being measured is greater than the HP 3585A/B's internal noise.

Measuring Signal-to-Noise Ratio

The NOISE LVL function can be used in conjunction with the OFFSET function to measure signal-to-noise ratio. The recommended procedure is as follows:

1. With the instrument sweeping or in the MANUAL mode, set the Marker to the peak of the signal. Make sure the NOISE LVL function is not activated.
2. Activate OFFSET and then press ENTER OFFSET.
3. Set the Marker to the point of interest on the noise and then activate the NOISE LVL function. Allow time for the noise reading to be calculated and observe the result.
4. The result is in units of dB/Hz. The result can be renormalized to any desired bandwidth (BWd) by adding 10*Log(BWd).
5. The result is actually the ratio of the noise to the signal. Negate the result to obtain the signal-to-noise ratio.

For more detailed information about using the NOISE LVL marker function, see the HP 3585A/B operating manuals.

Applying the Correction Factors

The NOISE LVL function automatically applies all the correction factors to yield an accurate measurement of the noise power density. However, if the level of a random noise signal is measured without utilizing the NOISE LVL function, the correction factors presented in this note can be used to correct the amplitude readings. Again, note that the peak detector correction factors are only valid if the amplitude readings are obtained when the instrument is in the MANUAL sweep mode or if the sweep time is 0.2 seconds. The following typical measurement examples illustrate how to apply the correction factors.

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Example 1

To measure the noise density of a random signal in a 30 kHz RBW, set the VBW to 300 Hz or less. This adequately averages the noise and eliminates video peak detector bias. Correct the amplitude readings as follows:

```
Uncorrected Amplitude (dBm)

- 45.2 dB      (RBW normalization from table 1)

+ 2.5 dB       (IF detection scheme correction factor)
_____________________________________________________

= Noise Power Density (dBm/Hz)
```

Example 2

When measuring the noise density of an interrupted signal that has a duration of 400 microseconds, the settling time of the analyzer must be considered. In this case, the settling time of the 300 Hz VBW filter is too long for a gated sweep to work correctly. When the VBW is 300 Hz and the RBW is 30 kHz, the settling time of the HP 3585A/B is 5.1 milliseconds. Because of the short duration of the signal, a VBW of 10 kHz or greater must be used. Set the VBW to 10 kHz and make sure the sweep time is 0.2 seconds or use MANUAL sweep mode. Correct the amplitude readings as follows:

```
Uncorrected Amplitude (dBm)

- 45.2 dB      (RBW normalization, table 1)

+ 2.5 dB       (IF detection scheme correction factor)

- 4.4 dB       (Peak detector correction, table 3)
_____________________________________________________

= Noise Power Density (dBm/Hz)
```

Since the 10 kHz VBW filter is not averaging the signal as much as the 300 Hz VBW filter would, you might need to reduce the variation in the noise readings by making several measurements and computing the average. You must average the amplitude readings in dB for the 2.5 dB IF detection scheme correction factor to be valid.

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Annex H

An example of measurement equipment and data for shutter opening force

Figure H.1 shows an example of measurement equipment for shutter opening force. The slide table can move with different speeds. The encoder which is inside the motor provides X signal as the stroke of the slide table and the load transducer provides Y signal as the shutter opening force for X-Y recorder respectively. Figures H.2, H.3, H.4 and H.5 are experimental data of shutter opening force under several measurement conditions.

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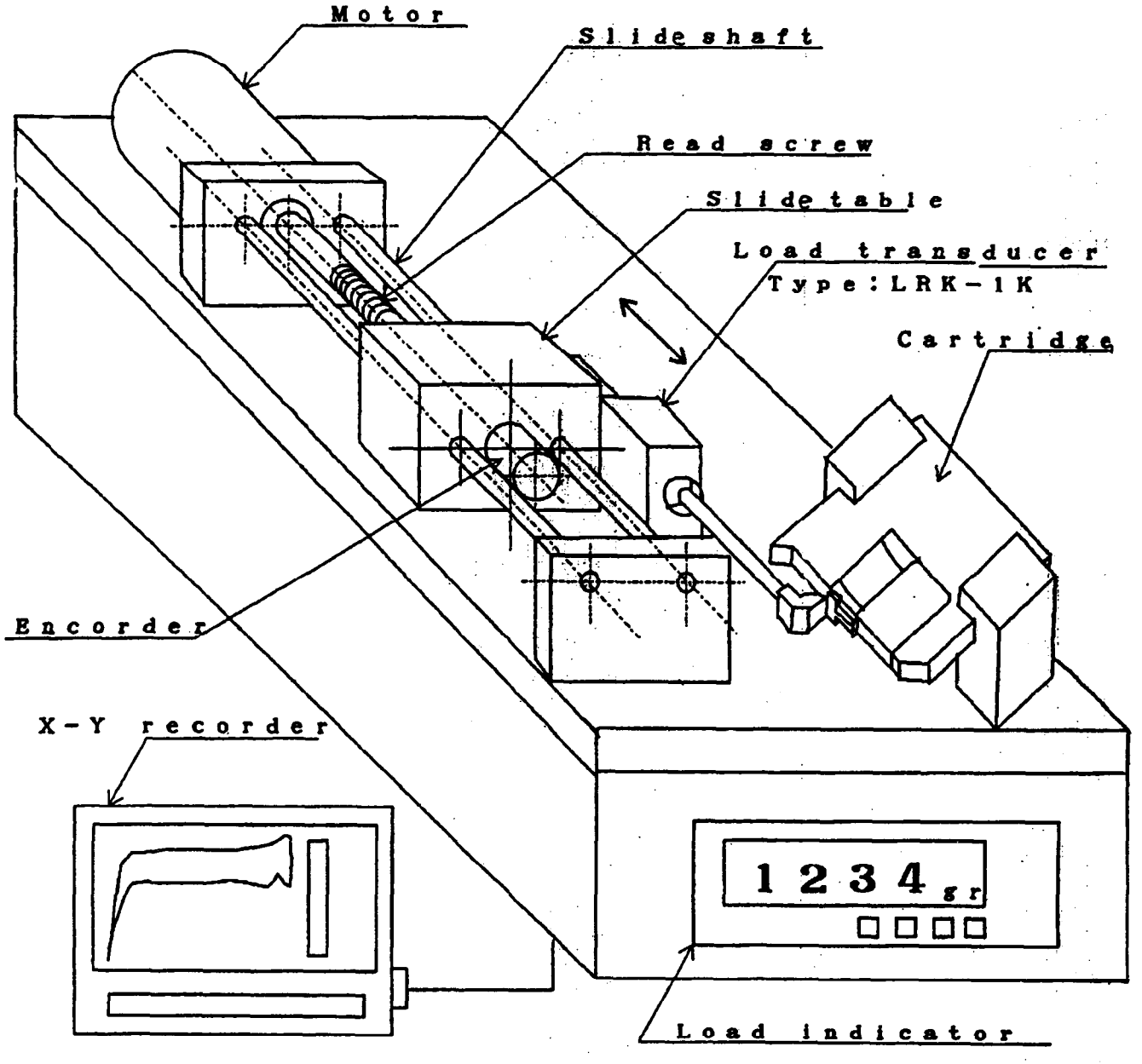

Figure H-1 An example of measurement equipment for shutter opening force

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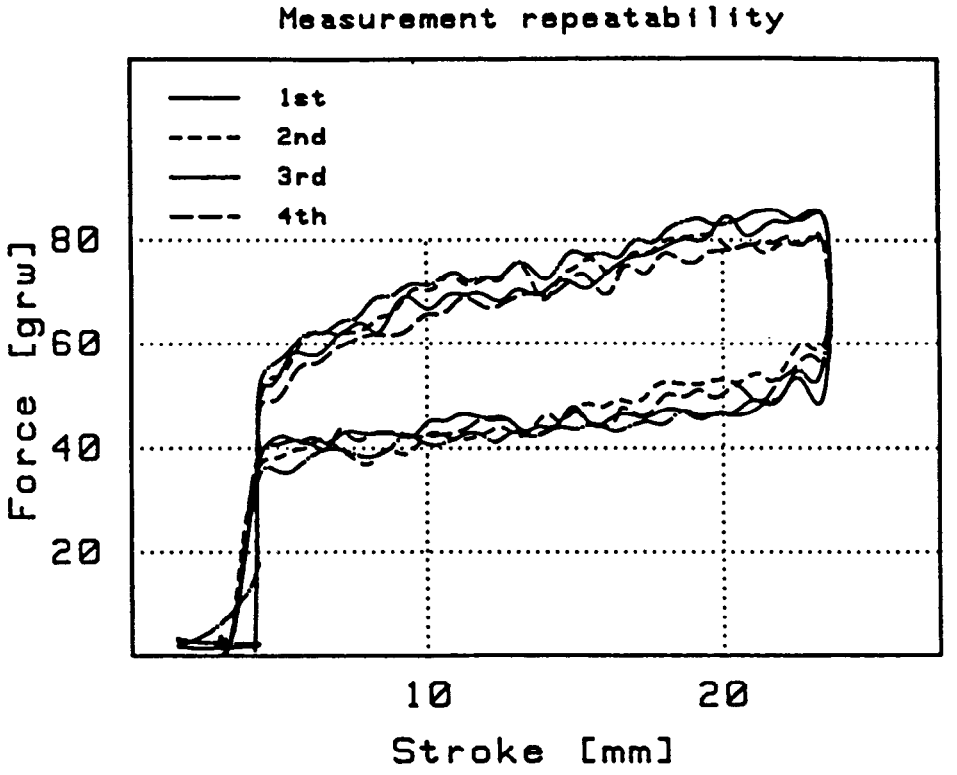

Figure H.3

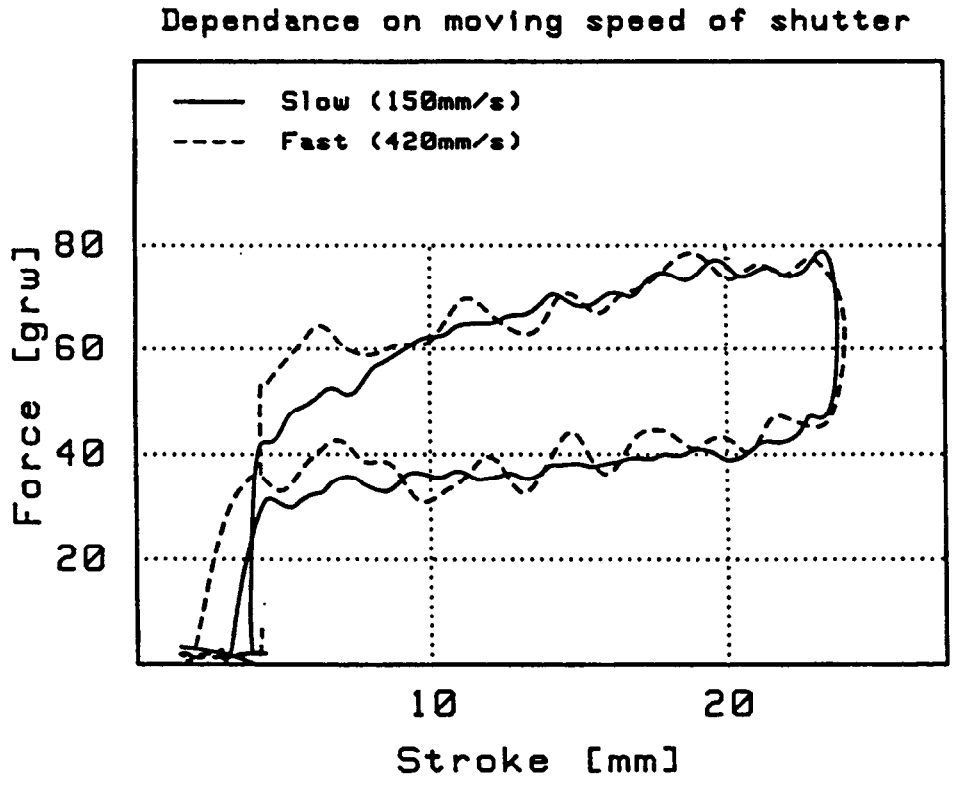

Figure H.2

Figures H.2, H.3 - Experimental data of the shutter opening force

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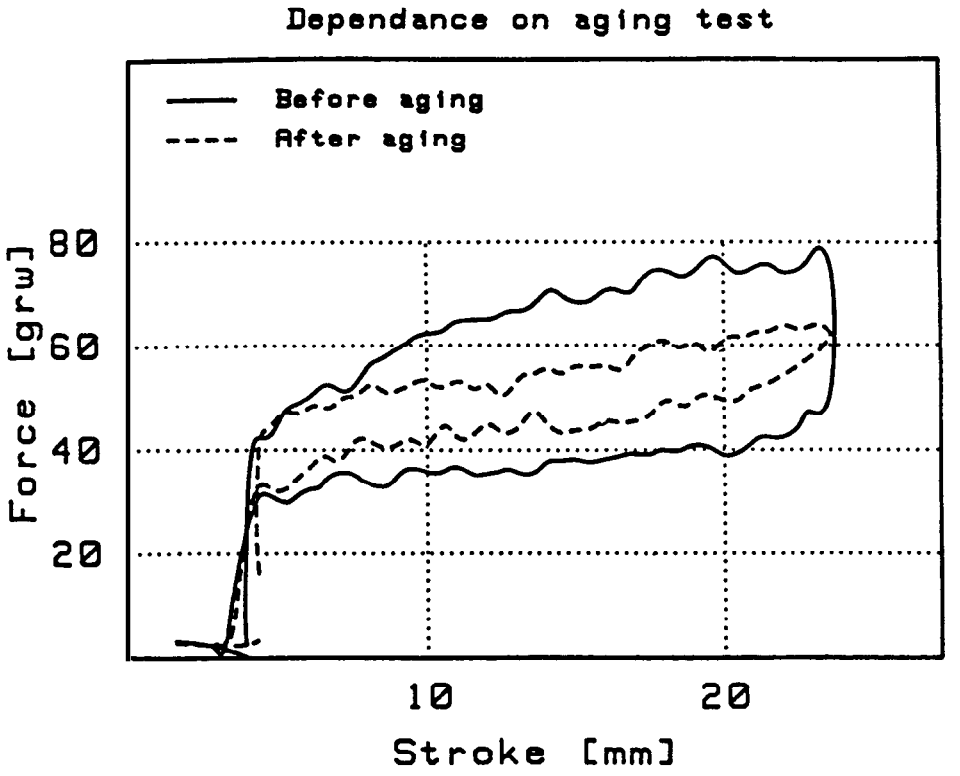

Figure H.4

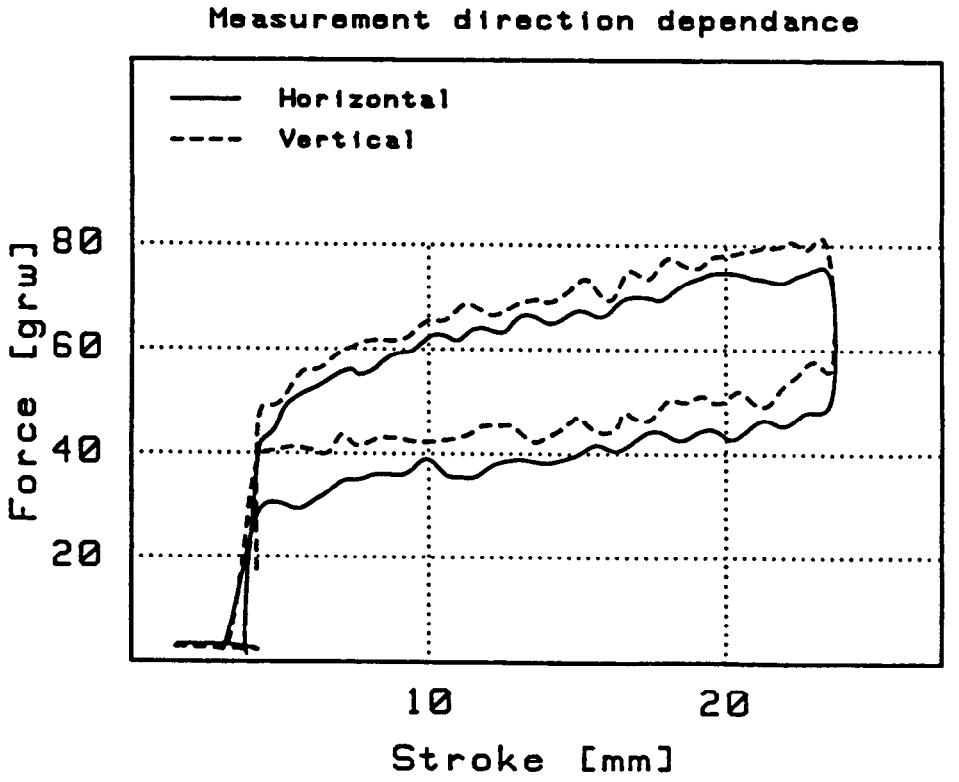

Figure H.5

Figures H.4, H.5 - Experimental data of shutter opening force

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