User's Manual
SD375 Dynamic Analyzer II
Part One

Legacy Manual

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SERIAL ________

OPERATOR'S MANUAL

SD375
DYNAMIC ANALYZER II

Scientific-Atlanta

Spectral Dynamics Division

United States: P.O. Box 23575 • San Diego, CA 92123-0575 • (619) 268-7100 • TWX 910-335-2022

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SECTION I

GENERAL INFORMATION

1.1 INTRODUCTION

This manual contains unpacking, initial checkout and operating instructions for the Spectral Dynamics Model SD375 Dynamic Analyzer II. The manual is divided into four sections. Each section covers a specific aspect of the instrument. This section contains a list of other documents available, a description of the instrument, a concept of operation and equipment specifications.

1.2 OTHER DOCUMENTATION

Spectral Dynamics produces two basic manuals for each equipment; an Operator's Manual and a Service Manual. The Operator's Manual is shipped with each instrument; the Service Manual with engineering drawings may be ordered separately.

The Service Manual contains a detailed theory of operation, calibration procedures, maintenance information, parts lists, engineering drawings and wire lists. The manual is written for technical personnel with experience in analog and digital circuits. Manual contents will provide the maintenance engineer with information that will enable the maintenance technician to repair and/or calibrate the instrument.

Technical papers are available from Scientific-Atlanta which provide user oriented background information. For a list of this material, contact either your local sales/service office or the San Diego Group.

1.3 EQUIPMENT DESCRIPTION

The SD375 is a dual microprocessor based, dual-channel frequency domain dynamic analyzer. It measures the signals present at two BNC connectors, labeled INPUT A and INPUT B, and the relationship *between* these signals.

The measurement results are displayed on a raster scan crt. The measurements are controlled via the touch control front panel.

There are two main parts to measurement display: a scaled trace and a cursor readout. The trace is an X-Y array of measured values, graphically represented with data points or lines, scaled to units and distributions selected by the operator via the front-panel controls. The cursor readout is, typically, a three-place accuracy numerical reading on a trace data point that the operator indicates using the front-panel cursor controls.

The basic measurement traces available are:

Y AXIS		X AXIS
Amplitude	vs	Frequency
Amplitude^2	vs	Frequency
Gain (B/A)	vs	Frequency
Phase, γ^2 (Coherence)	vs	Frequency
Amplitude	vs	Time
Amplitude^2 (Imaginary)	vs	Amplitude^2 (Real)
Gain (Transfer Function Imaginary)	vs	Gain (Transfer Function Real)
Correlation	vs	Time
Occurances	vs	Amplitude

The operator can adjust the range of the displayed trace with controls for linear and logarithmic traces on both the X and Y axis and apply a certain amount of output gain on the trace. Times two ($\times 2$) and times four ($\times 4$) expansions on the X axis are also available.

Display and cursor units available are:

Front Panel Selected Y Units for →	**AMP**	**AMP^2**	**Gain**	**Other (Forced by the Function Displayed)**
V	V	V^2	V/V	—
EU*	EU	EU^2	EU/EU	—
dB	dB	dB	dB	—
PSD	EU^2/Hz	EU^2/Hz	—	—
Phase	—	—	—	Degrees
γ^2 (Coherence)	—	—	—	γ^2
Occurances, (PD, PDH)	—	—	—	Occur, %
Correlation	—	—	—	Corr

*EU = Engineering or User Selected Units

Front Panel Selected X Units for →	**Freq**	**Time**	**Amplitude (± Full Scale)**
Hz	Hz	Sec	V O-P
RPM	KCPM	m Sec	—
Harmonics	Orders	—	—

The cursor controls allow the operator to obtain a readout for:

A Single Point (Normal Mode)

Power between Two Points (ΔP)

Distance between Two Points (ΔX)

Harmonic Orders on a Selected Fundamental

To enable you to store, retain and smooth data, you are provided with an averager-memory, into which you can average frequency, time or amplitude domain data. You can place the input memories in hold, (manually, on the basis of an external or data dependent trigger) *or* you can trigger-hold-test and average automatically.

In addition, the capability of performing Structural Transfer Functions adapts the SD375 to almost any application in design, production testing, and maintenance troubleshooting of rotating machinery. Direct read out of sound pressure levels makes it useful in a broad variety of acoustic studies.

Just a few of the many applications for your SD375 are:

- Noise and vibration studies of vehicles and farm/construction equipment
- Engineering instruction in vibration and signal analysis
- Drive-by and fly-by tests of new vehicles and aircraft
- Analysis of underwater sounds and sonar signals
- Modal analysis of automotive engines, frames and bodies
- Vibration analysis of gas and steam turbines to define failure mechanisms
- Medical and biological stimulus vs. reaction studies
- Structural-integrity and tool-chatter investigations of machine tools
- Aircraft flutter and vibration analysis
- Dynamic stress analysis of heavy off-highway equipment
- Railway equipment noise-reduction programs
- Household appliance development studies
- Computer disc-drive design

1.4 SD375 OPTIONS

NOTE

> The SD375 is configured to easily add these standard options initially, or later as your signal processing and analysis requirements dictate. Front panel controls and main frame accommodations for the options are built into every analyzer.

1.4.1 Digital Translator (-1 Option)

The -1 option provides six zoom (i.e., frequency magnification) factors — 2, 5, 10, 20, 50 and 100 for each analysis range. A zoom factor of 100, for example, increases the frequency resolution by 100 times the normal baseband resolution and, at the same time, improves the signal-to-noise ratio of the measurement. The factor best suited to the analysis task at hand can be instantly selected on the front panel for separating closely spaced frequency components.

When the translator (XLTR) is turned on, the center position of the zoom window is automatically established by the cursor location. If the cursor is moved, the window is automatically relocated within the selected full-scale analysis range. The cursor position always indicates the window's center frequency with the upper and lower window edge frequencies annotated at the left and right ends of the X-axis grid.

The CF SET control locks the center frequency at the current cursor position and enables the cursor to be moved to any point within the window for high resolution frequency readout. The ΔP cursor feature can be used to read the RMS level of the signal within the zoom window.

Translator gain of 1, 2, 4 or 8 recovers the dynamic range lost when zooming in with a narrow window on a portion of a broadband spectrum. This gain is inserted prior to spectrum analysis of the windowed signal and permits detection of signal amplitudes more than 80dB below full scale.

1.4.2 1/3 and 1/1 Octave Analysis (-2 Option)

Adding the -2 option to the SD375 combines 1/3 octave, 1/1 octave, and dual channel narrowband analysis capabilities into one instrument. Selection of the 1/3 or 1/1 octave display mode is provided from a menu via the LIST front panel touch control.

The -2 utilizes a *single pass parallel process* data acquisition method for synthesizing 1/3 and 1/1 octave spectra. It offers three distinctive advantages over serial multiple-pass techniques ...

First, the entire 1/3 or 1/1 octave spectrum is synthesized from the same segment of the data record, thus always assuring a valid spectrum.

Second, dual input buffer storage enables 1/3 or 1/1 octave processing of continuous impulsive signals.

Third, analysis time is reduced by utilizing overlap processing techniques on the lower frequency data group.

Thirty full 1/3 octave and ten full 1/1 octave bands of data plus the overall rms level are displayed on each 1/3 and 1/1 octave full scale analysis range. Data signals can be processed independently on CH A or CH B and the 1/3 octave spectrum stored in their respective averager memory locations. Post data manipulation (+, −, ÷), selected through the menu, can be performed on stored A and B octave spectra.

1.4.3 Digital I/O (-3xxx Option)

With the -3xxx option the SD375 can provide both the IEEE-488 *and* the RS-232 interface for complete remote front-panel control and convenient input/output of digital data. Therefore, due to the various peripheral interface and computer data output formats available, the -3 option uses a four digit option designator. For further information concerning this option, and option designations available, contact the nearest Scientific-Atlanta office or representative.

1.4.4 Synchronous Signal Generator (-4 Option)

This convenient signal source provides broadband white noise, band limited pseudo-random noise and single sinewave analog outputs for excitation of systems or networks for performance evaluation. The signal generator output mode is established from a PRGM menu and its output amplitude is selectable from 0.05V to 10V in a 1, 2, 5 sequence.

The pseudo-random noise is synced to the internal ADC clock and its sequence length matches the memory period of the analyzer. A trigger output, coincident with the start of each sequence, is provided. In the zoom mode, the pseudo-random frequency output is concentrated within the zoom window.

1.5 CONCEPT OF OPERATION

The function of this concept is to provide you with a working knowledge of how the SD375 performs signal processing, what the data is, where it comes from, where it goes, and what is done to it on the way.

1.5.1 SD375 Dynamic Analysis

The SD375, of course, is not a little black box with a tiny mathemetician in it calculating integrals. If you input a sinusoidal signal to the SD375, it does not see "A sin (ωt - θ)". It sees a time-distributed set of voltage levels. To achieve a frequency-distributed set of voltage levels the SD375 performs a numerical approximation algorithm called the Fast Fourier Transform, or FFT. The result is a "spectrum", or the frequency domain distribution of the time domain measurement.

The FFT, combined with appropriate weighting applied to the time domain data, (which prevents spurious frequency components from appearing due to the discontinuities at the beginning and the end of the time domain sample) is accurate within the frequency range of the instrument. Signals are filtered by a low-pass filter to prevent high-frequency components, beyond the range of the instrument, from showing up in the sample and causing spurious results.

This is the *basic* data handling of the SD375. A set of time-distributed voltage levels is run through an FFT, resulting in a set of frequency-distributed set of voltage levels. Each level is a "cell". Time domain information has 1024 cells. The resultant frequency domain information has 400 cells. The width of each frequency domain cell is 1/400th of the instrument's frequency range.

The memory period, or time-width of the time domain sample will be 400 $\times$ 1/frequency range (i.e., 100 kHz → 4 msec width). Each time domain cell represents a time increment of 1/1024th of that width. This can easily be seen by noting that the sampling rate is 2.56 $\times$ frequency range, or each sample is 1/2.56 fr seconds. With 1024 samples in a single time domain "ensemble", we obtain a total time for the sample of 1024/2.56 fr $= 400 \times 1/\text{fr}$ (fr = frequency range).

1.5.2 Architecture of the SD375, for Data Flow and Control

Figure 1-1 is a simplified block diagram of the SD375. Figures 1-2 through 1-7 show portions of this block diagram and give brief descriptions of the basic data flow of the SD375.

Input signals are brought in through a normalizing attenuator/amplifier, through a low-pass filter, and from there to the A/D. The output of the A/D is clocked into the input memory at the sampling rate determined by the frequency range. The input memories can then be read by the Array Processor. The Array Processor has two working memories for calculations, these being the Processor Memories. These Processor Memories are used for *all* calculations. In any one pass the Processor Memories may contain a time domain ensemble, then the resultant FFT, then the resultant average, etc.

There are two storage memories. One is the Averager Memory, used for storing results as averages are calculated. The other memory is the Storage Memory, used for storing the contents of the Averager Memory for later review. Average Memory is M1, Storage Memory is M2. The Array Processor does not average current data into M2. Data can be placed in M2 *only* by pressing M1 → M2, which directly transfers the Averager Memory contents into the Storage Memory. Both of these memories are twice as large as the Processor Memories, as each has an upper half, used for storing the real and imaginary parts of the cross-spectrum.

Memories M1 and M2 are general purpose average and storage memories. The CO, QUAD, G_{AA} and G_{BB} shown in the block diagram are the normal contents of these memories when in the Transfer Function or Power modes. SYNC TIME average will cause time domain data to be held in the Average Memory, transferrable to M2. PD data (probability density data from the STATISTICAL menu) may also be held in the Average Memory. SYNC TIME and PD will use only the lower halves of M1 or M2.

1.5.2.1 Real Time or Averaging

Normally, the A/D is constantly clocking new data into the Input Memories (this will not be the case when these memories are in HOLD). On each pass the Array Processor reads the contents of the Input Memories and places the time domain waveform in the Processor Memories. It then performs any necessary calculations on that data (usually an FFT). At this time, if an average is in progress, it adds the resultant to the current contents of the Average Memory.

1.5.2.2 Display Real Time, M1 or M2

The Real Time display will take the contents of the Processor Memory, resolve it with log, EU, PSD, etc., and generate the data ensemble that is sent to the crt, and the cursor values, which are placed in the "mailbox" (the "mailbox" is where the Z80 Control Processor and the 3002 Array Processor communicate with each other).

If M1 or M2 is being displayed, the Array Processor will first read the appropriate memory, then do any necessary calculations on the data. The resultant ensemble is *then* run through the display routines.

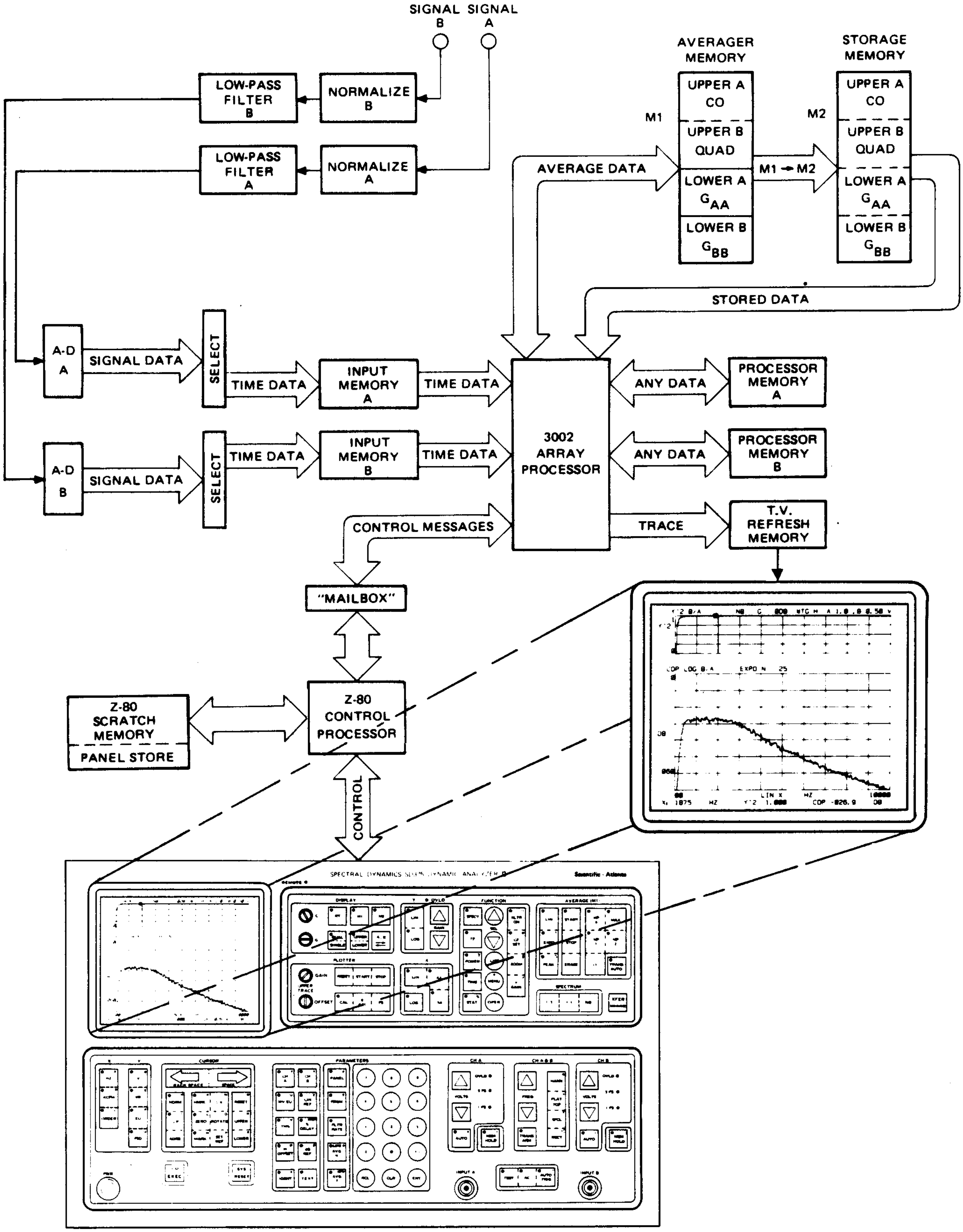
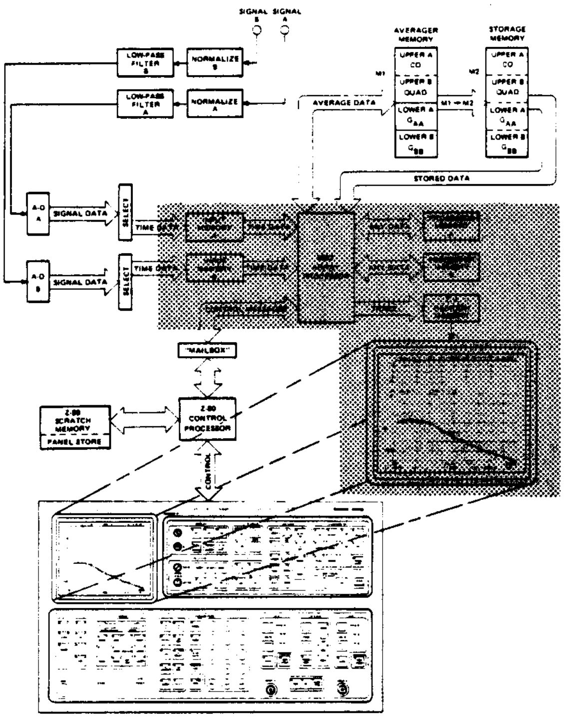
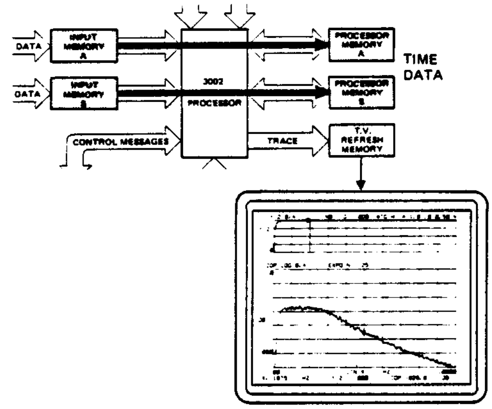


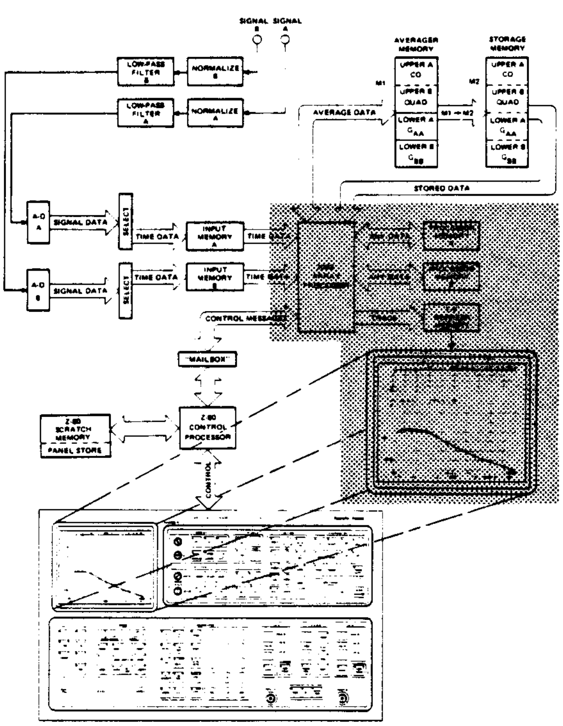
Figure 1-1. SD375 Simplified Block Diagram

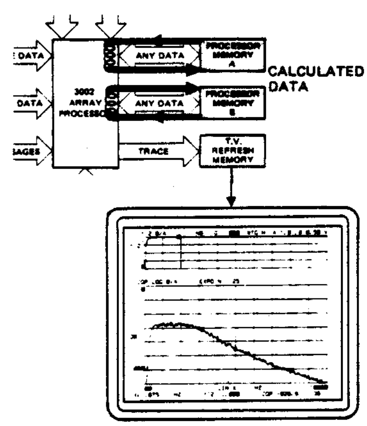




Step 1 — Signal in time domain is read from input memory into processor memory.

Figure 1-2. Step 1 Data Flow

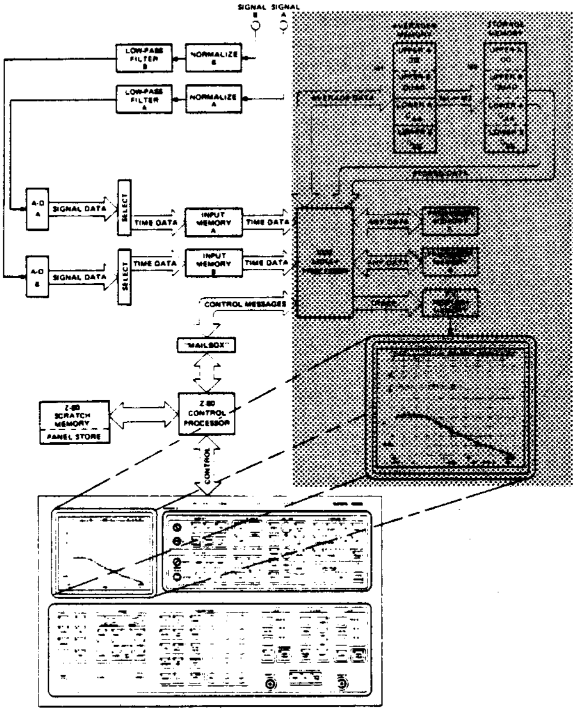


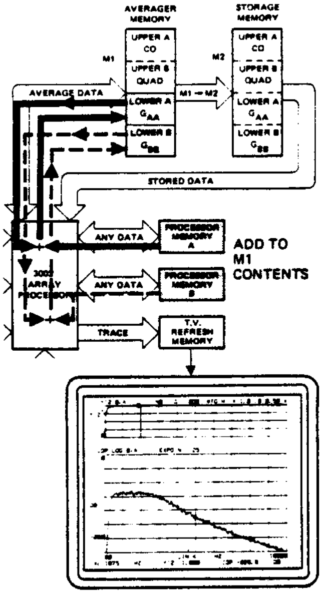


Step 2a — Calculations are performed on the contents of the processor memory and the results end up in processor memory.

The results depend on the function performed.

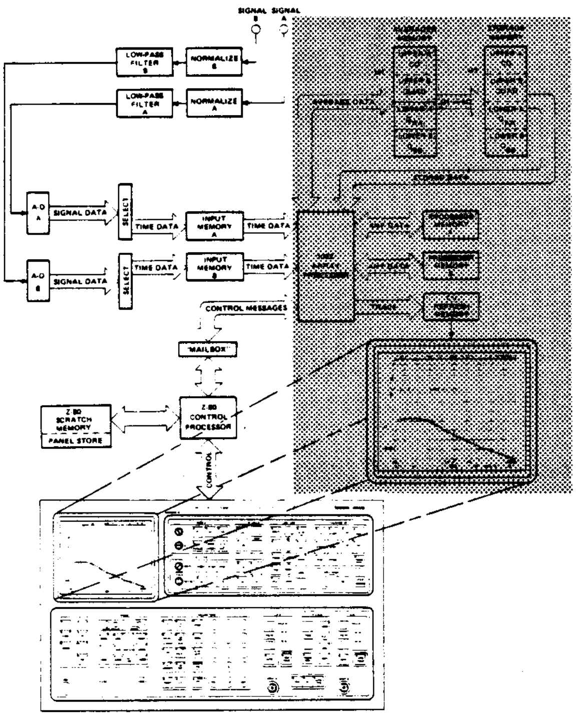
Figure 1-3. Step 2a Data Calculations

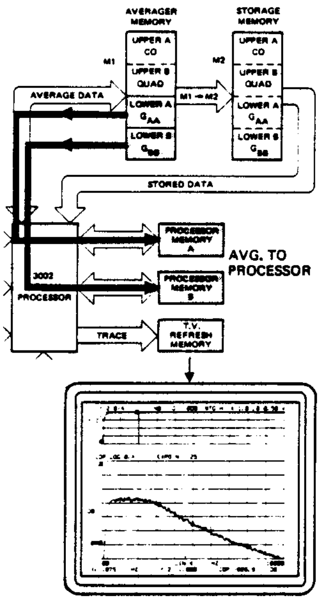




Step 2b — If an average is in progress, the result is "added" to the contents of the averager memory. If in TF or PWR, the CO & QUAD parts of the cross spectrum are averaged as well.

Figure 1-4. Step 2b Data Flow

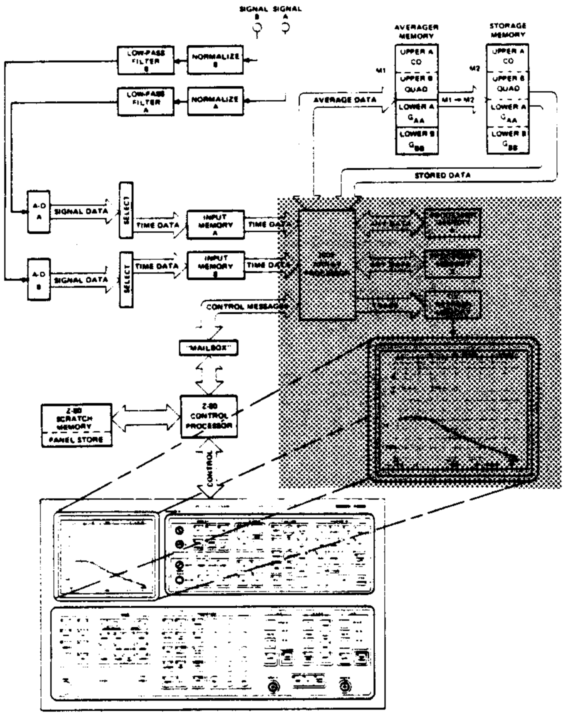


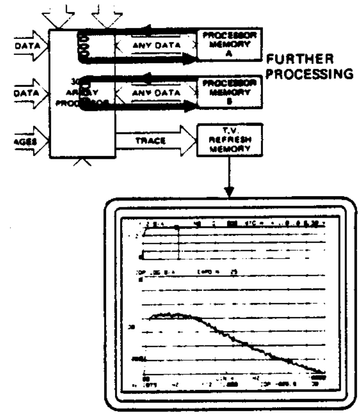


Step 2c — If SD375 is in M1 display, M1 is read into processor memory.

This will occur *without* steps 1-2b if the SD375 is not in an average mode.

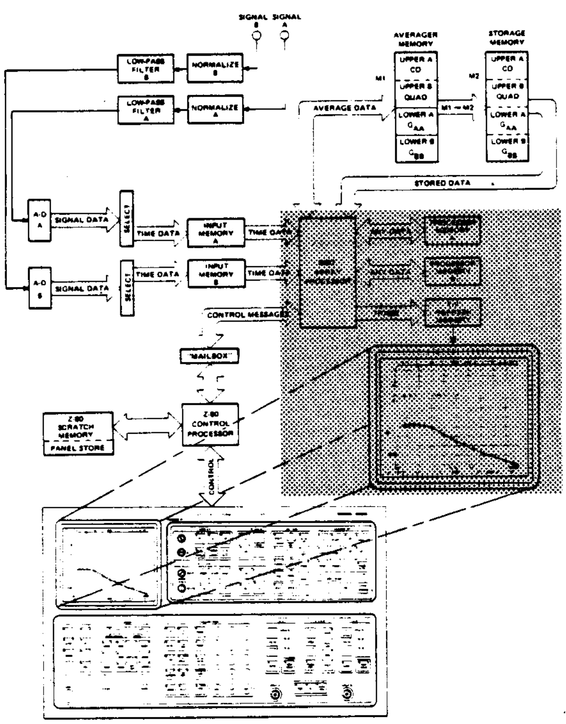
Figure 1-5. Step 2c Data Flow

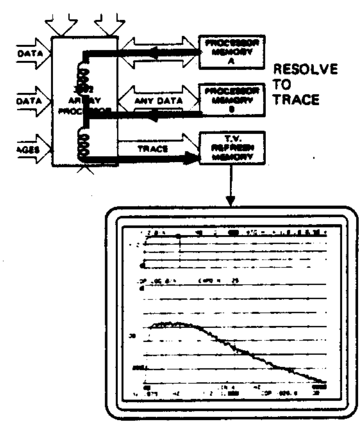




Step 3 — If further processing, like A/B, is required, it is performed. Results may end up only in processor memory A or B.

Figure 1-6. Step 3 Data Flow





Step 4 — Resolve processor memory data to trace resolution; output to crt.

Figure 1-7. Step 4 Data Flow

Understanding the normal data flow of the SD375 is important in performing tasks on the SD375. To properly analyze data, you should have an idea as to what it means and what sort of values to expect.

There are basically four types of data you will encounter while operating the SD375.

Spectrum (MAG Frequency) Complex Spectrum (e.g., MAG A, MAG B, BA*RE & IM)	400 cells
Amplitude Data	100 cells
Time Data	1024 cells

1.5.3 Numerical Specifics

Most of the following information is repeated in Section III as part of the description of the Primary Functions. While it's not required to have complete knowledge of the mathematics performed by the SD375, the formula provided with the following description can be used to give you an idea, as previously stated, as to what the data means and what sort of values to expect.

The SD375 deals with frequency domain information via an FFT on time domain samples taken. You need to know *what* quantities are actually dealt with by the SD375.

The pure fourier transform for a sample would be:

$$\mathcal{F}[a(t)] = A(j\omega)$$

$$\mathcal{F}[b(t)] = B(j\omega)$$

A $(j\omega)$ and $B(j\omega)$ are complex numbers that could be expressed in real and imaginary parts so that for any particular cell (which corresponds to the ω or radian frequency value; the value of ω being $2\pi f$),

$$A(j\omega) = a + jb$$

$$B(j\omega) = c + jd$$

A *complete* display of a spectrum would require a 3-dimensional display with a real axis (a or b), an imaginary axis (c or d) and an ω or frequency axis. Normal spectrum display, however, displays the $|A|$ or $|B|$ (magnitude) where:

$$|A| = \sqrt{a^2 + b^2} \quad \text{hence} \quad |A|^2 = a^2 + b^2$$

$$|B| = \sqrt{c^2 + d^2} \qquad\qquad |B|^2 = c^2 + d^2$$

The SD375, internally, handles the data in mag^2. These are the "power" data, and are the quantities:

$$\overline{G}_{AA} = \overline{a^2 + b^2}$$

$$\overline{G}_{BB} = \overline{c^2 + d^2}$$

The phase relationship *between* A and B is an important consideration, and must be preserved. Hence, the SD375 also works with a quantity called "cross spectrum." The value of cross spectrum can be seen by attempting the complex number calculation of transfer function.

$$H(j\omega) = \frac{B(j\omega)}{A(j\omega)} = \frac{c + jd}{a + jb}$$

By resolving the imaginary component out of the denominator (the imaginary component is the symbol "j", the $\sqrt{-1}$ complex number operator that allows the inclusion of the phase relationship in the transform) of the transfer function calculation using the complex conjugate of the denominator:

$$\frac{c + jd}{a + jb} = \frac{c + jd}{a + jb} \times \frac{a - jb}{a - jb} = \frac{(ac + bd) + j(ad - bc)}{a^2 + b^2}$$

We find that the denominator is obviously G_{AA}. The numerator is the *cross spectrum*, or G_{BA}. The SD375 stores G_{BA} in rectangular coordinates (real and imaginary) where:

$$\overline{ac + bd} = \overline{G}_{BA\ REAL} = (\overline{CO})$$

$$j(\overline{ad - bc}) = \overline{G}_{BA\ IMAG} = (\overline{QUAD})$$

When you display transfer function and phase, you are displaying the *magnitude* of the transfer function with the phase in the upper-scroll display. The following formulae show how this is achieved:

hence phase

$$TF = \frac{\overline{G}_{BA}}{\overline{G}_{AA}} = \frac{\overline{G}_{BA\ REAL} + j\,\overline{G}_{BA\ IMAG}}{\overline{G}_{AA}}$$

$$\phi = \tan^{-1}\left(\frac{\overline{G}_{BA\ IMAG}}{\overline{G}_{BA\ REAL}}\right)$$

and

$$|TF| = \sqrt{\left(\frac{\overline{G}_{BA\ REAL}}{\overline{G}_{AA}}\right)^2 + \left(\frac{\overline{G}_{BA\ IMAG}}{\overline{G}_{AA}}\right)^2}$$

One important factor must be noted in these formulae. When dealing with transfer function, power or correlation, the SD375 is always displaying the *average* memory data. The average quantity is denoted by: $\overline{G}_{AA}$, $\overline{G}_{BB}$, $\overline{G}_{BA\ REAL}$, $\overline{G}_{BA\ IMAG}$. Each quantity is averaged separately, then the functions to be displayed are calculated from these averaged quantities.

1.5.3.1 Transfer FUNCTION

Our first step is to present the specimen. The specimen is a black box, with an input and an output. The primary purpose of a dynamic analyzer is to determine what the specimen does to an input signal in order to get an output signal. The input signal may be an impact, the output the resultant vibration. The characteristic of the specimen which produced the output signal is the specimen's Transfer Function. If the Transfer Function can be accurately measured, the output can be calculated for any given input. If the user is designing or testing a specimen, and certain responses (outputs) are undesirable or unacceptable, the measurement of the Transfer Function can define the response for all "inputs" that may be found in the environment.

Just measuring the response may not be enough. There is no knowledge of the level and frequency content of the excitation which caused that response. A high response level at a certain frequency may be the result of a high excitation level at that frequency *or* it may show the effect of a system resonance amplifying a low level input. The output response is a result of both the input signal *and* the specimen. The Transfer Function is a characteristic of the specimen alone.

Unfortunately, it is not possible to place a probe on a specimen and just read the transfer function from a needle or crt. It is necessary to excite the specimen with some sort of input signal and measure the response. (Refer to Figure 1-8) With both, hopefully, it should be possible to determine the transfer function.

Suppose we were to place a 5 Vdc signal on the input. Upon measuring the output, we find it to be 2.5 Vdc. We then might theorize that the transfer function was a constant, H. Then $b = H \times a$, in this case $H = .5$ so $b = .5a$. Then we place a 500 Hz sinusoidal signal on the input, display that and the output response on an oscilloscope, and see that the *amplitude* of the response is 1/2 the amplitude of the excitation, but b is *not* 1/2 of a at the *same time*. (Refer to Figure 1-9)

If you could derive a formula for a(t) and b(t), observe the relationship and write a formula for the Transfer Function, f(t) so that $b(t) = f(t) \cdot a(t)$, you would discover that the formula falls apart when you change the frequency or the shape of the input signal. In fact, it is not possible, if the specimen has any sort of frequency response at all, to find a function f(t) such that $b(t) = f(t) \cdot a(t)$ for all possible a(t).

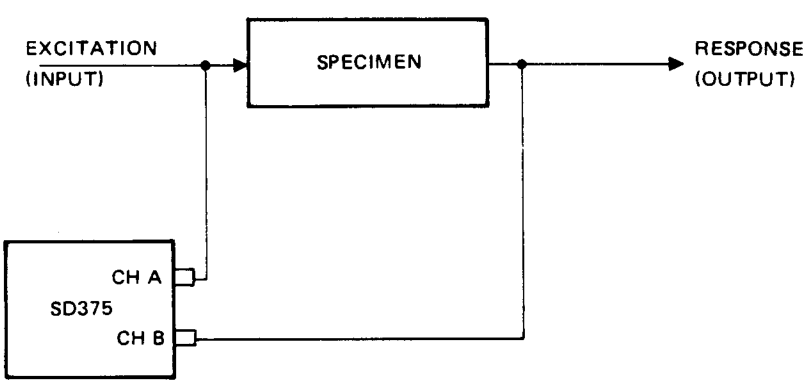


Figure 1-8. SD375 Transfer Function Interconnect

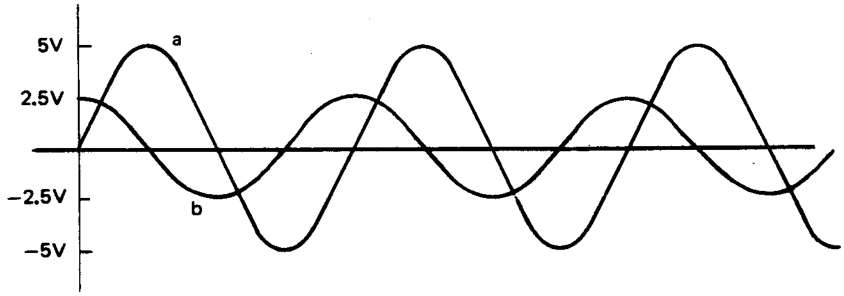


Figure 1-9. Phase Relationship of b and a

Transfer Function, as it is formally defined in the time domain, relates the excitation [a(t)] to the response [b(t)] via the "convolution" integral:

$$b(t) = a(t) * h(t)$$

The " * " operation is

$$a(t) * h(t) = \int_{-\infty}^{\infty} a(\lambda) \cdot h(t - \lambda)\, d\lambda$$

The convolution integral is not the "guiding light" of the transfer function phenomenon. The true value of this integral is the ability to translate frequency domain results back into time domain.

Suppose we measure a(t) and b(t) and translate the results into the frequency domain via a fourier transform, $\mathcal{F}$.

We obtain:

$$A(j\omega) = \mathcal{F}\,[a(t)]$$

$$B(j\omega) = \mathcal{F}\,[b(t)]$$

These are *frequency* domain expressions that define a sinusoidal amplitude-phase component of the measured signal for every frequency present in the signal..

The purely mathematical expression of the fourier transform is:

$$\mathcal{F}[x(t)] = X(j\omega) = \int_{-\infty}^{\infty} e^{-j\omega t}\, x(t)\, dt$$

translation back to the time domain requires the inverse transform,

$$\mathcal{F}^{-1}[X(j\omega)] = x(t) = \int_{-\infty}^{\infty} e^{j\omega t}\, X(j\omega)\, d\omega$$

These translations to and from the two domains (time and frequency) are standard in the analysis of response, and exceedingly useful if we note the following relationships:

$$b(t) = a(t) * h(t)$$

hence

$$\mathcal{F}[b(t)] = \mathcal{F}[a(t) * h(t)]$$

since (we won't derive it)

$$\mathcal{F}[x(t) * y(t)] = \mathcal{F}[x(t)] \cdot \mathcal{F}[y(t)]$$

we find that

$$B(j\omega) = A(j\omega) \cdot H(j\omega)$$

$$H(j\omega) = \frac{B(j\omega)}{A(j\omega)}$$

This is our most significant result. The frequency domain transfer function is very simply, the ratio of the frequency domain response to the frequency domain excitation. This is the way most of us are used to seeing transfer function. For example, the frequency response of a band-pass filter:

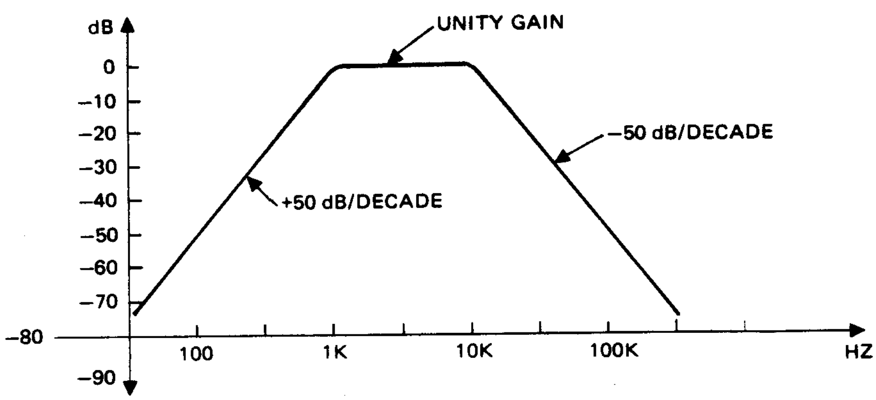
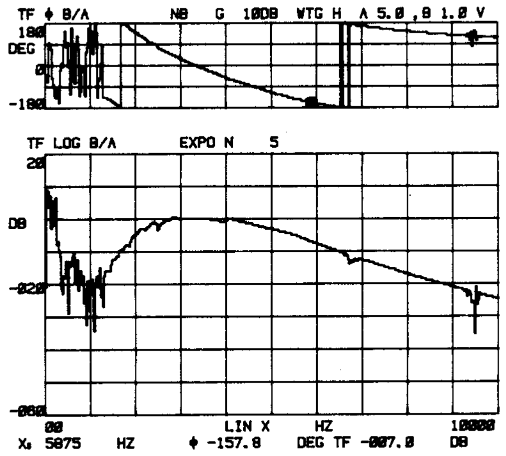


Figure 1-10. Example of Band-Pass Filter Frequency Response

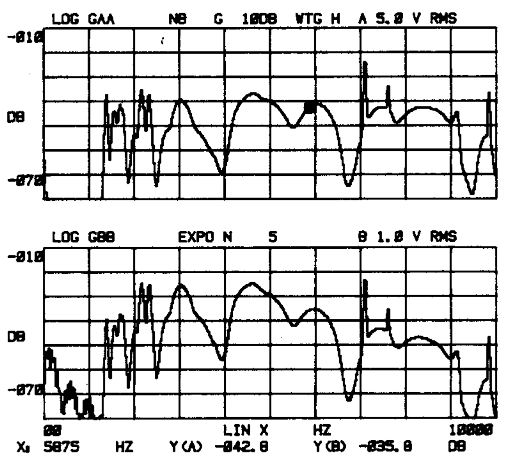
1.5.3.2 The Phenomenon of "Coherence" (γ^2)

Suppose we were measuring a band-pass filter whose transfer function was:



Example of Band Pass Filter Transfer Function

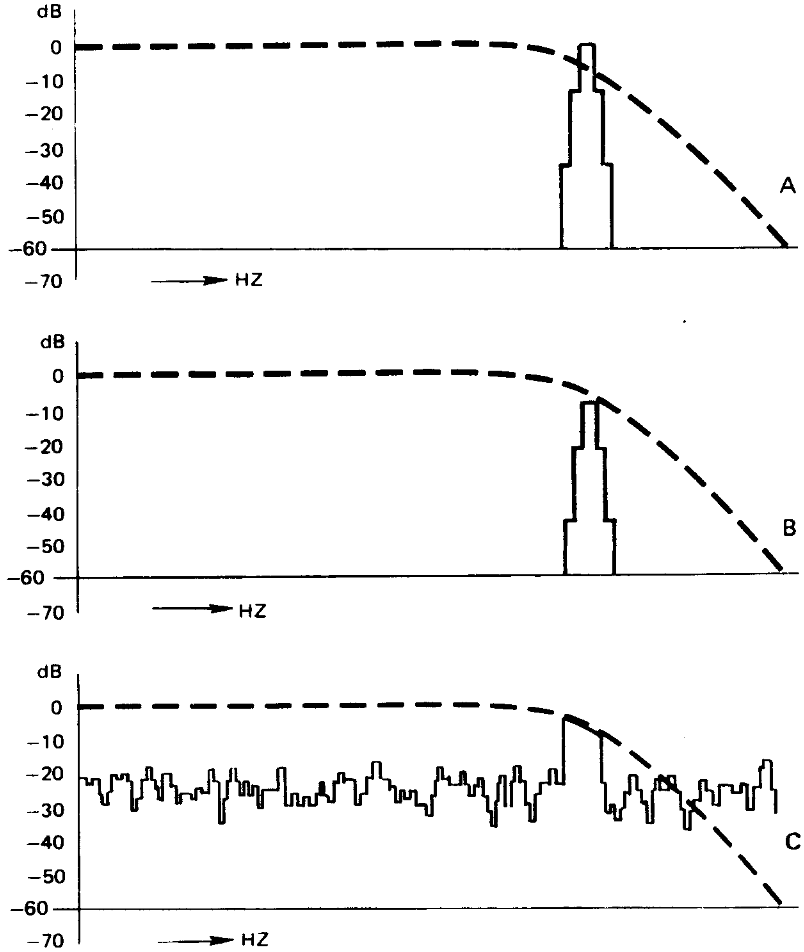
Any number of A-B frequency domain "pictures" represent data that could result in that TF. For example, the following spectra result in such a TF.



Examples of Frequency Domain Pictures

All that is required is that G_{BA}/G_{AA} have that form.

However, if we were to input to our specimen a *single* frequency, we would get the TF as shown in the following sketch.



Example of Single Frequency TF

The reason the TF curve takes this form is that the "data" in all the frequencies other than the excitation frequency is the (more than 70 dB down) "noise base" of the SD375. In other words, the only signal present at those frequencies is totally random very low level environmental noise.

Effectively, the TF measured at those frequencies is noise base divided by noise base. If we displayed the *phase* relationship, as well, we would observe a noisy phase relationship at those frequencies. That occurs because there is no consistent phase relationship to measure.

The -20 dB TF measured at these frequencies is, in fact, not a valid measurement. If we input random noise of some energy to A, the output B will also be random noise. But the *relationship* between A and B will be consistent, if the specimen has a consistent transfer function. The "noisy" phase and invalid gain shows up when there is *no* consistent relationship *between* A and B. Coherence is a measurement of this.

The quantity G_{BA} is averaged separately from G_{AA} and G_{BB}. G_{AA} and G_{BB} are the mag^2 of A and B spectra. G_{BA} is a *signed* quantity. A series of random, unrelated values averaged as mag^2 will result in a much larger quantity than a series of random values averaged as signed quantities. This will happen because the random phase relationship will produce both positive and negative values which will cancel each other out. If the relationship is totally random, the result will be very close to zero, when compared to the values averaged as mag². If a consistent relationship does exist, the phase will be consistent, yielding no "positive on this pass, negative on the next" to cancel.

Hence, if we render G_{BA} to a form compatible with G_{AA} and G_{BB}, the ratio between the two should be a value from 0 to 1 indicating the validity, or "coherence" of the values averaged.

NOTE

> There is *always* a relationship between A and B. Coherence tells you whether or not that relationship is a characteristic of the specimen or the random universe we live in.

We calculate coherence via:

$$\gamma^2 = \frac{|\overline{G}_{BA}|^2}{\overline{G}_{AA}\,\overline{G}_{BB}}$$

since (ignoring the average characteristics)

$$G_{BA} = |B|\,|A|_{REAL} + |B|\,|A|_{IMAG}$$

and

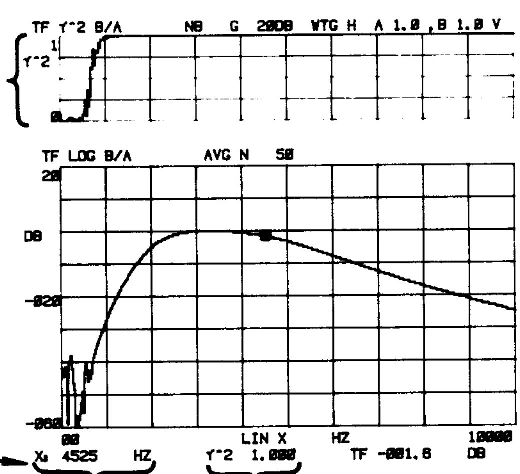
$$G_{AA} = |A|^2; \; G_{BB} = |B|^2$$

then

$$\frac{|\overline{G}_{BA}|^2}{\overline{G}_{AA} \cdot \overline{G}_{BB}} = \frac{(|B|\,|A|)^2}{|A|^2\,|B|^2} = 1$$

excepting, of course, where the A-B relationship is random, in which case $G_{BA}{}^2$ will approach 0 in relationship to $G_{AA} \cdot G_{BB}$. Thus we achieve our measurement of "coherence".

Coherence is shown in the upper display. The Y axis scaling, you'll notice, is from 0 to 1.



Coherence at 4525 Hz is 1.000

Example of Coherence (γ^2)

Table 1-1. Definitions of Functions and Symbols

All formulae will be expressed in terms of G_{AA}, G_{BB}, T_A, T_B, CO, QUAD and their averages.

G_{AA}	- Mag^2 or Power Spectrum, Channel A
G_{BB}	- Mag^2 or Power Spectrum, Channel B
G_{AA}	- Spectrum, Channel A
G_{BB}	- Spectrum, Channel B
T_A	- Time Domain Data, Channel A
T_B	- Time Domain Data, Channel B
G_{BA}	- Cross Spectrum
CO	- $G_{BA\ REAL}$
QUAD	- $G_{BA\ IMAG}$
ϕ	- Phase angle of FFT
[ ]	- Inverse FFT
γ^2	- Coherence
(M1)	- Contents of Memory 1 (Averager Memory)
(M2)	- Contents of Memory 2 (Storage Memory)
(SYNC)	- FFT of Time Averaged Data
(ZOOM)	- Translated data (the "-1" Option)

Any quantities with an "overbar" are averaged quantities. For example, $\overline{G}_{AA}$ = Average of G_{AA}, $\overline{G}_{BA}$ = Average of G_{BA} = $\overline{CO} + j\overline{QUAD}$ (CO and QUAD are averaged separately), $\overline{T}_A$ = Averaged Time Domain data Channel A, etc.

1.6 SPECIFICATIONS

1.6.1 Inputs

Impedance:	100k ohms
Coupling:	DC, AC (−3 dB at 0.5 Hz), AC only on 10, 20, and 50 mV input ranges.
Range:	11 input level ranges are available, from 0.01 Vrms to 20 Vrms, in a 1, 2 and 5 sequence. The 0.01, 0.02, and 0.05 Vrms ranges are not available when using the 100 kHz analysis frequency range. Level ranges may be selected either manually or automatically.
Max Input:	50 Vrms
A/D Converter:	12 Bits
Digital Input:	16 bit digital input to each input memory through optional digital I/O.
Anti-Aliasing Filters:	Automatically selected on each channel for each frequency range with initial 120 dB/octave rolloff for 70 dB rejection of aliasing terms; 1, 2, 4, and 5 Hz frequency ranges utilize the 10 Hz lowpass anti-aliasing filter. Amplitude Match: ±0.3 dB Phase Match: 10 Hz to 5 kHz ±1° 10 kHz to 50 kHz ±3° 100 kHz ±5°
Sampling Rate:	2.56 × full scale frequency range selected on internal sampling control. External sampling control provided.
Sync Reference:	Accepts TTL level input as trigger reference for dual-channel time domain signal averaging or synchronous spectrum functions.
Overload:	Front panel LED indication on each channel.
Level Indication:	0.1 and 0.5 F.S. LED's on each channel.
Data Editing:	Rotate contents of input memory for CH A or CH B. Zero selected parts of input memory for CH A or CH B.
Auto Trigger:	Synchronizes data loading of input memories at keyboard selected threshold level.
Test Signal:	Replaces input signal with internally generated periodic signal.

1.6.2 Analysis

Resolution:	400 lines of real time or averaged spectrum information on each analysis range. Each channel processes a 1024 point transform.
Frequency Ranges:	21 total ranges from 1 Hz full scale to 100 kHz full scale in 1-2-4-5 sequence.
Real Time Frequency:	4 kHz for single-channel forward tranform. 2 kHz for dual-channel forward transform. (Through to output display).
Frequency Response:	±0.5 dB at filter centers over entire frequency range up to 30 kHz. ±1.0 dB at filter centers from 50 kHz to 100 kHz.
Frequency Accuracy:	±0.0025% of full scale.
Dynamic Range:	70 dB with averaging from full scale to minimum discernible signal.
Noise Floor:	Below 70 dB with averaging.
Amplitude Linearity:	±1 dB or ±0.05% of full scale to 70 dB below full scale, whichever is greater.
Weighting:	Rectangular, Transient, (SPCL), Flat Top or Hanning, selectable.
Processing:	1, 2, 4 or MAX transforms per memory period processing selectable in averaging modes.
Int/Diff:	Single and double integration and differentiation performed as post analysis operation on processed data. Results displayed and read out in correct engineering units.

1.6.3 Averager

Number of Averages (N):	1 through 2048 in any integer value. Averaged display always normalized.
Number of Averages (T):	Entered to the nearest second from 1 through 9999 secs. Averaged display always normalized.
Modes:	Linear, Exponential and Peak
Control (Local or Remote):	Start, Stop, Erase, +1, Auto Transient, and Transfer M1 to M2.
Domain:	Frequency — Averager memory M1 and M2 stores 400 lines of spectrum data or cross property information. Time — Averager memory stores 1024 time domain data values for each channel in LIN or EXPO modes. Utilizes sync reference input for triggering.

1.6.4 Transient Capture

Trans Arm (Local or Remote):	Sets transient capture circuitry to trigger on incoming data signal from CH A or CH B.
Threshold Level:	Keyboard entered as TH% of full scale input level for CH A or CH B.
Memory Hold (Local or Remote):	Independent control for CH A and CH B holds data signals in input memories.
Transient Averaging (Local or Remote):	Automatic sequence for averaging transient signals. Overloaded transients are automatically discarded from the process.
% Delay:	Delays, each channel, with respect to memory zero of that channel in 10% memory period steps.
Analysis:	Time waveform can be displayed and plotted from input memory, or the time waveform and corresponding spectrum can be performed with any of the four weighting functions.

1.6.5 System Functions: Computed and displayed for CH A and CH B

Real Time Spectrum
Averaged RMS Spectrum
Averaged Power Spectrum or Power Spectral Density
Sum, Difference, Ratio of RMS Spectrum or Power Spectrum
Equalized Ratio (Averaged Spectrum ÷ Stored Spectrum)
Synch Spectrum (FFT of Time Averaged Data)
Synch Ratio (of FFT's of Time Averaged Data)

Cross Spectrum, MAG, RE, IM and RE vs IM
Transfer Function, MAG, RE, IM and RE vs IM
Equalized Transfer Function (Averaged Transfer Function ÷ Stored Transfer Function)
Phase
Coherence

Coherent Output Power
Impulse Response

Time Mode (Input Signal)
Normalized Autocorrelation
Normalized Cross Correlation

Probability Density Histogram
Probability Distribution

1.6.6 Display

Type:	Built-in TV raster scan display.
Grids:	Complete grid lines automatically generated for nonparallax viewing in LIN or LOG, X or Y format for single or dual display. Grid intensity — front panel adjustable.
Format:	Single or dual channel, time or spectrum, cross-property magnitude and phase or coherence, real and imaginary, Co versus Quad, LIN or LOG vertical and horizontal selection.
Menu:	Prompts raster display to show available data display combinations in selected function group.
Annotation:	Identifies each data display as time RT, M1, or M2; control status including full scale input level, frequency range, average mode and number, X and Y parameters and cursor values.
Gain:	X Axis — LIN (X1) displays full 400 spectrum lines or full memory period of input time record. LIN X2 display 200 spectrum lines or 50% of input memory. LIN X4 displays 100 spectrum lines or 25% of input memory expanded over full display width. Data segment to be displayed selected by cursor position.
	Y Axis — LIN gain of X0.1, X0.316, X1, X3.16, X10, X31.6, X100 for spectrum or time amplitude display. LOG gain up to +40 dB and attenuation of −20 dB in 10 dB steps. Gain factors automatically accounted for in data scaling.

1.6.7 CURSOR

Values:	X Axis — Reads seconds or milliseconds in time mode and Hz, KCPM, or Orders in frequency mode. Reads difference from a defined X axis reference.
	Y Axis — Reads amplitude as V or EU in Time mode. Reads V, dB, EU, PSD, or ΔP in Spectrum mode. Reads V or EU in the power spectrum mode. PSD (EU^2/Hz) readout and display automatically normalized to a 1 Hz effective noise bandwidth. dB values referenced to full scale or a set reference level defined through the keyboard. Phase read in degrees.
Modes:	Normal — Single cursor dot on either data trace.
	Harmonic — Multiples of cursor fundamental are intensified with a true fine-tune alignment mode.
	ΔX — Permits reading Δt or Δf values from a defined X-axis cursor reference.
	ΔP — Provides digital calculation and display of RMS signal power from cell 1 to cursor location or between cursor frequency points defined in the ΔX mode.
	ADRS — Enables cursor to be positioned to a specific cell location entered through the keyboard.

Mark — Provides capability of selecting and identifying, by number, up to 8 data points on single or dual display. Selected data points are intensified. Data values of X and Y parameters for all 8 data points can be listed on crt display.

Zero — Selectively replaces any data value in either input memory with a zero amplitude value under cursor control. Input memories must be in the HOLD mode.

Rotate — Selectively rotates, left or right, the contents of either input memory. Input memories must be in the HOLD mode.

1.6.8 Parameters

Panel:	Store and recall up to 7 operator defined front panel setups which are "remembered" when power is turned off.
PRGM:	Used for selecting Integration/Differentiation, Digital Plotter and Digital I/O Menus.
PLTR RATE:	Four different analog plotter rates can be selected through the keyboard.
AVG N:	Integer ensemble number up to 2048 entered through keyboard.
AVG T:	Average time, in seconds, up to 9999 entered through keyboard.
CHA, CHB:	Selected respective channel, or both, to which calibration values or setup parameters apply.
MV/EU:	Transducer sensitivity value for direct readout of engineering units.
LIN Ref:	Engineering unit reference number represented by a given voltage value.
TH%:	Transient capture threshold crossing as a % of full scale input level, for CH A or CH B.
% Delay:	Delays, both channels, with respect to the beginning of the memory, in 10% memory period steps up to 99 memory period intervals.
θ Offset:	Phase offset adjustable in 1 degree increments to a maximum of ± 180 degrees.
dB Ref:	dB reference level established through keyboard entry of data at selected cursor location on the Spectrum Display.
IDENT:	Provides up to a 4 digit display identification number.

1.6.9 Output

Video:	Composite video signal provides data and annotation for display on external raster scan monitor or video hard copy device; e.g., TEK 4632-6 or SD422.
X-Y Recorder:	Features Simulplot (continuous crt display during plot mode) and X-axis sweep rate control for automatic slowdown during plot of spectrum peaks. Analog X, Y and pen lift outputs. Plots contents of input memory or expanded part of input memory. Independent front panel position and gain control for the second data trace. Plots single or dual trace displays. Simple two-point CAL operation.

1.6.10 Built-In Option Specifications

1.6.10.1 Digital Translator (-1 Option)

Zoom Factors:	2, 5, 10, 20, 50, 100; front panel selectable
Zoom Accuracy:	±0.001% of full scale analysis range
Zoom Control:	Established by cursor position. Cursor limits for each zoom factor are:

Zoom Factor	Cell Limits Lower	Cell Limits Upper
2	50	350
5	20	380
10	10	390
20	5	395
50	2	398
100	1	399

Signal Gain:	1, 2, 4 or 8 times; front panel selectable
Digital Output:	200 digital words of floating point data transferred through -3D00 I/O option
Remote Control:	All front panel XLTR controls plus cursor position can be remotely sensed and controlled through the -3D00 I/O option.

1.6.10.2 1/3 and 1/1 Octave Analysis (-2 Option)

Center Frequency and Band Numbers:

1/3 Octave

Center Freq. (Hz)	Band No.
1.6- 1,250	2-31
6.3- 5,000	8-37
12.5-10,000	11-40
25 -20,000	14-43
50 -40,000	17-46
100 -80,000	20-49

1/1 Octave

Center Freq. (Hz)	Band No.
2 - 1,000	3-30
8 - 4,000	9-36
16 - 8,000	12-39
31.5-16,000	15-42
63 -31,500	18-45
125 -63,000	21-48

Filter Characteristics:	Geometric mean frequency, effective bandwidth, and passband uniformity meet ANSI S1.11-1966 (R1975) Class III standards for 1/3 octave and Class II standards for 1/1 octave. These same parameters comply with IEC Publication 225.
Display Range:	1/3 Octave Mode — 30 full bands plus overall level 1/1 Octave Mode — 10 full bands plus overall level
Cursor Readout:	X-Axis — center frequency and band number Y-Axis — V, dB, dBR or Engineering Units (EU)
Analysis Time:	0.4 sec for 1/3 or 1/1 octave
Linearity:	±1 dB or ±0.1% of full scale, whichever is greater
Memories:	Two memories available for storing averaged spectra plus a third memory for displaying a real time spectrum.
Minimum Transmission Loss Variation:	±1 dB
Maximum Attenuation:	70 dB

1.6.10.3 Digital I/O (-3xxx Option)

I/O Interfaces

(1) IEEE 488 1978: Eight-bit parallel, byte serial with 3-wire handshake

(a) Programmed talk/listen mode
(b) Talk or listen-only — hardware or software selected
(c) Device clear and service request implemented
(d) Port control assignment — hardware or software selected

(2) EIA RS-232-C: Serial bit

(a) Baud rate: 110, 300, 600, 1200, 2400, 4800, 9600, 19,200
(b) Parity: Odd, even or none
(c) Characters: 6, 7 or 8 bit with 1 or 2 stop bits
(d) Format: ASCII or binary
(e) Duplexing: Echo or quiet
(f) Auto line feed: On or off
(g) Handshake: Hardware or software
(h) Port control assignment — hardware or software selected

Digital I/O Interface Compatibility Chart

I/O Designation	PDP-11 and Byte Format	IEEE 488	RS-232-C	HP - GL* Plotters	TEK 4662 Plotter**
-3D01	✓	✓	✓	✓	
-3D02	✓	✓	✓		✓

*Includes:
HP 7225A or B with 17601A (IEEE) or 17603A (RS-232-C) personality module;
HP 7220A (RS-232-C only — automatic four-color pen selection);
HP 7245A or B (IEEE only);
HP 9872B or C (IEEE only — automatic four-color pen selection).
**IEEE only

1.6.11 Miscellaneous

Operating Temp: 5°C to 45°C (40°F to 113°F)

Weight: 25 kg (55 lbs) Nominal

Dimensions: Width — 43,2 cm (17″)
Depth — 48,6 cm (19″)
Height — 26,7 cm (10.5″)

1.6.12 Power

105–125/210–250 Vac (switch selectable), 45–65 Hz at approximately 350 Watts.