

SSC-344

**DEVELOPMENT OF AN
ONBOARD STRAIN RECORDER**



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1990

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DEVELOPMENT OF AN ONBOARD STRAIN RECORDER

The ability to obtain accurate hull girder strain measurements during full scale testing is necessary to better understand the structural response of ships in a seaway. Ship Structure Committee Report SSC-317, "Determination of Strain Rates in Ship Hull Structures: A Feasibility Study", addressed the use of in-place instrumentation to obtain strain time histories. This report develops data requirements for a standard strain recorder. The structural response information can be used to validate load criteria and analysis.

A handwritten signature in black ink, appearing to read 'J. D. Sipes'. The signature is stylized with loops and a long horizontal stroke extending to the right.

J. D. SIPES
Rear Admiral, U.S. Coast Guard
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16. Abstract The data requirements for a standard strain recorder are developed to obtain ship structural response data for a number of applications. A review of the state-of-the-art in strain recording instrumentation is presented and compared to the ideal instrumentation. A specific standard strain recorder is recommended that is flexible in operation and capabilities. The standard strain recorder is capable of recording ship structural response data resulting from severe environments facilitating validation of load criteria and analysis for ship structural response.					
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

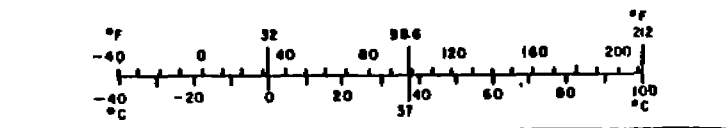
Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
m	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
m ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cup	0.24	liters	l
pt	pint	0.47	liters	l
qt	quart	0.95	liters	l
gal	gallon	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 m = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 285, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10-286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



METRIC CONVERSION FACTORS

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1.0 INTRODUCTION

This effort was started September 25, 1985 as Ship Structure Committee project SR-1303 under contract DTCG23-85-C-20071. The development of a Standard Strain Recorder is an integral part of the Ship Structure Committee's long range research plan. SSC-317, "Determination of Strain Rates in Ship Hull Structures: A Feasibility Study" specifically addresses the use of in-place instrumentation to obtain the required time histories. The SSC report entitled "Development of an Instrumentation Package to Record Full-Scale Ship Slam Data", SSC-274, identifies the strain recorder system as an integral part of the instrumentation package. Numerous projects designed to increase our understanding of the structural response of ships to in-service loading are envisaged for the future. These include an integration project with wave height measurement, possible full-scale collision and grounding tests, fabrication of a large scale hull girder model to be tested to failure and long term stress and strain rate data acquisition. Full scale strain data will be indispensable for inferring stress conditions in support of these projects. The statistical validity of collected data improves with the number of ships instrumented and the duration of these programs. In addition, the extreme weather conditions that are usually responsible for the higher stress levels are encountered relatively infrequently. An economical instrumentation package requiring minimal attention at sea would pave the way for acquiring an increasing volume of full scale data.

In developing a recommendation for a standard strain recorder, this project initially examines the requirements of previous and anticipated future full scale investigations. A requirement profile is established based on the authors' assessment of a "standard" marine investigative program. Selection of particular instrumentation is made based upon these requirements. Capabilities to satisfy more demanding experiments are addressed.

2.0 STRUCTURAL STRAIN DATA REQUIREMENTS

2.1 RECENT FULL-SCALE INVESTIGATIONS

In our quest to understand component stress levels and fatigue life cycles, we must mathematically relate these to measured relative strain. Therefore, to fully quantify absolute stress, we must first know the initial stress condition at the time the strain sensor is installed or calibrated. If a maximum stress or force is to be determined, careful structural analysis is required to predict the location and orientation of principal stresses. Understanding the structure of interest combined with experience from previous experiments can help to minimize the required number of data channels necessary to characterize the response of a structure. Instrumentation capabilities also can be most efficiently optimized with enhanced knowledge of the phenomena to be studied.

The majority of full-scale investigations to date have dedicated at least one channel to measurement of strains at the extreme fibers amidships. As an area of primary stress, determination of the midship section modulus occurs early in the structural design process. Experiments on board the UNIVERSE IRELAND and the FOTINI-L (1)* to determine longitudinal distribution of bending stress supported the concept that the region amidships is of primary concern when dealing with wave induced hull girder loading. Condition of ballast and stresses incurred during loading and unloading procedures can vary the stress distribution significantly. Nevertheless, strain measurement amidships produces the most universal data for comparison of the structural response of various vessels.

The concept of separating still water bending moments (SWBM) from wave induced bending moments is well documented in SSC 287 (2). It is essential that loading conditions are known at the time instrumentation is zeroed. Additionally, periodic fuel oil soundings and all ballast shifting should be noted for future correlation with measured data.

Various dynamic phenomena can be studied once we are able to separate the SWBM from the raw measured data. For a given loading condition the SWBM is essentially a constant value, or "DC term", upon which the dynamically varying wave-induced bending moments are superposed. It is usually possible to isolate dynamic occurrences by their respective frequencies.

The standard wave induced bending moment is of primary interest for several reasons. The naval architecture community has long sought experimental measurements to support the "standard" waves ($L/20$, $1.1L$, and $0.6(L^{.6})$) that are superimposed upon the ship's profile during the design stage (3). Long term bending moment amplitude measurements can verify the resultant safety factors associated with using these design standards. The frequency of occurrence coupled with associated stress levels establishes a fatigue profile for a

* Refer to reference at end of paper.

particular ship in service. Statistical analysis as applied by Little (4), et al and Stiansen (5) is particularly suited to extrapolation of life cycle data. Identification of pure wave induced phenomena is difficult due to the generally random wave encounter frequency. Higher frequency phenomena can be filtered out as with the STEWART J. CORT (6) to identify wave induced data.

In the case of episodic or extreme waves, extreme stress amplitudes and log entries are used to isolate these occurrences within the data. Since analytical modeling of these extreme seas is difficult, stress magnitude data is of great interest. Knowledge of geographical location and frequency of occurrence will support statistical prediction of a worst case encountered stress for a particular ship in a given service.

Several dynamic phenomena are easy to identify due to the fact that they correspond to the first mode natural frequencies of the hull. The process of whipping is triggered by a single or multiple slamming event causing transient hull girder vibrations primarily in the first mode. Measurements with five ships in the ENCOUNTER BAY class (7) exclusively dealt with whipping stresses encountered in service off Good Hope. Extreme data for the S.S. SEA-LAND McLEAN (8) was the result of whipping stresses superposed on other wave-induced stresses. The phenomena of springing, also at the ship's first mode natural frequency, occurs when the wave encounter frequency matches the natural frequency. Experiments with the EDWARD L. RYERSON (9) and more recently the STEWART J. CORT (10) were conducted to determine the magnitude of stresses produced by springing. Relatively short waves that can prevail for long periods of time on the Great Lakes coupled with low primary hull bending frequencies increases the incidence of springing. A reduction in speed or alteration of course are the sole remedies. Habitability problems and fatigue considerations are typical unsatisfactory by-products of springing.

The process of slamming can be responsible for stresses throughout the ship as with whipping but is usually associated with local loading of the bottom plating and framing near the bow. The significant physical properties associated with slamming are outlined in SSC 274 (11). Some full-scale experiments, as with the WOLVERINE STATE (12), have attempted to correlate bow pressures with measured stress. Structural response to slamming occurrences will continue to be of interest and triggered stress recording activated by a slam indication package (11) is essential. Current data storage technology may permit recording of transient events using mid event triggering.

Recent measurements involving ice breaking craft (13) have involved extensive instrumentation packages during "sea trial" type experiments. Localized stresses in the bow region are of particular importance during ice ramming. Midship stress and machinery foundation response is also of interest. Structural material toughness is critical due to operation in extreme temperature, and as such, an accurate time history of stress rate is required when analyzing structural members. The requirement to correlate data to ice properties and operate the vessels to their limits for investigative purposes results in intensive data collection runs with numerous personnel using redundant back-up equipment.

Another area of stress that lends itself to strain measurement analysis is that produced by sloshing cargo or ballast. Tank wall stress values have the ability to become quite large when the natural frequencies of liquids within tanks corresponds to the motion of the ship. However, measurements aboard the ESSO MAYLASIA (1) along the forward bulkhead determined tank sloshing loads to

be quite small for the conditions encountered. This highlights the need for long term statistical data. Due to the sensitive nature of its cargo, the spherical tanks and supporting structure of the LNG AQUARIUS (14) were instrumented to measure stress over one year of service. Full scale data will continue to supplement analytical and scale model results to further our understanding of this dynamic phenomena.

A troubleshooting application for strain gauge installation involves areas of expected or known stress concentrations. Measurements at hatch corners took place aboard the SEA-LAND McLEAN (8). To determine stress levels and fatigue life cycle histories other transition areas such as deckhouse edges have been instrumented as cracks appear. Extreme care concerning placement and orientation of sensor installation is required in these instances due to the large stress gradients.

This overview of various stress phenomena and associated measurable strains of interest aboard ships provides insight into the range of instrumentation requirements that are to be addressed in this report.

A survey of recent full scale strain data investigations was undertaken to serve as the basis for determining end-user requirements. Information on the following topics has been summarized and will be presented in Section 2.3, Tables 2-1 thru 2-7 for the results of this survey.

- Ship characteristics
- Principal phenomena studied
- Gauge type, number and location
- Cabling
- Signal conditioning
- Data storage
- Measured frequency range
- Record length and intervals
- User interface/activation method
- Results

The following ship instrumentation projects have been surveyed for this project:

POLAR SEA
MANHATTAN
ARCTIC
PIERRE RADISSON
LOUIS S. ST. LAURENT
SISU
YMER
CANMAR KIGORIAK
ROBERT LEMEUR
WOLFE
AQUARIUS
SEA-LAND McLEAN
STEWART J. CORT
CHARLES M. BEEHGLY
ROGER BLOUGH

NIHON
DART EUROPE
ENCOUNTER BAY CLASS
BOSTON
FOTINI-L
UNIVERSE IRELAND
IDEMITSU MARU
ESSO MAYLASIA
R.G. FOLLIS
WOLVERINE STATE
CALIFORNIA BEAR
HOOSIER STATE
MORMACSCAN
EDWARD L. RYERSON
ONTARIO POWER

2.2 SUMMARY OF SHIPBOARD INSTRUMENTATION REQUIREMENTS

2.2.1 Strain Gauges

Appendix A contains a generalized discussion of strain measurement methods. The metallic foil bonded strain gauge is widely accepted as the most versatile sensor in use today.

2.2.1.1 Strain Range

It is safe to assume that the material yield point is a sufficient extreme for most strain measurement. For structural carbon steel with $E = 30 \times 10^6$ lb/in² and a yield point @ 40×10^3 lb/in², a maximum tensile strain at yield is equal to .0013 inch/inch. This can be expressed as 1300 μ e with most electrical resistance bonded gauges linear to at least ± 5000 μ e. This strain range is a very modest percent of most strain gauges range.

2.2.1.2 Gauge Material

The strain sensing alloy and backing material should exhibit the most durable and stable characteristics possible. Our relatively low strain range requirement enables a selection of a robust backing material and an environmentally capable gauge alloy.

2.2.1.3 Attachment Method

In most cases it is preferable to use a bondable type strain gauge with proper adhesive and surface preparation. For instances where environmental conditions or access limitations are restrictive, a weldable type gauge consisting of an individual gauge or array of gauges pre-bonded to a foil back might be appropriate. The additional surface interface associated with weldable gauges produces increased risk of failure due to fatigue and or corrosion. In all cases, a non-corrosive tin/silver solder and sufficient strain relief should be utilized for installation of lead wires.

2.2.1.4 Installation Weatherproofing

The most overwhelming cause for failure of strain gauges in a marine environment is insufficient protection that permits saltwater intrusion and subsequent deterioration of leadwire connections. Proper attachment of the gauge itself to the specimen may also be compromised with this type of scenario.

Specialized strain gauge protective coatings exist so that with proper surface preparation and application they can effectively saltwater-proof a gauge installation. Successive layers of polyurethane and epoxy compounds can produce a sufficiently flexible yet durable moisture protection system. Encapsulated strain gauges are also available for this application. Additional mechanical protection may want to be considered, depending upon installation location. A waterproof conduit for leadwires is also required. The Teledyne installation for the ABS program (1) is an example of a system that could be utilized where absolute survivability outweighs cost considerations.

2.2.2 Data Transmission

For many installations, such as the SEA-LAND McLEAN (15), intermediate junction boxes have been utilized to allow completion of the bridge circuit closer to the actual gauges. For all wire runs, the low output signal level increases the susceptibility to noise interference. Shielded cable is essential for either installation during wireway construction or retrofitting. Suitable shielding can consist of either braided wire, foil, or solid conductive conduit. Another noise problem with cabling involves crosstalk between conductors. This typically occurs between the excitation and the signal conductors and can be reduced by isolating these wires as remote twisted pairs individually shielded within the bundle. Cabling must physically be protected along its entire length from the strain gauge to the rear of the instrument cluster. This can involve the use of either heavy walled conduit or armored cable, depending upon the wire location and duration of the experiment. Existing wireways are often convenient but can be a prime source of induced electromagnetic noise. Data transmission noise is perhaps the second greatest cause of degradation to system reliability after gauge failure itself. Cost of shipboard cable installation will inevitably be significant due to the need to penetrate watertight members and the labor intensive nature of running wires.

2.2.3 Signal Conditioning

Signal conditioning amplifiers for strain gauge circuits typically provide excitation voltages, calibration and balance capabilities along with filtering of amplified signals. Most units are of a modular construction suitable for rack mounting. Module quantities can be exactly matched to job requirements as far as number of measured channels.

Frequency response range is usually DC to over 10 kHz which far exceeds our dynamic requirements. The pressing demands of a shipboard measurement system are the result of long cable runs, extended unattended operation and environmental fluctuations. Several amplifier/conditioners address these problems directly while others rely on an interface with a control computer. Desirable system characteristics include selectable bridge excitation voltage, fully adjustable extended gain range, built-in bridge completion resistors, automatic shunt calibration, isolated excitation power supply, and multiple output levels.

The number of strain data signal channels can vary greatly depending upon the nature of the investigation. For statistical midship primary bending stress data collection, a single channel with active bridge arms port and starboard may be sufficient. This configuration makes it possible to electrically separate horizontal from vertical bending stresses and has become the standard baseline measurement for comparison between various investigations. Detailed investigations such as the SEA-LAND McLEAN (15) involving 97 strain gauge sensors and the M.V. ARCTIC (16) with 169 strain gauges have necessitated extensive amplifier/conditioner arrangements. This is a result of having any recording sequencing or multiplexing of signals occurring after amplification and bridge conditioning.

2.2.4 System Control

System control devices perform two basic functions in the data acquisition process. As intermediary instruments between amplifiers and recording devices, they are responsible for formatting the data. Algorithm execution for data recording activation sequences is also accomplished by the system controller. With some exceptions, the standardized automated recording format for ship instrumentation projects has been 30 minutes of data every four hours. Some provision is made to continuously record during heavy weather conditions. More recent investigations involving the LNG AQUARIUS (14), SEA-LAND McLEAN (16), STEWART J. CORT (6), and CHARLES M. BEEGLY (17) have utilized a preset activation threshold keyed off a particular channel to initiate data collection.

Where data channels outnumber recorder channels as with the SEA-LAND McLEAN (15), the controller can sequentially assign a single recorder channel to various signal inputs. If the controller is also doing an analog to digital conversion of the data prior to storage as with the M.V. ARCTIC and the M.V. ROBER LEMEURE (16 and 18), multiplexing is commonly performed. The analog to digital conversion rate must be sufficiently fast to preserve resolution at the upper frequency of interest. The necessary sampling rate can be determined assuming a required 10-20 samples per hertz multiplied by the number of signals being multiplexed per channel. Consideration of digital versus analog recording is of primary interest when data storage devices are analyzed.

The frequency range of interest must essentially start at the DC level for this is the condition the instrumentation is in during dockside calibration as with the ABS ships (1). First mode frequencies may be as low as .05 hz with large loaded oil carriers or nearer to .72 hz as shown by Stiansen (5) with the FOTINI. An accepted upper limit frequency for most analyses has been 2 hz. With analog recording techniques, data are typically recorded to 50 hz and then processed through a lowpass filter shoreside. It is usually desirable to observe frequencies above 2 hz to identify higher order phenomena such as blade frequency response and localized structure behavior. Digital recording configurations such as with the M.V. ARCTIC (16) have sampling rates that are variable to 1000 samples per second suitable for reproducing data to 100 hz.

2.2.5 Storage Devices

Analog recording involves the continuous preservation of a signal that is proportional to the apparent level of strain. Earlier investigations utilized strip chart recorders to accomplish this. More recently, multichannel magnetic tape recorders that perform a frequency modulation on the signal of interest have become the accepted industry standard. The ABS program (1), BOSTON (19), SEA-LAND McLEAN (15), LNG AQUARIUS (14) and others have all used 14 channel FM magnetic reel to reel tape recorders. The dynamic capabilities of one inch tape @ 15/16 of an inch/sec is suitable to accommodate 14 channels. Typical continuous recording limits are around 12 hours with standard size reels. This generally corresponds to four days of automated data recording between tape changes which can be considered a baseline system attendance guide.

2.3 DATA REQUIREMENT CONCLUSIONS

The requirements of previous strain recording investigations and anticipated future studies can provide the framework for building an instrumentation system. Tables 2-1 through 2-7 summarize the strain data characteristics as determined by the full-scale investigation survey. Of paramount concern for any instrumentation installation is the ability to set-up and maintain the equipment with a minimum amount of effort. For this reason, "state-of-the-art" technology is understood to represent a utilization of devices that are available in production with a reasonable track record. This enables us to concentrate on the integration of components rather than the burn-in period associated with infant technology.

The broad range of measurement applications requires a system that is of modular construction to facilitate expansion or modification. This is consistent with today's component board technology.

Strain sensing elements must, above all, be durable in service conditions. For certain installations such as with arctic operations, the installation environment may limit the practical service life of the installed strain gauge. Anticipated maximum strain rates and expected service cycles are shown in Table 8 and are well within the operational capabilities of most commercially available strain gauges.

Frequency response requirements are depicted graphically Figure 2-1 and are summarized in Table 2-8 and span a relatively broad range. The majority of applications are less than 20 HZ with activity in the DC to 2 HZ range of primary interest. Desired bandpass characteristics vary with phenomena and as such the instrumentation should be configurable at the user's discretion.

The system controller must have the ability to process simultaneously all channels of information. Sequencing algorithms should be user programmable and have the ability to key off of real time threshold levels. Concurrent controller tasks include support of the mass storage device, calibration command generation, data acquisition to buffer memory, system self check program and possibly signal processing.

Data storage capabilities should maximize the medium's capacity and minimize the required attendance skill. The marine environment dictates the use of a robust configuration because equipment physical interaction and component exposure is a problem particular to storage devices.

The above summary of required instrumentation specifications, as dictated by shipboard structural strain data acquisition, provides a basis for review of available equipment.

SHIP NAME	TYPE	LENGTH	WEIGHT	SPEED
POLAR SEA	Icebreaker	364' (LBP)	12,200 (DISP)	N/A
MANHATTAN	Icebreaking Tanker	1006' (LOA)	106,947 (DWT)	N/A
ARTIC	Icebreaking Bulk Carrier	645' (LBP)	37,136 (DISP)	15.5 kts
PIERRE RADISSON	Icebreaker	283' (LBP)	6349 (DISP)	13.5 kts
LOUIS S. ST. LAURENT	Icebreaker	334' (LBP)	13,800 (DISP)	13 kts
SISU	Icebreaker	315' (DWL)	7777 (DISP)	N/A
YMER	Icebreaker	315' (DWL)	7777 (DISP)	N/A
CANMAR KIGORIAK	Icebreaking Supply Vessel	278' (LWL)	6694 (DISP)	15 kts
ROBERT LEMEUR	Icebreaking Supply Vessel	260' (LWL)	5759 (DISP)	N/A
WOLFE	Icebreaking Supply & Bouy Vessel	202' (LBP)	3015 (DISP)	13 kts
AQUARIUS	LNG Carrier	936' (LOA)	95,000 (DISP)	20.4 kts
SEA-LAND McLEAN	High Speed Containership	946' (LOA)	50,315 (DISP)	33 kts
STEWART J. CORT	Great Lakes Bulk Carrier	1000' (LOA)	74,000 (DISP)	14 kts
CHARLES M. BEEHGLY	Great Lakes Bulk Carrier	806' (LOA)	41,250 (DISP)	N/A
ROGER BLOUGH	Great Lakes Bulk Carrier	858' (LOA)	60,400 (DISP)	N/A
NIHON	High Speed Containership	845' (LWL)	58,000 (DISP)	26 kts
DART EUROPE	Containership	760' (LOA)	28,034 (DWT)	N/A
ENCOUNTER BAY CLASS	High Speed Containership	746' (LOA)	28,800 (DWT)	N/A
BOSTON	Containership	522' (LOA)	20,250 (DISP)	N/A
FOTINI-L	Bulk Carrier	820' (LOA)	61,000 (DWT)	17 kts
UNIVERSE IRELAND	Tanker	1135' (LOA)	312,000 (DWT)	N/A
IDEMITSU MARU	Tanker	1122' (LOA)	210,000 (DWT)	N/A
ESSO MAYLASIA	Tanker	1062' (LOA)	198,800 (DWT)	N/A
R. G. FOLLIS	Tanker	784' (LOA)	66,500 (DWT)	N/A
WOLVERINE STATE	Dry Cargo	520' (LOA)	22,000 (DISP)	N/A
CALIFORNIA BEAR	Dry Cargo	563' (LOA)	13,400 (DWT)	N/A
HOSSIER STATE	Dry Cargo	520' (LOA)	22,000 (DISP)	N/A
MORMACSCAN	Dry Cargo	483' (LOA)	12,400 (DWT)	N/A
EDWARD L. RYERSON	Great Lakes Ore Carrier	730' (LOA)	34,900 (DISP)	14.6 kts
ONTARIO POWER	St Lawrence Bulk Carrier	675' (LWL)	29,939 (DWT)	N/A

N/A = information not available

Table 2-1
SHIP CHARACTERISTICS of PREVIOUS INVESTIGATIONS

SHIP NAME	ORGANIZATION	PURPOSE OF INVESTIGATION
POLAR SEA	USCG	Confirm structural adequacy and infer ice loads, levels and distribution. Emphasis on acquiring large database for statistical analysis.
MANHATTAN	N/A	Determine load levels and design criteria
ARCTIC	Transport Canada R&D Center and German & Milne	Ramming loads to determine safety levels; compare open water and in ice to predict lifetime maximums and potential fatigue problems.
PIERRE RADISSON	Transport Canada R&D Center and German & Milne	Forebody impact pressures with 1st and multi-year ice; prototype testing of real-time bow area stresses.
LOUIS S. ST. LAURENT	CCG	Strain and ice pressure measurements to predict design pressures and ice load criteria.
SISU	VTT Research	Extensive system for collection of long-term statistical and dedicated trials data.
YMER	Swedish Expedition YMER 80	Correlate hull and machinery loads to ice conditions.
CANMAR KIGORIAK	CCG	Stress measurements to determine local and global ice loads and dynamic ship response.
ROBERT LEMEUR	CCG	Stress measurements to determine local and global ice loads and dynamic ship response.
WOLFE	CN Marine & German & Milne	Measure rigid body motions and acceleration for icebreaking resistance studies.
AQUARIUS	General Dynamics & Energy Trans. Corp.	Compare long-term stress distribution predicted with 13 months of measurements to initial design criteria.
SEA-LAND McLEAN	ABS, SSC & Sea Land	Extensive measurement program with correlation to waves, models and theory; statistical strain data acquisition and wave height measurement.
STEWART J. CORT	USCG, MARAD, ABS & Industry	Continuation of research to update Great Lakes load line and strength requirements. Do in-service limits approach fatigue limits?
CHARLES M. BEEHGLY	USCG	Attempt to correlate hull stress level with apparent heading to waves.
ROGER BLOUGH	Owner, MARAD	Attempt to analyze superposition of dynamic and static loads
MINION	Lloyds	Measurements undertaken to verify calculations. Directional components isolated. Interest in machinery space amidships.
DART EUROPE	Lloyds	Relationship of rolling, torsional, and longitudinal stress.
ENCOUNTER BAY CLASS	OCL	Concern of stress at hatch corners due to large deck openings.
BOSTON	SSC & Sea Land	Investigation as similar vessel to WOLVERINE STATE with greater depth and larger deck openings.
FOTINI-L	ABS	Part of an extensive program to gather long-term wave-induced bending stress data for predicting extreme values of seaway loading on existing and future ships. Naval architects as end-users of data.
UNIVERSE IRELAND	ABS	N/A
IDEMITSU MARU	ABS	N/A
ESSO MALAYSIA	ABS	N/A
R. G. FOLLIS	ABS	N/A
WOLVERINE STATE	SSC	Data filtered to show only wave-induced longitudinal bending. First long-range study on U.S. dry cargo vessels. Plating unfairness studied.
CALIFORNIA BEAR	SSC	N/A
HOOSIER STATE	SSC	Desire for analog records for future investigation. Attempt to integrate results with ISSC.
NORMACSCAN	SSC	Comparison data to WOLVERINE project
EDWARD L. RYERSON	SNAME	Great Lakes springing phenomenon.
ONTARIO POWER	Natural Resource Con. of Canada	Ocean conditions for modified Great Lakes design.

Table 2-2
OBJECTIVES of PREVIOUS INVESTIGATIONS

SHIP NAME	PHENOMENA STUDIED	GAUGE LOCATION	TYPE	QUANTITY
POLAR SEA	Local Ice Loads	Bow Area	Strain	160
MANHATTAN	Local & Hull Bending Ice Loads	Bow Below DWL, Hull Shell & Deck	Electrical & Scratch Gauges	6 Groups
ARCTIC	Bow & Hull Bending Ice Loads	Bow, Midship Hull & Deck	Aitech Type SG 129, Normal & Shear	259
PIERRE RADISSON	User Interface System, Bow Area Ice Loads	Forebody Shoulder	Impact & Strain Gauges	72
LOUIS S. ST. LAURENT	Icebreaking Stress Distribution	Bow Area Below DWL	Scratch & Electrical Strain	40
SISU	Icebreaking Vibratory Stress	Forebody & Shoulder at DWL	Strain	26
YMER	Icebreaking Hull & Machinery Strains	Forebody at & below DWL	Hottinger LP21 Electrical Gauges	27
CANMAR KIGORIAK	Local & Global Ice Loads	Forebody Shear, Midship Bending & Shear	Strain	56
ROBERT LEMEUR	Local & Global Ice Loads	Forebody Shear, Midship Bending & Shear	Strain	54
WOLFE	Icebreaking Shaft Torsional Strain	Prop Shafts	Torque Strain Bridge	2
AQUARIUS	Stress in Spherical Tank, Supports & Hull	Tank, Support Strut & Hull Amidships (P&S)	Micro-Measurement WK-15-125AD-350	9 Arrays
SEA-LAND McLEAN	Bending & Shear Stresses, Stress Concentrations	Midship, Forward & Aft (Deck & N.A.) & Hatches	Microdot SG 189 120 Ω 1/4 Bridge	97
STEWART J. CORT	Midship Bending, Shear Stresses, Twisting & Frame Bending	Forward & Aft (Btm. & N.A.), Midship Btm. Shell & Deck	Electrical Resistance, Dyadic Configuration	6 Ch.
CHARLES M. BEEHGLY	Bending Stress	Deck Amidships & 1/4 Pts. (P&S)	N/A	N/A
ROGER BLOUGH	Midship Dynamic & Static Bending	Midship, 3/4 Point & Aft Deck	N/A	N/A
NIHON	Vertical & Horizontal Bending, Warping	N/A	Extensometer & Unbonded Strain Gauges	8
DART EUROPE	Fore & Aft Strains	Amidships Main Deck (P&S), Deck Edge & Hatch Sides	Multidirectional Arrays, Unidirectional at Hatch	N/A
ENCOUNTER BAY CLASS	Whipping Stresses	Midship (P&S) at Upper Longitudinal	N/A	N/A
BOSTON	Fore & Aft Strains	Main Deck & N. A. Amidships (P&S)	BLH Type: FAB-28-S6 & FAB-25-12-S6	7 Ch.
FOTINI-L	Fore & Aft Strains, Springing, Longitudinal Distribution Aft	Main Deck Amidships & (4) Places Aft (P&S), Side Shell at 1/4 Pt.	BLH Type: FAB 28-S6 & FAB 50-25-S6	7 Ch.
UNIVERSE IRELAND	Fore & Aft Stresses, Longitudinal Stress Distribution for Seaway & Loading	Main Deck Amidships, Fore & Aft (P&S)	BLH Type FAB-28-S6 & FAB-50-35-S6	5 Ch.
IDEMITSU MARU	Midship Bending	Midship (P&S) on Deck at Frame & Longitudinal Intersection	BLH Type: FAB-28-S6	1 Ch.
ESSO MAYLASIA	Fore & Aft Strains, Tank Sloshing	Midship (P&S), (4) locations on Forward Bulkhead	BLH Type: FAB-28-S6 & FAB-50-35-S6	5 Ch.
R. G. FOLLIS	Midship Bending	Amidships (P&S)	BLH Foil Epoxied to Steel & Spot Welded	N/A
WOLVERINE STATE	Fore & Aft Strains, slamming	Main Deck Amidships (P&S)	BLH Type: FAB-28-S6	N/A
CALIFORNIA BEAR	Midship Bending	Main Deck Amidships (P&S)	Electrical Resistance	N/A
HOSSIER STATE	Fore & Aft Strains	Main Deck Amidships (P&S)	Electrical Resistance	N/A
NORMACSCAN	Fore & Aft Strains	Main Deck Amidships (P&S)	Electrical Resistance	N/A
EDWARD L. RYERSON	Springing & Plate Stress Distribution	Main Deck Amidships & at L/3 forward	Stress Transducer Configuration	N/A
ONTARIO POWER	Bending Stress	Main Deck Amidships and at Forward & Aft 1/4 Pts	Electrical Resistance	N/A

Table 2-3

STRAIN SENSORS of PREVIOUS INVESTIGATIONS

SHIP NAME	AMPLIFIER/ CONDITIONER	CABLING	FREQUENCY
POLAR SEA	N/A	N/A	32 Hz Sampling
MANHATTAN	N/A	N/A	N/A
ARCTIC	Vishay Signal Conditioning Amplifier, 32 Ch. Multiplexer, A/D Converter	Multiconductor	75 Hz - 1000 Hz Sample Rate
PIERRE RADISSON	50 Ch. Signal Conditioning Amplifier	N/A	N/A
LOUIS S. ST. LAURENT	Bridge Completion & Balance Unit, HP 3052A Data Acquisition System	3-CORG 14, Collectively Screened	15 Hz Sampling
SISU	32 Ch. DC Amplifier, Input Filter, Summing Unit & Microprocessor	N/A	200 Hz Sampling
YMER	N/A	Multiconductor	N/A
CANMAR KIGORIAK	64 Ch. Signal Conditioning Amplifier, FET Multiplexer & A/D Subsystem	100% Shielded Signal Triplets with Low Pass Filter	5 Hz Bandwidth
ROBERT LEMEUR	64 Ch. Signal Conditioning Amplifier, FET Multiplexer & A/D Subsystem	100% Shielded Signal Tables with Low Pass Filter	5 Hz Bandwidth
WOLFE	N/A	Screened Cable	N/A
AQUARIUS	Vishay 2100, 10 Ch. Signal Conditioner	Cabling Through Intrinsic Safety Barriers	N/A
SEA-LAND McLEAN	50 Ch. Signal Conditioner with 0 to 50 Hz Bypass & Selectable Channels	Standard Lengths to Junction Boxes, Ship Cabling to Instrumentation	0-50 Hz Bypass
STEWART J. CORT	N/A	N/A	Processed to 2 Hz
CHARLES M. BEEHLY	N/A	N/A	N/A
ROGER BLOUGH	N/A	N/A	N/A
NIHON	N/A	N/A	N/A
DART EUROPE	N/A	N/A	N/A
ENCOUNTER BAY CLASS	N/A	N/A	N/A
BOSTON	Statham Instruments Stain Gauge Signal Amplifier # CA9-56	N/A	N/A
FOTINI-L	B&F Instruments #'s 2423 & 600-10	Shielded 6 CVV5 - 1.25 Installed at Construction	DC-50 Hz Recorded
UNIVERSAL IRELAND	B&F Instruments #'s 2423 & 600-10	7 Conductor Armored Type 250-V-MRYC-7, Conduit on Deck	DC-50 Hz Recorded
IDEMITSU MARU	B&F Instruments #'s 2423 & 600-10	Armored Cable Type 250-MRYC-7 Installed at Drydocking w/o Splices	DC-50 Hz Recorded
ESSO MAYLASIA	B&F Instruments #'s 2423 & 600-10	7 x 1.5 mm ² x 24 x 1.5 mm ² Type LMKKB Run in Existing Cableways	DC-50 Hz Recorded
R. G. FOLLIS	B&F Instruments #'s 2423 & 600-10	Shielded Cables CS-80-7 x 1.5 mm ² in 1 1/4" & 2" Conduit	DC-50 Hz Recorded
WOLVERINE STATE	N/A	N/A	N/A
CALIFORNIA BEAR	N/A	N/A	N/A
MOSSIER STATE	N/A	N/A	N/A
MORMACSCAN	N/A	N/A	N/A
EDWARD L. RYERSON	N/A	N/A	N/A
ONTARIO POWER	N/A	N/A	N/A

Table 2-4

SIGNALCONDITIONING of PREVIOUS INVESTIGATIONS

SHIP NAME	DEVICE	ACTIVATION	SEQUENCE	NUMBER OF RECORDS	SERVICE
POLAR SEA	N/A	N/A	N/A	N/A	3 & 4/83
MANHATTAN	Magnetic Tape	Continuous During Icebreaking & Ramming	N/A	N/A	1969 & 1970
ARCTIC	TEAC SR-70, Honeywell 5600E Tape, 1852 Visicorder & Floppy Disk	During Ramming & Open Water	Continuous & 12 Hr.	N/A	7-11/79, 6/81, 8-11/82 & Summer, 84
PIERRE RADISSON	(2) 28 Ch. FM Tape, CRT & Visicorder	Continuous Real Time	N/A	N/A	7-8/78 & 8/83
LOUIS S. ST. LAURENT	25 Ch. UV, Chart, Visicorder & Analog Tape	Record During Ramming	N/A	N/A	3/73 & 11/80
SISU	Cassette, Visicorder, & Storage Scope With FFT	Record During Icebreaking	N/A	N/A	Baltic: 2/79, 1/81 & Winter, 82
YMER	6 Ch. UV & 4 Ch. FM Recorders	Record During Icebreaking	N/A	N/A	6-10/80
CANNAR KIGORIAK	HP 209836 with Floppies, 28 Ch. FM Back-Up Tape	Record During Ramming	5 Sec. Impact Recording	402	6, 7, & 10/83
ROBERT LEMEUR	HP 209836 with Floppies, 28 Ch. FM Tape Back-Up	Record During Ramming	10 Sec. Measurements	220	6-7/83
WOLFE	Honeywell & Coleclec Visicorders	Record During Ramming	N/A	N/A	3/69
AQUARIUS	Honeywell 5600C FM 14 Ch. Magnetic Tape	Timed, Manual or Acceleration Triggered	30 Min./2 Hrs.	N/A	Indonesia to Japan, 5/77-6/78
SEA-LAND McLEAN	(2) APEX 14 Ch. FM Tape	Timed, Manual or Stress Level w/Group Sequencing	30 Min./4 Hrs.	5000	U.S. to Europe, 10/72 - 3/75 (28 Voyages)
STEWART J. CORT	DEC PDP 11/03 Digital Tape Storage	Timed, Manual or Stress Level w/Group Sequencing	30 Min.	N/A	Great Lakes, '72, 10-12/79
CHARLES M. BEEHLY		Manual or Stress Threshold	30 Min./Random	136/'73	Great Lakes, '72-'74
ROGER BLOUGH	N/A	N/A	N/A	N/A	1972-74
NIHON	N/A	N/A	N/A	N/A	Round World, 1972
DART EUROPE	N/A	N/A	N/A	N/A	North Atlantic, 1970-71
ENCOUNTER BAY CLASS	N/A	N/A	N/A	N/A	UK to Australia 1969-70
BOSTON	AMPEX 14 Ch. FR-1300	Primarily Timed Automatic	15 Min./4 Hrs.	883	North Atlantic, 12/68 - 3/70 (7 Voyages)
FOTINI-L	Teledyne Geotech 14 Ch. Model #19429	Timed & Threshold	30 Min./4 Hrs.	2800	Pacific 9/67 - 11/70 (17 1/2 Voyages)
UNIVERSE IRELAND	Teledyne Geotech 14 Ch. Model #19429	Timed & Threshold	30 Min./4 Hrs.	2683	Persian Gulf & Europe, 7/68 - 12/70 (11 Voyages)
IDEMITSU MARU	Teledyne Geotech 14 Ch. Model 19429	Timed & Threshold	30 Min./4 Hrs.	2127	Persian Gulf & Japan, 11/67 - 6/69 (14 Voyages)
ESSO MAYLASHA	Teledyne Geotech 14 Ch. Model #19429	Timed & Threshold	30 Min./4 Hrs.	3760	Persian Gulf & Europe, 4/68 - 9/70 (15 Voyages)
R. G. FOLLIS	Teledyne Geotech 14 Ch. Model #19429	Timed & Threshold	30 Min./4 Hrs.	1572	Worldwide, 1/68 - 4/70 (18 Voyages)
WOLVERINE STATE		Unattended Equipment	30 Min./4 Hr.	5245	North Atlantic, 12/61 - 5/69 (61 Voyages)
CALIFORNIA BEAR	Magnetic Tape	N/A	30 Min./4 Hrs.	1237	North Pacific, 11/66 - 10/68 (13 Voyages)
HOSSIER STATE	N/A	Unattended Equipment	30 Min./4 Hrs.	1186	North Atlantic 11/60 - 12/63 (34 Voyages)
NORMANSCAN	N/A	N/A	30 Min./4 Hrs.	1562	Atlantic 4/64 - 2/67 (18 Voyages)
EDWARD L. RYERSON	N/A	N/A	30 Min.	539/'67	Great Lakes, 1965-68
ONTARIO POWER	N/A	N/A	N/A	N/A	North Atlantic, 1965-66

Table 2-5
DATA RECORDING of PREVIOUS INVESTIGATIONS

SHIP NAME	CREW INTERFACE	RESULTS	COMMENTS
POLAR SEA	Dedicated System Operator		
MANHATTAN	Dedicated System Operator	Peak Stress in Frame Flange = 23,000 PSI	Max Ice Load = 730 PSI
ARCTIC	Dedicated System Operator	Yield Stress Exceeded Locally with 1100 $\mu\epsilon$	N/A
PIERRE RADISSON	Ship Structural Feedback Device	28,000 PSI Measured in Intermediate Frame	N/A
LOUIS S. ST. LAURENT	Dedicated System Operator	5850 PSI Peak Panel Load	N/A
SISU	Dedicated System Operator	N/A	N/A
YMER	Dedicated System Operator	Peak Stress at 80% Yield	N/A
CANMAR KIGORJAK	Dedicated System Operator	Peak Bending Strain = 562 $\mu\epsilon$, Peak Shear Strain = 337 $\mu\epsilon$	N/A
ROBERT LEMEUR	Dedicated System Operator	N/A	N/A
WOLFE	Dedicated System Operator	N/A	N/A
AQUARIUS	System Prompt Light for Log Entry & Tape Change	N/A	Cal Signal of 2 Min & 1 Min of Short
SEA-LAND McLEAN	Some Voyages Attended, Crew Change Tape & Log Entry	13,000 PSI Bending Max at Force 10	Dockside Calibration with 5 Load Configuration
STEWART J. CORT	Changes Tape	Max Stress: 29,400 Combined; 16,400 Springing with 42 Kt Wind, 15' Sea	Encounter Freq = .29 Hz, Shunt Cal & N.A. Check
CHARLES M. BEEHGLY	Manual Start-Up & Tape Change	Max Stress: 29,600 Combined; 26,500 Springing with 40 Kt Wind, 10' Sea	N/A
ROGER BLOUGH	N/A	Max Double Amplitude; 16,350 PSI with 75% < 1,500 PSI & 98% < 5,000 PSI	Worst Condition with 40 Kt Wind, 8' Sea at 10°
NIHON	N/A	Head Sea Data Close to Calc. Following Sea Data < Calc	Horizontal Bending Stress = Warping
DART EUROPE	N/A	Whipping Stress = .82 Wave Bending Stress	Midship Stress = F (Wave Ht) & 1/4 Pt. Stress = F (Roll <)
ENCOUNTER BAY CLASS	N/A	Max Stress = 9 Tons/in ² at .75 Hz	Fatigue Cracks Developed
BOSTON	System Cal with Weighed Containers	Max Vert Stress: 13,400, Horiz: 2,800 Peak-Through	Vessel Similar to WOLVERINE STATE with Larger Deck Openings
FOTINI-L	Instruments in Pilot Room	Max Peak-Through = 17,200 PSI at Force 9, Springing at .72 Hz	1/4 Pt. Bending = 80% Midship
UNIVERSE IRELAND	Instruments in Chart Room	Max = 9,400 PSI at Force 10	1/4 Pt. Bending = Midship
IDEMITSU MARU	Equipment in Instrument Room with Remote in Chart Room	Max = 8200 PSI at Force 7	Max Stress = 9100 (Hogging)
ESSO MAYLASIA	Instruments in Engineer's Change Room	Max = 13,000 PSI at Force 8	Tank Sloshing Loads Low
R. G. FOLLIS	N/A	N/A	N/A
WOLVERINE	N/A	1400 Recordings of Slamming, Statistical Data Collected	Slamming Only at Light Draft
CALIFORNIA BEAR	N/A	N/A	N/A
HOSSIER STATE	N/A	N/A	N/A
NORMASCAN	N/A	N/A	N/A
EDWARD L. RYERSON	N/A	Springing: 15,000 PSI Max, Wave Induced: 7,500 Max	Springing Frequency 3-6 x Wave Induced
ONTARIO POWER	N/A	Max Stress = 19,229 in Head Seas	Ship Strengthened for Ocean Service

Table 2-6
SYSTEM PERFORMANCE of PREVIOUS INVESTIGATIONS

SHIP NAME	SYSTEM RELIABILITY AND/OR PROBLEMS
POLAR SEA	N/A
MANHATTAN	N/A
ARCTIC	Computer problems due to circuit board failure and to control room overheating. Strain gauge drift. Gauges no good by 3rd season. Tape drive problems with dust.
PIERRE RADISSON	N/A
LOUIS S. ST. LAURENT	Poor resolution in doppler speed log.
SISU	N/A
YMER	Electrical interference problems with strain gauge signals.
CANNAR KIGORIAK	N/A
ROBERT LEMEUR	Acquisition signal noise problems
WOLFE	N/A
AQUARIUS	Difficult to acquire intrinsic safety approval. Occasional problems with various system elements - repaired at port.
SEA LAND McLEAN	N/A
STEWART J. CORT	Difficulty with wave buoy transmission. Anchor drop test unsuccessful due to hull springing in calm water.
CHARLES M. BEEHGLY	Wave buoy data not reliable.
ROGER BLOUGH	N/A
NIHON	N/A
DART EUROPE	N/A
ENCOUNTER BAY CLASS	N/A
BOSTON	N/A
FOTINI-L	Percentage data acquisition effectiveness equals 45%
UNIVERSE IRELAND	Percentage data acquisition effectiveness equals 59%
IDEMITSU MARU	Percentage data acquisition effectiveness equals 62%. Poor wave buoy performance.
ESSO MAYLASIA	Percentage data acquisition effectiveness equals 82%. Launch and battery problems with wave buoy.
R. G. FOLLIS	Percentage data acquisition effectiveness equals 33%.
WOLVERINE STATE	Calibration difficulty with dry cargo. 80% voyage usable data.
CALIFORNIA BEAR	N/A
HOOSIER STATE	Calibration difficulty with dry cargo. 45% voyage usable data.
MORMACSCAN	80% voyage usable data.
EDWARD L. RYERSON	N/A
ONTARIO POWER	N/A

Table 2-7
SYSTEM RELIABILITY of PREVIOUS INVESTIGATIONS

PHENOMENA	FREQUENCY of OCCURRENCE	THEORETICAL MAXIMUM STRAIN RATE	REQUIRED RECORD LENGTH	SEQUENCE	TRIGGER
EPISODIC WAVES	Occasional	1×10^{-3} in/in/sec	1min	Continuous in Rough Weather	Acceleration or Stress Level
SLAMMING	0.1hz.	1×10^{-3} in/in/sec	1min	Continuous in Rough Weather	Acceleration or Stress Level
ICE LOADS	0.2-2hz.	7×10^{-3} in/in/sec	30sec	Continuous	Manual Activation
VIBRATION	2-50hz.	5×10^{-3} in/in/sec	30sec	Random Sampling	Acceleration Level Threshold
FATIGUE	0.05-5hz.	10^{-4} in/in/sec	Minimum 1 Voyage	Sampling or Continuous	Manual Activation
SLOSHING	0.05-0.2hz.	10^{-5} in/in/sec	5min	Once per Watch	Acceleration Level Threshold

Table 2-8. SUMMARY of DATA RECORDING REQUIREMENTS

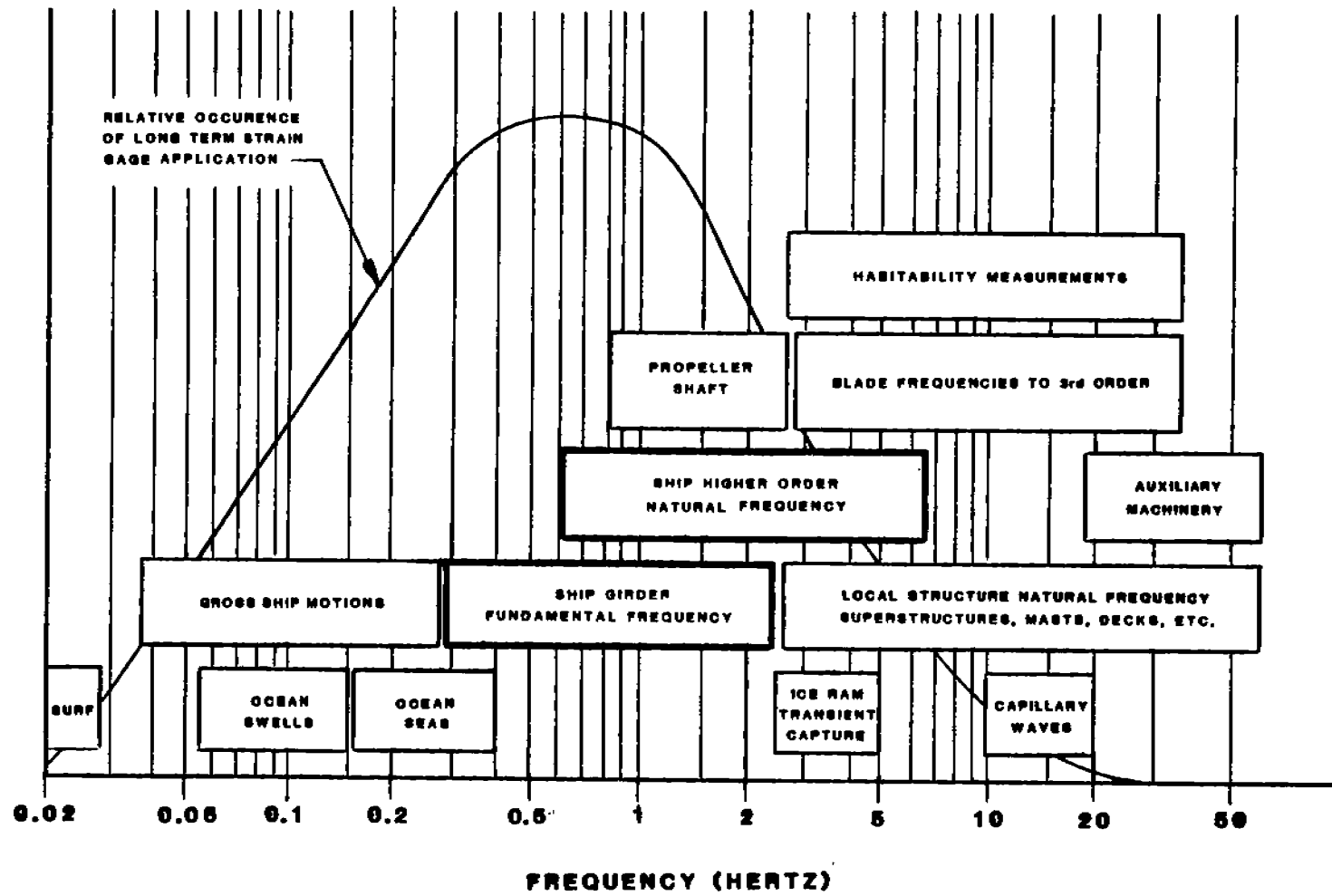


Figure 2-1.
SHIPBOARD STRAIN PHENOMENA FREQUENCY SPECTRUM

3.0 INSTRUMENTATION INVESTIGATION

3.1 CATEGORIZATION OF INSTRUMENTATION CONFIGURATIONS

3.1.1 Integrated Systems

This type of instrumentation package consists of a dedicated stand alone unit capable of performing all acquisition and storage activities with limited provision for real-time display. These systems usually have the ability to substitute plug in conditioning modules which produce a customized hardware package. A centralized processing unit and data storage structure is applied to the acquisition of various types of signals. Figure 3-1 shows an integrated system functional block diagram.

Advantages of Integrated Systems

- Rugged, self contained systems
- Relatively low noise environment (if well designed)
- Ease of set-up & operation
- Single vendor hardware compatibility
- Overall low cost.

System Disadvantages

- Limited upgrade potential
- Long cable runs to signal source
- Relatively high entry level cost.

3.1.2 Hybrid Systems

These types of configurations utilize a centralized stand alone data acquisition unit in conjunction with independent components such as amplifiers, filters, signal conditioners, and excitation sources. A dedicated control computer matched to the size and complexity of the job would act as host to the front end devices. Figure 3-2 depicts the arrangement of these devices.

Hybrid System Advantages

- Optimization of individual components possible
- Full upgrade capability
- Wide variety of input signals possible
- Variable data formats possible.

System Disadvantages

- No single source vendor
- Complexity
- Interfacing requirements of various components
- Requirements for custom software generation
- Possible intermittent signal noise problems
- Cost.

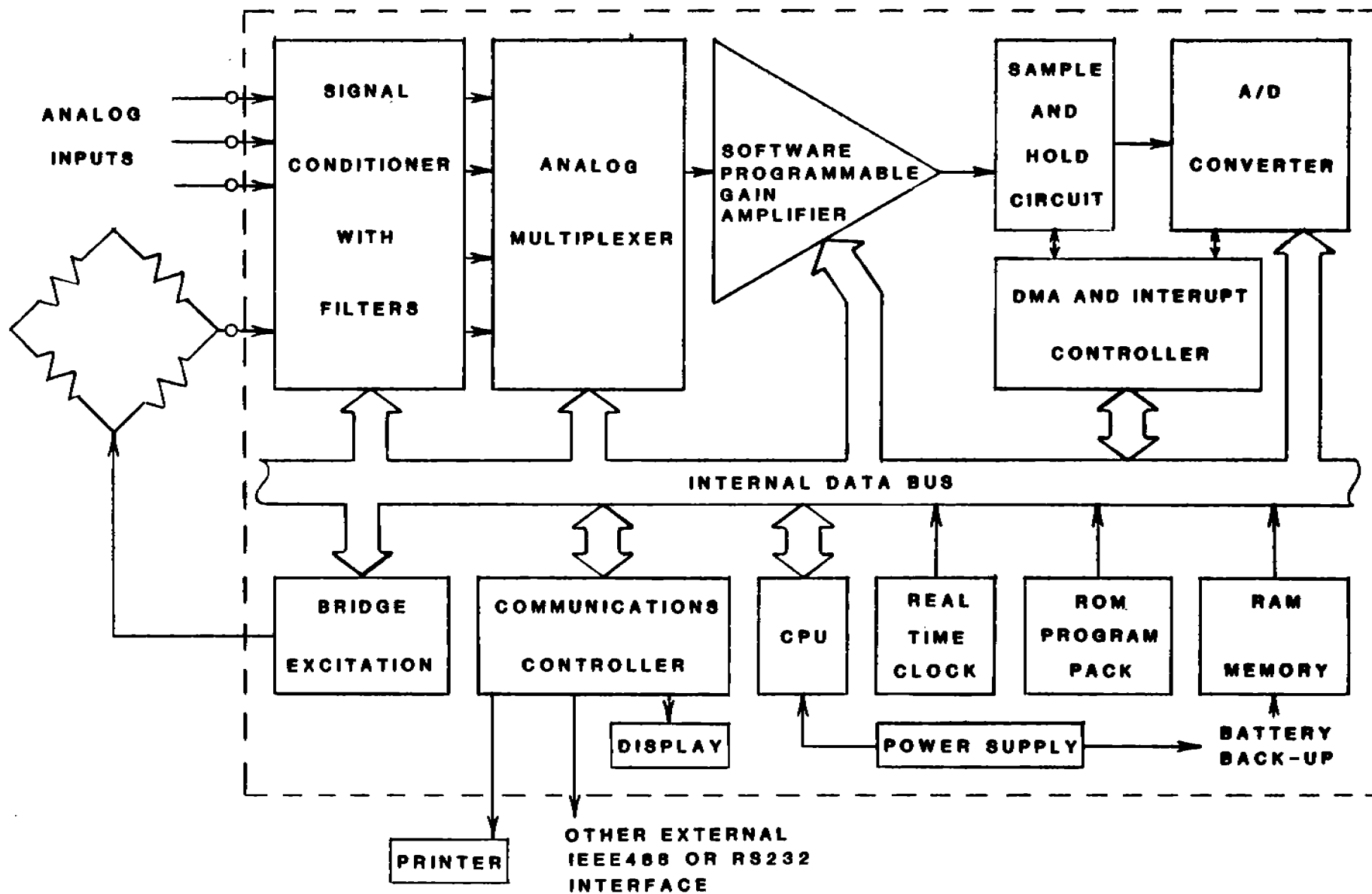


FIGURE 3-1
INTEGRATED SYSTEM FUNCTIONAL BLOCK DIAGRAM

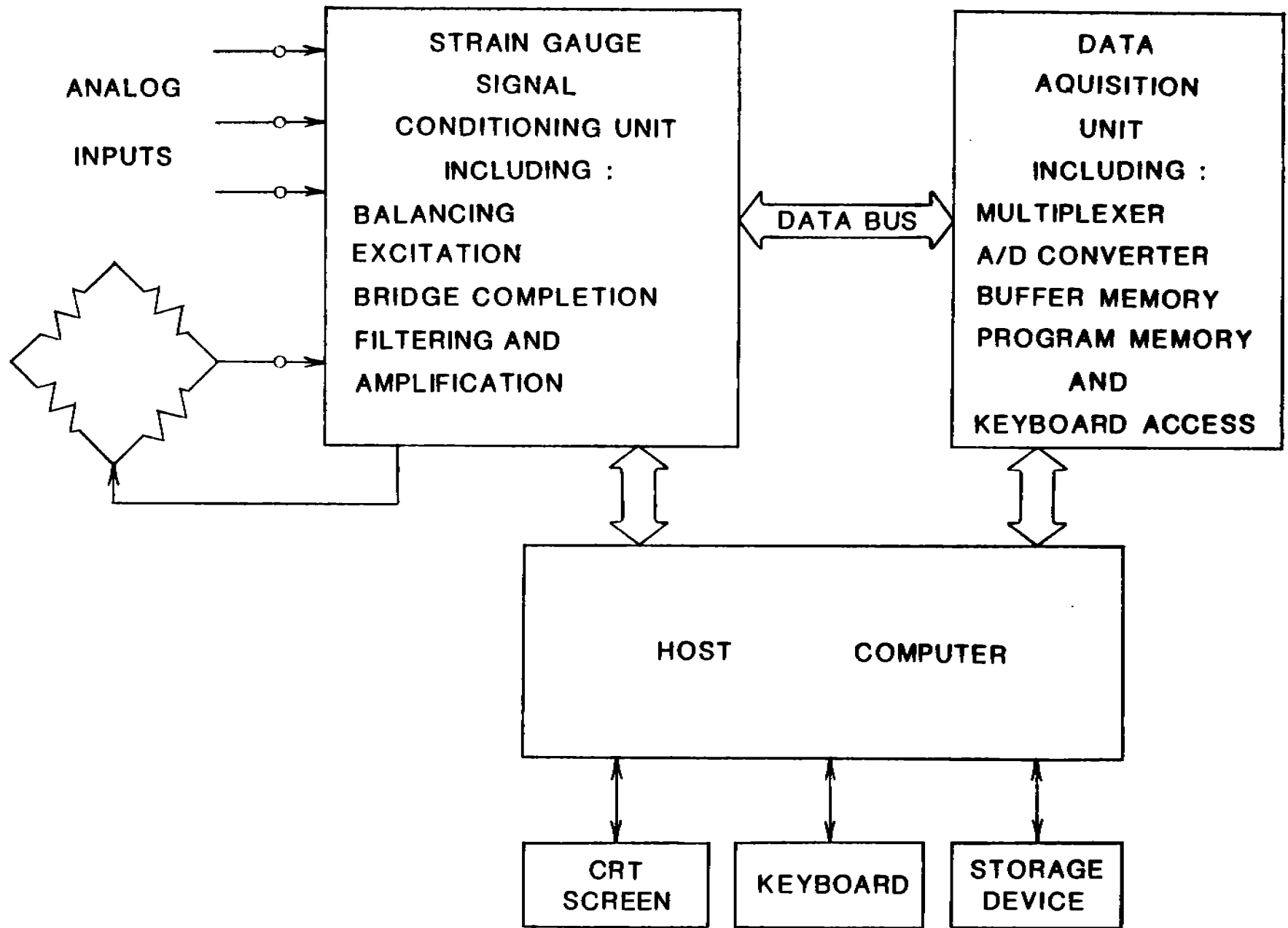


FIGURE 3-2
HYBRID SYSTEM FUNCTIONAL BLOCK DIAGRAM

3.1.3 Distributed Intelligence Synthetic Systems

Components of a smart instrument package essentially operate as stand alone devices with dedicated microprocessor control. Overall processing speeds can be reduced by having subtasks performed in an optimum manner due to the customized matching of component to process task. Various levels of on-board data storage typically exist throughout such a system. Each component is responsible for data input/output control and system communication. Figure 3-3 illustrates the network concept associated with these systems.

Advantages of Distributed Intelligence Synthetic Systems

- Ability to utilize individual state-of-the-art components
- Increased custom configuration potential
- High processing speeds
- High overall system capacity.

System Disadvantages

- No single source vendor
- Considerable custom hardware and software development
- Intercommunication problems
- Multi-source trouble-shooting effort required
- Cost.

3.2 INSTRUMENTATION EVALUATION

Many types of devices from the vast array of data acquisition equipment can be ruled out as candidate equipment when the conclusions of Section 2.0 are considered. The following discussion provides an overview of some product features and shortcomings.

3.2.1 PC Devices

The recent proliferation of I/O interfaces for personal computers has produced several specialized data acquisition packages. The industry standard has become IBM compatibility. Impressive throughput rates such as 71,000 samples/sec with Analog Devices' RTI-800/815 I/O board and 130 kHz with Data Translation's BT 2821 board make the utilization of PC equipment seem attractive. The problem with these expansion boards is the limited number of channels and the PC's limited number of expansion slots. In addition, signal processing often takes place within the relatively noisy environment of the PC's chassis.

The PC can also communicate to its peripheral devices via RS232 or IEEE 488 interfaces. The communication protocol required for this type of connection tends to slow the data transfer rate. An alternative configuration utilizes BUS extension interfacing cards that allow an external system to tie into the computers internal BUS. This overcomes many PC shortcomings, but still relies on the overall CPU computational power to simultaneously perform all acquisition and control tasks. Today's PC's currently do not meet the data handling requirements of a comprehensive shipboard strain data acquisition project.

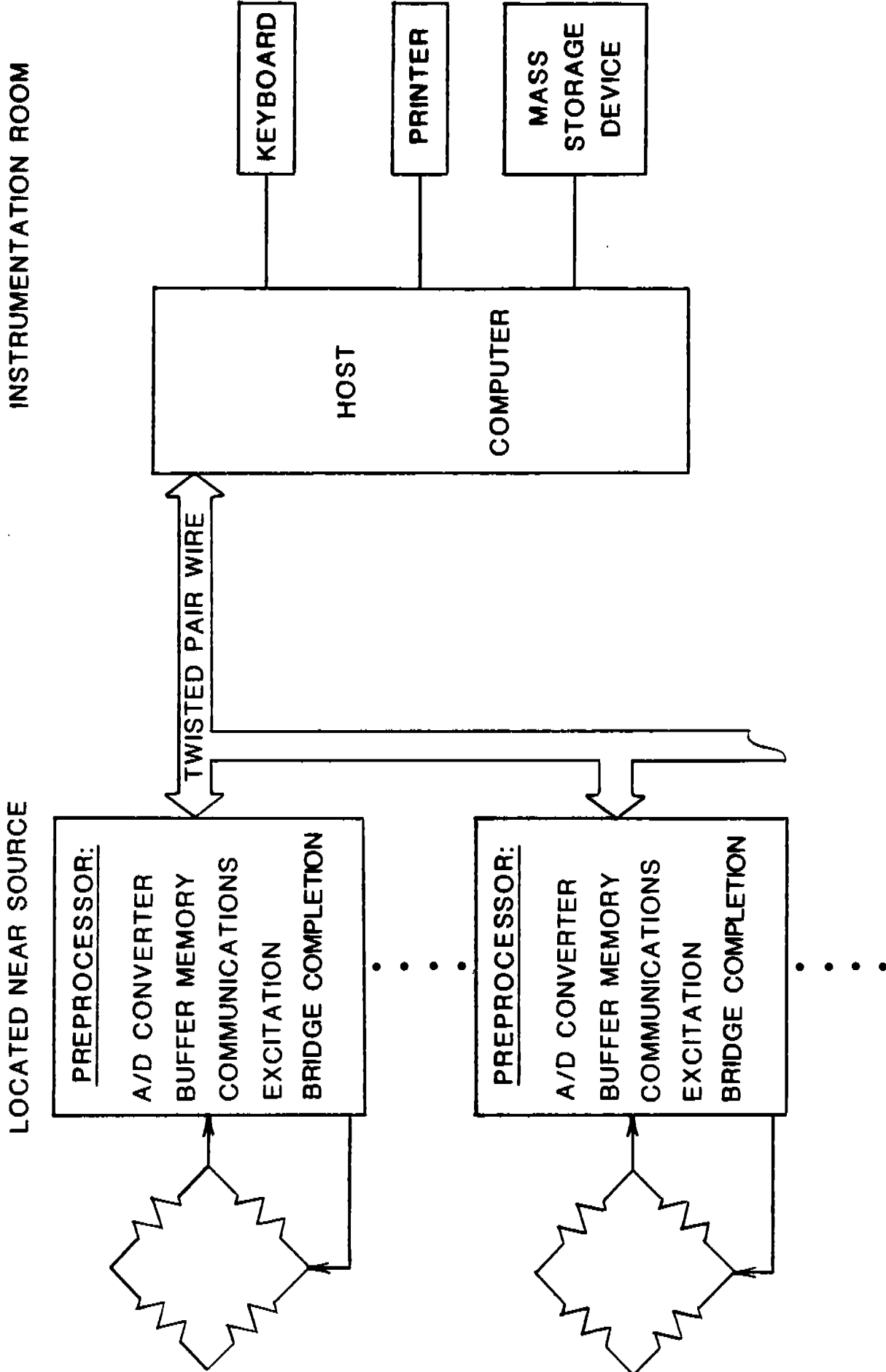


FIGURE 3-3
 DISTRIBUTED INTELLIGENCE SYNTHETIC SYSTEM FUNCTIONAL BLOCK DIAGRAM

3.2.2 Front Panel Controlled Signal Conditioners

The traditional strain gauge conditioner/amplifier is a rack-mountable device that sports a series of knobs and switches. Parameters such as gain level, filter selection, calibration mode, bridge balance, and excitation level are manually adjusted to suit specific strain gauge applications. This arrangement is useful for measurements being attended by technical personnel or for applications where the set-up requirements frequently vary.

Today's technological trend is towards devices that are controlled by the host computer. Measurement parameters are software encoded and communicated to the conditioning/amplifying hardware. There are several advantages to this type of arrangement:

1. Critical settings cannot accidentally be changed.
2. Calibration algorithms can readily be incorporated into the data acquisition sequence.
3. Overall cost can be reduced by eliminating the expensive front panel user interface hardware.
4. Set-up configuration's residing in non-volatile memory are instantly recoverable after a power failure and are readily available for data interpretation.

3.2.3 Data Loggers and Chart Recorders

There is a wide variety of industrial data loggers that offer impressive sampling rates. Although throughput frequencies may meet the requirements of a shipboard strain recorder, more often than not, these devices are oriented towards reporting data in a tabular fashion. Some impressive strain gauge computer systems offer the accuracy needed for static measurements but lack sufficient dynamic capabilities.

Another type of device that is used to capture either long-term or transient phenomena is a chart recorder. State-of-the-art chart recorders now offer analog to digital conversion with memory back-up and host computer control. However, the primary hard copy output presents data in a form not suitable for future manipulation and analysis.

3.2.4 Reel-to-Reel Tape Recorders

The utilization of open reel type recorders has been the standard practice to date for preservation of shipboard strain data. In FM mode these devices offer an excellent frequency range when recording analog signals (20). However, advances in analog to digital signal conversion quality makes the utilization of the more condensed digital storage technology feasible. Various other storage mediums, in addition to reel-to-reel tape, are suitable for recording and playing back digitized signals.

Elimination of the reel-to-reel analog tape recorders has several advantages:

1. High cost associated with these machines is mitigated.
2. Attendance skills required to change tapes are reduced.
3. Critical record/playback speed correlation necessary to reproduce frequency encoded information is less acute.

3.2.5 Disk Drive Digital Storage

Long-term shipboard application of floppy disk systems is somewhat suspicious due to the constant exposure to a corrosive atmosphere. Although the disks themselves seem attractive for mailing data to and from the ship, the drive mechanisms involve delicate contacting components easily subject to damage.

The more robust hard disk system that appears isolated from the environment must still endure the ship's oscillations whose effect is unknown on this ultra high speed spinning device. Although storage capacity is not a problem, the question of transferring data off of the ship persists.

4.0 DESCRIPTION OF IDEALIZED EQUIPMENT

Integration of Section 2.0 conclusions with a knowledge of available instrumentation technology produces a description of idealized shipboard strain data measurement instrumentation. Idealized equipment implies a component by component optimization without regard to systems integration difficulties. Practical considerations and resolution of the conflicting requirements that are exhibited in the features of the ideal components will be discussed in Section 6.0.

4.1 STRAIN GAUGES

The idealized strain gauge system would involve reliable, hermetically sealed, adhesive gauges that exhibit long-term stability. At the same time surface preparation and weatherproofing should be minimized. Also, overall cost and leadwire attachment should facilitate redundant gauge installation.

4.2 DATA TRANSMISSION CABLING

Through utilization of preprocessors near to the strain gauges themselves, long cabling runs could be done with simple twisted pair wire. This would create a network system where channels would be gauged to nearby intermediate processing stations that house modular power supplies and signal conditioners. Problems with excitation, signal degradation and induced noise would be minimized. An overall reduction in cabling costs would also be realized.

4.3 SIGNAL CONDITIONER/AMPLIFIER

High speed bus communication is a prerequisite for the strain gauge conditioner and bridge completion component. Host computer control with manual front panel back-up would be desirable, but expensive. Gain levels and filter cut-off frequencies should be variable over a wide range at the user's discretion. Per channel isolation, automatic calibration and balance, variable output level, long-term stability and linearity are all desirable features.

4.4 CONTROLLER

An ideal controller would utilize the most current technology for high speed analog to digital conversion with resolution to 16 bit at the user's discretion. Other tasks, such as data transfer, user interface and system check-out should not interrupt the data sampling process. A sophisticated acquisition algorithm residing in non-volatile memory must exhibit the capability for simultaneous transient and historical data capture. A direct memory access (DMA) to the storage device is desirable to permit this degree of performance. Aside from processing digital data, instrumentation control capabilities are a requirement of the controller. The limiting factors affecting overall process speeds are illustrated in Figure 4-1 (21).

4.5 SOFTWARE

Application software for data acquisition should be standardized around an existing program oriented towards high speed execution. FORTRAN would be a suitable programming language in that it permits reasonable operating speeds with some resemblance to the English language. This is also the most widely accepted language among engineers. The selection of a standardized base program also enhances the possibilities of finding similar analytical programs that examine data in the same format.

The range of software application must cover all controller functions in the areas of data acquisition and instrumentation control. It is essential that programs be efficient and well documented.

4.6 STORAGE DEVICE

A clear choice as storage medium would be the data cartridge tapes now available. It is quite apparent that digitization of data is desirable from the standpoint of storage requirements. A streaming tape or data cartridge has the ability to store up to 134 M bytes of this type of information in a durable, handleable package. Figure 4-1 graphically represents the relative storage capacities of various media. Although the storage capacity of the cartridge tape is exceeded somewhat by other systems shown in Figure 4-2, the rugged durability and convenience of the cartridge make it the ideal selection. An integrated system that is specialized enough for this application yet allowed a building block approach to suit investigation complexity would be a good solution to the requirements stated in Section 2.3. The hardware capabilities would need to approach that of a synthetic system. This requires a product produced by a leading edge technology company that is more concerned with product performance as opposed to packaging and promotion.

4.7 OPERATIONAL REQUIREMENTS OF THE IDEALIZED INSTRUMENTATION PACKAGE

The forementioned idealized systems is derived from data requirements and represents, at least theoretically, the ideal system. However, there are operational requirements that must be considered to ensure that the idealized system will operate in a shipboard environment and thus provide reliable data. These operational requirements include environmental compatibility, electric power interface compatibility, EMI considerations, maintenance of repair considerations and manning requirements.

4.7.1 Environmental Compatibility

The components of the Strain Recorder System should be chosen to be capable of either surviving or being isolated from the environmental conditions in which each is installed. The data collection and storage package is susceptible to damage from vibration, corrosion, and extremes of temperature and humidity; it should therefore be located in an enclosed space in which the environment is controlled, e.g., in an electronic equipment room. The package should be equipped with vibration isolating mounts, and it should be located such that it is not subject to accidental mechanical damage. The strain gauges may be required to be mounted in extreme environmental locations, such as on a

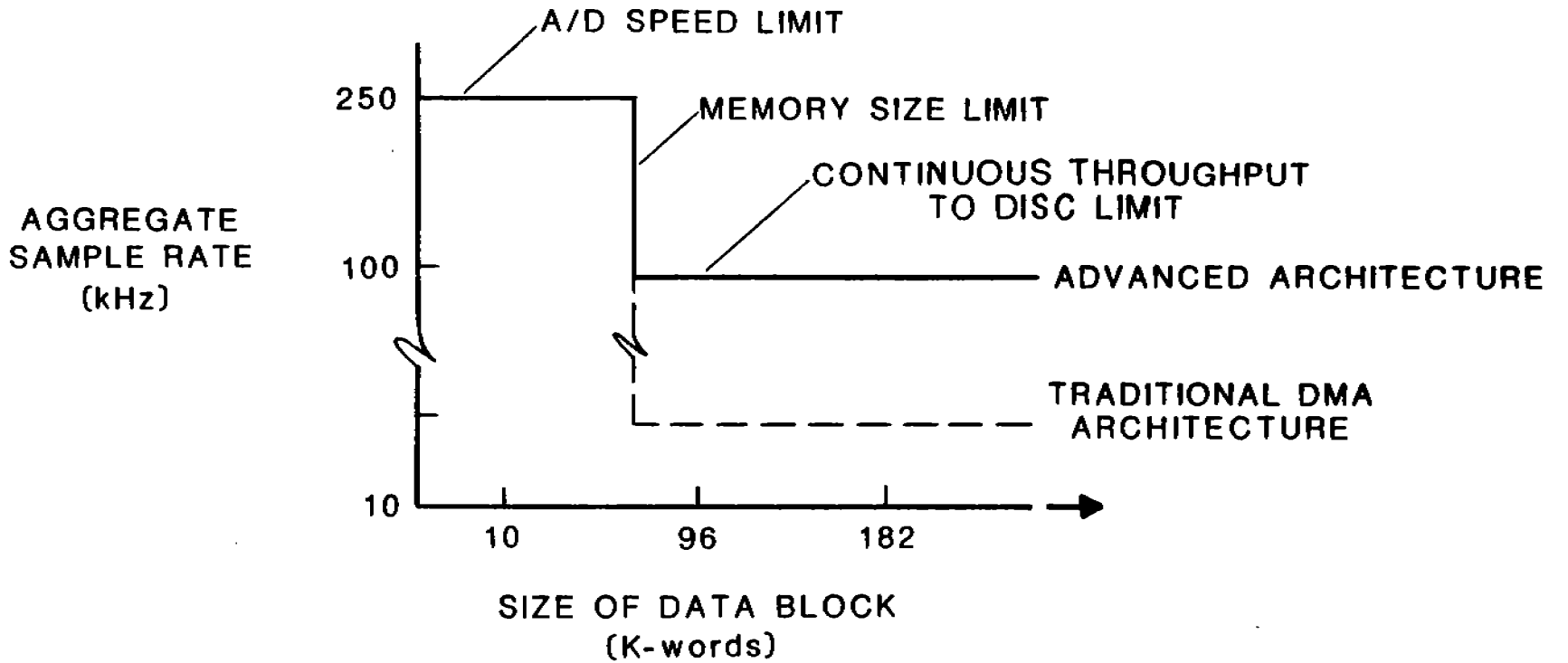


Figure 4-1
 MICROCOMPUTER-BASED DATA ACQUISITION SYSTEM
 OPERATIONAL LIMITS

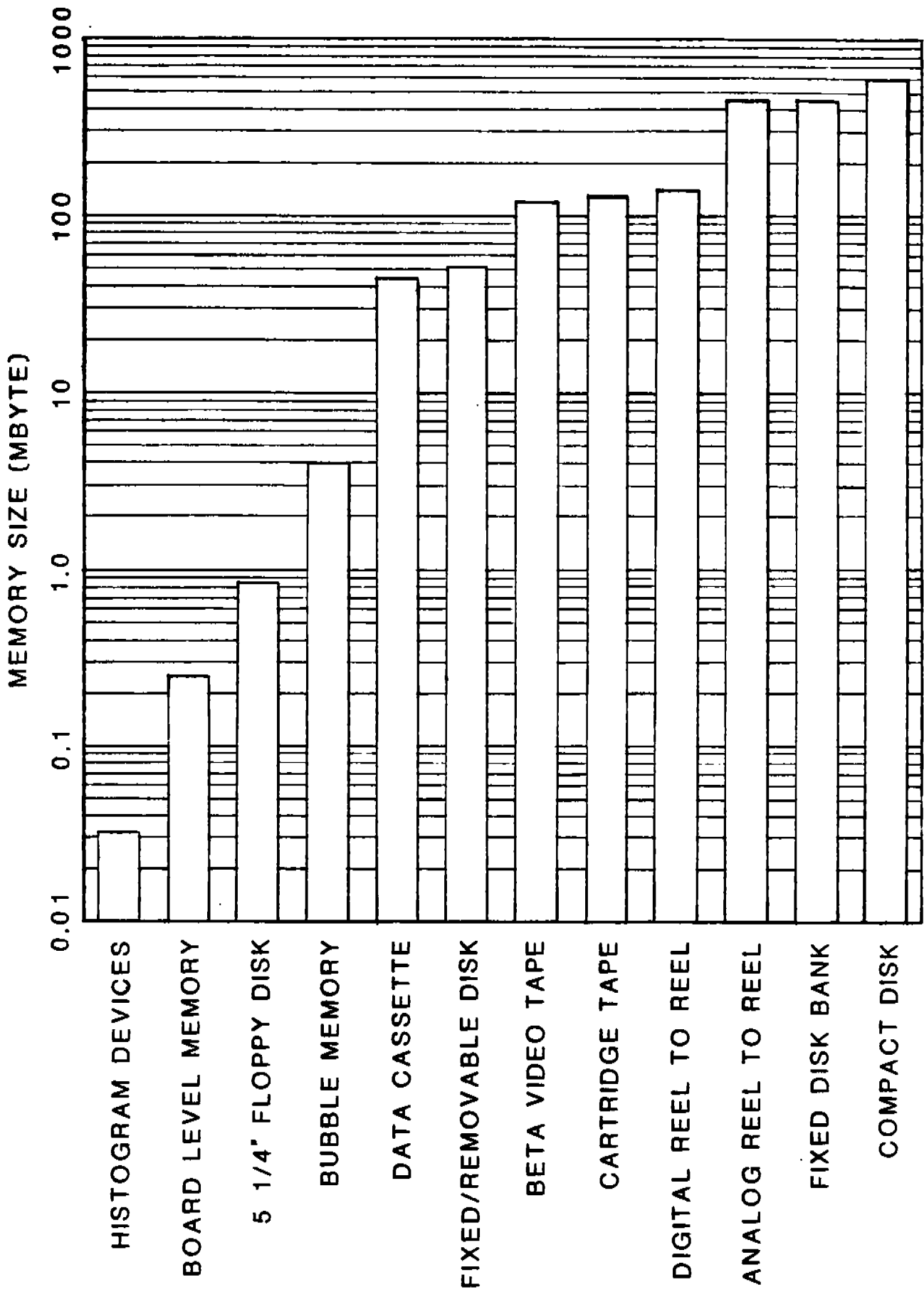


FIGURE 4-2
TYPICAL STORAGE CAPACITY OF VARIOUS MEDIA

weather deck, in a machinery space bilge, or within a cargo tank containing corrosive chemicals. Therefore, they must be selected to be able to withstand and perform reliably within the temperature and vibration extremes in which they are located; additionally, it may be required to coat each strain gauge, after connection of its cable, with a suitably impervious coating which will not affect the accuracy of the gauge. The run of cable from the strain gauges to the data collection and storage package should be within environmentally controlled spaces where possible; where the cable is subject to corrosion, high temperature, or accidental mechanical damage, it should be run through suitably coated conduit.

Because of the susceptibility of strain gauges and signal cables to environmental or accidental damage, it is prudent to install additional strain monitoring points to allow the collection of sufficient data in the event that some of the point are disabled. This is especially important in areas of severe local environment, and where it is anticipated that high spatial resolution is required for significant analysis.

4.7.2 Electric Power Interface Compatibility

Most data collection and storage devices are designed to operate in a shoreside industrial environment. However, the available shipboard electric power often fluctuates outside the nominally acceptable range in which those devices are capable of operating reliably. Shipboard power, while nominally 120 Vac 60 Hz, is characterized by prolonged voltage dips, sharp spikes, and wide frequency variations, in addition to the electrical noise discussed under "EMI Considerations" below. Power interruptions are also a common shipboard occurrence. It is recommended that the built-in power supplies (i.e., converters from line current to electronic device operating current) for the data collection and storage devices be capable of either accommodating and providing useful output within that range of extremes; or be capable of sensing out-of-tolerance conditions, shutting down power to the electronic circuits, and recovering when power is restored.

It is also recommended that, for continuity of data collection and retention of information stored in volatile memory, an uninterruptible power supply (UPS) be provided for the necessary equipment. The UPS contains an internal battery which is kept recharged during normal operation and which supplies power to the connected equipment when the normal line current fails or falls below a minimum level. The UPS also aids in filtering out spikes and electrical noise in the line current.

To minimize the effect of poor quality shipboard power, the power supply to the data collection and storage package should be taken from a switchboard or power panel which is known to provide reliable power to other electronic equipment. If this is not available or not practicable, then the power should be taken from lighting or other panels to which the fewest motors, hair-dryers, etc., are connected.

4.7.3 EMI Considerations

Electromagnetic Interference (EMI) is a stronger consideration in shipboard installations than in industrial installations for a number of reasons: closer installation of various pieces of equipment in a given space; poorer regulation of power supply; operation of radio communication and navigation equipment; and corrosion of cable shields and connector seals. The Strain Recorder System will be particularly susceptible to EMI for the following reasons: data collection from the strain gauges is at very low voltage levels, such that induced noise amplitudes are significant compared to signal amplitudes; the run of cable from the farthest strain gauges to the data collection and storage package allows increasing noise levels while the signal level attenuates; components of the system may be located in high EMI environments; modern solid state electronic equipment is more susceptible to EMI than the existing equipment onboard older ships, such that little attention may have been paid to reducing the EMI environment when those ships were built; the Strain Recorder System power cables may pick up EMI due to their run and the panel to which they are connected; and the data storage medium is susceptible to poor handling and storage practices while onboard.

The effects of EMI will be noticed in several major and minor ways: loss of low-level strain data, even when the higher levels are clear; loss of higher frequency strain data, even when the lower frequencies are clear; apparent malfunctions in the internal electronic control and recording systems due to false signals; erasure of stored data; and destruction of sensitive solid-state components due to induced current.

At the time of installation design for a specific ship, it is recommended that serious consideration be given to the selection and installation of sensitive components of the Strain Recorder system to minimize the effects of the existing EMI environment. The practices referred to in the following documents should be adhered to:

IEEE-45, "Recommended Practices for Electric Installations on Shipboard";

MIL-STD-1310, "Shipboard Bonding, Grounding and Other Techniques for Electromagnetic Compatibility and Safety";

MIL-STD-1605, "Procedure for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ship)".

Where practicable, the components should be located in areas where the EMI environment is minimal; this includes cable runs. The location of storage for recording media should be chosen to minimize EMI effects. Additionally, the personnel handling the recording media should be instructed in the proper handling of those items. The ship's crew should be instructed not to place portable equipment which can induce EMI effects near the components of the Strain Recorder System, including the power and signal cables.

The components selected should have a demonstrated history of reliable operation in a high-EMI environment. The provision of a UIPS (see "Electric Power Interface Compatibility" above) will aid in the reduction of electrical noise entering through the power supply. Low-loss, shielded cables, both for the power supply and for the signal leads, should be selected. Shielded,

sealed connectors should be selected and properly installed. The use of multiplexer/amplifiers should be considered where there will be long runs of cable from multiple strain gauges in the same part of the ship. The use of fiber-optic signal cables and sensors should be considered in extreme EMI locations.

Where EMI cannot be eliminated at an individual monitoring point, the use of multiple strain gauges with separate cables may be necessary.

4.7.4 Maintenance and Repair Considerations

Components should be selected which will require the least preventive maintenance. Such components are typically used for either remote or severe environment industrial installations. Features such as gasketed covers for storage medium drives, and filtered cooling air intakes are desirable.

If onboard personnel are qualified to repair the components to the system, then spare parts per the manufacturers' recommendations should be carried. Appropriate manuals, test equipment, and tools should be provided. It is especially important to instruct the shipboard crew that repairs to cables and connectors be accomplished per the original installer's practices, to minimize the introduction of EMI effects. Similarly, repairs to strain gauge installations should be accomplished in order to assure accuracy of data collection.

4.7.5 Manning Considerations

The duration and frequency of the instrumentation system operation are a function of the phenomenon of interest as discussed earlier. However, for optimum performance the systems should be monitored by qualified personnel to ensure that the strain recorder system is working properly.

There are two alternatives in manning:

1. Place a representative of the instrumentation company onboard who is familiar with the operation of all sensors and conditioning and recording equipment.
2. Train a radio operator and/or deck officer in the operation of all conditioning and recording equipment without making him responsible for sensor maintenance or repair. This trained member of the crew should be capable of troubleshooting and repairing conditioning and recording equipment. In this regard a self-diagnostic package should be included for instrumentation operation. Because present crew working rules require they work one-half of the year, two personnel for each position will have to be trained for multi-year instrumentation programs.

The following considerations should guide the selection of the manning option when the specific instrumentation program is developed.

- a. It has been difficult to obtain instrumentation personnel to ride ships for long periods of time and the frequent travel for rotations adds to the overall cost.

- b. Ship crews have improved technically in recent years with the addition of machinery automation and computer-aided radar plotters.
- c. There would be a definite asset in having crew participate and company support such a program.
- d. On a total cost basis, if the ship owner would support some of the crew overtime, the cost should be less. It would be easier and more practical for a ship owner to support his own crew overtime than the cost of an outside third party.

5.0 SURVEY OF OFF-THE-SHELF CANDIDATE EQUIPMENT

5.1 VENDORS CONTACTED

Numerous suppliers of strain gauge instrumentation equipment have been queried regarding the applicability of their equipment to our project. A broad range of data acquisition devices were considered. A summary of some of the manufacturers contacted and their products appears as Table 5-1.

5.2 DESCRIPTION OF SUITABLE CANDIDATE CONFIGURATIONS

Several specific products have emerged as qualified devices for a shipboard strain instrumentation system. A summary of their characteristics has been assembled in Table 5-2. Included is a system component description outlining required hardware integration. The advantages and disadvantages of various approaches is also highlighted. Approximate cost information refers to base configurations. Channel capacities vary with system.

Specification summaries similar to the example in Figure 5-1 appear in Appendix D. Incoming manufacturer's data has been carefully screened to include only those devices meeting the basic requirements of this application.

5.3 APPLICABILITY OF SURVEYED INSTRUMENTATION

All candidate configurations were examined according to requirements of various shipboard strain data acquisition projects. The synthetic systems offer the best individual component performance specifications and the most flexibility for developing one-shot packages. However, reliability and standardization considerations favor integrated single source instruments that utilize state-of-the-art subassemblies. Patch cords and connectors associated with hybrid and synthetic systems are a prime source of signal noise and continuity problems. Additionally, troubleshooting is more straightforward when dealing with an integrated piece of equipment.

<u>STRAIN GAUGE MANUFACTURERS</u>		<u>CONTACT</u>	<u>TITLE</u>	<u>TYPE</u>
Measurements Group, Inc.	Raleigh, North Carolina	Mike Tierney	REP	MTG
BLH Electronics	Waltham, Massachusetts	Michael Morrell	APL ENG	LTR, TEL
Omega Engineering	Stamford, Connecticut	Catalog Only		
Eaton Corporation	Los Angeles, California	Alan Stillwell	SLS MGR	TEL, LTR
HITEC Corporation	Westford, Massachusetts	Mike Tierney	REP	MTG
<u>SIGNAL AMPLIFIERS/CONDITIONERS</u>				
Brewer Engineering Laboratories	Marion, Massachusetts	Roger Masson	SNR ENG	TEL, LTR
Measurements Group, Inc.	Raleigh, North Carolina	Mike Tierney	REP	MTG
Pacific Instruments	Concord, California	Ed Pugh	REP	MGR
Encore Electronics	Saratoga Springs, New York	Marcel Zucchini	PRES	TEL, LTR
Bruel & Kjaer Instruments	Marlborough, Massachusetts	Erich Thalheimer	SUP ENG	TEL, LTR
Precision Filters, Inc.	Ithaca, New York	Ed Pugh and Donald Chandler	REP PRES	MTG LTR
Valdine Engineering Corporation	Northridge, California	Lynn Swann	REP	LTR
Tinsley Strain Measurements Ltd.		Harry Brown	REP	MTG
Aries Instruments	Ontario, Canada	Terry Vandersluis	REP	MTG
TransAmerica DeLaval Inc./ CEC Instrument Division	Pasadena, California	Catalog Only		
TIAC Manufacturing, Inc.	British Columbia, Canada	Howard Malm		TEL
<u>DATA ACQUISITION SYSTEMS</u>				
Measurement Group, Inc.	Raleigh, North Carolina	Mike Tierney	REP	MTG
Hewlett Packard	Palo Alto, California	Rick Holiday	SLS	MTG
Tektronics	Beaverton, Oregon	Fred Clancy	SLS ENG	MTG
Adac Corporation	Woburn, Massachusetts	Anthony Lapone	SLS MGR	MTG
Honeywell Test Instruments	Denver, Colorado	Bob Starnes	SLS	LTR
TransAmerica DeLaval DataLab Products	Forestville, Connecticut	Catalog Only		
Neff Instrument Corporation	Monrovia, California	Barry Pogach	REP	MTG
Hottinger Baldwin Measurements, Inc.	Framingham, Massachusetts	Robert Haggerson	MGTG VP	LTR
Data Translation	Marlboro, Massachusetts	Darlene Mann	SLS	TEL, LTR
Compudas Corporation	Ithaca, New York	Rob Levine	APL ENG	TEL, LTR
Cyber Systems, Inc.	Anaheim, California	Mike Tierney	REP	MTG
Valdine Engineering Corporation	Northridge, California	Lynn Swan	REP	LTR
John Fluke Mfg. Co., Inc.	Everett, Washington	Harry Rundall	SLS ENG	LTR
Phoenix Data, Inc.	Phoenix, Arizona	Ed Pugh	REP	MTG
Datamte Corporation	Minnetonka, Minnesota	Brian Gallob	TECH	TEL, LTR
Action Instruments	San Diego, California	Tom Pettit	REP	LTR
Cyborg Corporation	Newton, Massachusetts	Tom Pettit	REP	LTR
Kinetic Systems Corporation	Lockport, Illinois	R. H. Wischerman	MGTG VP	LTR
Analogic Corporation	Danvers, Massachusetts	Barry Fogel	REP	LTR
Daytronic Corporation	Miamisburg, Ohio	Drew Hyatt	REP	TEL, LTR
Terrasience Systems Ltd.	British Columbia, Canada	James Reith	MGR	MTG
Tinsley Strain Measurement Ltd.		Harry Brown	REP	MTG
Racal Decca/Racal Marine Systems Ltd.	Surrey, England	Christopher Champ	MGTG MGR	MTG
Optim Electronics	Germentown, Maryland	Robert Bower	APL ENG	MTG
Colorado Data Systems	Englewood, Colorado	Charlie Synder	REP	MTG
Analog Devices	Norwood, Massachusetts	John Carter	SLS ENG	MTG
Kelthley Instruments, Inc.	Cleveland, Ohio	Rita Bryan	SLS	LTR
Gould Electronics	Cleveland, Ohio	Catalog Only		
Genrad, Inc.	Concord, Massachusetts	Catalog Only		
Digital Equipment Corporation	Concord, Massachusetts	Mary Seibert	SLS	MTG
TransEra Corporation	Provo, Utah	John Carlson	REP	LTR
Brown Brothers	Edinburgh, Scotland	-		
Doric Scientific Division	San Diego, California	Tom Pettit	REP	LTR
AEG-Telefonken	Hamburg, West Germany	Von Schack		
Signal Technology, Inc.	Goleta, California	Jim Barker	SLS	TEL, LTR
Modular Data Systems, Inc.	Houston, Texas	Ken Murphy	SLS DIR	TEL, LTR
Biles & Associates	Houston, Texas	Don McKay	MGR	TEL, LTR
Acrosystems	Beverly, Massachusetts	Barry Pogach	REP	MTG

Table 5-1. INSTRUMENTATION MANUFACTURERS CONTACTED

<u>DATA RECORDING DEVICES</u>		<u>CONTACT</u>	<u>TITLE</u>	<u>TYPE</u>
Teac Corporation	No. Hollywood, California	Catalog Only		
Kyowa Densyo Corporation	Closter, New Jersey	Yoichi Ushio	SLS MGR	LTR
Acurex Corporation Autodata Division	Mountain View, California	Sandy Staufenberg	MGTG	LTR
J&W Instruments	St. Paul, Minnesota	George Weinfurter	REP	TEL, LTR
Bascom-Turner Instruments, Inc.	Norwood, Massachusetts	Catalog Only		
Dianachart	Rockaway, New Jersey	David Brodie		LTR
Molytek, Inc.	Pittsburgh, Pennsylvania	Bill Zeitler	REP	LTR
Honeywell Test Instrument Division	Denver, Colorado	Bob Starnes	SLS	TEL, LTR
Iomega Corporation	Roy, Utah	Catalog Only		
Perkin-Elmer	Oceanport, New Jersey	Catalog Only		
Tiac Manufacturing, Inc.	British Columbia, Canada	Catalog Only		
3M Data Recording Products Division	St. Paul, Minnesota	John Carlson	REP	LTR
Racal Recorders, Inc.	Vienna, Virginia	Leo Tenny	US SLS	TEL
Measurement Technology	Denver, Colorado	Catalog Only		
<u>STRAIN MEASUREMENT SERVICES</u>				
Brewer Engineering Laboratories	Marion, Massachusetts	Roger Masson	SNR ENG	TEL, LTR
Strainstall	Isle of Wight, U.K.	Collin Spinks	MGR	TEL, LTR

Table 5-1. (continued)

COMPANY & MODEL NUMBER	DEVICE FUNCTION	SYSTEM ADVANTAGES	SYSTEM DISADVANTAGES	APPROX. COST
Pacific 8250	Amplifier/Conditioner	Remote autobalance & calibration. Variable excitation voltage. Wide frequency range. Fast processing speeds. Data format suitable for analysis.	Necessary component integration cost Front panel set-up controls	\$50K
DEC Microvax II w/TK 50 streaming tape	Controller & Storage Device			
Signal Technology DACS	Software			
Measurements Group 2310Y HP 1000 HP 9144A	Amplifier/Conditioner Technical Computer Tape Cartridge	Remote calibration, excitation & balance. Good frequency response. Excellent support of computer peripherals. High execution speeds. Automatic test system software. Convenient storage medium.	Component interfacing. Required HP compatibility. Cost Front Panel Set-Up Controls	\$41K
NEFF System 620 DEC PDP 11/34A Signal Technology DACS	Computer Front End Computer Software	Complete Computer Control Set-Up 16 Bit A/D Conversion Resolution High System Throughput Rate Programmable Per Channel Filtering Data Format Suitable for Analysis	Cost Set-Up Requirements Restricted Portability	\$75K
Analog Devices Aim05 W/Mac Sym 120	Strain Gauge Card & Computer	On-Board Bridge Completion. Programming Base. Overall Cost.	Limited Frequency Range. Slow Operating Language. CPU Limitations.	\$25K
Optim Megadac 2000	Data Acquisition System	Compact, self-contained unit. Remote CPU Compatibility, Preprocessing Capability, Cost.	Limited Configurations. Overall CPU Power. Data Logging Orientation.	\$20K
Colorado Data Systems 53A-HAX w/53A-220 & 53A-518 Cards HP 1000	Data Acquisition & Conditioning Controller	DMA with host computer. High speed transient performance. On card bridge completion. Long range stability.	Required HP compatibility. Limited signal port access. Required multiplexing for A/D conversion. Limited buffer storage.	\$32K
Cyber Systems, Series 900 DEC PDP-11	Front End Computer	DMA Access. NBS traceable calibration source. Offset D/A Converter. Excellent stability and linearity. Large channel capacity.	Cost. Limited Portability. Specialized Software Package.	\$75K
Analogic Corp. ANDS 5400 DEC LS1-11 or PDP-11 Interface	Front End Computer	Self-Test capability. Hardware Offset Compensation. 16-Bit A/D Conversion Resolution. Automatically optimized autozero time. Long term stability.	Limited Standard Bandwidth. Cost.	\$50K
ADAC PROMBASYS 3M HCD 134	Data Acquisition Cartridge Storage	Self-Contained System. PROM memory storage. Q-BUS compatible. Cost CMOS battery backed RAM	Limited speed w/strain gauges. I/O basic programming language	\$10K
Terrasience System 40	Data acquisition system	Marine orientation. High Capacity. Cost	Limited storage capacity	\$61K

Table 5-2 CANDIDATE CONFIGURATIONS

Manufacturer: CYBER Systems, Inc.
Address: 2750 East Cerritos Avenue, Anaheim, CA 92806
Phone Number: (714) 634-2800
Contact: Mike Tierney, (703) 373-5520
Device Name: Mini Das
Model Number: System 100
Device Function: Standalone portable data acquisition system
Frequency Range: DC to 2 KHz with solid state multiplexer
Bridge Excitation Voltage: 0-15V constant voltage floating power supply via
9351-EX option
Bridge Balance: Internal 120 Ω or 350 Ω bridge completion resistor via
9351-BR option (Auto)
Signal Filtering: N/A
Shunt Calibration: All R-CAL relays simultaneously energized during
calibration (Auto)
Signal Output: 8 contact closure & 8 TTL for out of limit; real time data
output
Gain Control: Random, user control: 80 MV RTI gains of 64 to 2048
Channel Quantity: 32
A/D Conversion Technique/Resolution: 12 Bit providing 5 μ V/Bit in Gain=1;
2.44 μ V/Bit in gain=2048
Activation Method: Panel switch activates turn key 'acquire' software
Programability: Menu driven programs: setup, verify, calibrate, acquire,
transfer & diagnostic
Storage Capacity: 32K word transient data memory
Data Reduction Capabilities: Various math packages including Rosette Analysis
External Interface: Screen terminal input, RS232 output @ 800 samples/sec
System Stability: Temp: 1 μ V/ $^{\circ}$ C, Time: 5 μ V/8 hours
System Linearity: .025% of full scale from best straight line
Absolute Accuracy: CAL supply: .015% + 3 μ V, CMR: 110dB @ 64-2048 gain, 85
dB @ 1-32 gain
Size: 10.5"H x 17"W x 34"D
Weight: 75 lbs
Maintenance/Attendance Requirements: Mass storage interface or 9 track tape
Set Up Requirements: Turnkey software interface
Cost Per Channel: \$940 @ 32 channels (\$30K/system)

Figure 5-1

SAMPLE FORMAT for INSTRUMENTATION SPECIFICATION ANALYSIS

6.0 RECOMMENDATION FOR STANDARD STRAIN RECORDER

6.1 DESCRIPTION OF EQUIPMENT RECOMMENDED FOR SELECTION

Two instrumentation packages closely meet the requirements of typical marine structural data acquisition projects. Both systems emphasize reliability and expandability with an emphasis towards strain gauge applications. The Terrascience System 40 offers a user configurable software format and orientation towards intensive investigations that require numerous channels. For a singular 'sea trial' type experiment where attending personnel are utilizing technical computers on board, the synthetic system architecture of the Terrascience unit makes this package a natural selection. However, for the more generalized full-scale investigation project, as profiled earlier in this report, a more menu-driven device with a lower entry cost is more appropriate. Optim Electronics MEGADAC 2000 is configured in a building block arrangement and can provide full feature performance for a basic system capable of handling the number of channels typically required for this shipboard application. Many past and future investigative experiments involve statistical acquisition of primarily midship bending stress information and do not require the extensive multiple channel capability of the Terrascience System 40. Also, these types of projects do not require an expanded interface to the real-time data as is afforded with a sophisticated host computer. A summary of features for both the Terrascience System 40 and the Optim Electronics MEGADAC 2000 is contained in Appendix E. A comparison of the idealized instrumentation and the recommended system is summarized in Table 6-1. This table is a guide to the description that follows.

6.1.1 Detail of System Architecture

The instrumentation system recommended for selection is an integrated package called the MEGADAC 2000 produced by Optim Electronics. The device is a microprocessor based data acquisition system whose orientation is towards the conditioning and storage of low level signals, such as strain gauge data. It's modular construction permits the accurate dynamic capture of analog data from a wide range of active and passive transducers. Throughput rates of 20 Khz can be realized directly to the mass storage medium and up to 128 channels can be accommodated. Capacity and/or processing speed may be increased by the parallel operation of multiple units. Complete performance specifications are summarized in Table 6-2 (22). Several system features of the MEGADAC 2000 make it particularly well suited to this application. First, the organizational format for designing and implementing recording algorithms is versatile and well documented. Data is acquired based on a variety of parameters and then stored in a universal fashion with all calibration and time history information preserved. The format of the software encourages thorough experimental techniques.

The capture of transient data is enhanced by a large capacity circular memory. When a recording trigger is met, data in memory is transferred to mass storage. Pre-trigger data recording is made possible because the memory is constantly updating with new information. A brief "Data History" is always available at the time of triggering. Trigger sources and levels along with record activation/duration characteristics are programmable and contribute to the systems inherent flexibility.

Table 6-1. COMPARISON OF IDEAL INSTRUMENTATION TO RECOMMENDED INSTRUMENTATION

	<u>Ideal Instrumentation</u>	<u>Recommended Instrumentation</u>
Strain Gauges	Hermetically sealed adhesive gauges exhibiting long term stability (4.1)	Encapsulated foil (6.2.1) adhesively attached except in poor installation conditions where weldable gauges are recommended.
Data Transmission Cabling	Use of twisted pair wire to minimize noise and reduce cost (4.2)	Identical ends in a twisted pair configuration (6.1.2.1)
Signal Conditioner/ Amplifier	High speed bus communication, channel isolation, automatic calibration balance, long term stability (4.3)	Automated sampling at sampling speeds to 20 Hz. Auto-balance software feature to permit observations of long term data offset.
Controller	Resolution to 16 bit direct access memory (4.4)	Resolution to 16 bit, A/D conversion (Table 6-2).
Software	Fortran based language well documented (4.5)	IBM PC compatible (6.1.2.2), complete documentation available.
Storage Device	Durable data cartridge tapes (4.6)	Digital cartridge tape storage and tape drives for continuous data acquisition, 112M bytes storage between tape changes (6.1.2.1)
Operational Environment	Recording and processing components shall be located in a manned space within a controlled environment (4.7.1)	4-45°C at 10-80% humidity, non-condensing (Table 6-2).
Electric Power	120V 60 Hz, with UIPS (4.7.2)	120V - 220V 60Hz (Table 6-2)

* Numbers in parentheses indicate the sections of the report that describe the requirements in greater detail.

**Table 6-1. COMPARISON OF IDEAL INSTRUMENTATION TO RECOMMENDED INSTRUMENTATION
(CONTINUED)**

	<u>Ideal Instrumentation</u>	<u>Recommended Instrumentation</u>
EMI Considerations	Per standards IEEE45, MIL-STD-1310, MIL-STD-1605 (4.7.3)	To be evaluated for specific host ship.
Maintenance and Repair Considerations	From a data acquisition and requirements view point the instrumentation system must be completely reliable for the duration of the experiment. Minor maintenance should be permitted in between sampling cycles and recording of transient events. (4.7.4)	The recommended system provides the ruggedness, as evidenced by experience in similar applications. Self diagnostics are incorporated to facilitate repair and to prevent major malfunctions.
Manning	Trained operator to monitor the system. (4.7.5)	User friendly interface, self capability of sampling at any order with no speed degradation, self initiated diagnostics (6.3.1). Storage tape changes are a function of the number of channels, sampling frequency and exact storage option selected (6.1.2.1).

Table 6-2. MEGADAC 2000 PERFORMANCE SPECIFICATIONS

Maximum Sampling Speed:	20 kHz (Units may be stacked to multiply throughput speeds)
System Gain:	1:1 to 8000:1 in incremental steps on a per channel basis
Sampling:	Any order with no speed degradation; channels may occur numerous times in one scan
Synchronization:	Internal clock or external synchronization
Maximum Input Channels:	128
Excitation Current:	3.6 mA @ 350 X per bridge arm
Bridge Completion:	120 X, 350 X or 600 X internal or external to 7 volt compliance
Resolution:	0.125 microstrain @ gain = 1:1000 with 16-bit A/D conversion
Gauge Power Dissipation:	0.012 watts
Setting Accuracy:	0.01%
Temperature Stability:	25 PPM per degree C
Tracking of Matched Pair Currents:	5 PPM per degree C
Data Reduction Capabilities:	Data compression/expansion; statistical analysis; data filing and plotting of reduced and time based data
Memory Buffer:	128K or 512K byte
Mass Storage:	48 Mbyte cartridge expandable to 192 Mbytes
Power Requirement:	120 watts @ 110V OR 220V
External Interface:	RS232C serial or IEEE 488 parallel option
Operational Environment:	4-45 degrees C @ 10-80% humidity (non-condensing)
Size:	17" W X 12.25" H X 21" D
Weight:	35 lbs (excluding mass storage)

A third outstanding feature of the MEGADAC 2000 is its built in cartridge tape drive diagnostics. These type of capabilities are indicative of a device designed and built for field service.

A functional block diagram depicting the systems computational architecture is presented as Figure 6-1. The resident firmware (permanent software) enables the system to be controlled either via a front panel keyboard or host computer. Initial set-up via a host computer permits a visualization of formats on a full size monitor. The eighty character liquid crystal display on the MEGADAC's front panel scrolls through the same information and is ideally suited for operational verification or level checking. The programmable portion of the firmware is divided into two segments called the Mode Table and the Scan Table. Both tables are saved in battery-protected storage and at the user's discretion can be automatically recalled should power to the system be interrupted.

The Mode Table enables the user to establish a profile for communication with the MEGADAC. Parameters determined here include: duplex mode, status reporting, resolution, communication protocol, format & address codes.

The Scan Table contains system directions for processing the input-output channels. The entries in the table are examined when the user records data into or plays data from the unit. The scan table consists of base entries which contain information applicable to all channels and scan entries containing channel particulars. Base entry parameters include: samples per scan, clock rate, clock mode, auto tape mark, auto balance, scan mode, start algorithm, stop algorithm, repeat code, monitoring format, limit determination, Pre-Trigger information, and channel address.

6.1.2 Rationale for Chosen Approaches to Problem Solution

6.1.2.1 Hardware

The overall design consideration given to an integrated instrument intended to accurately process low level analog signals assures an environment of low electromagnetic interference. Signal paths within the unit are optimized and an overall protection is provided by the system's chassis.

The use of remote terminal blocks to permit bridge completion near the active strain gauge arms greatly improves the overall signal-to-noise ratio. An currents and amplifier inputs run on identical leads in a twisted pair configuration. A complete outline of potential strain gauge circuits is contained in Appendix B.

For applications with very long lead lengths, ambient temperature changes, and high resolution, several configurations recommending constant current excitation have been put forth (24), (25), and (22) to eliminate errors induced by variable leadwire resistances. A per channel excitation module has been selected that provides two precision constant current sinks with tracking temperature coefficients, excitation and return. This configuration assures the integrity of each channel's signal throughout its acquisition path.

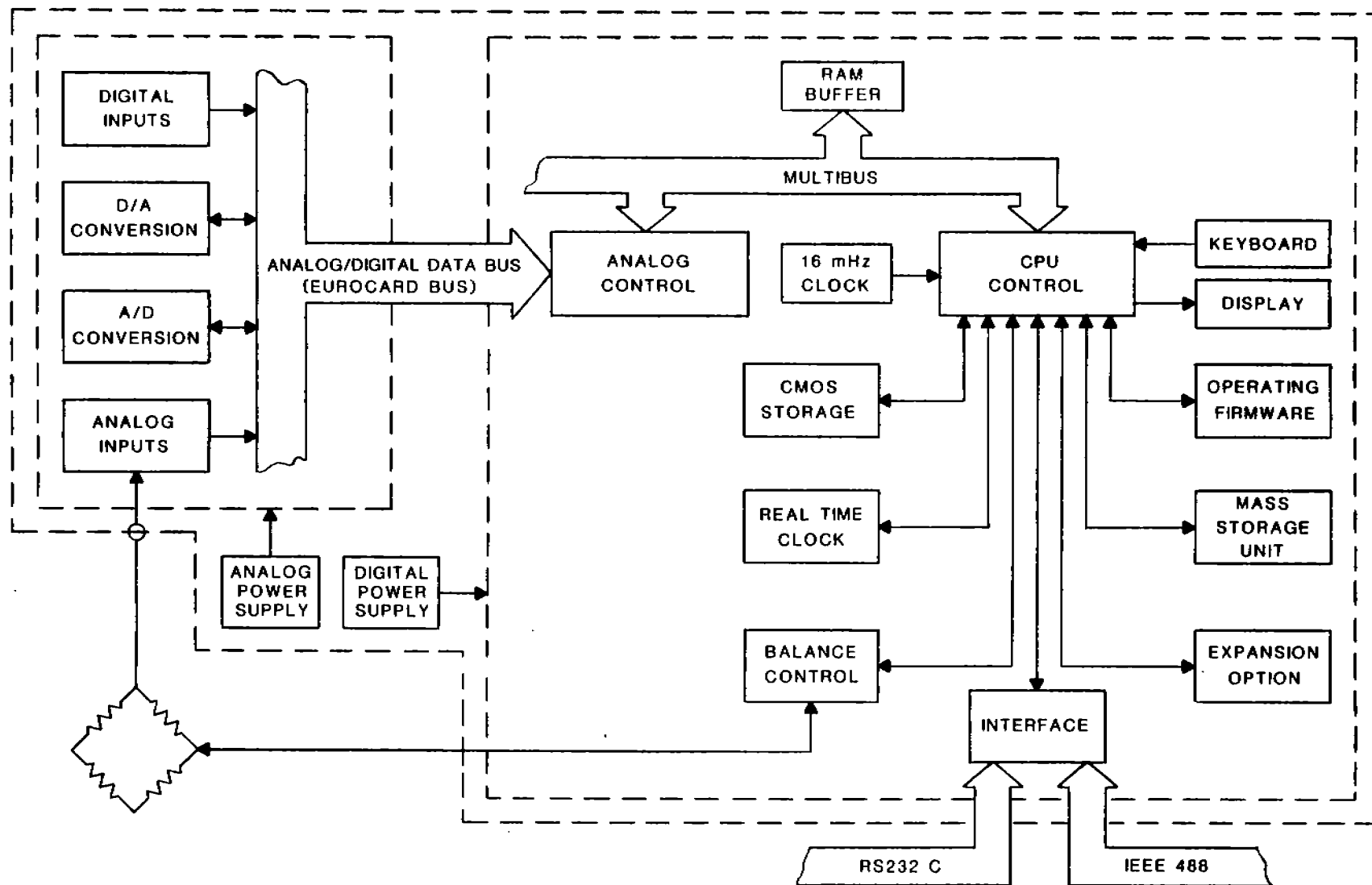


Figure 6-1
MEGADAC SYSTEM 2000 BLOCK DIAGRAM

The selected analog to digital converter is a 14-bit successive approximation device that is programmable with gains to 400:1. This type of architecture provides an optimum balance between speed, resolution and cost per channel. A low-pass anti-aliasing filter is configurable individually per channel. This permits the optimization of signal-to-noise ratios based on expected physical response frequencies.

The utilization of digital cartridge tape storage was recognized early in this investigation as a superior medium from the standpoint of handling and capacity. The ability of the MEGADAC to control four tape drives in sequence increases the storage capacity between tape changes to 192 M bytes. This is equivalent to recording 20 channels of 10 HZ data continuously for 27 hours. Various uses of economical sampling techniques can increase this time period by several orders of magnitude.

6.1.2.2 Software

The design philosophy of the MEGADAC system uses the high speed performance of the data acquisition system to record data and the optional convenience of set-up and analysis with the popular IBM PC-AT/XT. Figure 6-2 illustrates the relationship of the various files created with the full system.

The Transducer Library is a database of transducers containing all the parameters needed to operate and obtain valid data. Each transducer is listed, independent of assigned channel, along with engineering conversion units, gain factor, excitation sources, calibration information, factored range and resolution. Thus, a permanent record is in place and updated to accurately reference calibration information for each voyage. The auto-balance feature can be disabled from any channel to permit the observation of long term changes in data offset.

Parameters that are unique to each investigation are programmed into the Experiment Table. This is where procedural steps and bookkeeping activities are documented. Channels can be mathematically manipulated to account for strain gauge geometry. Access to other databases within the software package is achieved directly.

A separate portion of the software performs a reduction on measured data. Statistical computation and data compression/expansion are two examples of useful processes achieved here. Data can be formatted for further analysis by commonly utilized P.C. programs such as LOTUS 1-2-3. A read-only data retrieval unit can be configured at a home base alongside a P.C. to analyze data after a voyage. This ability to analyze long-term statistical data as well as very fast transients on a channel per channel basis in other than real-time facilitates the post voyage study of shipboard strain data by a greater number of end users. Embodied within the software package is a very sophisticated color plotting subroutine. Time based data can be scaled to show great detail in a very small window or mathematically massaged using the "graphics data manipulator". All features are menu driven and system familiarization time is minimal.

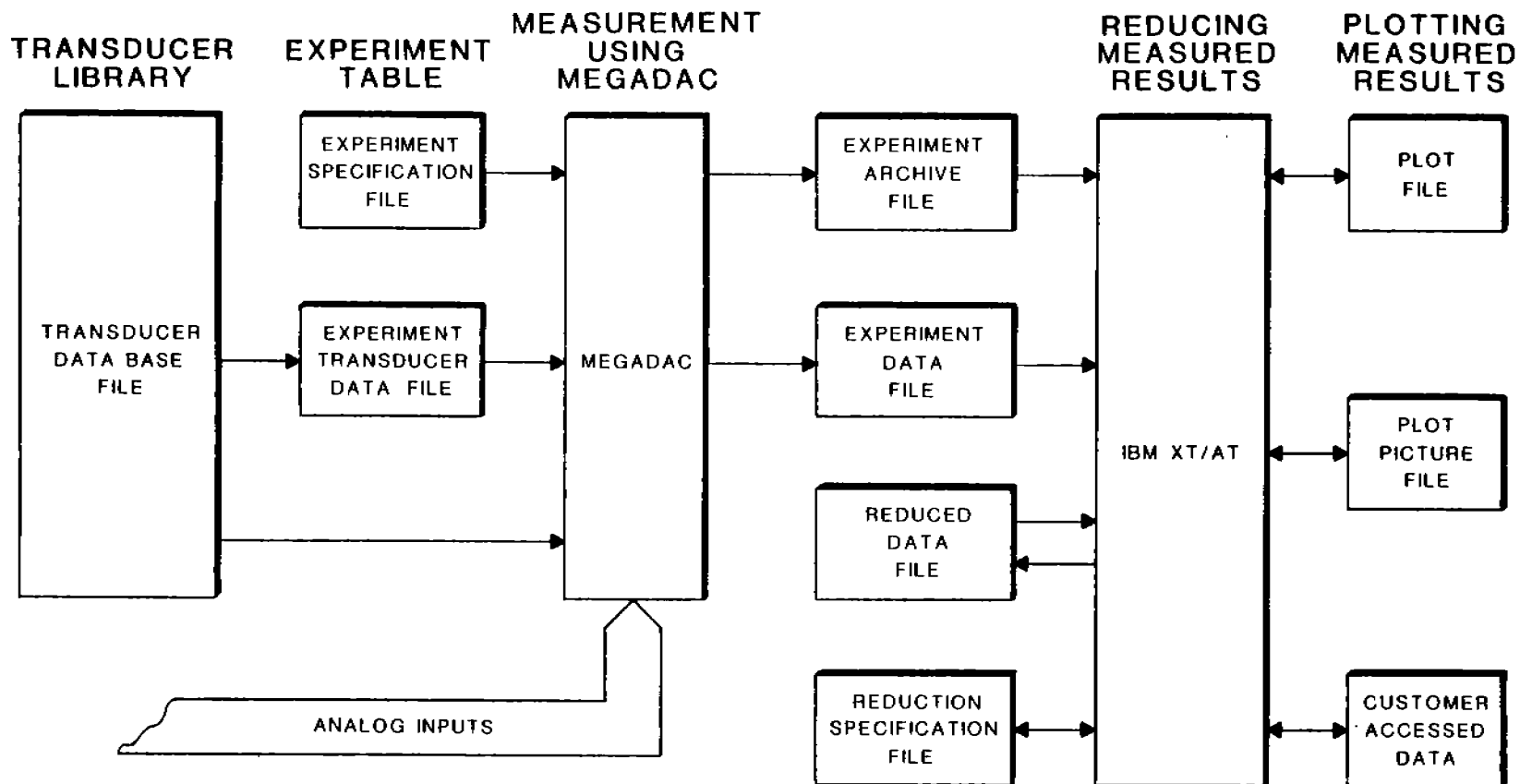


Figure 6-2.
SOFTWARE RELATIONSHIP of DATA ACQUISITION UNIT
and PERSONAL COMPUTER

6.1.3 Detailed Component Costing

A major trade off that became apparent in the early stages of this project was that of a system having the capabilities to meet the most demanding environments and one that would be cost effective for the more modest projects. What has evolved from this investigation is an arrangement in which the initial cost of a fully capable system for a small number of channels is low without purchasing instrumentation capabilities far beyond that which is required for the experiment. Requirements for more complex experiments with large data channel requirements would be met by adding additional instrumentation modules. This approach appears to be the best way to standardize pieces of equipment for a wide variety of tasks. Set-up technology and data analysis hardware would essentially be the same for a wide range of applications.

As has been previously identified, suitable candidate equipment that can be purchased and assembled in a modular fashion is preferable. This allows the overall project cost to be consistent with job complexity and yet suffer no degradation in performance with the smaller jobs. Table 6-3 lists material cost, excluding installation labor, of the modular components of the recommended shipboard strain data acquisition system. Table 6-4 represents the material required to perform two hypothetical investigations of varying scope. The 5 channel project is similar to the ABS program while a 96 channel scenario represents a SL-7 or icebreaker effort.

6.2 INSTALLATION OF EQUIPMENT RECOMMENDED FOR SELECTION

6.2.1 Strain Gauge Selection and Installation

Based on the rationalization presented in Section 2.2.1.3, the primary selection as a strain gauge type is an encapsulated foil gauge that is secured to the test specimen with a specified adhesive. Interviews with various users have revealed that when properly installed, these gauges are less prone to failure compared to weldable type gauges. In-service experience shows that the so called "hermitically sealed" weldable gauges require additional weatherproofing. Additionally, the reduced cost of the adhesive type gauges makes it more economical to install adjacent back-up gauges at each location. It should be noted that in extremely poor installation conditions, superior results can probably be achieved with the weldable type gauge. Figure 6-3 illustrates a built-up weatherproofing scheme that is recommended by the Measurements Group, Inc., for use in saltwater environments. Careful attention to surface preparation, application, curing times and temperatures as specified by the manufacturer is a prerequisite to proper gauge performance. Leadwire resistances and resistances to ground should be carefully checked upon completion of gauge installation.

6.2.2 Cable Installation

As is illustrated in ABS' 1971 Report (1), cable installation can require a significant labor effort and is easiest to plan and do at the time of ship construction. In most cases this is not possible so the next best time is during an overhaul when time and accessibility is increased. All work should be carefully planned and well documented.

**COMPONENT COSTS of PROPOSED SHIPBOARD STRAIN
DATA ACQUISITION SYSTEM (Cost in 1986 dollars)**

Table 6-3

ITEM DESCRIPTION	MODEL #	MANUFACTURER/SUPPLIER	QUANTITY	COST	COMMENT
Encapsulated K-Alloy	WK-XX-125-AD-350	Measurements Group, Inc. Raleigh, N.C.	5	\$41.00	Exact gauge designation will vary to suit application
Strain Gauge Adhesive Kit M-Bond	600	↓	4 bottles each solution	40.00	See Figure 6-3
Polyurethane Gauge Coating	M-Coat A		(4) 1 oz. Bottles	15.00	
Nitrile Rubber Gauge Coating	M-Coat B		(4) 1 oz Bottles	27.00	
Epoxy Gauge Coating	M-Coat G		300 Grams	65.00	
6 Conductor Shielded 24 AWG Cabling	ALPHA 6076		Seacoast Electric Passaic, New Jersey	Per 1000 Ft.	250.00
Data Acquisition Main- frame Unit	2200 C	Optim Electronics Germantown, MD.	128 Channel Capacity	14,400.00	Includes Firmware & 16-Bit controller
Analog Input Module	AD1614-D	↓	16 Channels	1,680.00	14-Bit Resolution A/D
Strain Gauge Current Energization Module	SCI 88C/350		8 Channels	2,680.00	Precision Dual Current
Screw Terminal Block	ST8 1614/SCV		16 Channels	480.00	For Remote Termination
Cartridge Tape Expansion Chassis	2000 CM-3		3 Drives	9,850.00	Optional
RS232C Cartridge Tape Reader	2000 CR-1		1	4500.00	
64 MByte Capacity Cartridge Tape	475004		1	42.50	
OPUS 2000 User Software	OES 136		1 Copy	3,950.00	

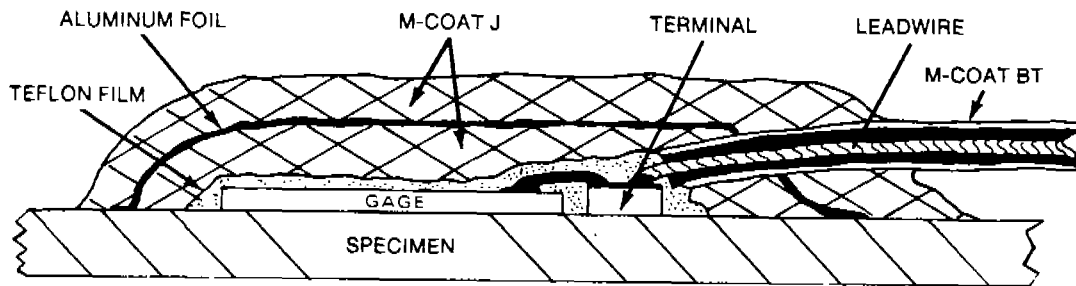
ITEM	5 CHANNEL		96 CHANNEL	
	QUANTITY	COST	QUANTITY	COST
Strain Gauges	20	\$164	384	\$3,149
Adhesives & Weatherproofing	2 Kits	294	15 Kits	2,205
Cabling	2000'	500	12,000'	3,000
Data Acquisition Unit	1	14,400	1	14,400
Input Module	1	1680	6	10,080
Excitation Module	1	2680	12	32,160
Extension Chassis			1	2,950
Remote Terminal	1	480	6	2,880
Additional Tape Drives (Optional)	-		3	9,850
Storage Tapes	6	225	24	1,020
		\$20,453		\$81,694

OPTIONAL SHORE BASED EQUIPMENT

IBM Compatible PC	\$3,500
OPUS Software	3,950
Tape Reader	<u>4,500</u>
	\$11,950

Table 6-4

**INSTRUMENTATION COSTS for REPRESENTATIVE
INVESTIGATIONS (1986 Dollars)**



CROSS-SECTIONAL VIEW OF TYPICAL LONG-TERM INSTALLATION

Figure 6-3. STRAIN GAUGE WEATHERPROOFING SCHEME

Courtesy of the Micro-Measurements Division, Measurements Group, Inc.,
Raleigh, North Carolina, USA

Exact cable specifications should be determined by the strain gauge and instrumentation manufacturers based on the length of each run. In no instance should instrumentation cable be spliced in mid-span. Provision must be made for physical as well as electrical protection. If dealing with an exposed portion of cable, use of a multiconductor wire with a protective armor sleeve may be required. Stuffing tubes for bulkhead and deck penetrations should be consistent with others used throughout the ship and with regulatory body standards.

6.2.3 Instrumentation, Installation and Check-Out

Location of the instrumentation package is based on several considerations. Of primary concern is the nature of the investigation. Increased accessibility is required if large amounts of data are going to be recorded in a short period of time. If the investigation is more statistical in nature, a remote instrumentation location that permits periodical attention may be suitable.

Another factor to be considered when arranging the hardware is the responsibility of the attending personnel. A location that is convenient to his regular activities will increase the likelihood of attentive service to the equipment.

The compact size of the selected instrumentation package (17" x 12.25" x 21") virtually eliminates the need to identify a unique space for equipment installation. An existing instrumentation room, office or stateroom with a temperature stable environment becomes a more realistic alternative given the modest space requirements. Although a stabilized power supply is internal to the instrumentation package, it is good practice when working with low level analog signals to avoid having motors, air conditioning equipment, heaters or dimmer circuits on the same power line.

A check-out procedure for the instrumentation is detailed in the technical manual for the equipment. A comprehensive diagnostics package that covers all measurement and communications functions including the tape drive system is resident in the system firmware. Prior to termination of cabling at the instrumentation, all circuits should be checked for continuity.

6.2.4 Calibration

Calibration objectives can be thought of as being twofold (26). First, an overall system check is required to determine scaling factors for each gauge location. The most often recommended way to achieve this is by applying external loads of known magnitude. For shipboard experiments, this involves the systematic loading and unloading of cargo or ballast in known locations. During this procedure, data points are stored periodically when corresponding stresses can be calculated. This creates a calibration curve for each transducer. The remaining unknown is the zero offset value to be used. This establishes a baseline reference for observation of long term trends. It is virtually impossible in a ship to install strain gauges or zero instrumentation to reflect a state of zero stress. Residual building stresses, local effects and inaccuracies in still water bending moment calculations cast a high degree of uncertainty regarding absolute state of stress as is highlighted in Chang's discussion of (27).

A second objective of the calibration procedure is to determine influence coefficients for the overall structure to relate measured strains to applied loads. This creates the last link for relating mathematical modeling to full scale test data. A relatively sophisticated structural model can reside within data reduction software to present real-time loading information.

6.3 OPERATION OF INSTRUMENTATION

6.3.1 Start of Voyage Procedure

If an outline for the investigation has been developed previously, the system need only be powered up to be operational. Verification of programmed parameters is possible via front panel or remote P.C. device. It is essential that all initial readings be taken at a time when the condition of all cargo holds, ballast and fuel tanks is known and recorded. Lastly, sufficient data storage cartridge tapes should be on hand to satisfy the type and duration of the data gathering voyage.

6.3.2 Verification of Operation Procedures

A self-initiated diagnostic health check is activated upon power up of the data acquisition unit. The following are tested: microprocessor RAM memory; drive motion & speed, acceleration & deceleration; head positioner motion; lamp current; write-to-read loopback through encoding and decoding logic; and normal device status. Written messages on the front panel display indicate proper or improper operation of system functions. Additionally, the user can invoke a menu driven test sequence that examines front panel, memory, analog, cartridge and voltage criteria.

6.3.3 Procedure to Change Storage Media

Status indicator lights and a diagnostic health monitoring routine control all facets of cassette storage operations. When a multiple array of tape storage units is used, sequential switching of storage decks is automatic. The tape cartridge manufacturer guarantees the data retrieval abilities on compatible tape drive units.

6.3.4 System Troubleshooting

Once power to the unit is established, all system troubleshooting is done on a self-diagnostic basis. Individual strain gauge channels can be scanned for verification of correct signal outputs.

6.4 DATA ANALYSIS

6.4.1 Mechanics of Data Retrieval

All recorded data is accompanied by an encoded delimiter at the beginning of each record. Experiment identification and a time mark are among the information included here. This format permits the high speed scanning of storage tapes for particular records.

The front panel of the data acquisition unit can be used as a quick check device to examine previously recorded data. Further statistical summation and manipulation of time based data is usually accomplished on a per channel basis interfacing a personal computer. This can be done by either bringing a P.C. to the ship, removing the data acquisition unit for shoreside use, or utilized a remote cartridge reader interfaced to a P.C.

6.4.2 Format of Data

The standard analog to digital converter provides 16- bit binary (+/-32767) resolution and is calibrated at +/-32000 counts. Data is transmitted either via IEEE 488 parallel or RS232C serial interface at baud rates to 19,200.

7.0 AREAS FOR FUTURE INVESTIGATION

7.1 STRAIN GAUGE ATTACHMENT AND WEATHERPROOFING TECHNIQUE ADVANCEMENTS

The least known structural response characteristics are often for those structures operating in severe environments. As a result, many strain gauge installations are beset with problems and subsequent failures (16, 28). Several comparative studies (29, 30) have been performed to evaluate available gauges and installation requirements. Gauge reliability appears proportional to the care taken during installation and quality of installation and operational environment. Organizations such as the Society for Experimental Mechanics (31) frequently publish literature on technical innovation regarding strain gauge installation. Additionally, many strain gauge manufacturers publish useful technical notes that detail instructions for use of their new products. Although significant advancements have already been made, additional improvements for adhesives and protective coatings can be expected.

7.2 USE OF FIBER OPTICS

The appeal of utilizing a fiber optic data transmission system for strain gauge data is due to the inherent susceptibility to noise interference of the low level electrical signals. Another attractive feature would be for use in areas where intrinsic safety is important. Strain gauge instrumentation aboard the LNG AQUARIUS involved a lengthy approval process due to the required cable paths (14). Unfortunately, handling techniques and cost considerations make the use of fiber optic data transmission impractical at this time.

Another application for fiber optic technology is for a continuous strain monitoring system (32). The referenced article proposes the installation of such a system based on optical time domain reflectometry which relates the magnitude of reflectance to average tensile strain. The advantage of such a continuous system is that exact locations of maximum stress need not be predetermined. This concept is being investigated for arctic structures.

7.3 SPECIFIC AREAS FOR SYSTEM IMPROVEMENT

7.3.1 Filter Development

Although the proposed data acquisition system offers excellent resolution and repeatability, improvements in overall signal to noise ratios can be made. Use of sophisticated filter circuits is one way to achieve this. Filters with extremely sharp cutoff characteristics are presently cost prohibitive for the multi-channel requirements of this type of investigation. New developments in microcircuitry will probably permit improvements to signal bandpass characteristics in the future.

7.3.2 Error Source Reduction

The tables represented in Appendix C isolate various sources of induced strain gauge error. These errors are the result of both gauge installation and wiring problems. Future refinements in techniques and materials will enhance the overall performance of strain measurement systems.

7.4 CUSTOM SOFTWARE DEVELOPMENT

7.4.1 Complex Test Algorithm

Combinations of time base and level triggering with complex sequencing may require developing some advanced control software. A specific investigation that is long enough in duration may warrant production of a streamlined algorithm.

7.4.2 Data Reduction Programs

Future development in the area of data reduction software should be oriented towards use of today's generation of personal computers. Computational and graphics capabilities of these machines are suitable for the type of data reduction anticipated and their widespread proliferation will allow a greater number of end users to analyze the shipboard structural strain data as compared with previous measurement programs. Particular data reduction programs to suit an individual's needs either exist or can be developed in a straight forward manner.

7.5 INTEGRATION INTO SSC LONG RANGE GOALS

Development of a shipboard structural strain recorder ties in closely with other Ship Structure Committee projects aimed at understanding the response of ships in waves. Equipment selection has been based in part on the ability to interface to and accept input from other sensor sources. Future investigation should address formatting for parallel recording of navigational data, weather conditions wave height information, ship motion data, and log book entries.

8.0 REFERENCES

- 1 Teledyne Materials Research, "ABS Program for the Collection of Long-Term Stress Data From Large Bulk Carriers, Final Report", April 1971, Tech Report No. E-1024/Q14.
- 2 Dalzell, J.F., Mainair, N.M. & HSU, M.W., "Examination of Service and Stress Data of Three Ships for Development of Hull Girder Load Criteria", SSC Report No. 287, April 1979.
- 3 Comstock, J.P., (Editor), Principles of Naval Architecture, Society of Naval Architects and Marine Engineers, June 1977, New York.
- 4 Little, R.S., Lewis, E.V. & Bailey, F.C., "A Statistical Study of Wave Induced Bending Moments on Large Ocean Going Tankers & Bulk Carriers", Transactions, SNAME, 1971, p. 117.
- 5 Stiansen, S.G., & Mansour, A.E., "Ship Primary Strength Based on Statistical Data Analysis", Transactions, SNAME, Vol. 83, 1975.
- 6 Walters, I.J., "Instrumentation of the M/V STEWART J. CORT 1973 Season", DOT USCG Report No. CG-D-25-73, September 1974.
- 7 Meek, M. et al, "The Structural Design of the O.C.L. Containerships", Transactions, RINA, 1972, p. 241.
- 8 Wood, W.A. & Stambaugh, K.A., "SL-7 Research Program Summary, Conclusion and Recommendations" SSC Report 313 (SL-7-28) August, 1981.
- 9 Lewis, E.V. & Wheaton, J.W., "Study of Combined Wave and Springing Stresses of the EDWARD L. RYERSON", SNAME Technical & Research Program S-2, Ottawa, 1971, p. G-1.
- 10 Groh, D.A. & Plude, G.H. "The Long Ships into the Seventies", SSC - SNAME Ship Structure Symposium 1975, 1976, p. I-1.
- 11 Band, E.G.V., & Euler, A.J., "Development of an Instrumentation Package to Record Full Scale Ship Slam Data", SSC Report 274, 1978.
- 12 Wheaton, J.W., Kano, C.H., Diamant, P.T. & Bailey, F.C., "Analysis of Slamming Data From the S.S. WOLVERINE STATE", SSC Report 210, 1970.
- 13 Ghoneim, G.A.M. et al, "Global Ship Ice Impact Forces Determined From Full Scale Tests and Analytical Modelling of the Icebreakers CANMAR KIGORIAK and ROBERT LEMEUR", SNAME Presentation Paper, ICE TECH, November, 1984.
- 14 Wheaton, J.W. & Boentgen, R.R., "Stress Instrumentation System Aboard LNG AQUARIUS", SNAME New England Section, October, 1978.

- 15 Fain, R.A., "Design and Installation of a Ship Response Instrumentation System Aboard the SL-7 Class Containership S.S. MC LEAN", SSC Report 238, 1973.
- 16 German & Milne Inc. & Fenco Consultants Ltd., "M.V. ARCTIC Instrumentation and Data Collection System for Ship Operations in Ice", Manual for Transport Canada Research & Development Centre, August 1979.
- 17 Stianson, S.G. Mansour, A.E., & Chien, Y.N., "Dynamic Response of Large Great Lakes Bulk Carriers to Wave Excited Loads", Transactions, SNAME Vol. 85, 1977.
- 18 Canadian Marine Drilling Ltd., "KIGORIAK and ROBERT LEMEUR 1983 Ice Impact Tests. Refinement of Model Ship/Ice Interaction Energies", Final Report for Canadian Coast Guard Northern, September 1985.
- 19 Fain, R.A., Cragin, J.Q. & Schofield, B.H. "Design & Installation of a Ship Response Instrumentation System Aboard the Container Vessel S.S. BOSTON", SSC Report 211.
- 20 Minagawa, K. & Terano, T., "Data Recorder", Kyowa Electronic Instruments Co., Ltd., 1985, Japan.
- 21 "Dual Ported Data Acquisition Boards Provide High Performance Without Host Intervention", 1986, Data Translation Inc., Marlboro, Massachusetts.
- 22 "Technical Manual for the MEGADAC Series 2000", Release 3.0 July, 1986. Optim Corporation, Germantown, Maryland.
- 23 Window, A.L., & Holister, G.S., Strain Gauge Technology, Applied Science Publishers, London, 1982
- 24 Krevzer, M. "Comparing the Effect of Lead and Switch Resistances on Voltage and Current Fed Strain Gauge Circuits", Vol 1, 1985, No. 1 HBM, West Germany.
- 25 "Practical Strain Gauge Measurements", Hewlett Packard, Application Note 290-1, September 1981.
- 26 Boenteen, R.R., & Wheaton, J.W., "Static Structural Calibration of Ship Response Instrumentation Aboard the SEA-LAND MCLEAN", SSC Report 263, 1976.
- 27 Bogenteen, R.R., Boylston, J.W. & Wheaton, J.W., "Instrumentation - The Only Way to Go", SSC & SNAME Ship Structure Symposium 1975.
- 28 Witney, K.C., & Muller, B., "Installation and Results of the MOLIKPAQ Instrumentation System", Offshore Technology Conference, Paper No. 5116, 1986.

- 29 Wnuk, Jr., S.P., "On the Use of Bonded Weldable Strain Gauges for Field Measurements in Hostile Environments", International Conference on Measurements in Hostile Environments, SSSM-SESA, August 31, 1981
- 30 McIrvin, L.L., & Graff, R.A., "Evaluation of Weldable Strain Gauges for Use on Rails in the Fast Track", 1980, Transportation Test Center, Pueblo, Colorado.
- 31 Manual on Experimental Stress Analysis, Third Edition, Society for Experimental Stress Analysis, Westport, CT. 1978.
- 32 McKeehan, D.S., Friffiths, R.W., & Halkyard, J.E., "Marine Applications for a Continuous Fiber Optic Strain Monitoring System", Off-shore Technology Conference, Paper No. 5119, 1986

9.0

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The efforts of numerous individuals significantly contributed to the thoroughness of this investigation. As a subcontractor, Mr. Andrew Kendrick of German & Milne, Inc., provided valuable insight into the data requirements and available instrumentation to support icebreaker full-scale experiments. Professor Robert Zubaly was supportive in the data requirement assessment phase of the project by providing the original literature search data sheets that were the basis for his SNAME publication TR 2-26, "An Evaluation of Full-Scale Wave Loads". It should be noted that Professor J. Harvey Evans' concise summary of recent full scale investigations in SHIP STRUCTURAL DESIGN CONCEPTS, SECOND CYCLE provided initial direction for the first phase of this project.

Various users of strain gauge instrumentation in a shipboard environment supplied practical input regarding installation and operational difficulties. This resource also became the driving force in specification of state-of-the-art instrumentation guidelines due to the inherent technology lag within published literature. The technical assistance from Mr. Robert Bower of Optim Electronics should also be acknowledged.

Finally, the authors would like to recognize the expert guidance provided by the SR-1303 Project Technical Committee. Their commulative experience with ship structural investigations proved to be invaluable.

APPENDIX A STRAIN MEASUREMENT

A.1 STRESS - STRAIN RELATIONSHIP

Stress in a material can not be measured directly and must be computed from other measurable parameters. The various conditions of strain measurement can be summarized as follows:

- A. Orientation of principal axes known:
 - 1. Uniaxial strains may be measured with a single gauge oriented in the axial direction
 - 2. Biaxial plane strains may be measured with a two gauge system oriented in the directions of the principal axes.

- B. Orientation of principal axes not known:
 - 1. A three gauge rosette is required to define the principal axes and the strain components in a plane strain system.

The total strain in any particular direction can be considered as the sum of three separate parts: strain due to temperature change, Poisson strain which is unaccompanied by stress, and primary strain which can be related to stress by Hooke's law. Temperature effects can be compensated by utilizing a dummy gauge in the circuit or by using self compensating gauges. In a biaxial stress field, the maximum and minimum values of stress lie along mutually perpendicular directions, namely the principal planes. The direction of principal stresses coincides with that of principal strains and no shearing stresses or strains are present. The mathematical expression relating principal stresses to principal strains is:

$$\sigma_x = \frac{E}{1 - \nu^2} (\epsilon_x + \nu \epsilon_y)$$

- with ν = Poisson's Ratio
- σ_x = Stress in 'x' direction
- E = Young's Modulus
- ϵ_x = Measured strain in 'x' direction
- ϵ_y = Measured strain in 'y' direction

Thus, even if the direction of principal stress is known, strain must be measured in the transverse direction to derive a value for that stress.

A.2 MEASUREMENT DEVICES

A.2.1 MECHANICAL DEVICES

The earliest forms of strain measurement employed various types of mechanical devices. Extensometers are one class of instrument that rely solely on mechanical response to changes in material strain. Simplicity and excellent long term stability characteristics are two reasons these devices continue to find applications today despite their minimum required gauge length and relatively poor resolution of microstrain.

A variation on purely mechanical instrumentation has recently taken the form of a fatigue damage indicator (A-1). The device relies on its geometry to

amplify relative displacements. Sensing elements of fine metallic strips are arranged to break sequentially in a calibrated fashion to reflect specimen cyclic loading. This instrument has been used successfully to monitor the fatigue history of a jack up rig in tow to its destination. Fatigue information is presented in a cumulative fashion with no relational time base. Additionally, no recorder data is available for future analysis.

The vibrating wire strain gauge is a device that has been previously recommended for measuring still water bending moments in ships (A-2). The device consists of a thin steel wire held in tension between two terminals attached to the specimen. The tension and corresponding wire natural frequency change with strain changes. Excellent long term stability is available with this type of device with many applications involving embedment of the gauges into concrete. The vibrating string relies upon the forcing provided by a magnet and coil which essentially eliminates any dynamic strain measurement applications. Cost and gauge length are two other factors limiting widespread use in a shipboard environment.

A.2.2 OPTICAL ARRANGEMENTS

A hybrid device called a photoelectric gauge uses mechanical optical and electric amplification to measure strain (A-3). A light beam is used in conjunction with a photocell detector to generate an electrical current proportional to strain. This type of instrument is generally not suited for dynamic applications as it is costly and delicate.

Another instrument that is purely optical utilizes interference fringes provided by optical flats (A-4). This is a highly accurate laboratory technique that again is too delicate for field use.

A.2.3 BRITTLE COATINGS

For investigations that require detailed analysis of stress concentrations and orientation, application of a brittle lacquer to an unstressed part can produce a qualitative assessment of the stress field after a load is applied (A-5). This technique is common for stress analysis involving machinery parts. A follow-up strain gauge installation at the indicated area of maximum stress can then give an indication of the magnitude of that stress. The entire analysis procedure is usually reserved for production machinery components that will experience severe in service fatigue.

A.2.4 ELECTRICAL DEVICES

Several types of strain gauges operate on the principle of proportionally varying electrical output to reflect changes in apparent strain. The most common device is the resistance strain gauge. Carbon resistor gauges have given way to the bonded type gauge made of fine wire or metallic foil. This is by far the most widely used configuration for general strain measurement. Its relative low cost and small size permit installation in quantity for dynamic applications.

APPENDIX B

STRAIN GAUGE CIRCUITRY

The bonded resistance strain gauge is inherently a low output electrical device. However, its relative stability and linearity as compared to capacitance, inductance and piezoresistive gauges make it the most accepted strain measurement tool. Resistance changes on the order of hundreds of micro-ohms/microstrain need to be detected with cable runs spanning hundreds of feet. This is usually accomplished with Wheatstone bridge circuits.

A Wheatstone bridge is most commonly used for converting the small gauge resistance change into a measurable voltage (B-1). Four resistors are arranged in a configuration as illustrated in Figure B-1. If $R_1/R_4 = R_2/R_3$ then V_{out} equals zero and the bridge is balanced. A change in R_1 produces a change in the output voltage. If in adjacent arms of the bridge a resistance change of equal magnitude and opposite polarity occurs, the output voltage will be twice what the single arm produces. A general equation relating output voltage to strain is:

$$V_{out} = \frac{K \epsilon N V_{in}}{4}$$

K = gauge factor,
V_{in} = bridge volts,
N = number of active arms,
ε = measured strain.

Various bridge configurations in use today are shown in Figures B-2 through B-4. The quarter bridge utilizes a single strain gauge for measurement of uniaxial strain. Its acceptance has grown as of late due to the development of temperature compensated foil strain gauges. The half bridge utilizes two strain gauges for the purpose of either measuring tension and compression simultaneously or for temperature compensation. The full bridge arrangement utilizing all arms of the circuit as active provides the highest resolution and greatest signal noise rejection. This configuration is useful when the measuring point is a long distance from the instrumentation or environmental variations are considerable.

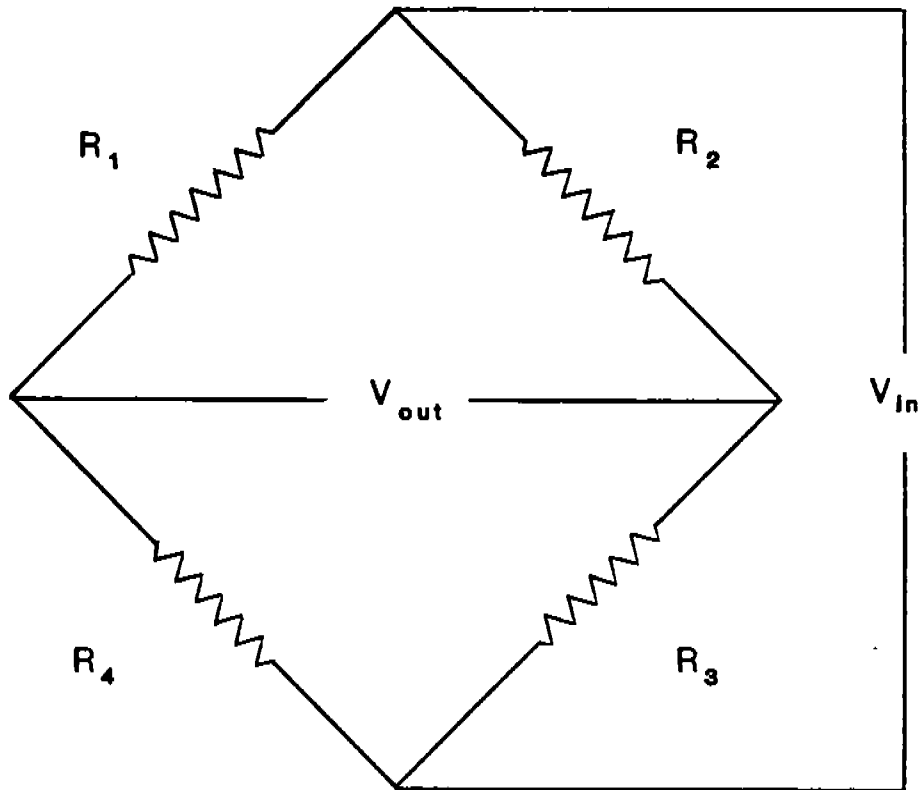


Figure B-1
WHEATSTONE BRIDGE

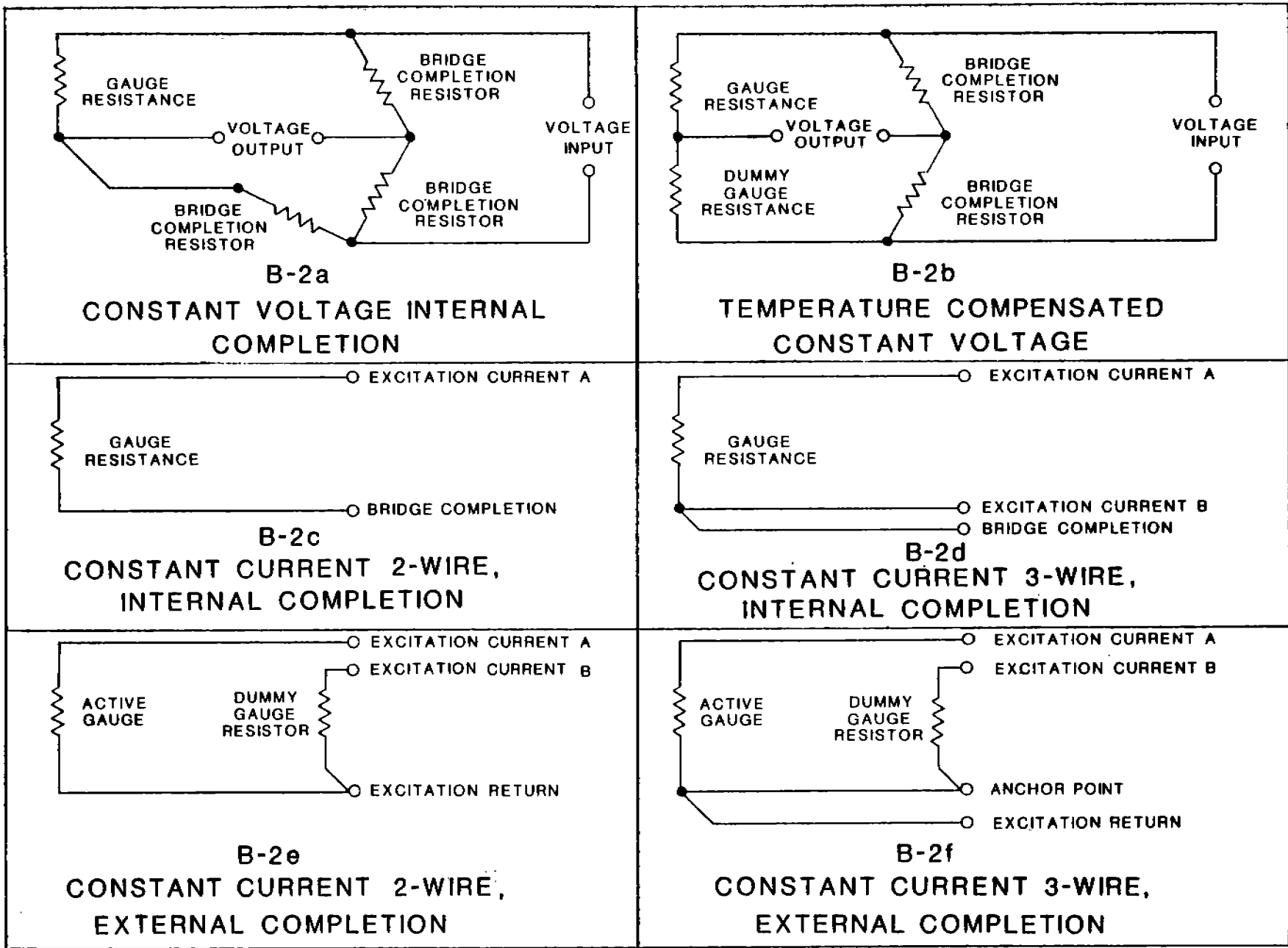
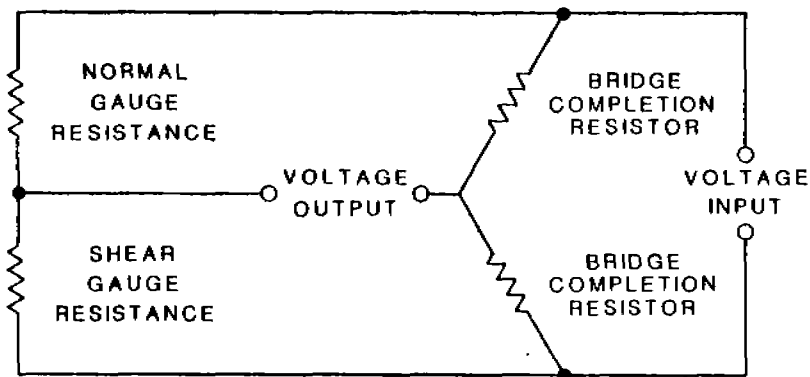
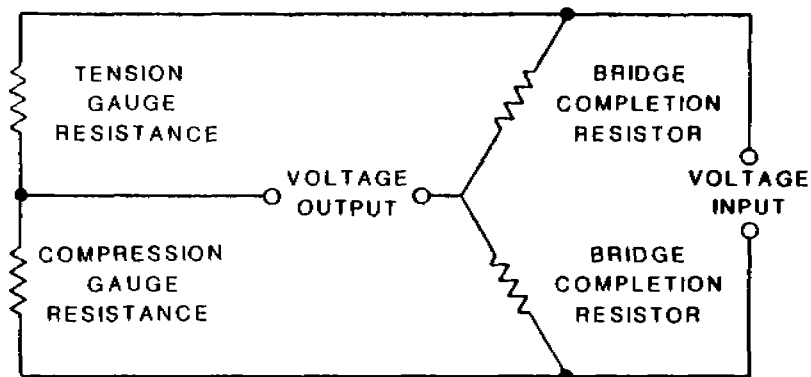


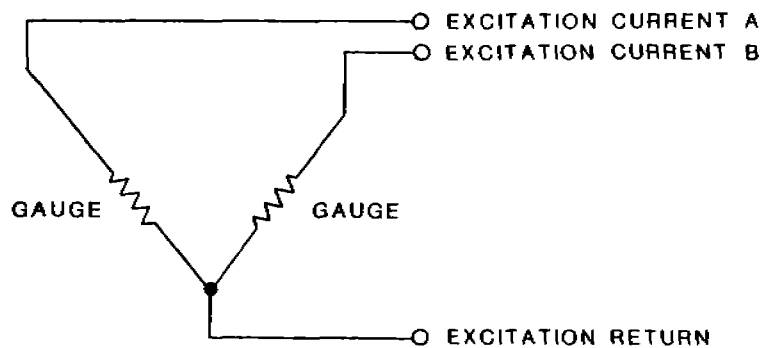
Figure B-2
QUARTER BRIDGE CONFIGURATIONS



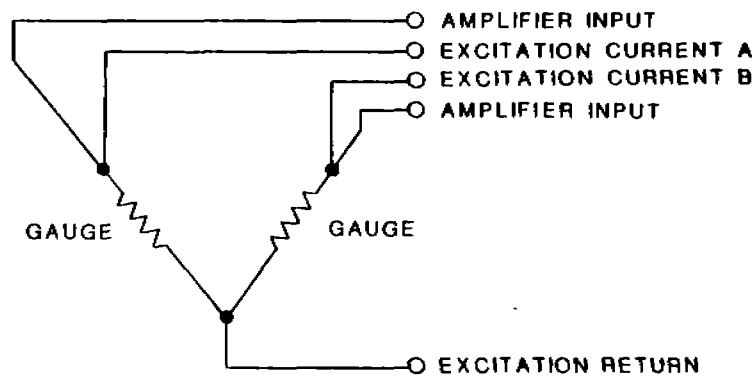
B-3a
CONSTANT VOLTAGE WITH
GAUGES AT 90°



B-3b
CONSTANT VOLTAGE 'BEAM'
ARRANGEMENT

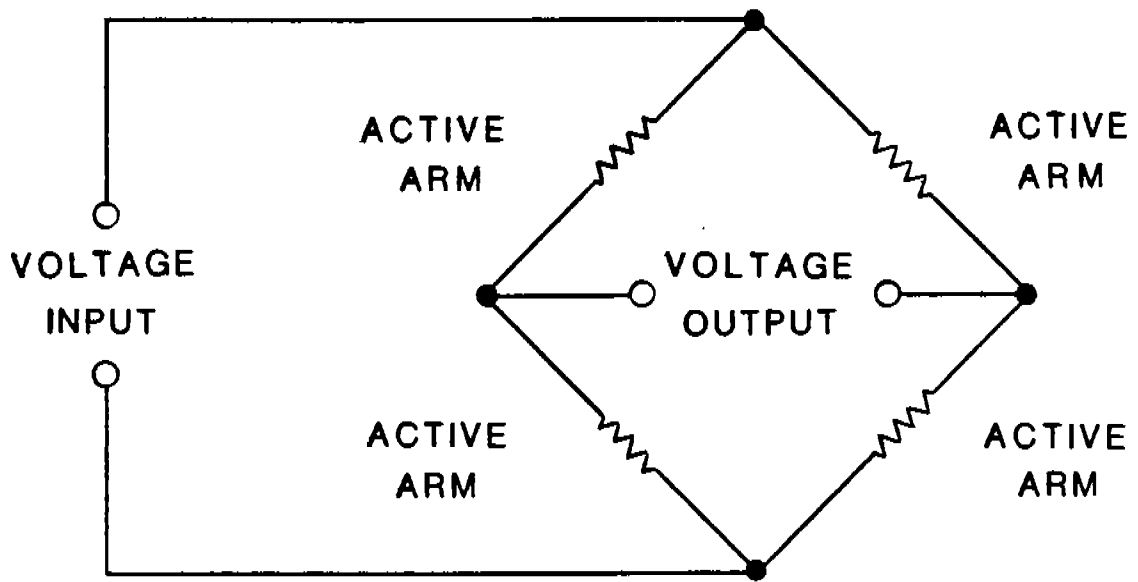


B-3c
CONSTANT CURRENT 3-WIRE

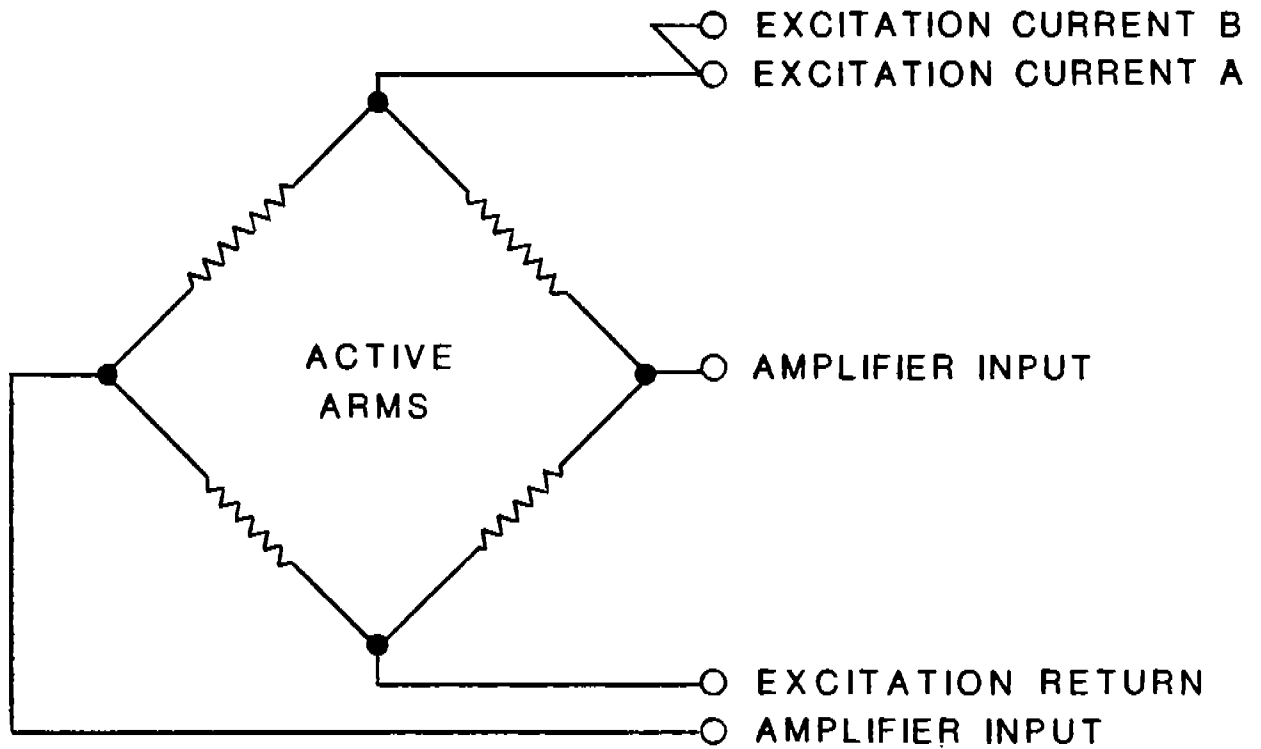


B-3d
CONSTANT CURRENT 5-WIRE

Figure B-3
HALF BRIDGE CONFIGURATIONS



B-4a CONSTANT VOLTAGE ARRANGEMENT



B-4b CONSTANT CURRENT ARRANGEMENT

Figure B-4
FULL BRIDGE CONFIGURATIONS

APPENDIX C ERROR ANALYSIS

C.1 ERROR SOURCES

To better understand the problem of strain measuring system errors, principal sources have been identified and categorized (C-1).

C.1.1 ERRORS IN GAUGE SYSTEM

C.1.1.1 Strain Gauge

- (a) Change in quoted gauge factor due to large strains.
- (b) Linearity.
- (c) Tolerance on quoted gauge factor
- (d) Exceeding quoted fatigue life.
- (e) Transverse sensitivity.
- (f) Mismatch of gauge self temperature compensation and structure.
- (g) Gauge length/strain gradient ratio.
- (h) Self-heating effect.
- (i) Ratio distances from structure neutral axis to structure surface and gauge axis.
- (j) Disturbance of strain field by gauge.
- (k) Magnetoresistance effect.
- (l) Resistance change repeatability (e.g., with cyclic strain).

C.1.1.2 Adhesive

- (a) Exceeding elongation capabilities.
- (b) Creep.
- (c) Hysteresis.
- (d) Insufficient cure; incorrect glue-line, inclusions and voids affecting strain transmission characteristics.

C.1.1.3 Protection

- (a) Coating attaching gauge grid and soldered joints.
- (b) Breakdown permitting grid etching and causing resistive and capacitive shunting paths.
- (c) Stiffening

C.1.1.4 Environment

- (a) Effects of water, acid, corrosive substances, etc. on coating.
- (b) Effects of pressure, solar and nuclear radiation.
- (c) Effects of electromagnetic and electrostatic fields.
- (d) Effects of thermal shock.
- (e) Temperature-induced output (apparent strain).
- (f) Gauge factor variation with temperature.

C.1.2 ERRORS IN SIGNAL ACQUISITION

C.1.2.1 Joints

- (a) Attack of soldered joints by active fluxes.
- (b) Ageing of solder.
- (c) Unsatisfactory joint, e.g. 'dry joint'.
- (d) 'Tin disease'
- (e) Generation of thermal EMFs.

C.1.2.2 Connections

- (a) change in contact resistance causing change in gauge factor desensitisation.
- (b) Effect of contact resistance change within bridge circuit.
- (c) Generation of thermal EMFs.

C.1.2.3 Lead Wires

- (a) Lead resistance causing gauge factor desensitisation.
- (b) Change in lead resistance with temperature.
- (c) Generation of thermal EMFs.
- (d) 'Noise' pick-up.

C.1.3 ERRORS IN SYSTEM READOUT

C.1.3.1 Bridge Completion

- (a) Change in resistance values with temperature.
- (b) Effects of switching within the bridge circuit.
- (c) Regulation in constant voltage or current modes.

C.1.3.2 Bridge Supply

- (a) Stability in out-of-balance mode of operation.
- (b) Effects of switching within the bridge circuit.
- (c) Regulation in constant voltage or current modes.

C.1.3.3 Signal Conditioning

- (a) Shunting effect of amplifier input and readout device.
- (b) Resolution and linearity of readout.
- (c) Drift and linearity of amplifier.

C.1.3.4 Electrical Noise

- (a) Switching or transmission noise.
- (b) Series and common mode voltages and rejection ratio.
- (c) Pick-up in electromagnetic and electrostatic fields.

C.1.4 ERRORS IN DATA PROCESSING

C.1.4.1 Gauge Position

- (a) Reduction or increase of recorded strain because of gauge misalignment.
- (b) Incorrect data because of gauge mislocation.
- (c) Non-cancellation of unwanted signals (e.g., bending effects).
- (d) Grid relationship for two and three gauge rosettes.
- (e) Strain gradients parallel to the plane of the gauge.
- (f) Strain gradients normal to the test surface.

C.1.4.2 Calibration

- (a) Effect of using incorrect gauge factor to compute calibration resistor.
- (b) Effect on calibration resistor of assuming nominal gauge resistance.
- (c) Effects of lead length and single arm shunting for full bridge calibration.

C.1.4.3 Material Constants

- (a) Difference between test material and structure constants affecting gauge factor.
- (b) Effect of material adiabatic temperature changes.
- (c) Assumption of measurement within elastic limit.

C.2 ASSESSMENT OF ERROR MAGNITUDE

As outlined in C.1, many potential sources of error make it difficult to use manufacturers' specifications to project an overall system accuracy assessment. Some acceptable limits to non-repeatable performance deviations can be summarized from the available literature. Repeatable system errors can be handled by calibration procedures and are therefore not of concern for this analysis. Various mathematical techniques for calculating overall system accuracy in a multiple component package are presented by Doebelin (C-2). The intention here is to highlight the magnitude of individual component errors.

C.2.1 TRANSVERSE SENSITIVITY

Transverse sensitivity errors are usually quite small in a biaxial strain field. When the actual strain in one axis is much greater than the orthogonal value, measurement errors in the minor axis can be significant. As a rough approximation, transverse sensitivity error can be thought of as proportional to the product of the measured strain ratio's and the transverse sensitivity coefficient. This coefficient is defined as the ratio of transverse to axial quoted strain gauge factors. Typical error values may be around 10%. When a rosette measurement arrangement is used, these errors can be assessed and mathematically compensated (C-3).

C.2.2 BRIDGE NON-LINEARITY

Many of the strain gauge bridge configurations illustrated in Appendix B produce an output that is not linearly related to actual specimen strain (C-4). Knowledge of a circuit's behavioral characteristics allows a computer based system to compensate for non-linearities within the software.

C.2.3 WIRING AND NOISE CONSIDERATIONS

The constant current excitation configuration virtually eliminates effects of leadwire resistance. Current source signals have successfully been transmitted 5000 feet with 0.5% accuracy variation due to ambient noise influence (C-5).

C.2.4 SIGNAL PROCESSING RESOLUTION

Some degree of error may be introduced in the analog to digital conversion process. Unless required to operate at excessive speeds, accuracy of typical 16-bit devices is around 0.05% (C-6).

C.2.5 OVERALL POTENTIAL ERROR ASSESSMENT

The aforementioned sources of error can be categorized as bias errors and precision errors (C-7). A total uncertainty factor can be thought of as a sum of the two types. Bias errors are fixed offset values that can usually be eliminated through calibration techniques. Precision errors are random in nature and caused primarily by noise. Elimination of precision errors from measured data is virtually impossible, however, much improvement can be realized through utilization of statistical techniques.

Appendix C
References

- C-1 Window, A.L., & Holister, G.S., Strain Gauge Technology, Applied Science Publishers, London, 1982.
- C-2 Doebelin, E.O., Measurement Systems, McGraw-Hill, New York, 1975
- C-3 "Errors due to Transverse Sensitivity in Strain Gauges", 1982, TN-509, Micro Measurement Division, Measurements Group Inc., Raleigh, north Carolina.
- C-4 "Errors Due to Wheatstone Bridge Nonlinearity" 1982, TN-507, Micro Measurement sDivision, Measurements Group, Inc., Raleigh, North Carolina.
- C-5 "The Handbook of Personal Computer Instrumentation for Data Acquisition, Test Measurement and Control", 1986, Burr-Brown Corporation, Tucson, AZ.
- C-6 "Technical Manual for the MEGADAC Series 2000", Release 3.0. July, 1986. Optim Corporation, Germantown, Maryland.
- C-7 "Measurement Accuracy", Application Note PI-105, Pacific Instruments, Concord, California.

**APPENDIX D
SPECIFICATION SUMMARIES**

D.1 STRAIN GAUGES

Manufacturer: Measurements Group

Address: P.O. Box 2777, Raleigh, N.C. 27611

Phone Number: (919) 365-3800

Contact: Mike Tierney @ Measurements, Inc.

Device Name: Metal Foil Strain Gauge

Model Number: WK-XX-125AD-350 (Typical)

Device Function: Widely used general purpose pattern; fully encapsulated K-Alloy

Frequency Range: ± 1.5 % strain range

Bridge Excitation Voltage: N/A

Bridge Balance: 350 % $\pm .3$ %

Signal Filtering: N/A

Shunt Calibration: N/A

Signal Output: N/A

Gain Control: N/A

Channel Quantity: 1

A/D Conversion Technique/Resolution: N/A

Activation Method: N/A

Programability: N/A

Storage Capacity: N/A

Data Reduction Capabilities: N/A

External Interface: High endurance lead wires, use conduit

System Stability: -452 to 550°F, self compensating

System Linearity: 10^7 cycles @ ± 2200 $\mu\epsilon$ fatigue life

Absolute Accuracy: N/A

Size: .4" x .22" matrix size; .125" x .125" active gauge

Weight: N/A

Maintenance/Attendance Requirements: M-coat system for submerged application

Set Up Requirements: Utilize a variety of room temperature and elevated temperature bonding compounds

Cost Per Channel: 5/\$41

Note: N/A = Information not applicable or not available.

Manufacturer: BLH Electronics
Address: 75 Shawmut Road, Canton, MA 02021
Phone Number: (617) 821-2000
Contact: Michael W. Morrell
Device Name: Half Square Grid, General Purpose Transducer Quality
Model Number: SR-4, FAB-50-355X
Device Function: Constantan Foil, Glass Carrier
Frequency Range: 2% maximum strain limit ($\pm 20,000$ $\mu\text{in/in}$) one cycle @ room temperature
Bridge Excitation Voltage: N/A
Bridge Balance: $350 \Omega \pm .5$
Signal Filtering: N/A
Shunt Calibration: N/A
Signal Output: N/A
Gain Control: 2.1 gauge factor
Channel Quantity: N/A
A/D Conversion Technique/Resolution: N/A
Activation Method: N/A
Programability: N/A
Storage Capacity: N/A
Data Reduction Capabilities: N/A
External Interface: Nickel clad, copper ribbon .002" x .012" x 1.2" lead material
System Stability: -320° to 450° temperature compensation
System Linearity: N/A
Absolute Accuracy: N/A
Size: .9" x .37" matrix size, .5" grid length
Weight: N/A
Maintenance/Attendance Requirements: .125" maximum safe bending radius
Set Up Requirements: Heat cured epoxy mounting best; apply barrier scheme
Cost Per Channel: N/A

Manufacturer: Eaton Corporation, Electronic Instrumentation Division
Address: 5340 Alla Road, Los Angeles, CA 90066
Phone Number: (213) 822-3061
Contact: Alan Stillwell or Roberts Engineering @ (215) 688-6525
Device Name: Weldable Strain Gauge
Model Number: SG 128/129
Device Function: Rapid installation strain gauge, waterproof
Frequency Range: $\pm 20,000 \mu\text{in/in}$ rating
Bridge Excitation Voltage: 50 mA maximum excitation current
Bridge Balance: $\frac{1}{4}$ bridge, 120 Ω & 350 Ω
Signal Filtering: N/A
Shunt Calibration: N/A
Signal Output: N/A
Gain Control: 1.98 gauge factor
Channel Quantity: 1
A/D Conversion Technique/Resolution: N/A
Activation Method: N/A
Programability: N/A
Storage Capacity: N/A
Data Reduction Capabilities: N/A
External Interface: (3) no. 28 AWG nickel clad solid copper wire, insulated
with fiberglass good to 100'
System Stability: -452° to 600°F, self temperature compensated
System Linearity: $>10^6$ cycles fatigue life
Absolute Accuracy: G.F. $\pm 3\%$
Size: .125" x 1" attachment base; .91" active length
Weight: N/A
Maintenance/Attendance Requirements: Possibly use SG 122 with polyurethane
cover
Set Up Requirements: Spot weld installation
Cost Per Channel: \$176

Manufacturer: HITEC Corporation
Address: Nardone Industrial Park, Westford, MA 01886
Phone Number: (617) 692-4793
Contact: Mike Tierney @ Measurements, Inc., (703) 373-5520
Device Name: Weldable Strain Gauge
Model Number: HBW
Device Function: Hermetically sealed bonded foil strain gauge
Frequency Range: $\pm 5000 \mu\text{in/in}$
Bridge Excitation Voltage: N/A
Bridge Balance: 350 Ω standard, 120 Ω optional
Signal Filtering: N/A
Shunt Calibration: N/A
Signal Output: Single element, bending or shear configuration
Gain Control: 2.1 gauge factor
Channel Quantity: 1
A/D Conversion Technique/Resolution: N/A
Activation Method: N/A
Programability: N/A
Storage Capacity: N/A
Data Reduction Capabilities: N/A
External Interface: 3 or 4 conductor #22AWG from transition junction (vinyl
or silicone coating)
System Stability: -50°F to 300°F
System Linearity: 6 or 9 PPM temperature compensation
Absolute Accuracy: N/A
Size: .125" x .062" active grid with 1" x .5" S.S. carrier shim
Weight: N/A
Maintenance/Attendance Requirements: N/A
Set Up Requirements: clean surface with abrasive medium and tack weld gauge
and transition unit
Cost Per Channel: \$35 - \$120

D.2 SIGNAL CONDITIONERS

Manufacturer: Encore Electronics, Inc.

Address: Road 2, Route 50, Saratoga Springs, New York 12866

Phone Number: (518) 584-5354

Contact: Marcel Zucchini

Device Name: Strain Gauge Amplifier

Model Number: 610 (New model # is 617)

Device Function: Signal Amplifier

Frequency Range: 0-50 KHz

Bridge Excitation Voltage: Switch selectable for 0-15Vdc & 15 mA or 30 mA

Bridge Balance: Switch selectable for $\frac{1}{4}$ static, $\frac{1}{4}$ dynamic and full bridge

Signal Filtering: Selectable 4 pole active filter with -3dB points @ 10, 500, 1000, 5000, 16,000, 32,000 and 50,000 Hz

Shunt Calibration: External or Internal

Signal Output: ± 10 V Max, 100 mA Pk

Gain Control: Switch selectable fixed gains from 1 to 5000 $\pm 2\%$ in log steps with vernier control

Channel Quantity: 7 per rack

A/D Conversion Technique/Resolution: N/A

Activation Method: Manual

Programability: N/A

Storage Capacity: N/A

Data Reduction Capabilities: N/A

External Interface: 5 Pin connector input, 3 pin output

System Stability: Within \pm microvolts RTI for 24 hours after 1 hour warm-up

System Linearity: Noise = 5 μ V rms RTI @ DC to 50 KHz

Absolute Accuracy: CMRR = 100 dB DC to 70 Hz

Size: 19"W x 7"H x 16"D

Weight: N/A

Maintenance/Attendance Requirements: N/A

Set Up Requirements: N/A

Cost Per Channel: N/A

Manufacturer: Pacific Instruments
Address: 2355 Whitman Road, Concord, CA 94518
Phone Number: (415) 827-9010
Contact: Ed Pugh, (703) 527-3262
Device Name: Transducer Conditioning Amplifier
Model Number: 8250
Device Function: Excitation, balance, calibration & amplification
Frequency Range: 0 - 100 KHz
Bridge Excitation Voltage: .1 to 15 Volts
Bridge Balance: Selectable ratiometric or precision fixed reference, remote
trigger autobalance available
Signal Filtering: Switch selectable 12dB/octave bessel; 10,000Hz, 1KHz, 10KHz
& wideband
Shunt Calibration: Two step bi-polar single or double shunt selected by
remote
Signal Output: $\pm 10V @ 10 mA$ & $100 mA$ with variable gain from .1 to 1 &
adjustable zero offset
Gain Control: Switch selectable from 1 to 1000 with variable or calibrated
gain
Channel Quantity: 1
A/D Conversion Technique/Resolution: N/A
Activation Method: TTL logic activates calibration and auto-balance: + 5 VDC
@ 10 mA
Programability: N/A
Storage Capacity: N/A
Data Reduction Capabilities: N/A
External Interface: Via 8202 mainframe
System Stability: $\pm .01\%$ for 6 months; $\pm .004\%/^{\circ}C$
System Linearity: $\pm .01\%$ terminal linearity
Absolute Accuracy: $\pm .1\%$; CMR 120dB DC to 60 Hz for gain = 1000
Size: 5.25"H x 1.63"W x 17.75"D
Weight: 5 lbs
Maintenance/Attendance Requirements: N/A
Set Up Requirements: N/A
Cost Per Channel: N/A

Manufacturer: Measurements Group, Inc.
Address: P.O. Box 27777, Raleigh, N.C. 27611
Phone Number: (919) 365-3800
Contact: Mike Tierney, (703) 373-5520
Device Name: Signal Conditioning Amplifier
Model Number: 2310Y
Device Function: Generates high-level signals from strain gauges
Frequency Range: DC coupled to 25 KHz $-.5\text{dB}$ max
Bridge Excitation Voltage: 12 settings from .5 to 15 Vdc $\pm 1\%$ max
Bridge Balance: Counter EMF injection @ preamp; typically 2 sec; 2 year non-volatile digital storage
Signal Filtering: Low-pass active 2-pole butterworth @ 10,000Hz, 1KHz, 10KHz & wide-band
Shunt Calibration: Single access any bridge arm, 120 Ω & 350 Ω , optional remote operation
Signal Output: $\pm 10\text{V}$ @ 5 mA; $\pm 1.414\text{V}$ @ 5 mA & $\pm 10\text{V}$ @ 75 mA
Gain Control: 10-turn counting knob plus decade multiplier for 1 to 11000 $\pm 1\%$
Channel Quantity: 1
A/D Conversion Technique/Resolution: N/A
Activation Method: With option 4: 6 internal relays for shunt CAL, auto balance & bridge excitation
Programability: N/A
Storage Capacity: N/A
Data Reduction Capabilities: N/A
External Interface: Via BNC or output receptacle
System Stability: $\pm 2 \mu\text{V}/^\circ\text{C}$ max
System Linearity: @ DC = .02%
Absolute Accuracy: CMR=100 dB min @ DC; Noise = 1 $\mu\text{Vp-p}$ RY1 @ .01 to 10 Hz
Size: 8.75H x 1.71W
Weight: 6 lbs
Maintenance/Attendance Requirements: Front panel set-up
Set Up Requirements: Filter, remote sense & shunt calibration selection are dip switches on board
Cost Per Channel: \$1375

Manufacturer: Validyne Engineering Corporation
Address: 8626 Wilbur Avenue, North Ridge, CA 91324-4498
Phone Number: 1-800-473-5851
Contact: Lynn Swan @ Advanced Engineering Controls, (301) 366-4764
Device Name: Strain Gauge Conditioner
Model Number: SG502
Device Function: Conditioner, Multiplexer, A/D converter & Controller for
standard bus systems
Frequency Range: 15 channels/sec conversion rate
Bridge Excitation Voltage: 4Vdc, 300mA; 2 Wire remote voltage sensing
capability for long runs
Bridge Balance: Operates with full bridge input
Signal Filtering: N/A
Shunt Calibration: N/A
Signal Output: 250 $\mu\epsilon$ will produce full 12 bit (5096 counts) output
Gain Control: $\pm .5$ to 100 mV/V, switch selectable
Channel Quantity: 8
A/D Conversion Technique/Resolution: 12-bit resolution
Activation Method: N/A
Programability: 2 alarms per channel
Storage Capacity: 2 bytes data in and 2 bytes data out buffers
Data Reduction Capabilities: N/A
External Interface: 26 Pin IDC input; 56 pin card edge connector standard bus
output
System Stability: .01% FS/ $^{\circ}$ C
System Linearity: $\pm .05\%$ RS
Absolute Accuracy: CMR = 115dB
Size: 4.5"H x 1"W x 6.5"D
Weight: N/A
Maintenance/Attendance Requirements: Via host computer
Set Up Requirements: Dip switch configuration
Cost Per Channel: N/A

Manufacturer: Precision Filters, Inc.
Address: 240 Cherry Street, Ithaca, N.Y. 14850
Phone Number: (607) 277-3550
Contact: Ed Pugh @ (703) 527-3262
Device Name: Multimode Conditioner
Model Number: 316/416
Device Function: Signal Conditioning & Programmable Filter/Amplifier
Frequency Range: N/A
Bridge Excitation Voltage: Isolated supply voltage .1 to 15V @ 100 mA
Bridge Balance: Programmable; 1, 2 or 4 active arms with $\pm .1\%$ resolution
Signal Filtering: Programmable: 6 pole with 30 cut-off frequencies
Shunt Calibration: Programmable $\Delta\Omega = 16, 8, 4, 2, 1.5 \text{ \& } .25$; series or shunt
Signal Output: BNC connectors
Gain Control: Programmable gain 1-1000 $\pm 1\%$
Channel Quantity: 16
A/D Conversion Technique/Resolution: N/A
Activation Method: Front panel or computer control
Programability: N/A
Storage Capacity: N/A
Data Reduction Capabilities: N/A
External Interface: GPIB, HP-1B or RS232; 15 Pin Cannon DA-15P input
System Stability: $\pm 01\%$ or 500 $\mu\text{V}/8 \text{ hrs}$; $.005\%/^{\circ}\text{C}$ or 100 $\mu\text{V}/^{\circ}\text{C}$
System Linearity: $<1^{\circ}$ Phase change
Absolute Accuracy: 100 dB CMRR
Size: N/A
Weight: N/A
Maintenance/Attendance Requirements: N/A
Set Up Requirements: Front panel or computer control
Cost Per Channel: \$4,512 (\$72,200/16 Ch.)

D.3 DATA ACQUISITION UNITS

Manufacturer: CYBER Systems, Inc.

Address: 2750 East Cerritos Avenue, Anaheim, CA 92806

Phone Number: (714) 634-2800

Contact: Mike Tierney, (703) 373-5520

Device Name: Mini Das

Model Number: System 100

Device Function: Standalone portable data acquisition system

Frequency Range: DC to 2 KHz with solid state multiplexer

Bridge Excitation Voltage: 0-15V constant voltage floating power supply via
9351-EX option

Bridge Balance: Internal 120 Ω or 350 Ω bridge completion resistor via
9351-BR option (Auto)

Signal Filtering: N/A

Shunt Calibration: All R-CAL relays simultaneously energized during
calibration (Auto)

Signal Output: 8 contact closure & 8 TTL for out of limit; real time data
output

Gain Control: Random, user control: 80 MV RTI gains of 64 to 2048

Channel Quantity: 32

A/D Conversion Technique/Resolution: 12 Bit providing 5 μ V/Bit in Gain=1;
2.44 μ V/Bit in gain=2048

Activation Method: Panel switch activates turn key 'acquire' software

Programability: Menu driven programs: setup, verify, calibrate, acquire,
transfer & diagnostic

Storage Capacity: 32K word transient data memory

Data Reduction Capabilities: Various math packages including Rosette Analysis

External Interface: Screen terminal input, RS232 output @ 800 samples/sec

System Stability: Temp: 1 μ V/ $^{\circ}$ C, Time: 5 μ V/8 hours

System Linearity: .025% of full scale from best straight line

Absolute Accuracy: CAL supply: .015% + 3 μ V, CMR: 110dB @ 64-2048 gain, 85
dB @ 1-32 gain

Size: 10.5"H x 17"W x 34"D

Weight: 75 lbs

Maintenance/Attendance Requirements: Mass storage interface or 9 track tape

Set Up Requirements: Turnkey software interface

Cost Per Channel: \$940 @ 32 channels (\$30K/system)

Manufacturer: CYBER Systems, Inc.
Address: 2750 East Cerritos Avenue, Anaheim, CA 92806
Phone Number: (714) 634-2800
Contact: Mike Tierney @ (703) 373-5520
Device Name: Multiplexer Acquisition Subsystem
Model Number: Series 900
Device Function: Data Acquisition Front End
Frequency Range: Scan rate up to 20,000 sample/sec (15.6 Hz throughput with
128 channels)
Bridge Excitation Voltage: ± 10 volts
Bridge Balance: Programmable with user installed resistor
Signal Filtering: User installed single or double pole passive filter
Shunt Calibration: programmable with user installed resistor
Signal Output: N/A
Gain Control: Random, under user control
Channel Quantity: 128 (to 1024)
A/D Conversion Technique/Resolution: 12-bits providing 5 mV/bit @ Gain=1,
2.44 μ V/Bit @ 2048
Activation Method: N/A
Programability: Via RS232 port for ASCII code
Storage Capacity: 4096 step scan list memory
Data Reduction Capabilities: N/A
External Interface: RS 232
System Stability: $.5 \mu$ V/ $^{\circ}$ C' max 5 μ V/8 hrs
System Linearity: .025% F.S.
Absolute Accuracy: NBS Traceable calibration source; CMR = 110dB
Size: 19"W x 15.75"H x 22"D
Weight: N/A
Maintenance/Attendance Requirements: N/A
Set Up Requirements: Resistor insertion; interface to host CPU
Cost Per Channel: N/A

Manufacturer: Analogic Corporation
Address: 14 Electronics Avenue, Danvers, MA 01923
Phone Number: (617) 777-4500
Contact: Barry Fogel @ Commonwealth Controls, (301) 796-5960
Device Name: Modular Data Acquisition/Distribution System
Model Number: ANDS 5400
Device Function: Computer Front End Device
Frequency Range: Up to 100,000 analog transactions/sec
Bridge Excitation Voltage: N/A
Bridge Balance: Duty cycle modulated; 16-bit equivalent resolution; full or partial bridges
Signal Filtering: On board filtering
Shunt Calibration: Per channel calibration input; autozero capability
Signal Output: N/A
Gain Control: 1, 2, 4, 8, 16 & 32 \pm .001%
Channel Quantity: 28
A/D Conversion Technique/Resolution: 16 bit successive-approximation to \pm .0015% linearity
Activation Method: Asynchronous or synchronous operation with external events
Programability: Extensive PDP-11 & LSI-11 software library
Storage Capacity: See host computer
Data Reduction Capabilities: N/A
External Interface: Programmed I/O direct memory access with host via 16 bit words
System Stability: 6 PPM/ $^{\circ}$ C maximum
System Linearity: \pm .002% FSR
Absolute Accuracy: \pm .01/ \pm .05 % FSR guaranteed
Size: 5 $\frac{1}{4}$ " H rack mount chassis (19")
Weight: 40 lbs
Maintenance/Attendance Requirements: Recalibration approximately every 6 Mos.
Set Up Requirements: Host computer & (6) data/address front panel switches
Cost Per Channel: N/A

Manufacturer: Analog Devices
Address: P.O. Box 280, Norwood, Mass 02062
Phone Number: (617) 329-4700
Contact: John Carter, (301) 992-1994
Device Name: Strain Gauge Input and MACSYM 120 Computer
Model Number: AIM05/ with Macsym 120
Device Function: Analog input for Macsym systems
Frequency Range: 0-2Hz standard; up to 5 KHz with user supplied
Bridge Excitation Voltage: Switch selectable +5V or +10V
Bridge Balance: Accepts 1, 2, and 4 active arm inputs, 120 Ω and 350 Ω on board completion resistors
Signal Filtering: Resistor programmable low pass filter
Shunt Calibration: Software controlled calibration relay utilizing gauge manufacturer's Cal resistors
Signal Output: Terminal and storage disk
Gain Control: Switch selectable (G=1, 128 V/V)
Channel Quantity: 4/card - 56/system
A/D Conversion Technique/Resolution: 12-bit
Activation Method: Software controlled
Programability: CP/M-86 from Digital Research
Storage Capacity: 10 MB fixed disc in Macsym 120
Data Reduction Capabilities: Macbasic - compiled real-time multitasking
External Interface: Serial Asynchronous RS 232C port output; solder connector or screw terminal input
System Stability: ± 25 PPM/ $^{\circ}$ C
System Linearity: $\pm .0025\%$ FSR max
Absolute Accuracy: .02%
Size: 11.7"H x 15.4"W x 15.6"D
Weight: 27 lbs
Maintenance/Attendance Requirements: Data retrieval
Set Up Requirements: Hard wire input amplifier to gauges and resistors
Cost Per Channel: N/A

Manufacturer: ACRO Systems, Inc.
Address: P.O. Box 487, Beverly, Mass 01915
Phone Number: 617-927-8885
Contact: Barry Pogagh @ PDC, (215) 887-9610
Device Name: Data Acquisition System
Model Number: ARCO 900
Device Function: PC based precision data acquisition and control
Frequency Range: 0 - 20 KHz
Bridge Excitation Voltage: 5Vdc @ 50 mA per channel (.03% accuracy) on board
Bridge Balance: 120 Ω or 350 Ω $\frac{1}{4}$, $\frac{1}{2}$ and full bridge internal under
software control
Signal Filtering: All channels isolated excitation and signal
Shunt Calibration: Individual auto cal of zero and span under software control
Signal Output: RS232 serial to 19200 baud rate and IEEE 488 with TI 9914
Gain Control: \pm 200 mV F.S. input
Channel Quantity: 4/card; 60/chassis
A/D Conversion Technique/Resolution: 12 bit successive approximation
Activation Method: Software Controllable
Programability: Via host computer using any language; Labtech Notebook
software
Storage Capacity: To 32K/board
Data Reduction Capabilities: Engineering units, statistical analysis
External Interface: RS 232, RS 422 or IEEE-488 output; screw terminal input
System Stability: \pm (30 PPM or input plus 30 PPM range) / $^{\circ}$ C
System Linearity: N/A
Absolute Accuracy: \pm .1% of input plus 1 count
Size: 19" rack mount, low profile 5.2"H x 1.7"W x 19"D (each module)
Weight: N/A
Maintenance/Attendance Requirements: Self diagnostics
Set Up Requirements: Modular assembly
Cost Per Channel: N/A

Manufacturer: Colorado Data Systems
Address: 3301 W. Hampden Avenue, Unit C, Englewood, Col 80110
Phone Number: 1-800-237-2831
Contact: Charles Snyder @ Creative Marketing, (703) 442-9100
Device Name: Smart Hardware System
Model Number: 53A-Hax with 53A-220 & 53A-518 cards
Device Function: Computer front end automatic test equipment (ATE)
Frequency Range: 500,000 measurements/sec (transient digitizer)
Bridge Excitation Voltage: Individual + & -, 0 to 18VDC with remote sensing capabilities
Bridge Balance: On card completion for $\frac{1}{4}$, $\frac{1}{2}$, or full bridges; solder terminals
Signal Filtering: 10 Hz low pass or user defined
Shunt Calibration: Via Program control for each channel
Signal Output: N/A
Gain Control: Nine levels, switch selectable from 100 to 2500 with <100 PPM/°C drift (3.7 μ V/°C worst)
Channel Quantity: 32/Card cage
A/D Conversion Technique/Resolution: 12 bit: .12% FS accuracy
Activation Method: External or internal trigger, post or pre, TTL or DC threshold
Programability: ASCII characters
Storage Capacity: 262K in transient digitizer
Data Reduction Capabilities: Within host computer
External Interface: HP-1000 Hi-speed interface (computer sees teletype); 10/chain possible
System Stability: Internal reference: 10 mV \pm .5%, 1 year
System Linearity: .05%
Absolute Accuracy: N/A
Size: 17"W x 10 $\frac{1}{2}$ "H x 22 $\frac{5}{8}$ "D
Weight: 60 lbs
Maintenance/Attendance Requirements: Yearly calibration
Set Up Requirements: Program host computer
Cost Per Channel: \$600 (\$19K/32 CH) w/o computer

Manufacturer: Pacific Instruments
Address: 2355 Whitman Road, Concord, CA 94518
Phone Number: (415) 827-9010
Contact: Ed Pugh, (703) 527-3262
Device Name: Transient Data Recorder
Model Number: 9821/9822
Device Function: Condition, Sample, Digitize & Store High Speed Analog Data
Frequency Range: 0-200 KHz
Bridge Excitation Voltage: Use with 8250/8255
Bridge Balance: N/A
Signal Filtering: N/A
Shunt Calibration: One segment of memory set aside for calibration data via
program commands
Signal Output: Data output in 12-bit words, (8) active TTL control interfaces
Gain Control: N/A
Channel Quantity: 1 (10 per rack)
A/D Conversion Technique/Resolution: 12-Bit A/D
Activation Method: Pre or post triggering
Programability: All TDR functions are programmable through the rack
controller via 16 bit port
Storage Capacity: 128 K words
Data Reduction Capabilities: Data scaled & plotted with 9820-100 controller
External Interface: 16 bit TTL parallel interface to CPU
System Stability: 0°C to 50°C operating range
System Linearity: 1 LSB over temperature range
Absolute Accuracy: $\pm .05\%$ full scale plus 50 PPM/°C
Size: 7"H
Weight: N/A
Maintenance/Attendance Requirements: N/A
Set Up Requirements: Program via controller, interface to signal conditioner
Cost Per Channel: 4K with controller @ 10 CH

Manufacturer: Compudas Corporation
Address: Box 4735, Ithaca, N.Y. 14852-4735
Phone Number:(607) 257-3003
Contact: Rob Levine
Device Name: Compudas
Model Number: 3
Device Function: Programmable Data Acquisition System
Frequency Range: Up to 3300 samples/sec conversion rate
Bridge Excitation Voltage: Internal hardware option
Bridge Balance: Internal hardware option
Signal Filtering: N/A
Shunt Calibration: N/A
Signal Output:Up to 720 channels of 4-20 mA/0-10V
Gain Control: Individual channel programmable gains of 1, 3, 10, 30, 100, 300
or 1000
Channel Quantity: 420 maximum, 30 per resistance bridge network
A/D Conversion Technique/Resolution: 12 bit successive approximation
Activation Method: EPROM based system permits automatic unattended start-up
Programability: Via DABIL/86 data acquisition basic interactive language
Storage Capacity: 128K bytes RAM and 64K EPROM expandable to 768K RAM and
256K EPROM
Data Reduction Capabilities: Software programmable
External Interface: (R) RS232 ports at 50 to 19.2K baud and GPIB 3000
interface
System Stability: Less than 1 $\mu\text{V}/^\circ\text{C}$ @ high gains from continuous auto-zero
function
System Linearity: Greater than 100 dB CMRR
Absolute Accuracy: Resolution to 1.2 μV
Size: 10.25" x 16.5" x 22.25"
Weight: 75 lbs
Maintenance/Attendance Requirements: Digital tape interface
Set Up Requirements: System programming
Cost Per Channel: \$300 @ 30 CH without recording

Manufacturer: Gen Rad, Inc.
Address: 300 Baker Avenue, Concord, MA 01742
Phone Number: (301) 964-1314
Contact: In Columbia, MD.
Device Name: Computer Aided Test System
Model Number: GR 2515
Device Function: Programmable, portable data acquisition
Frequency Range: DC to 25.6 KHz
Bridge Excitation Voltage: N/A
Bridge Balance: N/A
Signal Filtering: 15 selectable anti-aliasing filters
Shunt Calibration: N/A
Signal Output: Adjustable attenuation
Gain Control: 8 sensitivity ranges from 672.5 mV to 8V peak input
Channel Quantity: 4 (option to 16)
A/D Conversion Technique/Resolution: >70dB dynamic range with 12 bit A/D
conversion
Activation Method: Free Run, auto arm trigger and manual arm trigger modes
Programability: TSL II signal processing language
Storage Capacity: 10 M bytes on winchester & 500 K on mini-floppy;
processing, arithmetic, and averaging.
Data Reduction Capabilities: Time, frequency and amplitude domain
External Interface: Data link to mini's and VAX 11/700's
System Stability: N/A
System Linearity: Amplitude flatness $\pm .25$ dB over entire frequency range
Absolute Accuracy: 2 30 Alias-free lines for every 1024 input points
Size: 10.5" x 16.8" x 24"
Weight: 75 lbs
Maintenance/Attendance Requirements: N/A
Set Up Requirements: Select front panel configuration
Cost Per Channel: N/A

Manufacturer: Datamyte Corporation
Address: 14960 Industrial Road, Minnetonka, Minn 55345
Phone Number: (612) 935-7704
Contact: Brian Gallob
Device Name: Data Processor/Recorder
Model Number: Datamyte 400 with 411A signal conditioner and 451 rainflow program
Device Function: Long term, unattended field data processing/recording
Frequency Range: 0 to 200 Hz
Bridge Excitation Voltage: 10V for 350 Ω and 5V for 120 Ω
Bridge Balance: -100 mV to +100 mV RTI, 10 position switch with multiturn potentiometer.
Signal Filtering: 3 Pole butterworth; digital filtering via operator settable hysteresis level
Shunt Calibration: User selected CAL resistor
Signal Output: ASCII code to standard RS 232C port
Gain Control: 5 to 100 via 5 position switch
Channel Quantity: 1
A/D Conversion Technique/Resolution: 2400 Hz sampling rate
Activation Method: Continuous or via switch closure connector
Programability: Various plug-in program packs
Storage Capacity: 65,280 counts per band with 32 bands
Data Reduction Capabilities: Peak-valley, level crossing, time @ X-4 and rainflow programs
External Interface: 300 to 4800 Baud rate via RS232
System Stability: Operating range = -20°F to 140°F; 0-100% humidity and MIL STD 810C Shock
System Linearity: N/A
Absolute Accuracy: Output resolution 3%
Size: 7" x 7.5" x 3.3"
Weight: 5 lbs
Maintenance/Attendance Requirements: Download data
Set Up Requirements: Initialize via standard terminal
Cost Per Channel: N/A

Manufacturer: Hottinger Baldwin Measurements, Inc.
Address: P.O. Box 1500, Framingham, MA 01701
Phone Number: (617) 875-8282
Contact: Robert Haggerson
Device Name: Digital Measuring Unit
Model Number: DK-38-S6
Device Function: Transducer Indicator
Frequency Range: Utilizes 25 Hz measuring rate
Bridge Excitation Voltage: $5V \pm 2\%$
Bridge Balance: Accepts full bridge input via 6 wire connectors
Signal Filtering: .25 Hz, 1Hz, 4Hz, 40Hz and 50 Hz
Shunt Calibration: 2.498 mV/V internal calibration
Signal Output: 6 Digit display in engineering units; communication @ 300 to
19,200 baud rate
Gain Control: Zero & sensitivity balancing
Channel Quantity: 16
A/D Conversion Technique/Resolution: $\pm 2mV/V$ into 200,000 discrete steps
utilizing 225 Hz carrier frequency
Activation Method: N/A
Programability: 16 Measurement programs with 7 year storage
Storage Capacity: Range settings, alarm levels and additional functions
Data Reduction Capabilities: Engineering units
External Interface: IEEE 488 and V.24
System Stability: Temperature: $\leq .002\%$; 48 Hrs $\leq .001\%$
System Linearity: Deviation $\leq .002\%$ of full scale
Absolute Accuracy: .0025%
Size: 7"H x 13.7"W x 17"D
Weight: 23 lbs
Maintenance/Attendance Requirements: Change paper and interface to analog
recorder
Set Up Requirements: Measurement program selection
Cost Per Channel: \$355 (\$5680 for 16 CH)

Manufacturer: John Fluke Manufacturing Co., Inc.
Address: P.O. Box C9090, Everett, WA 98206
Phone Number: 1-800-426-0361
Contact: Harry Rundall, (301) 770-1570
Device Name: Data Acquisition System
Model Number: 1752A with A17-20 Signal Conditioning Subsystem
Device Function: Data acquisition
Frequency Range: A/D conversion rate = 1000/sec (optional 4000/sec)
Bridge Excitation Voltage: 10 Vdc or 3.3 Vdc \pm 2%
Bridge Balance: Accepts full bridge input
Signal Filtering: Selectable filter value
Shunt Calibration: Automatic self-calibration every 17 seconds
Signal Output: -10V to +10V, 3 mV/V sensitivity
Gain Control: N/A
Channel Quantity: 16
A/D Conversion Technique/Resolution: 14 bit A/D converter multiplexed to 16 channels
Activation Method: N/A
Programability: Via removable keyboard using Enhanced Basic or Fortran
Storage Capacity: 400K floppy; 136K read/write memory expandable to 10M byte
Data Reduction Capabilities: Three dimensional arrays, and subprograms with Compiled Basic
External Interface: RS232C and IEEE-488 ports
System Stability: \pm .0025%/°C
System Linearity: \pm .1% span
Absolute Accuracy: .02%; resolution to 124 μ V
Size: 5.25"H x 17"W x 21.5"L
Weight: 35 lbs
Maintenance/Attendance Requirements: Touch screen user interface
Set Up Requirements: Front panel arrangement
Cost Per Channel: N/A

Manufacturer: Neff Instrument Corporation
Address: 700 S. Myrtle Avenue, Monrovia, CA 91016
Phone Number: 1-800-423-7151
Contact: Barry Pogach @ PDC Corporation (215) 887-9610
Device Name: System 620
Model Number: Series 300 Signal Conditioner & Series 600 Amplifier/Multiplexer
Device Function: Computer Front End
Frequency Range: 100 KHz throughput rate
Bridge Excitation Voltage: Adjustable from 4V to 10V with 10 millivolts
resolution
Bridge Balance: 25,000 Ω 15 turn cermet potentiometer; terminals provided
for four completion resistors
Signal Filtering: Programmable per channel: 1Hz, 10Hz, 100Hz and 1KHz
fourth-order bessel filter
Shunt Calibration: Shunt resistive or voltage substitution selected by
DTL/TTL logic, Preamp, Auto-Cal
Signal Output: Unfiltered \pm 5mA available @ rear panel
Gain Control: Programmable for channel: \pm mV F/S to \pm 10.24V F/S or autoranging
Channel Quantity: 64
A/D Conversion Technique/Resolution: 16-bit output from three overlapping
conversions of six bits each
Activation Method: Self calibration and diagnostics; all other control
through host
Programability: Software drivers available
Storage Capacity: 56K data buffer in series 500 controller
Data Reduction Capabilities: N/A
External Interface: Standard DMA and IR BUS interfaces
System Stability: \pm 1 μ V/ $^{\circ}$ C Δ from Auto Cal Temp; \pm (.02% F/S + 2 μ V) for
30 days
System Linearity: CMRR 120dB max DC to 60 Hz with 350 Ω Source unbalance
Absolute Accuracy: $<$ \pm .1% error
Size: (2) 7"H x 19"W x 30"D Rack-mount units
Weight: N/A
Maintenance/Attendance Requirements: Host computer controlled
Set Up Requirements: Host computer and minimal front panel controls
Cost Per Channel: $>$ \$700 (40K with 64 ch) less host computer

Manufacturer: Neff Instrument Corporation
Address: 700 S Myrtle Avenue, Monrovia, CA 91016
Phone Number: 1-800-423-7151
Contact: Barry Pogach @ PDC Corporation, (215) 887-9610
Device Name: Data Acquisition System
Model Number: System 470 with 470054 cards
Device Function: PC based data acquisition system
Frequency Range: Throughput rates to 10 KHz
Bridge Excitation Voltage: $5V \pm 10 \text{ mV}$
Bridge Balance: Terminals provided for four completion resistors
Signal Filtering: 10 Hz filter
Shunt Calibration: Programmable one-step shunt resistor
Signal Output: Front mounted jacks for monitoring excitation and output voltages
Gain Control: Programmable from $\pm 5 \text{ mV}$ to 10.24V
Channel Quantity: 64
A/D Conversion Technique/Resolution: 16 Bit output from three overlapping conversions of six bits
Activation Method: Software controlled by host
Programmability: NDAS-PC software for IBM PC/XT
Storage Capacity: 2048 reading data buffer
Data Reduction Capabilities: Host computer
External Interface: IEEE-488 or RS232 output; 8 wire plus ground input
System Stability: .01% @ constant temp; $\pm .005\%/^{\circ}\text{C}$
System Linearity: $\pm 10 \mu\text{V}$ channel to channel zero offset
Absolute Accuracy: < .1% error
Size: 7"H x 19"W x 23.5"D
Weight: N/A
Maintenance/Attendance Requirements: N/A
Set Up Requirements: Optional control/display channel
Cost Per Channel: \$250 (\$15K for 64 CH) less host computer

Manufacturer: Gould Electronics
Address: 3631 Perkins Avenue, Cleveland, Ohio 44114
Phone Number: (216) 361-3315
Contact: N/A
Device Name: Data Acquisition System
Model Number: DASA 9000 with 4386 Waveform Recorder and 13-4615-30 signal conditioner
Device Function: Data acquisition/signal analysis system for transient and waveform studies
Frequency Range: DC to 50 KHz
Bridge Excitation Voltage: +5V or +10V @ 100 mA
Bridge Balance: N/A
Signal Filtering: Rolloff = 12dB/octave; internal selection low pass
Shunt Calibration: N/A
Signal Output: Stored digital data via IEEE-488 bus to signal analysis subsystem
Gain Control: N/A
Channel Quantity: 8
A/D Conversion Technique/Resolution: 8-bit successive approximation
Activation Method: Trigger from keyboard or on events
Programmability: Proprietary instrument operating system software for advanced waveform calculations
Storage Capacity: 1500 transients; 32K words/channel
Data Reduction Capabilities: N/A
External Interface: RS 232 serial port
System Stability: .08%/°C
System Linearity: $\pm .1\%$ F/S
Absolute Accuracy: N/A
Size: 7.3"H x 19.3"W x 15"D + computer
Weight: 41 lbs + computer
Maintenance/Attendance Requirements: N/A
Set Up Requirements: Front panel adjustments
Cost Per Channel: N/A

Manufacturer: Keithley Instruments, Inc.
Address: 28775 Aurora Road, Cleveland, Ohio 44139
Phone Number: (216) 248-0400
Contact: Rita Bryan
Device Name: Scientific Workstation
Model Number: Series 500 with AIM G input module
Device Function: PC Based Data Acquisition
Frequency Range: 10 channels @ 1KHz data acquisition speed
Bridge Excitation Voltage: +10V
Bridge Balance: External
Signal Filtering: 20 μ V p-p Noise
Shunt Calibration: External
Signal Output: \pm 30mV/t 100mV
Gain Control: Software Controlled x 50 or x 166.6
Channel Quantity: 36 Max
A/D Conversion Technique/Resolution: 12-bit successive approximation
Activation Method: Software controlled triggering
Programmability: Soft 500 basic language base on interrept-driven
foreground/background architecture
Storage Capacity: Utilizes host computer
Data Reduction Capabilities: DADISP software: Handles time data in
spreadsheet form and analysis such as FFT
External Interface: IBM or Apple PC's
System Stability: \pm .0025%/ $^{\circ}$ C
System Linearity: \pm .01% max
Absolute Accuracy: \pm .6%
Size: N/A
Weight: N/A
Maintenance/Attendance Requirements: N/A
Set Up Requirements: N/A
Cost Per Channel: N/A

Manufacturer: OPTIM Electronics
Address: 12401 Middlebrook Road, Germantown, MD 20874
Phone Number: (301) 428-7200
Contact: Robert Bower
Device Name: MEGADAC System 2000
Model Number: 2200C with AD 484-FD Cards
Device Function: High speed data acquisition and recording system
Frequency Range: 20,000 samples/sec maximum rate
Bridge Excitation Voltage: ± 5 V
Bridge Balance: $\frac{1}{4}$, $\frac{1}{2}$ or full bridge; internal 120, 250 or 600 ohm resistors
Signal Filtering: 160 Hz 3 pole filter
Shunt Calibration: N/A
Signal Output: RS252 link @ 300 to 19200 baud
Gain Control: 1:1 to 8000:1; selectable per channel
Channel Quantity: 64
A/D Conversion Technique/Resolution: 12, 14 or 16-bit
Activation Method: Pre trigger storage possible; limits; time of day, etc.
Programmability: Firmware operating system & IBM PC interface using OPUS 2000 software
Storage Capacity: 512K byte RAM & 60M byte cartridge tape (expandable to 240M bytes)
Data Reduction Capabilities: Via host computer
External Interface: IEEE 488 & 8 bit parallel (RS232) output; subminiature DA15P conn. input.
System Stability: .005%/°F
System Linearity: .03% F.S.
Absolute Accuracy: 13 nano volts/ $\sqrt{\text{Hz}}$ noise
Size: 21" x 19" x 12.25"
Weight: 70 obs with modules and tape drive
Maintenance/Attendance Requirements: Change tape
Set Up Requirements: Select record mode, alarm unit, scan sequence, burst or step scan
Cost Per Channel: N/A

D.4 DATA RECORDERS

Manufacturer: Measurement Technology

Address: P.O. Box 36223, Denver, Colorado 80236

Phone Number: 1-800-523-2356

Contact: N/A

Device Name: Recording Oscillograph

Model Number: 2008 with M1055 signal conditioner

Device Function: N/A

Frequency Range: 37 chart speeds

Bridge Excitation Voltage: Adjustable one volt step, 3V to 12V DC for (20)
350 Ω bridges

Bridge Balance: Yes

Signal Filtering: Post conditioning active filters

Shunt Calibration: Yes; cal signal in 30 discrete steps - 3mV to 1.2V

Signal Output: Buffered voltage output for tape recorders

Gain Control: Span adjust

Channel Quantity: 20

A/D Conversion Technique/Resolution: N/A

Activation Method: N/A

Programmability: Identifier imprint, remote programmer optional

Storage Capacity: N/A

Data Reduction Capabilities: N/A

External Interface: 7-pin locking DIN type input connector

System Stability: N/A

System Linearity: N/A

Absolute Accuracy: N/A

Size: 8.75"H x 17"W x 16.25"D

Weight: 57 lbs

Maintenance/Attendance Requirements: Change 300' paper: warning light @ 10%

Set Up Requirements: N/A

Cost Per Channel: \$500 (\$10K/20 CH)

Manufacturer: Racal Recorders, Inc.
Address: 2102-C Gallons Road, Virginia, VA 22180
Phone Number: (703) 893-4084
Contact: Leo Tenney
Device Name: Data Recorder
Model Number: 14DS
Device Function: 1/2" 14 channel analog tape recorder - reel to reel
Frequency Range: FM: DC-625Hz, DR: 100Hz to 4.75 kHz @ 15/16 in/sec
Bridge Excitation Voltage: N/A
Bridge Balance: N/A
Signal Filtering: Automatic filter selection on relay
Shunt Calibration: N/A
Signal Output: Continuously variable from 0 to $\pm 3V$
Gain Control: 12 position input sensitivity switch from .1V to 20 Volt scale
Channel Quantity: 14
A/D Conversion Technique/Resolution: N/A
Activation Method: N/A
Programmability: N/A
Storage Capacity: 3600 ft. triple play tape (12.8 Hz continuous)
Data Reduction Capabilities: N/A
External Interface: N/A
System Stability: N/A
System Linearity: $\pm .3\%$
Absolute Accuracy: N/A
Size: 6.1"H x 19"W x 24.4"D
Weight: 62 lbs
Maintenance/Attendance Requirements: N/A
Set Up Requirements: Tape speed and attenuation selection
Cost Per Channel: \$1,700 (\$24K/14 CH)

Manufacturer: TEAC Corporation
Address: c/o B.J. Wolfe Enterprises, 10760 Burbank Blvd. N. Hollywood, CA 91601
Phone Number: (213) 877-5518
Contact: Tom McDunna @ Sarrell, 1-424-9460
Device Name: N/A
Model Number: XR-510
Device Function: FM DR option video cassette data recorder
Frequency Range: DC-313Hz @ 15/32 in/sec
Bridge Excitation Voltage: N/A
Bridge Balance: N/A
Signal Filtering: N/A
Shunt Calibration: Choice of (4) autocalibration voltages
Signal Output: $\pm 1-5VP$; $\pm 10 \text{ mA}$ (20Ω)
Gain Control: Auto range capability
Channel Quantity: 14
A/D Conversion Technique/Resolution: N/A
Activation Method: Optional Controller
Programmability: Microprocessor controlled including self diagnosis
Storage Capacity: T-120 Tape = 5.8 hrs
Data Reduction Capabilities: N/A
External Interface: Optional GP-IB interface
System Stability: $\pm .5\%$ after 20 mins warm-up in $0^{\circ}-40^{\circ}\text{C}$
System Linearity: $\pm .5\%$
Absolute Accuracy: 42 dB SNR (RMS)
Size: 14.5"H x 16.5"W x 10.25"D
Weight: 48 lbs
Maintenance/Attendance Requirements: N/A
Set Up Requirements: N/A
Cost Per Channel: \$1500 (\$20,600/14 CH)

Manufacturer: 3M Data Recording Products Division
Address: 3M Center, St Paul, Minnesota 55144-1000
Phone Number: (612) 735-1110
Contact: Chris Binner, also, K.D. Associates @ 261-1311 (D.C). John Carlson
Device Name: Data Cartridge Drive System
Model Number: HCD-134
Device Function: Data acquisition storage media
Frequency Range: N/A
Bridge Excitation Voltage: N/A
Bridge Balance: N/A
Signal Filtering: N/A
Shunt Calibration: N/A
Signal Output: Optional RS 232 interface or unique parallel I/F
Gain Control: Microprocessor controlled
Channel Quantity: 32 Tracks, serpentine
A/D Conversion Technique/Resolution: N/A
Activation Method: Automatic initialization upon cartridge insertion
Programmability: N/A
Storage Capacity: 134M bytes fully corrected user data
Data Reduction Capabilities: N/A
External Interface: SCSI @ 2.4M bytes/sec burst; 70K bytes/sec data transfer
rate
System Stability: 5° to 45°C operating temperature; 20% to 80% relative
humidity
System Linearity: N/A
Absolute Accuracy: <1 hard error in 10¹² bits
Size: 5.75"W x 3.24"H x 8"D
Weight: 3 lbs
Maintenance/Attendance Requirements: Change tape cartridge
Set Up Requirements: Interface as disk system
Cost Per Channel: \$1820 for drive and controller

Manufacturer: Bascom-Turner Instruments
Address: 111 Downey Street, Norwood, MA 02062
Phone Number: 1-800-225-3298
Contact: N/A
Device Name: Electronic Recorder & Data Acquisition System
Model Number: 8120T with 104 differential amplifier
Device Function: Y-T recording of signals
Frequency Range: 40 points/sec to disk transfer
Bridge Excitation Voltage: N/A
Bridge Balance: N/A
Signal Filtering: Switch selectable filter on amp
Shunt Calibration: N/A
Signal Output: N/A
Gain Control: (10) ranges for each channel, 10mV to 10V input
Channel Quantity: 8 multiplexed
A/D Conversion Technique/Resolution: 12 bit, $\pm 1/2$ LSB with 25 μ sec
conversion time
Activation Method: Analog trigger
Programmability: Key in command sequence
Storage Capacity: 140,000 points on 8" floppy disk
Data Reduction Capabilities: Math functions and statistical analysis
External Interface: RS 232C port
System Stability: 2 μ V/ $^{\circ}$ C
System Linearity: $\pm .05\%$ F/S
Absolute Accuracy: $.2\%$ F/S
Size: 10.3"H x 15.7"W x 21.8"L
Weight: 57 lbs
Maintenance/Attendance Requirements: Change fan fold paper (100 sheets)
Set Up Requirements: Select range and zero settings
Cost Per Channel: \$700 (\$5K/8 CH)

Manufacturer: Kyowa Dengyo Corporation
Address: 10 Reuten Drive Closter, N.J. 07624
Phone Number: (201) 784-0500
Contact: Yoichi Ushio
Device Name: Histogram Recorder
Model Number: RHS-300A
Device Function: Long term, unattended data acquisition
Frequency Range: 500, 1000, 2000, 5000 & 10,000 strain/FS; 10 Hz frequency response
Bridge Excitation Voltage: Independent power supply for each channel = 2Vdc
Bridge Balance: 120 Ω or 350 Ω ; 2.00 G.F; $\pm 5000 \times 10^{-6}$ strain auto balancing
Signal Filtering: 50 Hz, 100 Hz & 500 Hz low pass filters
Shunt Calibration: N/A
Signal Output: 150-9600 baud, 7-bit ASCII code
Gain Control: N/A
Channel Quantity: 4
A/D Conversion Technique/Resolution: N/A
Activation Method: N/A
Programmability: Analysis program loaded from program pack i.e., Rainflow, Peak Valley
Storage Capacity: 8K-bytes CMOS RAM/channel; also set-up with 3 month back-up
Data Reduction Capabilities: Fatigue analysis: PK-Valley, Markovian, Range Pair & Rainflow
External Interface: GP-IB data transfer; recorder & terminal RS 232 ports
System Stability: -10° to 50°C to 95% RH operating range
System Linearity: N/A
Absolute Accuracy: N/A
Size: 15.8"W x 10.4"W x 4.6"H
Weight: 13.2 lbs
Maintenance/Attendance Requirements: LCD dot matrix display of LVL, memory and Bat Cond.
Set Up Requirements: 20 entry keys with terminal controller
Cost Per Channel: \$5,017 (\$20K/4 CH)

Manufacturer: Acurex Corporation Auto Data Division
Address: P.O. Box 7555, Mountain View, CA 94039
Phone Number: (415) 964-2300
Contact: Barry Pogach @ PDC Corporation, (215) 887-9610
Device Name: Autograph
Model Number: 800
Device Function: Data Recording System
Frequency Range: N/A
Bridge Excitation Voltage: N/A
Bridge Balance: N/A
Signal Filtering: N/A
Shunt Calibration: N/A
Signal Output: 0-10V, 0-20mA
Gain Control: N/A
Channel Quantity: 40
A/D Conversion Technique/Resolution: 14 bit + sign; 33 m sec integration
period @ 60Hz
Activation Method: Scans triggered by time or event
Programmability: Save & Load program on tape; RAM with battery back-up
Storage Capacity: 400K bytes
Data Reduction Capabilities: Math functions, statistical analysis, histogram
reports
External Interface: RS 232 output, input utilizing NETPAC distributed I/O
System Stability: N/A
System Linearity: N/A
Absolute Accuracy: N/A
Size: 12.25"H x 19"W x 19.5"D
Weight: 32 lbs
Maintenance/Attendance Requirements: Change 3M metallic salt paper
Set Up Requirements: N/A
Cost Per Channel: N/A

Manufacturer: Honeywell Test Instruments Division
Address: P.O. Box 5227, Denver, Colorado, 80217
Phone Number: (301) 667-4020/(703) 827-0625
Contact: N/A
Device Name: Portable Record/Reproduce Data Tape Recorders - 1/4" to 1"
Model Number: 5600 Series
Device Function: Intermediate Band or Wideband Data Recording
Frequency Range: FM to 250 KHz
Bridge Excitation Voltage: N/A
Bridge Balance: N/A
Signal Filtering: N/A
Shunt Calibration: N/A
Signal Output: N/A
Gain Control: N/A
Channel Quantity: N/A
A/D Conversion Technique/Resolution: N/A
Activation Method: N/A
Programmability: N/A
Storage Capacity: N/A
Data Reduction Capabilities: N/A
External Interface: N/A
System Stability: N/A
System Linearity: N/A
Absolute Accuracy: N/A
Size: N/A
Weight: N/A
Maintenance/Attendance Requirements: N/A
Set Up Requirements: N/A
Cost Per Channel: N/A

Manufacturer: Terrascience Systems LTD
Address: 1574 W. Second Avenue, Vancouver, D.C. Canada V6JIN2
Phone Number: (604) 734-3443
Contact: James S. Reith/Keith Witney
Device Name: System 40
Model Number: N/A
Device Function: Data acquisition
Frequency Range: N/A
Bridge Excitation Voltage: Adjustable/self contained
Bridge Balance: ± 5000 microstrain
Signal Filtering: Low pass with selectable bandwidth
Shunt Calibration: + and - 1000 microstrain (350 Ω)
Signal Output: Via multiplexer
Gain Control: 1 to 10
Channel Quantity: 1024
A/D Conversion Technique/Resolution: 12 bit/5mV over range $\pm 10.24V$
Activation Method: N/A
Programmability: N/A
Storage Capacity: 9M BYTES
Data Reduction Capabilities: N/A
External Interface: None required/PC can be added
System Stability: N/A
System Linearity: N/A
Absolute Accuracy: N/A
Size: Modular, rack mounted (19"W x 12"H x 12"D units)
Weight: N/A
Maintenance/Attendance Requirements: Minimal
Set Up Requirements: Plug in
Cost Per Channel: N/A

APPENDIX E

E.1 OPTIM ELECTRONICS MEGADAC 2000 FEATURES

E.1.1 MEGADAC SYSTEM 2000

E.1.1.1 Control Keypad

The 16-key keypad is used to establish functional conditions and operations, set and determine status, step through menus, select operating modes and parameters, select and enter Scan Tables and other program functions.

E.1.1.2 Numeric Keypad

The 12-key keypad is used to enter numeric data and select non-numeric parameters from the menus.

E.1.1.3 Display

The display is liquid crystal dot matrix. Two lines of forty characters each are used to show MEGADAC status, display operating and measuring parameters and perform on-line monitoring.

E.1.1.4 Plug-In Modules

There are 17 module positions accessed through the rear panel. One is reserved for the Analog-to-Digital converter. The other slots can be configured with differential input amplifiers (up to 128 channels), digital input/output, analog output modules (up to 32 channels), and signal conditioning modules or any module mix to satisfy the requirements of the measurements.

E.1.1.5 Rear Panel Connectors

The RS-232 and IEEE-488 rear panel connectors provide communications between MEGADAC and a host computer or data network. Only one of these connectors can be used at one time. The EXTERNAL BNC connector is used to provide external synchronization signals to MEGADAC when two or more MEGADAC units are operating together in a subsystem environment.

E.1.1.6 Mass Storage

- The Cartridge Tape provides 60 M bytes of on-line storage, recording at data rates up to 20 kHz in real-time. This can be expanded by adding three additional drives through rear panel connectors.
- The Winchester Disc option provides a 10 M byte hard disc for applications where relatively small quantities of data are recorded and high speed access is desirable. Only one Winchester can be connected to MEGADAC.
- In applications requiring IBM compatible tapes, an externally located 30 M byte 9-Track Tape Drive can be substituted for the cartridge tape. Only one drive can be connected to MEGADAC.

E.1.1.7 MEGADAC Options

- IEEE 488 Interface. The IEEE 488 interface functions with the standard GPIB in a talker or listener mode using IEEE 488 protocol with DMA transfers up to 500 k bytes per second.
- Parallel Interface. The parallel interface provides an 8-bit byte parallel port for both control and data signals using full handshake protocol.
- Cartridge Tape Drive. MEGADAC can support up to four cartridge tape drive units. Up to three tape drives are mounted in the MEGADAC 2000CM Cartridge Tape Expansion Chassis. The chassis can be rack-mounted or operated as a desk-top unit.

In addition, the MEGADAC 2000CR is an independent Cartridge Tape Reader for playback of data without needing a MEGADAC System unit. It has a 300 to 19.2 k Baud RS-232-C interface and can be equipped with an IEEE 488 interface

- Memory Extension. Extends MEGADAC buffer memory to 512 k bytes.
- Uninterruptable Power Supply. Provide continuous 110V ac, 60 Hz power to MEGADAC without loss of data of power during switchover.

E.1.2 APPLICATION SOFTWARE

An important aspect of any data acquisition system is how quickly it can be put into service and take meaningful data. MEGADAC can be used within minutes of unpacking because it needs no dedicated Direct Memory Access (DMA) or specialized high-speed interface; it is ready for operation either as a stand-alone device or when networked to an in-house computer.

The majority of the application software is incorporated in the MEGADAC mainframe as firmware. The user can, through a question and answer dialog, set channel and measurement parameters directly from the MEGADAC front panel. This method needs no computer knowledge and for field measurements, parameters can be established in the laboratory prior to sending the equipment on-site.

Many users already have the data reduction software necessary for result evaluation running on an in-house computer. The MEGADAC may be linked directly to a host computer by means of the RS-232 or IEEE-488 interfaces. For the RS-232, a Mode Table is stored in the MEGADAC.

The Mode Table stipulates the personality of the MEGADAC for the purposes of communicating with any host computer. It can be easily configured or changed at the touch of a button and is stored in battery-backed RAM memory in MEGADAC. For RS-232 links operating between 300 and 19200 Baud, Optim guarantees communication between the MEGADAC and the host computer regardless of the protocol involved.

E.1.3 SOME OPTIM USERS

E.I. DuPont	Carnegie-Mellon University
Harvard Medical School	American Motors
Babcock and Wilcox	Brown, Boveri, and Cie
Gulfstream Aerospace	U.S. Department of Agriculture
Boeing Co.	Champion
Federal Highways Administration	University of Delaware
DeHavilland Aircraft	University of Toronto
U.S. Army	General Motors Corporation
U.S. Navy	Goodyear Tire & Rubber
Rockwell International	University of Waterloo
Union Pacific	Pratt & Whitney
Ford Motor Company	Garrett Turbine Engine Company
U.S. Steel	Commonwealth Edison

E.2 TERRASCIENCE SYSTEMS LTD. SYSTEM 40 FEATURES

Terrasience's System 40 Data Acquisition System is a complete family of data measurement modules which are designed to condition and amplify signals from a wide range of sensor types.

- Strain gauges (in full, or 1/2, or 1/4 bridge configuration)
- Pressure Transducers
- Load Cells
- Displacement transducers
- Position transducer
- Thermocouples
- Thermistors & RTD's
- Inclinometers & Tiltmeters
- Torque transducers

Inputs are conditioned and/or amplified as required and are available for output in analog form at each I/O module.

The system is also compatible with computer control and may be built into larger scale systems in 32 channel segments sharing a common 16 bit data and control bus. The system uses a time division multiplexed analog signal controlled through unique addressing in each card cage. The multiplexed signal is then available for analog to digital conversion and storage on tape or disc medium. In system format, scan rates and sequences are variable and real time clock information may be added to the data stream for recording. With this capability, the system can be used as a stand-alone data acquisition system without the requirement for a controlling computer.

Performance features of this system include:

- Modular flexibility of design allows the user to "custom tailor" a system to his specific needs using different I/O modules.
- High speed - data throughput rate up to 12 kilobytes/sec.
- Expandability - system is expandable in 16 or 32 channel segments up to 1024 channels

- Accuracy of conditioning of 0.1% FS
- Exceptionally low drift/high stability (1.5 microvolts/C.)
- Common mode rejection 10dB minimum
- Selectable plug-in filters of 10Hz, 100Hz, 1KHz, 10KHz.
- Multiplexed format is compatible with either microprocessor control or system control by an SSC-40 System Controller unit, with a computer available for monitoring purposes.

Uses for such data acquisition equipment are many and varied and generally cover the broad spectrum of engineering, research and design and industrial users.

Specific examples:

- Aerospace design research
- Civil engineering stress measurement
- Structural research and monitoring
- Marine design and testing (hull design research and engine testing)
- Stress/strain analysis
- Temperature measurements
- Resource-base sample testing and analysis
- Scientific research projects.

E.2.2 GRAPHICAL DATA MONITORING AND PLAYBACK

The use of computers to generate graphical output provides a quick and easily interpretable method for the presentation and analysis of data. The capacity to present and analyze data in real time allows instantaneous recognition of any problems or conditions that require immediate decisions to be made. This overcomes the problems of conventional data loggers whose numerical output requires a high user awareness of normal conditions to determine the current status of the monitored system.

Terrascience Systems Ltd has developed a program to provide a real time display of data converted to engineering units on the screen in a convenient graphical form (scrolling strip charts). The user can call up numerical and graphical presentations on demand, and compare selected parameters with one another. Using the strip chart format, 5 channels on each of 5 strips (24 inputs) can be simultaneously plotted on charts in either monochrome or color and alarmed channels can be identified. These charts are automatically dumped to the built-in printer, or can be dumped on demand if interesting conditions should arise.

As well as the graphical output, the monitoring system can provide output similar to conventional data loggers, in printing out selected data at predetermined intervals or upon demand or alarm conditions. The system is capable of scanning up to 1024 channels of data, each with a sensor description, 4 alarm points, engineering units conversion, $y=mx+b$, and alarm

hysteresis. The Weir-Jones Program further offers the more useful option of logging sensors by their type, allowing each sensor group to be logged at separate intervals.

The features described above are all available for use in the playback analysis of previously acquired data.

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- SSC-340 Ice Forces and Ship Response to Ice - Consolidation Report by C. Daley, J. W. St. John, R. Brown, and I. Glen 1990
- SSC-341 Global Ice Forces and Ship Response to Ice by P. Minnick, J. W. St. John, B. Cowper, and M. Edgecomb 1990
- SSC-342 Global Ice Forces and Ship Response to Ice - Analysis of Ice Ramming Forces by Yung-Kuang Chen, Alfred L. Tunik, and Albert P-Y Chen 1990
- SSC-343 Global Ice Forces and Ship Response to Ice - A Second Season by p. Minnick and J. W. St. John 1990
- None Ship Structure Committee Publications - A Special Bibliography 1983