LOCKHEED AIRCRAFT CORPORATION

BURBANK, CALIFORNIA 91503

ASCA

October 21, 1966

Dr. Forelich Rainey
University of Pennsylvania
Philadelphia, Pennsylvania

Dear Dr. Rainey:

Thank you for the marked item which appears in the attached radio script.

The "Lockheed Digest" currently is heard each weekday in Los Angeles, Washington, Houston, Dayton, Huntsville, Boston, Norfolk, Cape Kennedy and Cleveland. It is also broadcast by several university radio stations and by the Voice of America.

Scientific and engineering people have too little time to read the many articles and reports published on technological advances, particularly those outside their primary fields. We broadcast the "Lockheed Digest" to touch upon a variety of the disciplines, hoping the broadcasts will be helpful to some of these men, and interesting to all of them.

Hence this note of "thanks" for your contribution.

Sincerely,

Bert W. Holloway

Bert W. Holloway
Director of Information

BWH/ls

THE LOCKHEED DIGEST
PRODUCED BY ENGINEERING PRODUCTIONS, INC., BOX 1, AMBASSADOR STATION, LOS ANGELES 5, CALIFORNIA

PROGRAM: # 952
DATE: Tuesday, October 25, 1966
STATION: Los Angeles, KFI, 6.55 a.m.
Washington, WGMS, 7.15 a.m.
Huntsville, WFIX, 7.15 a.m.
Houston, KTRH, 7.45 a.m.
Cleveland, WERE, 6.55 a.m.
Dayton, WAVI, 7.25 a.m.
Boston, WCRB, 7.25 a.m.
Norfolk, WVBC, 7.30 a.m.
Cape Kennedy, WMEG, 6.50 a.m.

Good morning. This is Orval Anderson with the Lockheed Digest, covering today's happenings in the world of science and engineering.

* * * * *

It has been a year now since the American Society for Engineering Education published its preliminary report, "Goals of Engineering Education". And the time has come, says Alberto Socolovsky, editor of the Electronic Engineer, for engineers and engineering societies to send in their comments and recommendations. One of the recommendations in the report, as you know, was that the first professional degree should be a five year master's degree. (Sept., p. 35)

* * * * *

X

According to SCIENCE Magazine, new technology and the inter-disciplinary approach will greatly expand the horizons of archeologists. One of the new tools, for example, is neutron-activation analysis, which can be used for nondestructive analysis of ancient pottery and metals.

Brookhaven National Laboratory showed that the fine orangeware found in the lowlands of Guatemala was made from clay deposits located in the highlands.

Oxford University reports the use of a number of techniques, including X-ray fluorescence, electric-beam X-ray scanning micro-analysis, beta-ray back-scatter meters, and optical-emission spectrometry. All these techniques help the Research Laboratory for Archeology trace the origin of manufacture, trade routes, the understanding of ancient technology, and they also help detect fakes.

/////Authors of the article are Dr. Forelich Rainey and Miss Elizabeth K. Ralph of the University of Pennsylvania.///// (Vol. 153 Nr. 3743 P. 1481)

* * * * *

Unidentified Flying Objects are with us again. The University of Colorado has been given a contract by the Air Force for more study. Meanwhile, NEW SCIENTIST Magazine makes an observation that sightings of the UFOs often coincide with the presence of very high voltage transmission lines.

And, it says, the believers in UFOs explain this by saying the UFOs hover over the very high voltage transmission lines to pick up power. However, a more convincing explanation, it says, is offered by Philip J. Klass, writing in AVIATION WEEK. Klass says the corona discharges, in the shapes of balls of luminous gas, form the optical illusion that is called an unidentified flying object.

(LOS ANGELES TIMES Oct. 8, p. 1

NEW SCIENTIST Vol. 31 Nr. 512 p. 463
AVIATION WEEK Vol. 85 No. 8)

* * * * *

A combined effort by Lockheed Propulsion Company and Kirkhill Rubber Company has produced a new low-temperature insulation material for rocket motors. The new material is capable of handling temperatures as low as minus one hundred twenty degrees Fahrenheit for extended periods. At the same time, the material shows good high-temperature qualities. According to TECHNOLOGY WEEK, the base of the development is an improved low-temperature polymer which has an extremely low-temperature brittle point. This polymer is substituted for plasticizers in the formulation of the insulation material. (Sept. 19, p. 4)

* * * * *

Dr. R. J. Van de Graff, chief scientist for High Voltage Engineering Corporation of Burlington, Massachusetts, has revealed some interesting progress toward uranium fusion. Two Van de Graff accelerators, working in tandem, have been able to speed uranium atoms to energies in excess of two hundred million electron volts. And he says a new design for tandem accelerators will produce even higher energies. (SCIENCE NEWS Vol. 90/10 p. 176)

* * * * *

Atomics International Division of North American will make a superconducting magnet for NASA, and the space agency will use it for experiments in plasma physics. The magnet will be wound with wire that is an alloy of titanium and niobium, and which has no resistance to electrical current at low temperatures. Twin superconducting coils will produce magnetic fields of twenty-five kilogauss each. They will be contained in vessels of liquid helium. (MISSILE/SPACE DAILY Sept. 8, p. 33)

* * * * *

Low-cost integrated circuits are now making it attractive to convert existing telephone networks to pulse-code modulation systems. And pulse-code modulation is an attractive idea, says ELECTRONICS, because there will be a rising demand for digital data transmission from every part of the world. Also, pulse code modulation means more channels on a line, and it can also lead to improved voice quality.

Author of the paper is Andre Chatelon, head of the transmission department of the Central Laboratory for Telecommunications in Paris. (Sept. 19, p. 139)

* * * * *

And that's it for today's Lockheed Digest, a program presented as a service to the scientific community by Lockheed Aircraft Corporation. This is Orval Anderson inviting you to listen again tomorrow.

###

March 8, 1968

Dr. Frank Stucki
Department 5110
Advanced Concepts
Lockheed Missiles and Space Co.
Research and Development Laboratories
Building 204
Palo Alto, California

Dear Dr. Stucki:

Thank you for your telephone call today in regard to portable magnetometers. I have enclosed a copy of our Monograph entitled "The Search for Sybaris" in which the problem of looking for ancient Sybaris is described. Unfortunately, it took 2-1/2 years for this manuscript to be published so it is already obsolete.

Ancient Sybaris is the most difficult challenge that we have encountered in the course of our experiments with geophysical prospecting instruments. In May, I plan to be working at a more suitable site -- namely, ancient Elis in Greece. A preliminary survey there last September, indicated that it may be possible to map out the city plan in the form of magnetic contours. The walls of the ancient city are massive, are buried only about one meter below the surface, but extend down to five meters. Also, many of them were filled with broken roof tiles and other fired ceramics which makes them quite magnetic.

Specifications for an "ideal" magnetometer for archaeological prospecting are as follows:

Sensitivity: 0.5 gamma (or 0.8 gamma), but also with less sensitive ranges so that anomalies up to 1000 gammas can be measured.

Operation Range: in terrestrial fields of 20,000 to 80,000 gammas.

Information Rate: continuous or with repetition rate of 1 second or less.

Mode of operation: with built-in difference circuit for gradiometer operation, (preferably with this capable of being switched off for taking readings with single heads when needed).
Freedom from sensitivity to orientation of heads required in gradiometer arrangement. Heads to be capable of being mounted vertically 5 meters apart.

Weights:
Head: less than 1 lb. (1 oz. or less would be better for the uppermost head in gradiometer arrangement).
Electronics, meter, and batteries: 5 lbs. or less.

Cost: under $500.00

If I have forgotten to mention some things, please don't hesitate to let me know.

Sincerely yours,

Elizabeth K. Ralph
Associate Director

EKR/ek

February 15, 1968

Mr. Starr Colby, Director of Advanced Programs
Missiles and Space Division
Lockheed Aircraft Corporation
P.O. Box 504
Sunnyvale, California 94088

Dear Mr. Colby:

On the Allen Scott television program entitled "Market," it was announced on Tuesday that Lockheed is planning to manufacture a portable magnetometer. Mrs. McCreedy in your Philadelphia office suggested that I write to you.

We are interested in portable magnetometers for archaeological prospecting. I have enclosed a reprint from Science in which some of our activities in the field are described (starting on page 6).

We now have a suitable cesium magnetometer made by Varian Associates, but there continues to be a dearth of less expensive magnetometers which could be available to all archaeologists in need of them. Also, for publication in our MASCA Newsletter (latest copy enclosed), we like to keep abreast of new developments in instrumentation.

If the magnetometers which you are planning to manufacture will be suitable for this small-scale land-based type of prospecting, we shall appreciate any information that you can send us about them.

Sincerely yours,

Elizabeth K. Ralph

EKR/abn

Lockheed
MISSILES
& SPACE
COMPANY

Thanks 1-1

In reply, refer to:
LMSC/A901377

27 June 1968

Dr. Froelich G. Rainey
Director, University Museum, MASCA
University Museum
University of Pennsylvania
33rd and Spruce Streets
Philadelphia, Pennsylvania 19104

Subject: PROPOSAL FOR A MAGNETIC GRADIOMETER FOR ARCHAEOLOGICAL PROSPECTING

Dear Dr. Rainey:

The Lockheed Missiles & Space Company is pleased to submit for your consideration the enclosed proposal. This is an offer to negotiate a firm fixed price contract in accordance with the provisions of the technical and cost proposals.

Messrs. Frank Stucki and J. A. Holly prepared the technical sections and may be reached at (415) 324-3311, Extension 45680, for further technical discussions. Mr. R. A. Hunziker is responsible for contract negotiations and may be reached at (408) 742-4640.

We are most pleased that you have considered Lockheed to assist you in your scientific pursuits.

Sincerely,

LOCKHEED MISSILES & SPACE COMPANY

J Patterson for
J. T. Grover, Manager
Research & Technology Marketing

Encl: a) Two(2) copies Technical Proposal, LMSC/D080253
b) Two(2) copies Contract Cost Proposal

Beth
Ralph

July 9, 1968

Re: LMCS/A901377

Dear Mr. Grover:

Thank you for your letter of June 27, 1968 and the enclosures, concerning your 'Proposal for a Magnetic Gradiometer for Archaeological Prospecting." As I mentioned to you when you telephoned, Dr. Rainey is out of the country at the present time, but is expected back in mid-July. I will bring your letter to his attention on his return, and you should be hearing from him shortly thereafter.

Sincerely,

(Mrs.) Julie Tonkin
Secretary to Dr. Rainey

Mr. J. T. Grover, Manager
Research & Technology Marketing
Lockheed Missiles & Space Co.
Sunnyvale, California

In reply refer to
LMSC 681359

Lockheed
MISSILES
& SPACE
COMPANY

RESEARCH LABORATORIES · 3251 HANOVER STREET · PALO ALTO, CALIFORNIA

18 July 1968

Dr. Froelick Rainey
Director
The University Museum
University of Pennsylvania
33rd and Spruce Streets
Philadelphia, Pennsylvania 19104

Subject: Proposal for a Magnetic Gradiometer for Archaeological Prospecting

Dear Dr. Rainey:

The Lockheed Missiles & Space Company is pleased to submit for your consideration the final copy of the subject proposal. This is an offer to negotiate a firm fixed price contract in accordance with the provisions contained in the technical and cost proposals.

Though our contacts with you have been few, we are hopeful that the proposal offers a solution to the detection of remanent magnatism of archaeological sites.

Mr. Frank Stucki or Mr. Joseph Holly, (415) 324-3311, Ext. 45680, may be contacted for further technical discussions. Mr. R. A. Hunziker, (408) 742-4640, is responsible for contract negotiations.

We are pleased that Lockheed was considered for assistance in your scientific endeavor.

Sincerely,

LOCKHEED MISSILES & SPACE COMPANY

J L Bennett

for J. T. Grover
Technology Marketing

JTG:mg

Enclosures: a. Two (2) copies Technical Proposal, LMSC-D080253
b. Two (2) copies Contract Cost Proposal

July 30, 1968

Mr. J. T. Grover, Manager
Research & Technology Marketing
Lockheed Missiles & Space Co.
Sunnyvale, California

Ref: LMSC/A901377

Dear Mr. Grover:

Dr. Rainey has left again, this time for vacation, and has asked me to reply to your letter of June 27. I have just returned and haven't studied your proposal with great care, but here are our initial comments:

Batteries:	are much too heavy for portable use. Need capacity only for 10 hours use per day. What voltage is required?
Sensors:	vertical boom with unit - 20 lbs. - is much too heavy. We prefer to measure total magnetic intensity rather than just the vertical component. Could it be operated with the upper sensor connected with a 100 meter cable and placed in the center of a grid?
Readout:	Through what temperature range would the crystal be stable? Lid of the case should be removable.
Cost:	Is there any chance of Lockheed's contributing to the cost of development?

I hope that these comments are not too discouraging.

Sincerely yours,

cc. Mr. Frank Stuck;

Elizabeth K. Ralph

EKR:kw

Lockheed
MISSILES
& SPACE
COMPANY

13 September 1968

Dr. Elizabeth K. Ralph
Associate Director,
Museum Applied Science Center for Archaeology
Philadelphia, Pennsylvania 19104

Dear Dr. Ralph:

This is to confirm the telephone conversation of August the 27th between you and Mr. Frank Stucki of our Advanced Concepts staff.

The batteries associated with the thin film magnetometer can be reduced from 28V to 12V and therefore would be considerably five pounds or less. Unfortunately the magnetometer cannot be used in the center of the grid as it senses in one axis only. The temperature range of the device is from -10°C to +100°. With regard to costs, our proposal to the museum was for the application of the magnetometer to your use. Having borne the costs of development to date, we are not in a position to continue further the refinement of the magnetometer for your application. However, additional activity related to other applications may allow a reduction in the funds required.

We would like to discuss the magnetometer in more detail and to that end, Mr. Stucki is planning to be in Philadelphia on Wednesday, September 18th. He will contact you relative to a definite appointment on that date.

Sincerely,

J. T. Grover, Manager
Technology Marketing

JTG:mc

RESEARCH LABORATORY FOR ARCHAEOLOGY
AND THE HISTORY OF ART

TEL. 55211

6 KEBLE ROAD
OXFORD

Doug Anderson

ETH/CAB

Matson
Chg. for outside samples

2nd October 1968.

Fro talked to Gross – Will look into it

Miss E. K. Ralph,
University Museum,
33rd and Spruce Streets,
Philadelphia,
Pennsylvania 19104,
U.S.A.

Dear Beth,

I called to see Stucki and found he was not there. However, I talked to Mr. Holly who is the second in command of the project, I think. He gave me a copy of the proposal dated 15th June 1968 and I am afraid I am most sceptical about the whole thing. I only say this because you asked me to give you my opinion.

I don't think they have really considered the implications of a gradiometer because they could not possibly have proposed the design outlined in the proposal if they had. Some of the reasons for this are given in the enclosed memo written by John Alldred. There are other small points also which it would be pointless to go into. The main point of the whole thing is that the thin film units that they propose are no smaller than the fluxgate elements already in use in many instruments, including the gradiometer described in the enclosed reprint. The method of using their sensors is exactly the same as was done by John five years ago and, indeed, are essentially the same device although working at a higher frequency. Incidentally the battery current drain in their proposition is considerably greater than ours.

My real advice, therefore, is that they will not be able to make a more compact instrument than the fluxgate gradiometer unless they accept a very much larger drift and inaccuracy than proposed. If they can, I will eat my hat! In the end they will have to put their sensors in the same type of mounting as we use.

Continued . . .

Incidentally, instead of spending $30,000 on one of their instruments, we would make you one (as we have done for Lerici and Scollar) for $4,000 - but I promise I am not trying to sell you anything!

It was pleasant, as usual, to see you again and I am sorry not to have been able to come to Philadelphia.

With best wishes.

Yours sincerely,

Teddy

E. T. Hall

Enc. (2)

October 10, 1968

Dr. E. T. Hall
Research Laboratory for Archaeology
and the History of Art
6 Keble Road
Oxford, England

Dear Dr. Hall:

Many thanks for your good letter. As it happened, Stucki was here in Philadelphia while you were in Palo Alto, but I am glad that you found Mr. Holly. Now that you and Mr. Alldred have clarified matters, I can understand why the thin film gradiometer would be no better and possibly more troublesome than the fluxgate type.

When Stucki first came here, he talked about a device so simple and small that it could be carried in one's pocket. When he came the second time, he realized that the gadget would have to be more complicated and suggested a 4 or 5 sensor arrangement. I then had a misguided notion that, perhaps, 4 sensors could serve to cancel out the extraneous magnetic fields and the single 5th one would serve as in a difference circuit, but would of course still be subject to changes in orientation. This didn't sound too practical, but Stucki returned to Palo Alto and then along came the proposal for the 2-sensor gradiometer which you saw.

Since I talked to you, Fro has contacted Mr. Gross who was the "boss" of Lockheed but is now retired and lives in Philadelphia. At the moment Mr. Gross is "looking into the matter," and on the basis of your advice, I hope that nothing will materialize.

Hope that you will travel here soon again and find time for Philadelphia.

With best regards,

Elizabeth K. Ralph

EKR/mrb

October 10, 1968

F. F. Stucki
Department 51-10, Building 204
Lockheed Palo Alto Research Laboratory
3251 Hanover Street
Palo Alto
California 94304

Dear Mr. Stucki:

Thank you for the information about the Twister and Terrastar.

In regard to the magnetometer proposal, Dr. Rainey has talked to Mr. Gross and the latest word is that Mr. Gross "will look into it." Therefore, we are now waiting to hear from him.

With best regards,

Elizabeth K. Ralph

EKR/mrb

PROPOSED LMSC GRADIOMETER

ANGULAR CONSIDERATIONS

defining
- F = total geomagnetic field
- V = vertical component
- H = horizontal component (Northwards)
- H' = horizontal component at magnetic bearing ϕ

A sensor whose axis deviates from vertical by an angle θ into a plane of magnetic bearing ϕ will measure a field

$$V' = V \cos\theta + H' \sin\theta \simeq V\left(1 - \tfrac{1}{2}\theta^2\right) + H'\theta \text{ for small } \theta$$
$$\simeq V + H'\theta$$

for a single sensor, a value of $H' = 0.2$ Oe and $\theta = 60$ seconds

yields $V' - V \simeq 6$ gamma

However a verticality of 60 seconds will not be achieved without the aid of a stable supporting platform or tripod with adjusting screws.

A true perfect gradiometer will indicate zero gradient in a uniform field, whatever its orientation.

If trying to measure a genuine gradient ΔV, where $\Delta H' \simeq 0$,

$$\Delta V' = \Delta V \cos\theta$$

and will be within 1% at $\theta = 8^{\circ}$ and within 5% at 18° representing a one gamma error in anomalies of 100 and 20 gamma respectively.

If however one sensor is vertical whilst the other deviates by θ, the observed gradient is

$$\Delta V' = V + \Delta V - V\cos\theta - H'\sin\theta$$
$$= \Delta V + V(1 - \cos\theta) - H'\sin\theta$$
$$\simeq \Delta V - H'\theta \text{ for small } \theta$$

i.e. although several degrees of tilt in a staff containing two parallel sensors introduces negligible error into a gradient measurement, two sensors misaligned by only 1/60 degree produce an error of $\sim$30 gamma per Oersted of H', and since H' will vary between + H and - H as the staff is rotated, is NOT a constant error.

This means that not only must the sensors be aligned to within $\sim$10 seconds during fabrication, the staff must not bend by more than this during operation.

There can be no doubt whatsoever that a 25 foot telescopic staff will fail this requirement by a few, if not several, orders of magnitude!

LINEARITY REQUIREMENTS

The proposal of two independant single sensor magnetometers subsequently fed to a differential indicator requires system sensitivities which are matched and stable to (for one gamma accuracy in a field of ½Oe) one part in 5.10^4 (20 ppm), and this in turn implies a comparable linearity.

Clearly for the feedback system proposed, the loop gain (excess of open-loop over closed-loop gains) requires to equal or exceed the factor by which the sensors alone fail to meet the desired matching, stability and linearity requirements, BUT ONLY IF the feedback windings are matched for solenoid constant to 1 in $5x10^4$. (It also requires the differential amplifier to have a common mode rejection ratio of 94 db; fortunately this is not impossible.)

Clearly some form of tertiary adjustment must be provided, and this can conveniently be the "balance" control. However care is required in using this to set "arbitrary" zeroes, as any change in the mean vertical field as measured (caused e.g. by tilting, which was shown earlier to produce no zero error and negligible gradient error in a perfectly aligned staff up to several degrees) will now produce a zero error.

SUMMARISING

No thought appears to have been given to the degree of parallelism required of the sensors, nor how it will be maintained.

No quotation is given for the permissible degree of tilt from the vertical for the staff in gradiometer configuration; if this turns out to be one minute as in the absolute mode, the device will be unusable for archaeological prospection.

The concept of two independent magnetometers <u>may</u> (but may well not) worsen rather than alleviate the problems of sensor matching by introducing wide dynamic range requirements.

Lockheed
MISSILES
& SPACE
COMPANY

Enclosure (b) to LMSC/A901377
27 June 1968

Contract Proposal

for

AN EXPERIMENTAL ARCHAEOLOGY

GRADIOMETER SYSTEM

for the

University of Pennsylvania Museum

CONTRACT PROPOSAL

Lockheed Missiles & Space Company proposes to negotiate a mutually acceptable fixed price contract with the University of Pennsylvania Museum for the design, construction and delivery of an experimental magnetometer system for archaeological survey work, based upon the proposed Contract Schedule set forth below.

CONTRACT SCHEDULE

Article I. STATEMENT OF WORK

A. Lockheed Missiles & Space Company, a Group Division of Lockheed Aircraft Corporation ("LMSC"), shall provide all necessary personnel, material, equipment, and facilities, and shall deliver the experimental gradiometer system defined below, in performing a program involving the design and construction of said gradiometer system for the University of Pennsylvania Museum ("the Museum").

B. In the performance of this contract, LMSC shall accomplish the following tasks:

Task 1. Project Direction. Provide project direction of the LMSC effort under this contract. This task will include technical supervision of the work, monitoring of the progress and status of the program, and technical liaison and coordination with the Museum.

Task 2. System Definition. Define the elements and performance requirements of the experimental system. This task will include the establishment of performance objectives of the system, identification of the system elements needed to satisfy these performance objectives, development of the detailed design requirements and criteria for these system elements, and preparation of the documents necessary for procurement of purchased components and material.

Task 2. (continued)

The delivered experimental gradiometer system shall consist of the following elements:

a) Four thin-film sensors for signal acquisition
b) A portable vertical boom, variable in length from approximately five to 25 feet, with prevision for mounting two sensors and a bubble level
c) A four-foot fixed length portable vertical boom, with provision for mounting two sensors and a bubble level
d) A signal-processing electronics subsystem. Approximate specifications: 2 watts, 12 cu. in.
e) A control and display panel, containing all operating and adjusting switches and controls, and a display meter calibrated for the ranges of 1-10 gamma, 10-100 gamma and 100-1000 gamma
f) A lead-acid battery to provide all electrical power for operation of the gradiometer system. Approximate specification: 120 watt-hours, 132 cu. in.
g) A carrying container for transportation of the system and operation in the field. The container will have provision for mounting the vertical booms during field operations, and shall be designed and constructed to be as light-weight as practicable.

Task 3. System Design. Prepare the detailed engineering design of the system in accordance with the design requirements established in Task 2. This task will include breadboard construction of the system electronics, documentation of the electronics design, and preparation of engineering drawings of the mechanical elements of the system.

Task 4. Fabrication and Assembly. Fabricate or procure and assemble the components and elements into the complete gradiometer system in accordance with the design prepared under Task 3. This task will include factory checkout of the system.

Task 5. Verification Testing. Perform field testing of the assembled experimental gradiometer system at a suitable location such as the LMSC Santa Cruz Test Base to calibrate the system, to verify system operation, and to assess the system performance against the performance objectives established under Task 2 using simulated targets and under simulated operational conditions. Following completion of the verification tests, the experimental system shall be delivered to the Museum.

Task 6. Operating and Maintenance Instructions. Prepare and deliver with the experimental gradiometer system two copies of Operating and Maintenance Instructions for the system. This document will include a description of the delivered system. The level of maintenance contemplated shall be that suitable for accomplishment by Museum personnel under field conditions.

Article II. PERIOD OF PERFORMANCE AND DELIVERY SCHEDULE

A. The period of performance of this contract shall be four months after receipt by LMSC of a duly executed contract.

B. The experimental gradiometer system and the Operating and Maintenance Instructions shall be delivered on or before the last day of the fourth month of the contract period. LMSC shall make every reasonable effort to comply with this delivery schedule, but delay in delivery shall not in and of itself constitute breach of contract.

Article III. CONSIDERATION AND PAYMENT

A. For the performance of this contract, LMSC shall receive a fixed price of $33,000.

B. The Museum shall pay LMSC the sum of $10,000 sixty days after contract execution. The balance of the price shall be paid upon delivery of the gradiometer system and the Operating and Maintenance Instructions.

Article IV. QUALITY AND DELIVERY

A. The Operating and Maintenance Instructions shall be prepared in accordance with good commercial practice.

B. LMSC shall exercise good workmanship in the construction and assembly of the experimental gradiometer system, and shall exercise reasonable best efforts to achieve the performance objectives established under Task 2.

C. No other warranties, express or implied, shall attach to the articles delivered under this contract.

Article V. RIGHTS IN DATA

All rights to the design developed under this contract shall remain with LMSC, and reproduction in any manner of the articles delivered under this contract is expressly prohibited.

15 JUNE 1968

LMSC D080253

PROPOSAL FOR A MAGNETIC GRADIOMETER FOR ARCHAEOLOGICAL PROSPECTING

Lockheed

MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA

15 JUNE 1968

LMSC D080253

PROPOSAL FOR
A MAGNETIC GRADIOMETER
FOR ARCHAEOLOGICAL PROSPECTING

Lockheed

MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA

ABSTRACT

The magnetic gradiometer proposed measures directly the vertical gradient of the earth's magnetic field and, if required, the total field intensity. The vertical gradient of magnetic intensity associated with remanent magnetism of archaeological sites can be detected. The system is composed of two thin-film sensors which are very small in size and mounted on a vertical boom to permit different separations of the sensors. The gradiometer mode permits a greater range of magnetic sensitivities then does a single sensor by cancelling out many of the large scale magnetic effects and permitting local magnetic effects to be observed.

CONTENTS

ILLUSTRATIONS

Section 1
INTRODUCTION

The Lockheed Missiles & Space Company has developed a thin film sensor which is being considered for both law enforcement and military applications. The use of the sensor as a magnetometer has been judged very satisfactory for traffic control. Applications are under consideration for security applications.

While a concentrated effort has been devoted to security applications, potential uses have been envisioned for archaeological explorations. The remanent magnetization of some of the most enduring relics of civilization, such as potsherd, brick, roof tiles and other types of fired clay, can provide a sufficient magnetic moment for detection by this thin film sensor.

Deeply buried structures of archaeological importance require a sensitivity detection of 1 gamma or better. To obtain this sensitivity, a special dual sensor mode for magnetic noise cancellation is required. This mode of operation which measures the small difference of intensity between the two sensors is called a gradiometer.

The gradiometer provides a means of operating in the relatively stable magnetic field of the earth. Moreover, magnetic noise introduced on this stable field is cancelled. The magnetic fields produced by the underlying archaeologic strata are local in origin and do not affect the sensors equally as does the earth's magnetic field. It is this small difference in magnetic intensity between the individual sensors that is the detected signal output.

LMSC offers to provide for customer evaluation, one experimental unit of a magnetic gradiometer for archaeological prospecting and magnetic mapping in accordance with the technical descriptions and schedules contained herein.

Some of the unique features of this magnetic detector are:

- High sensitivity
- Low power consumption
- Vertical magnetic component measurement only
- Absolute magnetic intensity measurement possible
- Field portability

Section 2
SYSTEM DESCRIPTION

2-1 MAGNETIC GRADIOMETER

The magnetic gradiometer for archaeological prospecting consists of the following component functions:

- Portable carrier for transporting and field use
- Two vertical booms for sensor mounting
- Two pairs of sensors for signal acquisition
- Electronics for signal processing
- Display meter and control panel for signal intensity and polarity indication
- Battery for electrical power

Two vertical booms are provided. One boom extending to a 4-foot height provides a means for reading large intensity magnetic anomalies. The other boom permits detection of magnetic anomalies of low intensity.

The second vertical boom, which can be raised to any height from approximately 5 feet to 25 feet, serves as mounting platform for the two sensors. The sensors are mounted at the extreme ends of the vertical boom as shown in Figure 2-1, thereby providing more flexibility in detecting archaeologic strata at various depths.

2-2 SENSOR

The thin-film sensors are the signal acquisition sources. The sensor has a sensitive axis which gives the sensor directional properties. Two sensors

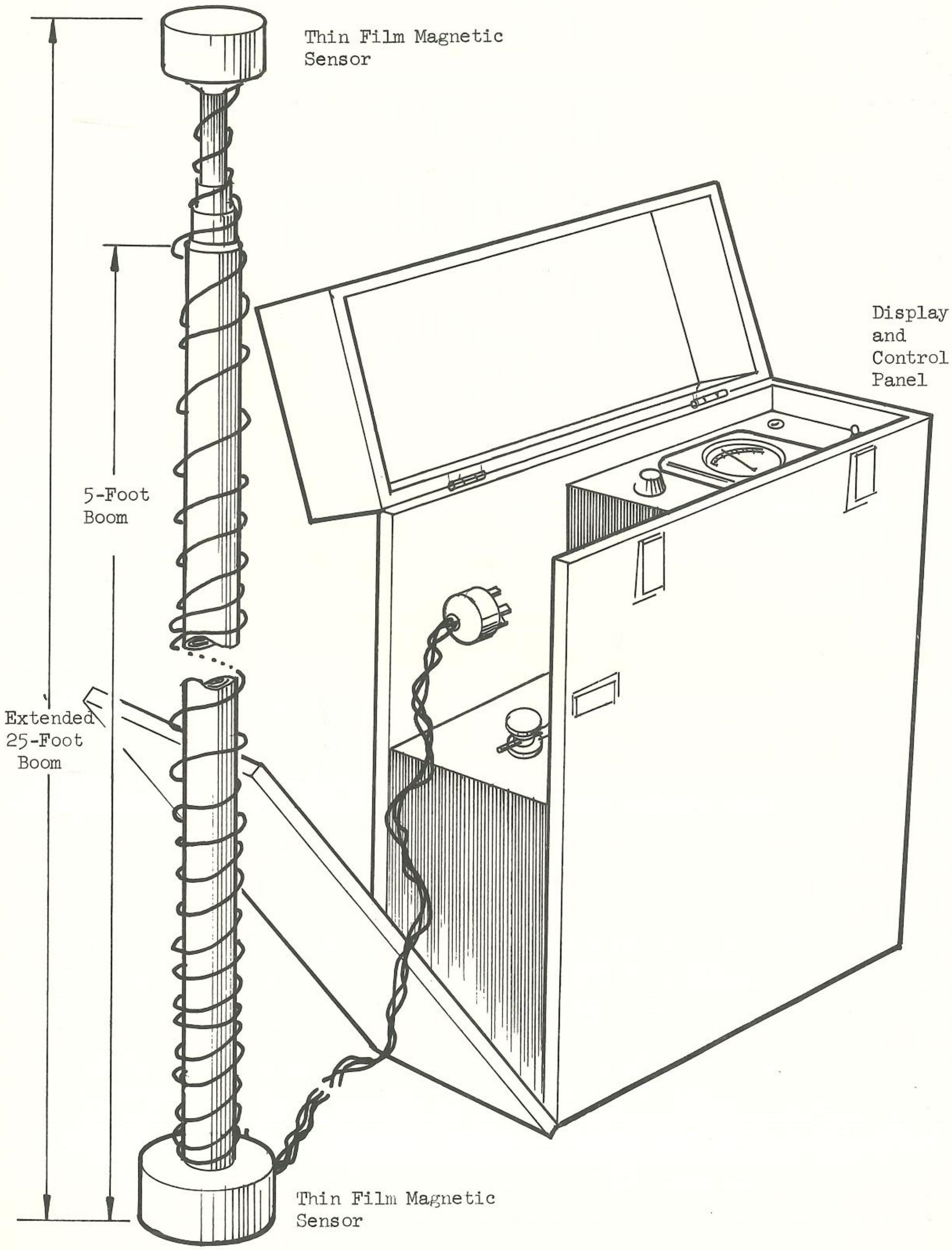

Figure 2-1 Magnetic Gradiometer

are used to form the gradiometer mode and are attached to the ends of the vertical boom with the sensitive axis in a vertical orientation. In this orientation, only the vertical magnetic component is measured when the boom is properly aligned with the bubble level. Hence only the magnetic component parallel to the sensitive axis is observed. A bubble level provides an easy reference for measuring the vertical magnetic component which has been deemed more important (Ref. 1) than the horizontal magnetic component. Misalignments of sensor orientation due to rotation of the boom at any grid point should not affect measurements.

The horizonal magnetic component is more difficult to measure as the alignment of the gradiometer in a fixed direction, i.e. true north rather than magnetic north, is required. This proposal effort concentrates only on the vertical component.

When one sensor is operated by itself in a single sensor mode, the resultant magnetic component can be measured. To operate in this mode, the sensor is removed from the boom and oriented along three axes until maximum intensity is observed.

The magnetic sensor shown in Figure 2-2 is essentially a thin permalloy (nickel-iron) film (Ref. 2) about 2,000 Angstroms-thick which is deposited either by vacuum or by electrochemical deposition on an inert substance. This substance is usually a glazed-alumina surface approximately $\frac{1}{2}$ inch by $\frac{1}{2}$ inch by 1/32 inches. Two orthogonal coils are then wound around the film. One of the coils, called the pump winding, is used to drive the film and thus sensitize the film for magnetic detection. The second coil, called the signal winding, serves to pick up a-c signals related to the intensity of magnetic detection. The second harmonic of the driving signal is picked up by this coil. This harmonic has been determined to be the most sensitive of all the harmonics present. The amplitude of the detected second harmonic is related to magnetic intensity

1. H.A. Slack et al, "The Geomagnetic Gradiometer" Geophysics Vol. 32, Oct. 1967, pp/877-92.
2. P.S. Castro and F. F. Stucki, #3,271,665, Sept. 6, 1966.

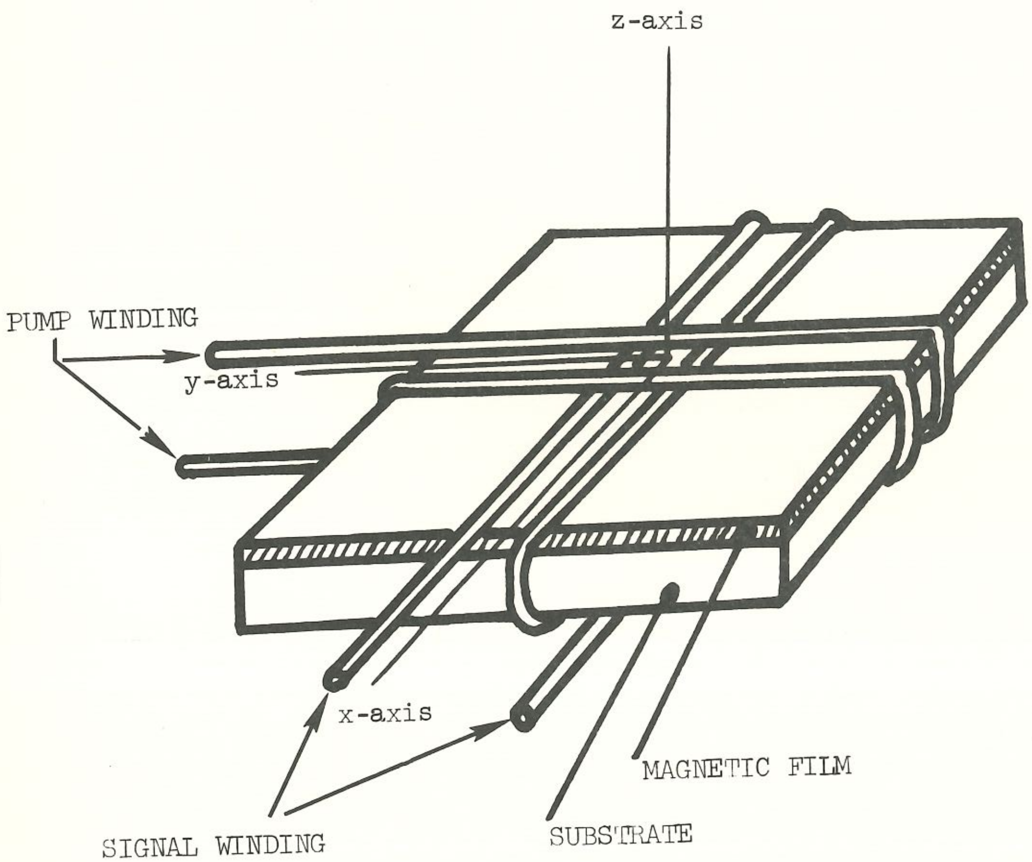

FIGURE 2-2 GEOMETRY AND WINDINGS OF A THIN FILM MAGNETIC SENSOR

of the component aligned with the film's sensitive axis. A third coil is contemplated for the application discussed in this proposal as part of the feedback loop. Experimentation will determine whether the feedback function can be combined with the two windings without unduly complicating the design.

2-3 ELECTRONICS

The electronics serves as a signal processing function between the sensors and the display meter. One of the unique features of the signal processing is that it is designed around the detection of one single frequency which is the second harmonic of the sensor pumping frequency. The singleness of frequency permits narrow band detection which in turn allows signal-to-noise improvements with less sophisticated circuits than for broadband detection. The combination of narrow band detection of the electronics with the noise cancellation effect of the gradiometer mode serves to promote a high sensitivity unit.

The sensors share a common driver but have separate channels for signal processing. Each sensor has its own feedback loop which takes care of any thin film dissimilarities. The output signal from each channel is applied to a differential amplifier whose output provides signal intensity and direction.

The electronics contained in approximately 12 cubic inches, weighs approximately 2 pounds and consumes 2 watts of electrical power.

2-4 DISPLAY AND CONTROLS

The display of the magnetic component is on a simple meter. This meter, used in conjunction with the control panel, is the indicating means for:

- Vertical component magnitude
- Resultant magnetic field magnitude
- Polarity determination of magnitude

It is expected that the field personnel will observe and record the meter reading in a log book. The meter face will display a 10-to-1 scale for each of the three sensitivity ranges.

The control panel will provide all the necessary adjustments for operating the single or dual sensor mode. The number of controls are kept to a minimum to permit ease of operation. However, controls which will give the unit versatility are:

- Power off-on switch
- Balancing adjustment
- Sensitivity range
- Battery voltage check

2-5 BATTERY

The electrical power source under consideration is the new maintenance-free lead acid battery. Significant improvements have been made in this type of battery to warrant use where rechargeable batteries are required as is the case here. The following advantages are offered by this type of battery:

1. No maintenance. There is no need to add water during the life of battery.
2. Operation in any position. No restrictions are placed on spatial orientation of this battery during discharge.
3. Long Life. Over 200 recyclings can be expected.
4. Portability. The batteries may be carried on shoulder straps or belt hooks if required. The cell case is made from impact-resistant polystyrene which can stand severe shock without cracking.

The operation of the battery will be for a minimum of 60 hours of continuous use before the need for recharge is required. An estimated 2 watts will be needed, which necessitates a 120-watt-hour source minimum. The lead acid battery providing approximately 12 watt-hours per pound will weigh 10 pounds. The size of the battery, based upon 1.1 watt hours per cubic inch, will be approximately 132 cubic inches with approximate dimensions of 5.6 x 2.3 x 10.3 inches.

If battery logistics is not a problem, the mercury cell is worthy of consideration. Its characteristics of 35 watt-hours per pound and 5 watt-hours per cubic inch can be achieved. These values would permit a power source of 120 watt hours, 3.5 pounds weight, and be contained in 25 cubic inches. However, mercury batteries are not classified as rechargeable and, when used, must be replaced.

Section 3
SYSTEM DESIGN

3-1 ELECTRICAL DESIGN

The electrical design will incorporate two modes of operation as selected by the user. The first mode will be a single sensor magnetometer operation for reading the intensity and direction of a magnetic field component along the sensitive axis of the sensor. The unit will have three ranges of sensitivity:

- 1 to 10 gamma
- 10 to 100 gamma
- 100 to 1000 gamma

and will include a provision for increasing the sensitivity by installing an improved sensor at a later date with only minor field changes. A polarity reversing switch will be used to provide up-scale readings and at the same time will indicate the direction of the magnetic field component along the sensor axis. A "slide-back" feature will be incorporated which will allow the full magnetometer range to be used at any ambient earth field by cancelling out this ambient field. In this way small changes can be observed.

In the second mode of operation, an additional sensor magnetometer similar to the first will be utilized to provide a gradiometer. Their combined outputs are subtracted through the use of a difference amplifier. This mode of operation will allow higher sensitivities to be used by providing cancellation of the homogeneous magnetic field noise appearing on the earth's field. The gradiometer sensitivities will be:

- 1 to 10 gamma per sensor separation length
- 10 to 100 gamma per sensor separation length
- 100 to 1000 gamma per sensor separation length

3-1.1 Electronics

The design philosophy of the individual magnetometer can be seen by referring to the block diagram in Fig. 3-1. An oscillator stage typically at a frequency of 500 KHz generates a reference signal to be used in the phase sensitive detector. A driving signal for the sensor is also obtained from the oscillator after passing through a frequency divider stage which divides the frequency by two. The signal output from the sensor occurring at a frequency (and thus equal to the oscillator frequency) is filtered and amplified by the tuned amplifier stage and applied to the signal terminals of the phase sensitive detector so that now the reference and signal voltages have the same frequency for proper operation of the phase sensitive detector. This frequency component of the output of the sensor is chosen because it displays the largest sensitivity to magnetic fields. The output of the phase sensitive detector will now be a bipolarity d-c voltage whose polarity represents the direction of the magnetic field component along the sensitive axis of the sensor and whose amplitude represents the magnitude of this component. The d-c voltage output of the phase sensitive detector is amplified and produces a current flowing through a third coil wound around the sensor generating a magnetic field tending to cancel the external magnetic field in a negative feedback arrangement. The result of this arrangement is to produce linearization of the magnetometer transfer response and is necessary if an accurate magnetometer/gradiometer is to be made.

A difference amplifier is used to subtract the individual magnetometer outputs if a gradiometer mode is desired; for single magnetometer operation, one of the magnetometer outputs is disconnected from the difference amplifier which then functions as a straight forward amplifier stage. The output of the difference amplifier is then displayed on a meter for visual indication after passing through a range-changing switch.

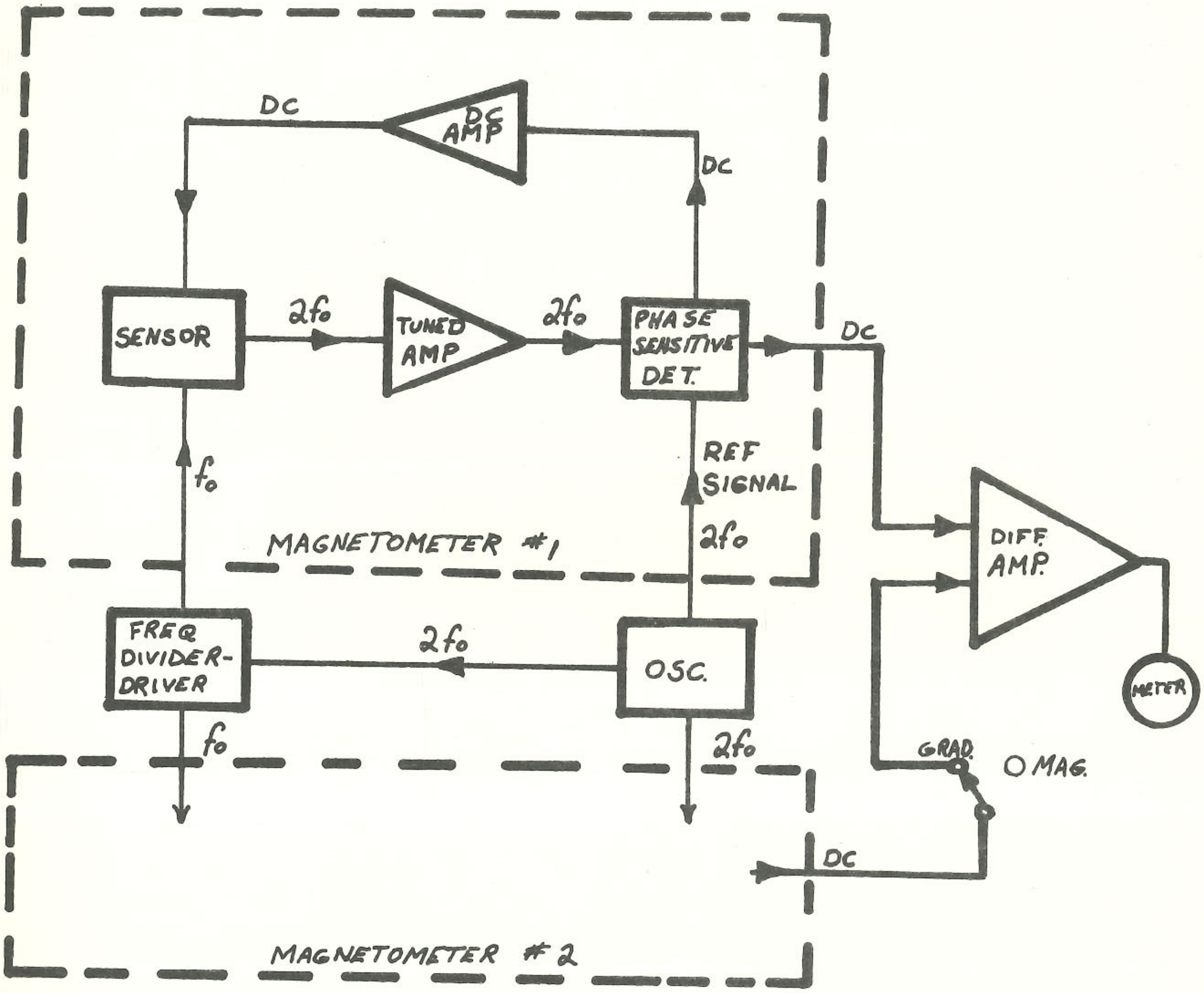

FIGURE 3-1 BLOCK DIAGRAM OF MAGNETIC GRADIOMETER

Integrated circuits will be used wherever possible throughout the circuit design for the weight and size savings they afford. Portability will be enhanced through the use of all solid-state circuitry. An estimate of the size of the electronics shows that a volume of 12 cubic inches is sufficient to house them. A modular approach will be used in packaging the electronics for ease of servicing and replacement of defective parts.

An example of the circuit module approach for the magnetometers is shown in Figure 3-2. These modules are listed for reference and an estimate of their volume is given in the same figure.

3-1.2 Circuit Features

A quartz crystal to provide stable operation over a nominal temperature range will be used as the frequency determining element of the oscillator. To divide this frequency by two, a flip-flop stage is used because of its simplicity and reliability.

A crystal filter will be used to determine the frequency selective characteristics of the tuned a-c amplifier. The crystal filter is chosen over conventional L-C filters because of its stability and excellent bandpass characteristics.

The d-c and difference amplifiers will be integrated circuit stages. These stages are commercially available and are well within the state-of-the-art.

A balanced-transistor pair will be used in the phase sensitive detector stage instead of the more conventional diode bridge, principally because of the greater transfer amplification possible in the transistor pair. Balanced transistor pairs are commercially available in one package and thus afford excellent temperature balanced characteristics.

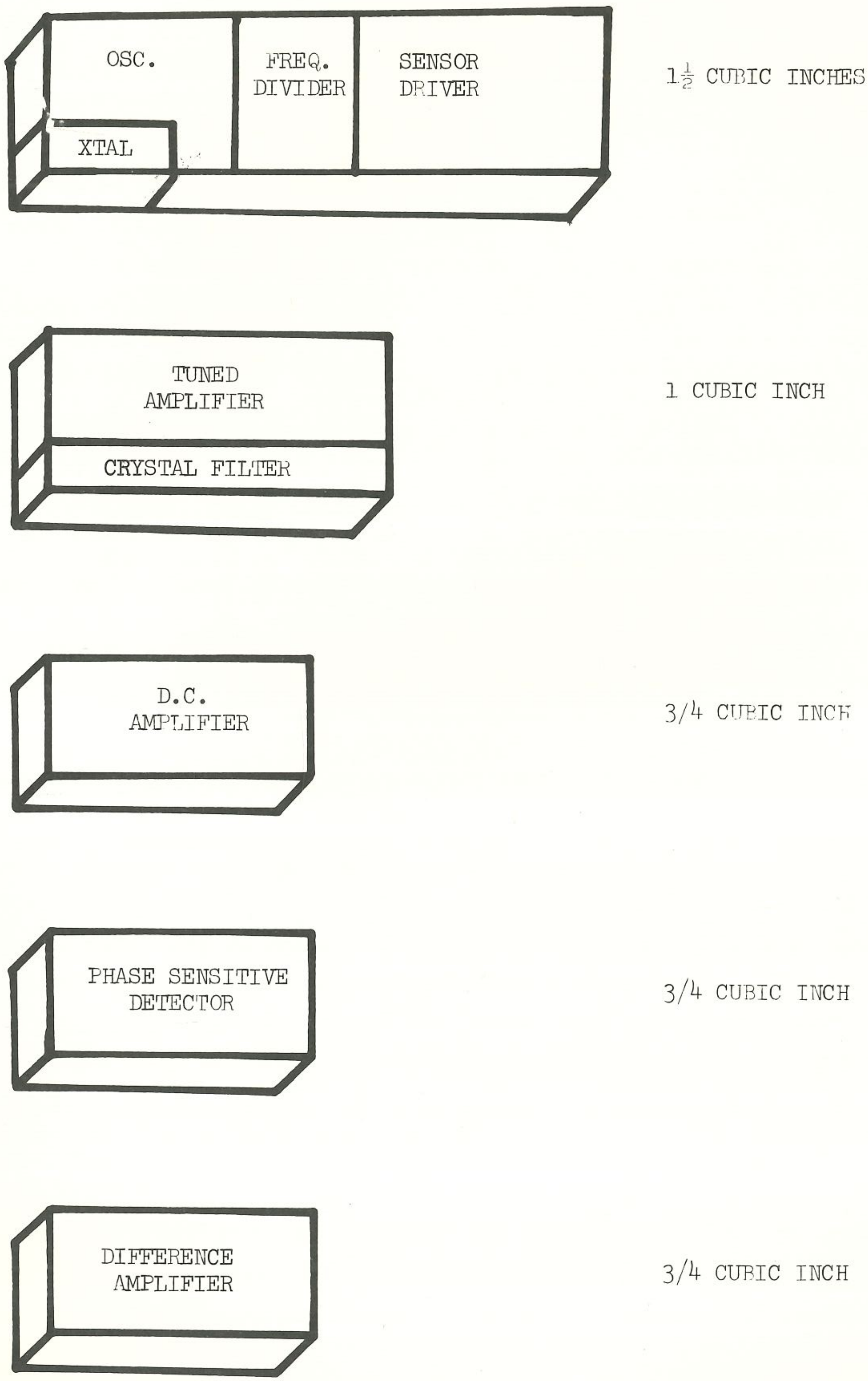

FIGURE 3-2 CIRCUIT MODULES OF MAGNETOMETER

3-1.3 Operational Features

The reading time of this unit is determined principally by the mechanical set-up time since the unit is essentially a continuous reading device.

In addition, because of the slide-back feature, the reference field or reference gradient is arbitrary and can be adjusted to give "zero" reading at any location in the field with differences measured with respect to the reading at this location.

3-2 MECHANICAL DESIGN

Figures 3-3 and 3-4 illustrate three options for making field measurements of the vertical magnetic component. Figure 3-3 shows the use of a short vertical boom for general magnetic mapping. The field man is depicted as holding the boom vertical while he reads the meter on the portable electronics. Figure 3-4A shows a 25-foot vertical boom. Figure 3-4B shows the field man steadying the vertical boom while he observes the field intensity meter. When the meter is sitting on the ground, it is most sensitive to low intensity measurements as all magnetic fields associated with the electronics are refrained from movement.

A non-magnetic carrier for the unit will be divided into three compartments. The electronics compartment will be dust sealed with only the display and control panel exposed. The battery compartment will be dust sealed to permit field installation of freshly charged batteries. A compartment will be provided for the standing of the vertical boom.

The small boom is used with the unit for rapidly assessing the vertical field intensity of a suspected archaeology site. The boom is easily leveled with

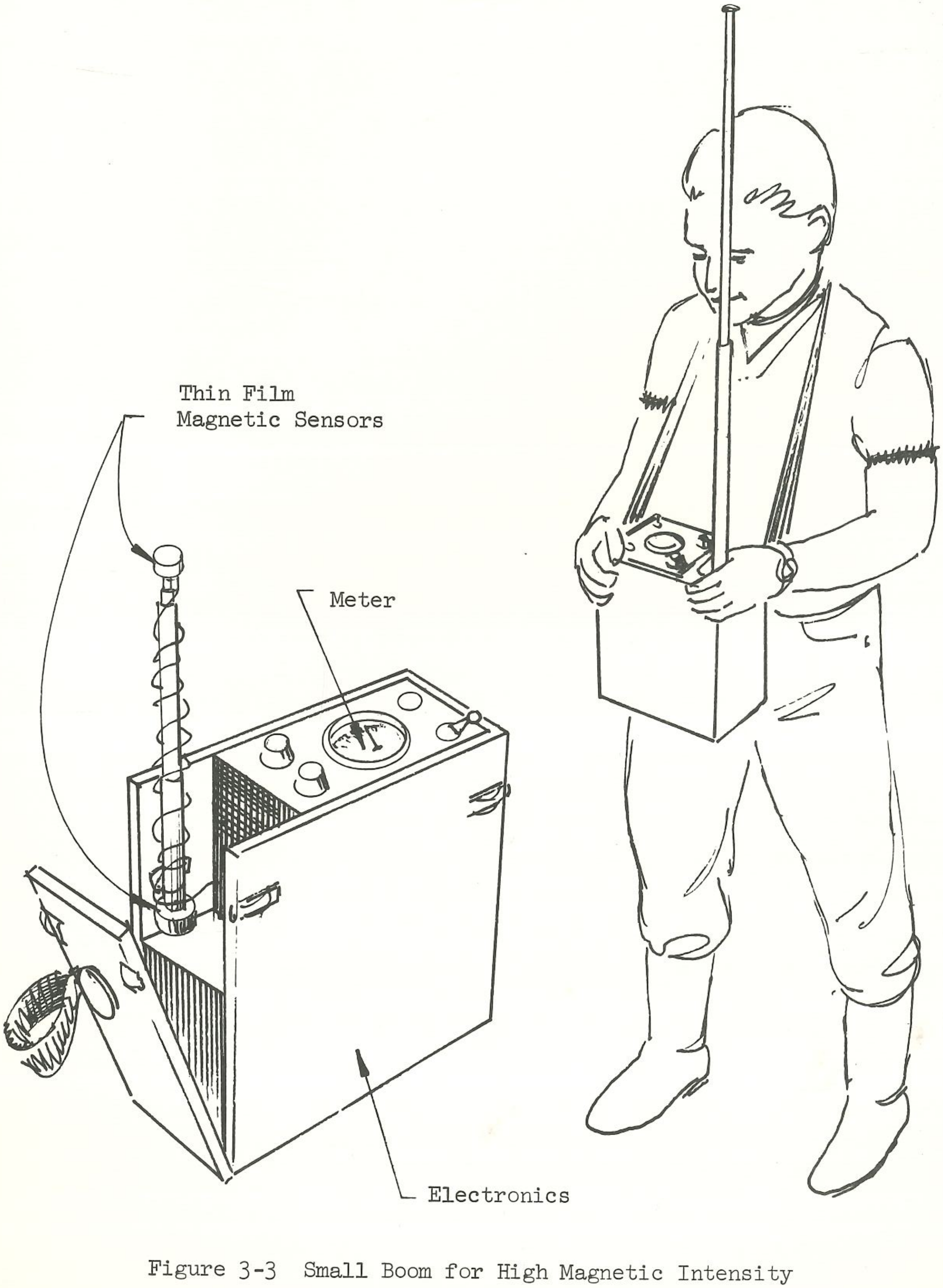

Figure 3-3 Small Boom for High Magnetic Intensity

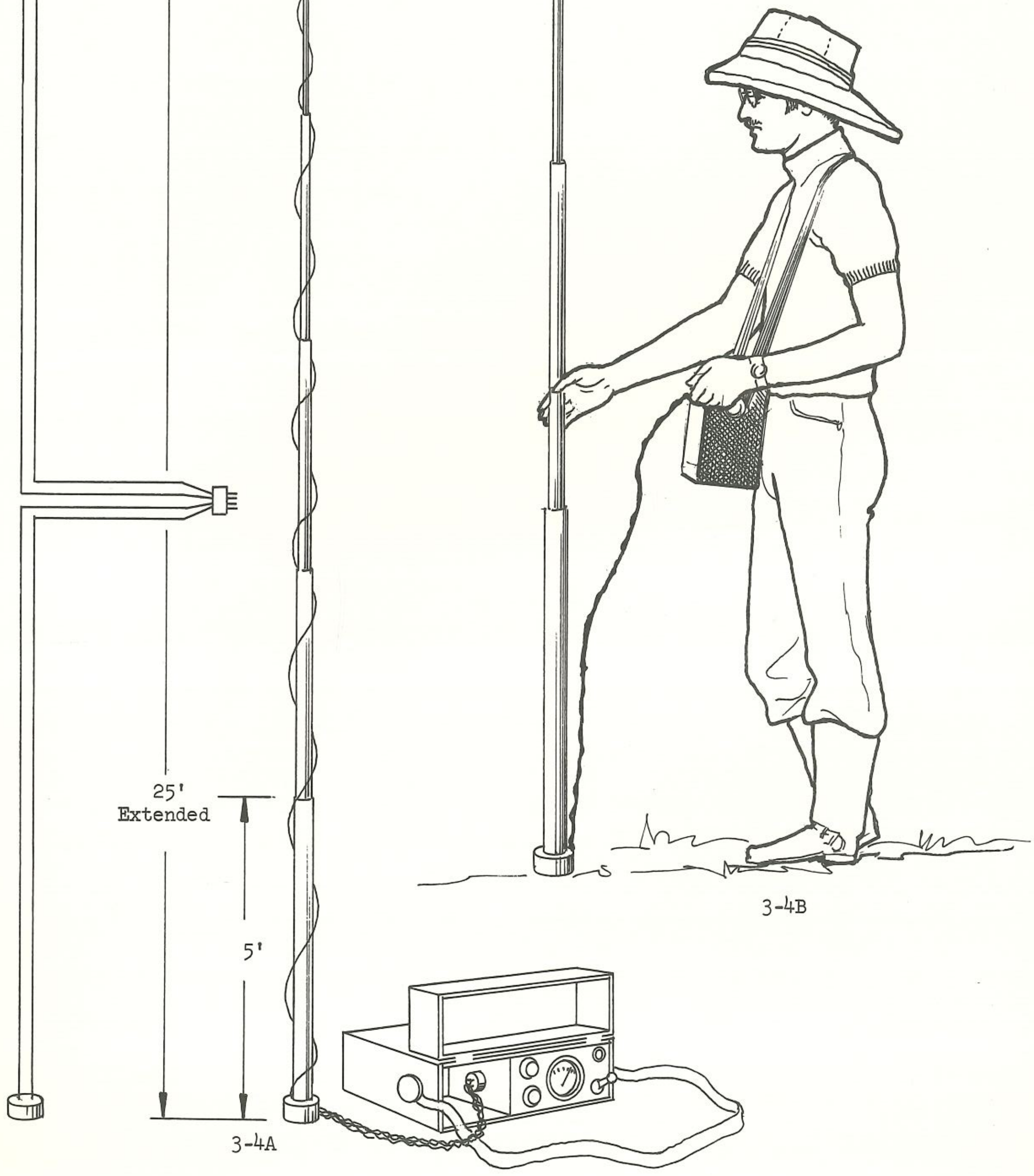

Figure 3-4 Options for Magnetic Mapping

a bubble level to within 60 seconds of arc of true vertical. The unit with vertical boom is expected to weigh approximately 20 pounds. Dimensions of the unit without the boom would be typically 5 inches x 9 inches x 9 inches. The unit would be expected to utilize the 100 to 1000 gamma sensitivity range in this configuration. The vertical boom is to be in two sections approximately 2 feet long per section to aid in storing and transporting the unit in the non-operating condition.

The large boom is used for mapping of low vertical field intensities. This boom in its collapsed condition is approximately 2 inches in diameter and 5 feet long. The boom is made of 6 sections of fiberglass tubing of diameters such that they telescope inside each other. The first section is 5 feet long, the remaining sections are in 4-foot lengths.

The boom in its fully extended position (25 feet) is most sensitive to deeply buried remanents. All precautions will be taken in the design and in the callout of operating procedures to permit the unit to work at its maximum sensitivity.

Section 4

ADVANCED CONCEPTS

The LMSC Magnetic Gradiometer for this Archaeology Prospecting proposal represents an immediate offer to furnish a single unit to meet a postulated operational need. The recipient should be aware that the final design configuration is a strong function of the actual needs. A design concept was postulated by LMSC with the aid of the University of Pennsylvania personnel providing design goals. Local conditions, as well as actual operational requirements may require alternate design configurations. Magnetic signals once received can be transmitted to a remote recording site. Generally speaking, the more data processing that is required, the more power which will be needed.

One possible add-on to the design is the radio wave transmission of the data with its identifying coordinates to a trailer equipped as a small data processing center. The operation would be semiautomatic with the field personnel entering the coordinates of each grid point and the intensity of the magnetic component automatically transmitted after the identifying coordinates. This transmitting of the data to the processing center would relieve the field personnel of having to record and analyze data. Moreover, the personnel in the processing center could observe and analyze the data in more convenient quarters and under more controlled conditions.

Figure 4-1 dramatizes the design concept with an RF link included. The vertical boom could be used as an omnidirectional antenna that broadcasts the coordinates and magnetic intensity to a remote processing center. At each grid point, the field personnel would provide an on-the-spot transmission of the coordinates of the measurement and measurement itself to the remote center. The LMSC

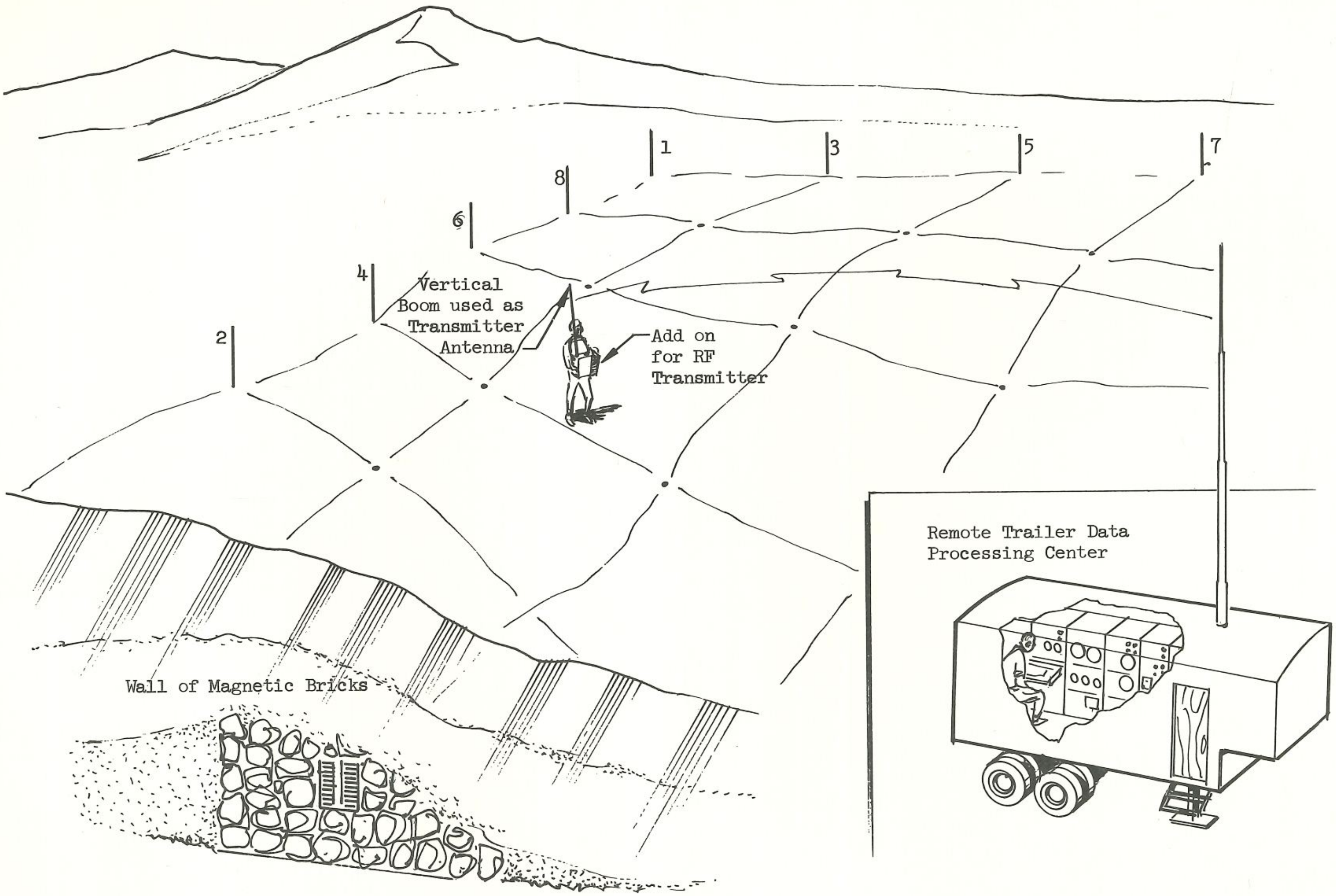

Figure 4-1 RF Link for Field Data Transmission

Magnetic Detection Instrument (Ref. 1) has an RF transmitter for relaying both the identifying code and magnetic intensity. To conserve power, pre-programming was included to provide a detection on-time of two percent and the RF transmitter came on only when magnetic detection occurred.

The next level of sophistication would be an automatic readout of the intensity on an X-Y plotter. The numerical printout would correspond to the actual grid marker positions in the field. The trailer personnel would draw the contour lines through numbers of the same magnitude.

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1. J. A. Holly, "Magnetic Detection Instrument Field Test Report," Oct. 14, 1966, LMSC-671435

Section 5
PROGRAM PLAN

5-1 SYSTEM CONCEPT

Lockheed Missiles and Space Company proposes to design, develop, fabricate, and deliver an experimental gradiometer system suitable to be carried by an archaeologist. This system has been described in Sections 1 through 4 of this document. Additional refinements like an RF link between the operating gradiometer and a fixed display and recording unit have been excluded from this experimental concept, in order to provide a working system in a minimum time and with minimum effort. However, this equipment may be added on at a later date without modification to the basic unit.

5-2 FABRICATION

The gradiometer system will be fabricated, assembled, and tested by technicians in the LMSC Advanced Concept Laboratory in Palo Alto, California.

5-3 TESTING

The experimental gradiometer system will mainly undergo laboratory testing. The gradiometer system will be exposed to a known field, and calibrated such that the different sensitivities can be accurately read off the indicating meter. The gradiometer will be mounted and tested in the vicinity of the LMSC laboratory to establish functional integrity of the system under simulated field conditions.

Section 6
MANAGEMENT PLAN

6-1 PERSONNEL

Key personnel proposed for this program have been selected on the basis of individual qualifications for specific project tasks. Each person selected is a senior man in his particular discipline and has previously held major technical responsibilities in similar or related projects. Following are the key people that would be involved:

FRANK F STUCKI, Advanced Concept Staff Engineer, R&D Division and head Advanced Concept Laboratory
M.S.E.E., 1951, Swiss Federal Institute of Technology

Mr. Stucki would bring six years of Lockheed experience to the proposed program in the fields of magnetic thin-film sensors, magnetic devices, magnetic memory and logic circuits, and high-speed magnetic amplifiers to the program. As a program manager for the proposed study he would have overall responsibility of this program. Prior to joining LMSC he worked at the Bell Telephone Laboratories.

JOSEPH A. HOLLY, Advanced Staff Engineer, R&D Division
M.S.E.E., 1951, University of Illinois

Mr. Holly is engaged in the application of microelectronics to telemetry equipment. He has been with LMSC for seven years, and has performed advanced analytical and engineering projects in the areas of missile receivers, guidance equipment, and special countermeasures equipment. He previously was employed by Sylvania Electronic Defense Laboratories, Bendix Aviation, and Bell Aircraft.

6-2 FACILITIES

The design and assembly of the gradiometer system will be done in Buildings 204 and 205 of the LMSC Palo Alto Research Facilities. Ample facilities for the design, fabrication, assembly, and testing are available for the completion of this program.

6-3 PROGRAM ORGANIZATION

The organization which is proposed to accomplish this program is shown in Figures 6-1 and 6-2. This program comes under the direct leadership of the Advanced Program Directorate of the LMSC Research and Development Division.

6-4 SCHEDULE AND MANPOWER ALLOCATION

Figure 6-3 the Program Master Schedule, shows LMSC's plan for developing the magnetic gradiometer. The design concept will be frozen at the end of two weeks, at which time the electronic design and breadboarding will begin. Design completion will occur at the end of the second month, with some preliminary fabrication already having been initiated. Assembly and bench checkout of the gradiometer will occur at the end of three months and will be followed by a three-week period of field testing by LMSC personnel. Operating and Maintenance Instructions will be prepared during the fourth month and will be delivered with the gradiometer during the last week of the fourth month. Figure 6-4 shows LMSC's planned Distribution of Effort for accomplishment of the program. Manhours are shown allocated by time,task, and applied skills. In addition, manhour totals are shown by month, task, and skill. Percentages of total effort are given by task. A further breakdown of the manpower planning is presented in Figure 6-5, the Technical Manpower Assignments. In this figure, specific assignments to the tasks have been made for the personnel assigned to the program.

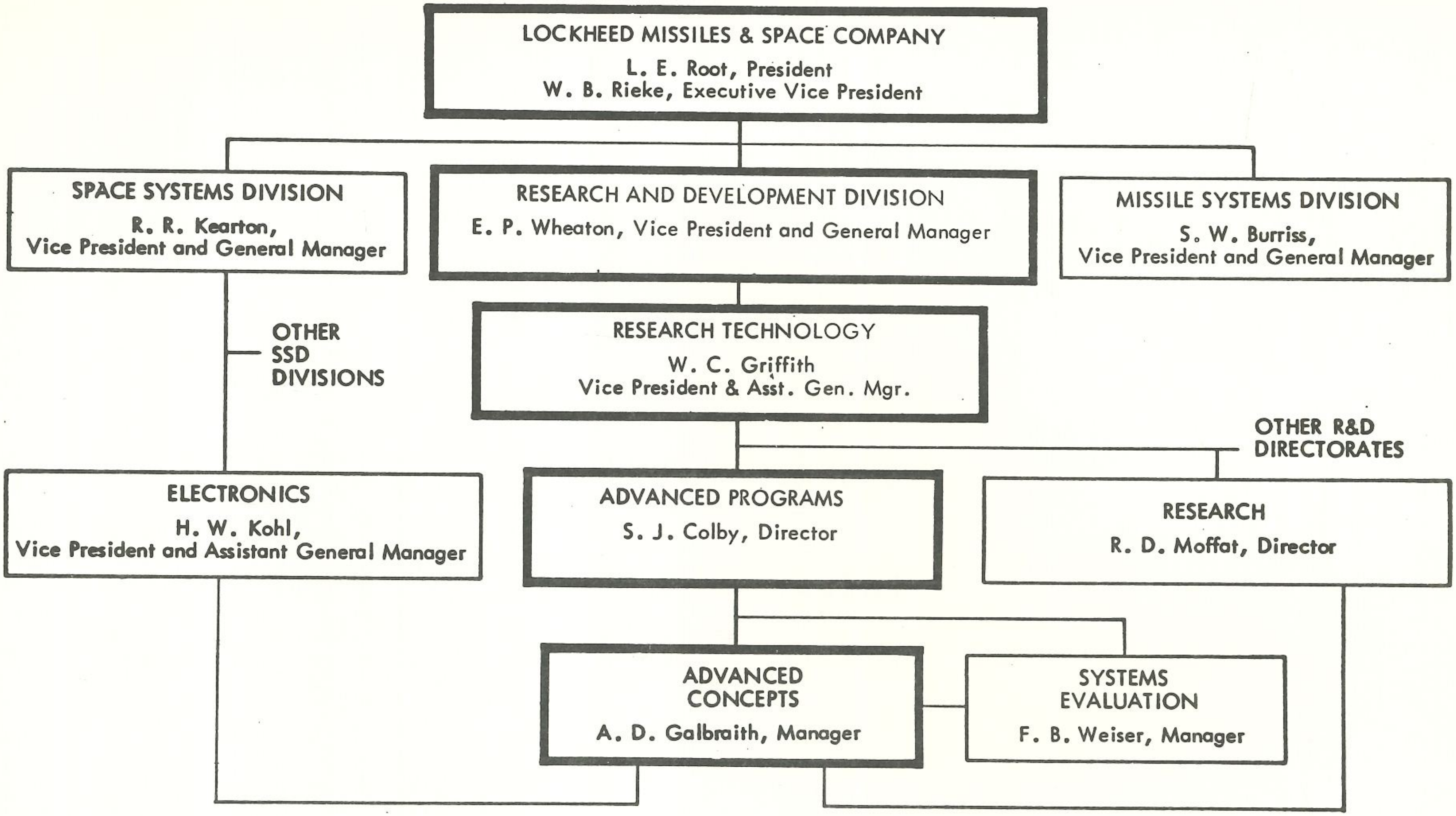

Fig. 6-1 Relationship of Project to LMSC Management

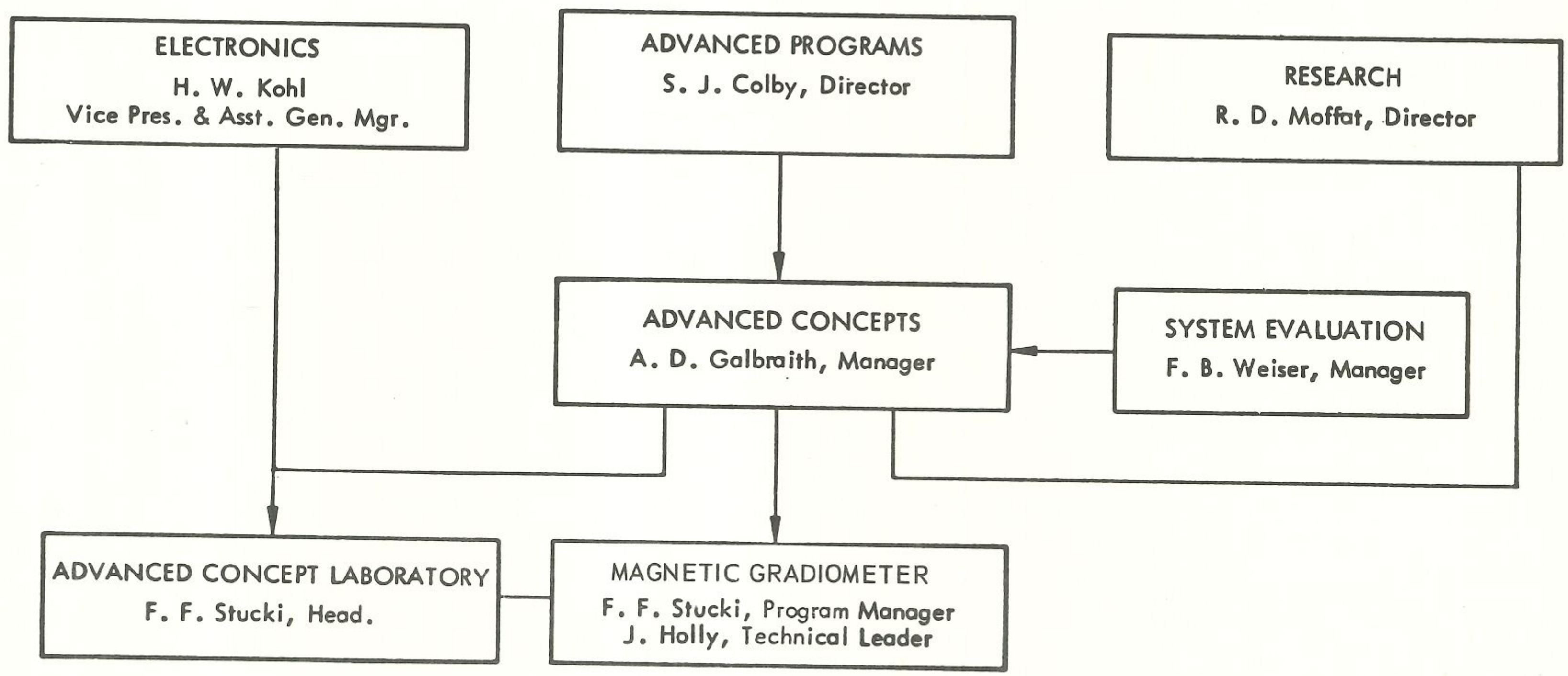

Fig. 6-2 Project Management

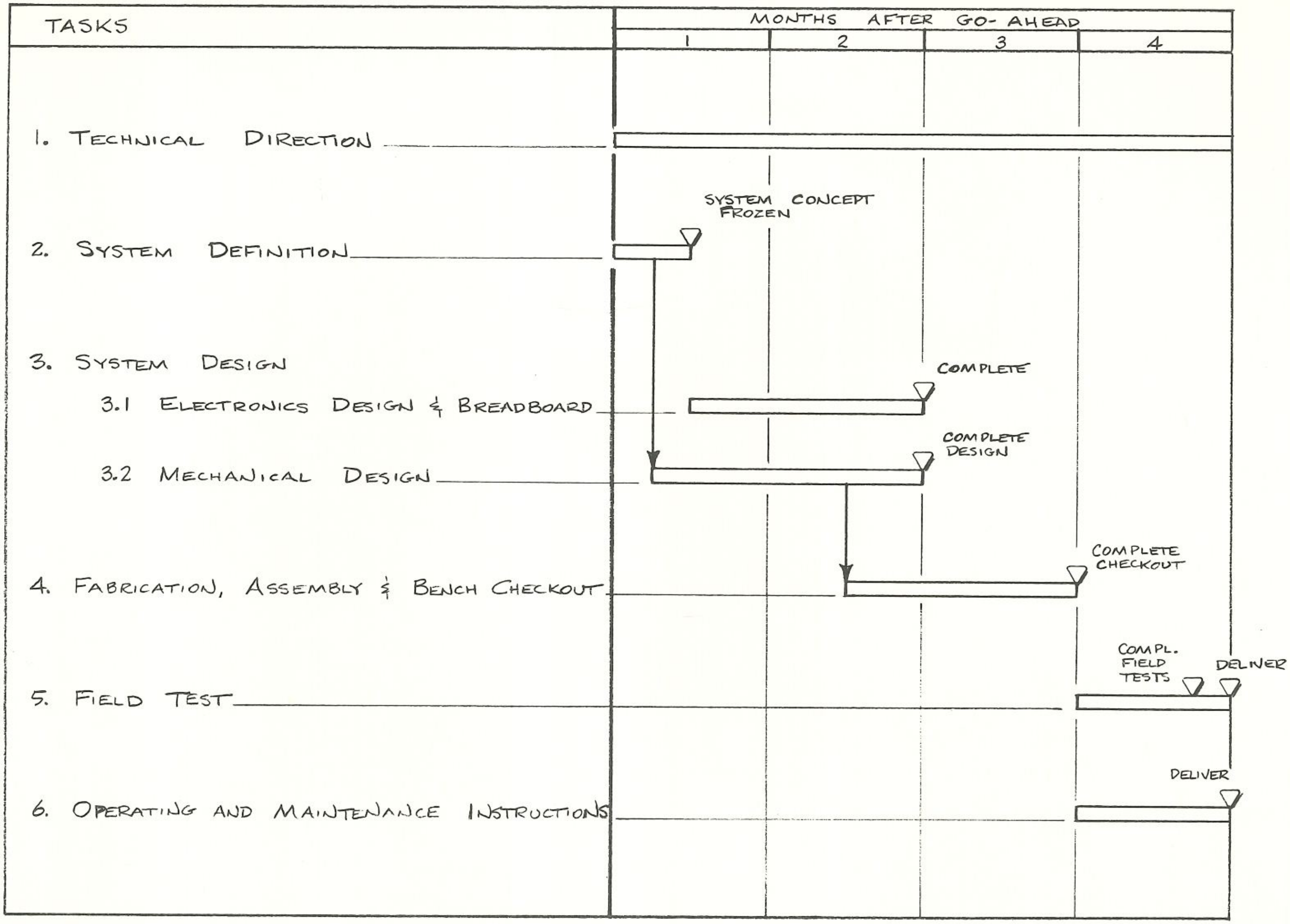

Figure 6-3 Program Master Schedule

DISTRIBUTION OF EFFORT BY
- TIME
- TASK
- SKILL

MONTHS AFTER GO-AHEAD 1	2	3	4	TOTAL MAN-HOURS	% OF TOTAL	TASKS	PROJECT DIRECTION	ENGINEERING	MANUFACTURING	PRODUCT ASSURANCE	TECHNICAL PUBLICATIONS
20	20	20	20	80	5.3	1. TECHNICAL DIRECTION	80				
80				80	5.3	2. SYSTEM DEFINITION		80			
						3. SYSTEM DESIGN					
80	220			300	20.1	3.1 ELECTRONICS DESIGN & BREADBOARD		220	80		
40	160			200	13.4	3.2 MECHANICAL DESIGN		200			
	140	350		490	32.8	4. FABRICATION, ASSEMBLY & BENCH CHECKOUT		100	360	30	
			220	220	14.7	5. FIELD TEST		100	120		
			125	125	8.4	6. OPERATING AND MAINTENANCE INSTRUCTIONS	20	60			45
220	540	370	365	1495	100.0		100	760	560	30	45

Figure 6-4 Distribution of Effort

NAME	SKILL	TASK	MONTHS AFTER GO-AHEAD 1	2	3	4	TOTAL
F. F. STUCKI	PROJECT DIRECTION	1.	20	20	20	20	80
		6.				20	20
			20	20	20	40	100
J. A. HOLLY	ENGINEERING	2.	80				80
		3.1	80	140			220
		4.		20	80		100
		5.				100	100
		6.				60	60
			160	160	80	160	560
A. H. ADAMS	ENGINEERING	3.2	40	160			200
			40	160	—	—	200
LABORATORY ANALYSTS	MANUFACTURING	3.1		80			80
		4.		120	200		320
		5.				120	120
			—	200	200	120	520
SHOP	MANUFACTURING	4.			40		40
			—	—	40	—	40
INSPECTOR	PRODUCT ASSURANCE	4.			30		30
			—	—	30	—	30
—	TECHNICAL PUBLICATIONS	6.				45	45
			—	—	—	45	45
TOTALS			220	540	370	365	1495

Figure 6-5 Technical Manpower Assignments