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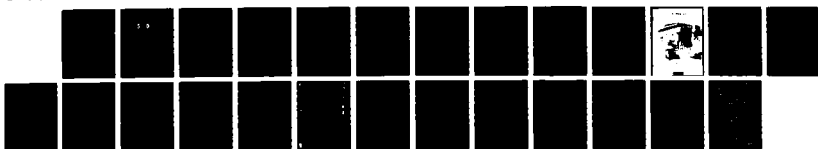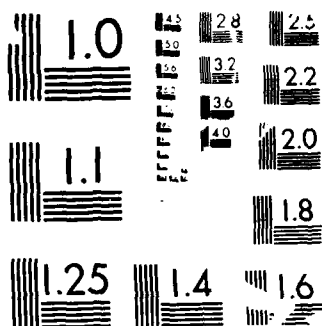   PHOTOFABRICATION TECHNOLOGY INC DERRY NH R E HOWE
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FINAL REPORT

SBIR Phase I Fesability Study
FEASibiLity*

OPTIMIZING FOCAL PLANE INTERCONNECTIONS

Jan. 1987

Contract DASG60-86-C-0067
U.S.Army Strategic Defense Command
Contr & Acq Mgt Ofc. DASD-H-CRR
P.O.Box 1500
Huntsville, AL 35807-3801

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Final Report to:

U.S.Army Strategic Defense Command
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Contract DASG60-86-C-0067

Attn. IST/SBIR

Optimizing Focal Plane Interconnections

Robert E. Howe, Principal Investigator

ABSTRACT

The interconnection of various elements in LWIR Focal Plane Arrays and associated signal processing electronics is currently more of a cut and try process than a straightforward design utilizing established performance parameters. Definition of this critical interface between detector and amplifier is hampered by the lack of baseline parameters relevant to the cryogenic environment and signal bandwidth of strategic defense systems.

The specific objective of the Phase 1 contract is to define, through an industry survey, sufficient parameters to enable a Phase 2 effort to design, fabricate, and test a baseline "generic" focal plane interconnection cable. The results of the survey confirmed that there is a significant need for the proposed design guidelines. These same results also indicate, however, that the scope of the necessary effort to fabricate and test a meaningful baseline interconnection cable is beyond the time and budgetary limitations of an SBIR Program Phase 2 contract.

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1. INTRODUCTION

Organizations involved in IR focal plane array system development are faced with a variety of interconnection challenges. This applies to the various interconnections between detector/array,
multiplexer, amplifier, and signal processing electronics. Once a system emerges from the laboratory, some practical form of multiple or mass termination interconnection is generally required.

Independent of the level of detector integration or hybridization, it is clear that future deployable systems cannot continue to rely on hand-wired or discrete point to point interconnections. In order to achieve "mass termination", some form of high-density flexible printed circuit seems indicated. The design of such flexible circuits is complicated by many factors, however. Primary among these are the need for an absolute minimum of both outgassing, and heat load on the detector coolers. The critical lack of relevant baseline data for the design of interconnection cables in a cryogenic environment hinders efforts to optimize these systems.

But a flexible printed circuit is a natural choice for such interconnections, since the polyimide film commonly employed in avionics flex circuits is easily able to withstand cryogenic temperatures without breaking or embrittlement. Intricate shapes and complex three-dimensional geometries can generally be accomodated with minimal tooling and manufacturing costs. Flexible circuits can also provide means for mass termination interface, with beam-lead like features at one end, and a solder pad connector interface at the other. The apparent availability of so ready an answer to interface problems has caused insufficient attention to the unique problems encountered in applications for the cryogenic, wide-bandwidth, and high density Far-IR focal plane array.

Indeed, it remains highly likely that until more suitable materials are developed, many focal plane cables will continue in outward appearance to resemble the "black box" avionics flexible printed circuits. Less apparent, however, is the nature of the inner conductor material, the hidden characteristics of the adhesives and bonding media, the shielding which may be sputtered or deposited, and the construction geometry at the point of termination. At the present time the performance and reliability of focal plane cable designs depends more on these hidden features than those which have been reduced to practice and can be conveniently handed over to a design graftsman

1.1.   Typical Focal Plane Cable

Figure 1 shows a typical focal plane cable, circa 1984. This assembly is from the HOE (Homing Overlay Experiment), and was designed and fabricated by the author at PTI. This circuit was a successor to the initial HOE focal plane cable. The

original circuit, built to print, was unable to survive the cryogenic environment, and was too delicate to withstand the necessary soldering operations. The original design had been subjected to numerous levels of review and approval; the failures it encountered were attributed to soley to inadequate manufacturing controls, rather than inappropriate design.

The unsuccessful design and the PTI redesign were, to outward appearances, virtually identical. But the failed circuit design neglected to account for residual stresses and metallurgical boundaries. The result was many months of program delay and a significant budget overrun. Even though the PTI circuit was a primative, brute-force approach, it successfully replaced one in which critical reliability problems created significant program delays. Unfortunately, the designs produced by many of the contractors involved in strategic systems development have matured very little since the HOE program. At the sub-systems and component level there are many questions, and few answers that are based on anything other than guesswork.

The author has participated in designs and production of LWIR and near-IR interconnection circuits for both strategic and tactical systems. But there has been little comprehensive design and performance information available to ganyone involved in the design of these systems. PTI conducted an informal survey of contractors in 1985 which indicated a general interest in all phases of cryogenic cable design.

The survey and preliminary testing conducted in late 1986 under this Phase 1 contract confirmed the earlier survey results. This survey indicated that information was needed in greater depth and detail than previously anticipated.

1.2.   Scope of Work
       The Scope of Work performed under this contract consisted of five tasks:

1.2.1 Develop compreshesive list of individuals and organizations to survey for desired operating characteristics of focal plane cables. Develop the questionaire and conduct a combined mail and telephone contact survey.

1.2.2 Evaluate the survey results and identify the number of configurations indicated to provide the range of performance criteria developed in the survey.

1.2.3 Provide a technical risk assessment of the indicated configurations, including identification of areas where additional research or materials development is indicated. Fabricate test coupons representative of LWIR cables and perform preliminary tests of selected paramaters.

1.2.4 Establish design goals (parameters) for each of the configurations determined in task 3) above.

1.2.5 Final report preparation and submittal.

2. Survey Preparation and Distribution

2.1. Preparation of Survey Questionaire

Preparation of the survey questionaire consisted of a review of the previously developed questionaire (Exhibit 1), discussion with various PTI customers engaged in focal plane array efforts, and the recommendations of an adhesives consultant. The result was a questionaire which was far more quantitative than the prior survey, and which focussed on greater depth of inquiry in the least well defined aspects of cryogenic cable performance. The resulting questionaire (Exhibit 2) was reviewed by several design engineers in industry before being distributed to 67 selected engineers and scientists to whom annonomity was promised in order to secure candid·responses.

Each survey was accompanied by a cover letter explaining the purpose of the survey effort and indicating that respondents would have the opportunity to provide inputs to the process of defining the design, manufacture, and testing of the baseline cable. They were also promised pre-publication results of the testing program if the Phase 2 effort were funded and distrubution of the information were permitted by the contract.

Significant assistance in developing the questions was provided by U.S.Government personnel, primarily from NASA and NBS. These centered on outgassing and cryogenic material behavior respectively.

3. Results of the Survey

After the sixty-seven questionaires were mailed, 23 follow-up telephone discussions determined that the surveys had been received, the recipient's willingness to participate, and the likely response time. A high percentage (18 of 23) remembered receiving the survey, and a significant number of those (14 of 18) indicated both that they would participate and that they would return the form within two weeks.

Four weeks after the surveys were mailed out, none had been returned. Thirty five followup calls were made, with contact established to twenty seven individuals. Only seven of these indicated that they felt that they could contribute significant information by completing the survey. Of the balance, four provided verbal responses which were useful, and sixteen felt that they did not have enough knowledge to respond meaningfully, but would be interrested in the results. Nine surveys were returned unopened as undeliverable. Two weeks later threef the seventeen individuals were contacted and their verbal responses noted. Three additional surveys were returned.

The net result of the survey responses (both verbal and written) confirmed the results of the previous informal survey. That is, that there is very little solid analytic or empirical information available for designers to use in establishing either detailed designs or systems performance estimates. Further, there is only a scattered technical basis for many of the design concepts where outgassing, thermal loading, and thermally-induced stress are concerned. Virtually every design is based on one or more areas of "gut feel" derived from limited prior experience.

4. Proposed Cable Configurations

Although those contacted in the survey proposed many configfurations, each along the lines of some current program requirement, a general consensus was reached on two configurations.

4.1. Shielded Single Layer Circuit
Many systems could be well served by a single signal layer design with minimal amounts of polyimide film and organic adhesives. In practice, many of these designs would range in length from several centimeters to perhaps as much as 50 centimeters. This configuration should be tested both with and without interdigitated shield lines, and each should have a thin, sputtered outer shield. This configuration is very similar to that developed for the HOE program mentioned in the Introduction.

4.2. Shielded Multilayer Circuit
A more complicated, multilayer circuit utilizing plated-thru-holes and several signal and shield layers as well as an interface for thermasonic/eutectic bonding would provide valuable information on the performance limits of high detector count arrays. Extensive thermal cycling and test-to-destruction analysis of plated thru holes was of major interest to many respondents, especially at the dissimilar metals junction between the copper plating and the nickel alloy conductors.

5. Technical Risks

5.1. Vacuum Outgassing
The greatest technical risk for a Phase 2 Contract identified by several respondents was in the area of vacuum testing for outgassing. Langmiur's equation

$$(dw/dt = 0.439A \quad M/T \quad P \quad)$$

is the classic starting point for predicting the outgassing rate of materials exposed to high vacuum. Acrylics and epoxies are commonly employed in focal plane cables used inside the dewar. Outgassed products from these materials could consist of low molecular weight acrylic or epoxy molecules from incomplete cross-linking or cure. They could also be the result of processing aids employed by the formulators of the resin; antifoam, surfactant, rheology adjusting, and other additives

contribute to the undesirable volatiles. These materials are
particularly difficult to characterize because, like imputities,
they are not part of the idealized chemical formulation. Since
these additives are generally proprietary, significant effort may
have been expended to conceal their true nature, further
complicating efforts to characterize the outgassing performance
of the interconnection cable. Further, chemical composition and
the chemical reactions during the cure cycle can be affected by
the lot to lot variations in raw materials and normal day to day
processing variations.

Where some hard vacuum and space applications require less than
1% TML and less than 0.1% CVCM, meaningful testing of these
characteristics began to be quickly viewed by the research team
as posing rather significant challenges. As additional
information was gained during the course of the study, two
additional concerns became apparent: the spectral absorbtion
characteristics of the condensates, and the volatiles which
degrade the vacuum.

Procurement of specialized, high-cost, long lead-time capital
equipment, and extensive, sophisticated testing by designers and
researchers in industry has achieved only partially satisfactory
results in this area. No doubt, these efforts could achieve
better results if a closer liasson with fabricators existed.
Nevertheless, this portion of the PTI fesability study clearly
suggests that no outgassing effort should be attempted within the
scope of an SBIR Phase 2 program. In fact, several survey
respondents suggested that the equipment costs alone would exceed
$750,000 and that meaningful tests would require a period of 18
months to 2 years after equipment installation and setup.

5.2.   Optimizing Adhesive Characteristics
        The next area of high risk would be to respond to
requests to optimize the characteristics of the adhesives
employed in the circuit manufacturing process. Major
corporations and governmental laboratories have expended
considerable time and money in this field, and it is unlikely
that PTI could significantly improve on their efforts within the
scope of the allowable Phase 2 budget. Rather than attempt to
improve on the available adhesives, two or three candidate
materials with which some experience has been gaines are
recommended: the DuPont acrylic, Pyralux, and the GE
polyetherimide, Ultem.

5.3.   Thermal Impedance
        Thermal impedance (heat loading) represents a major
concern for most LWIR systems, yet the survey respondents
indicate that the mechanisms for estimating and verifying designs
leave much to be desired. On a theoretical basis, thermal
conductance of focal plane cables plays a major role in the
thermal budget of sensor systems. This is especially true as the
number of detector signals increases with larger and larger
arrays. It is generally assumed that cable thermal conductance
is dominated by the metallic conductors and sputtered shielding
layers. This assumption is only valid in relative terms, as we

shall see, because many of the conductor materials chosen for such cables have thermal conductances only an order of magnitude greater than the dielectric materials which comprise the cable body.

For the isotropic materials of which current cables are constructed, unidirectional steady-state heat flow is related to thermal gradient by the Fourier-Biot equation:

$$Q/A = -k \, dT/dx,$$

where Q is the rate of heat flow through area A with a temperature gradient dT/dx. The proportionality constant, k is referred to as the thermal conductivity. This equation describes diffusive energy transport, as indicated by the dT/dx gradient. Dynamic thermal environments where k is independent of the temperature change give rise to another proportionality constant,

$$= k/(DC),$$

where   is the thermal diffusivity which characterizes how a temperature difference propagates through a material, D is mass density, and C is the specific heat. In general, the design assumption that the metallic conductors in the cable are the primary contributors to thermal conductivity is correct. However, as discussed in virtually all of the literature from Touloukian(4) forward, thermal conductivity data is often ambiguous, and for many materials there is a total lack of data(5). Where such data exists, widely divergent results are common because of the difficulty in obtaining accurate measurements.

The most commonly employed material for conventional avionics flexible circuits is copper. But with a nominal thermal conductivity of k = 3.9 w/cm K, a 0.010" (0,025) wide conductor of 1 oz copper (0.00145" or 0,0037 thick) 12" (30,48) long would require

$$w = kAK/l = 3.9 \times 0,025 \times 0,0037 \times 300 \,/\, 30,48$$
$$= 3.55 \text{ milliwatts per conductor @ 300K}$$

Thus a cable only one inch long with 100 conductors would require over 4 watts of cooler power just to maintain the detectors at 300K below room ambient. It is obvious why alternative materials and the minimum thickness of material are desirable. Several alternatives are, in fact, commonly employed. One alloy, Constantan(45Ni, 55Cu) has microstructure which lends itself to the photoetching of very fine lines. With a thermal conductivity of k = 0.21 w/cm K, only about 5% of copper, the thermal load becomes

$$w = 4.26 \times 0.0533 = 0.227 \text{ watts @100 traces, 1" long}$$
$$\text{or} \quad w = 0.002 \text{ watts per trace 12" long}$$

Further improvements in heat load are possible because of the previously mentioned microstructure. Constantan foil rolled to 0.0005" (0,0013) would gain a factor of 3 reduction in load, and

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TECHNOLOGY

Multilayer Focal Plane Cable Set
Fabricated for controlled thermal conductivity. Each cable has plated-thru-holes, 51 conductors @ 0.0015" lines/0.002" spaces. Thermal gradient: 14°K to 300°K.

Figure 1
-10-

would allow production of circuit traces as narrow as 0.001"
(0.0025) for a final heat load of only 0.008 watts in the 100
trace one inch cable.

Unfortunately, as Hust(6) points out, the specimen size chosen for
determination of the conductivity data is highly variable. For
example, copper would use a specimen 0.1cm (0.1) diameter by two or
three cm long, while Constantan may have been developed with a
specimen 2 cm diameter by 2 cm long. Not only is the comparative
data suspect, but clearly neither specimen has any relevance to the
conductor geometry encountered in a focal plane cable.

Finally, thermal conductivity for both copper and Constantan
varries significantly with temperature. Copper increases as
temperature drops so that at 20K it is nearly three times the
conductivity at 300K. Thereafter it drops rapidly so that at 4K
it is essentially back at 3.9 w/cm K. Constantan, on the other
hand, decreases steadily so that at 20K it is less than 1% of the
conductivity of copper at 20K. The 1% relationship is maintained
to 4K and below.

As previously mentioned, the general assumption that the conductors
are the dominant heat load is not always valid. The mechanical
requirements and distributed capacitance considerations can become
major factors driving the cable design. But the 300K conductance
of polyimide is generally taken at about 0.02 w/cm K, or 10% of the
conductivity of Constantan. But the polyimide content of a cable
may well exceed ten or twenty times that of Constantan unless
prudent design tradeoffs are made. Designers are frequently
unaware of this factor, and specify 0.002" or 0.003" polyimide
encapsulation in order to reduce distributed (plate) capacitance
loading. The effect of this on conductance readily shows the
problem:

$$w = kAK / l = 0.02 \times 5.08 \times 0.015 \times 300 / 30.48 = .015w$$

compared with 0.019w for the Constantan circuit. When the actual
conductivity at 4K is used, the presumed theoretical heat load
drops more than an order of magnitude, but is now likely dominated
by the undetermined characteristics of the polyimide.

Evaluation of cable configurations with various emissivities and in
a representative environment is not likely to provide meaningful
results without a high degree of coordination with a facility
capable of providing suitable test chambers. The scope of this
evaluation is clearly far beyond the time and budget of a Phase 2
effort.

Thermal cycling to cryogenic temperatures for test-to--
destruction analysis of the plated-thru-hole features, while posing
acceptable technical risk, should include involvement of a variety
of metallurgical specialsts from several disciplines. The tests
should also be integrated with the thermal loading and
materials-related outgassing study to provide relevant and useful
design data.

5.4. DC Impedance

Whereas near IR applications have serious limitations on the DC resistance of focal plane cable traces, the high-impedance detectors frequently encountered in far IR applications are far more forgiving. This is indeed fortunate, since the thermal conductivity so important in these LWIR systems has a direct relationship to the electrical resistivity. The relationship is characterized in the Wiedemann-Franz-Lorenz law(7):

$$k/* = k* = LK$$

where k is thermal conductivity, * is electrical conductivity, * is electrical resistivity, L is the Lorenz number, a proportionality constant, and K is the absolute temperature. Thus the design comparison in which the thermal conductivity was reduced to only 5% of the copper circuit value by use of Constantan should result in a twenty-fold increase in DC resistance. Published room temperature data yields

        copper @ 1.72 micro ohm-cm
        Constantan @ 50 micro ohm-cm; 50 / 1.72 = 29.

While the discrepancy is not trivial, it is not as important as the consideration of the actual resistance. Resistances for the cable previously are calculated to be:

        R = *1 / a, where 1 is length, a is cross-sectional area
                copper: R = 1.72 x 30,48 / 0,025 x 0.0037 = 0.57 ohm
                Constantan R = 16.4 ohm.

Reducing conductor thickness to 0.0005" (0,0013) and width to 0.001" (0,0025) yields calculated resistances per trace of:

        copper: R = 17 ohm
        Constantan: R = 492 ohm.

The nominal resistivity of the materials change with temperature as well;
        Copper: @ 300K = 1.7 micro ohm-cm; @ 4K = 0.016 (8)
        Constantan @ 300K = 50; @ 4K = 46.06 (9)
System designs need to incorporate DC resistance factors in design trade-offs, and innovative concepts utilizing thermal clamps in the mechanical design and electrical/thermal trace restrictions in the cable design to localize both thermal gradients and areas of high electrical resistance have been occasionally postulated. None have been explored in any depth to the proposer's knowledge.

There are no technical risks identified in a DC impedance testing program.

5.5. Distributed and Parasitic Capacitance
Capacitive loading of high- impedance signals increases as the bandwidth (spectral content) of the signals increases. Greater speed and sophistication of realtime digital signal

processing are of little value if the signals are distorted due to loading. The simplified equation(10) generally employed is:

$$C = 2.7 \, w \, * \, / \, s \, \{1 + s \, / \, * \, w \, [1 + 2.303 \, \log(\, 2* \, / \, s)]\}$$

where C is the plate capacitance for a single conductor and shield, * is the dielectric constant, 3.4 for polyimide, w is the trace width, and s is the spacing between trace and shield. The calculation yields

$$C = 2.7 \times 3.3 \times 3.4 \, \{1.42\} = 43 \, pf \, / \, foot, \, per \, side$$
$$= 86 \, pf$$

for a 12 inch cable with 0.010 lines and 0.003 dielectric. However the range of validity for this equation is limited to line widths greater than 0.020" and ignores interdigitated shield line effects. A more precise equation(11) which only assumes zero thickness traces is:

$$Z \, * \, k = 29.98 \, ** / \, \ln 2[(1 + *k')/(1 - *k')]$$

where k' = tanh(* w/2 b); w is trace width and b is the total distance between the two shield planes.

Test verification of the simpler equation was accomplished as part of the Phase 1 effort, but only within the confines of the limited geometry available within the Phase 1 budget. The first-order effect of dielectric thickness is very apparent in the model equation. A designer who requests that PTI fabricate a 12 inch cable 0.002" total thickness with no more than 27 pf distributed capacitance will need to wait for a significant breakthrough in the dielectric constant of materials.

Despite the low risk associated with these simple AC Impedance tests, it is not at all certain that meaningful results would be obtained from a study of these characteristics which was not coordinated with efforts to quantify the three risks which the author feels are beyond the scope of SBIR program limitations.

5.6.   Interconnection Geometry and Density
        There are no technical risks identified with the evaluation of a variety of geometries and circuit densities other than those imposed by the fabrication limits of the processes.

5.7.   Produceability and Cost
        A Produceability Study, by definition poses no risks, as its purpose is to determine the limits of current production and the projected costs of deployment quantities of the various geometries.

The following description is intended only to detail the photofabrication process as it relates to focal plane cables. The

process itself has a wider range of materials, applications, and techniques beyond those indicated.

5.7.1 Materials for photofabrication generally must be flat, smooth, and free from buckles, warp, or creases. Thus care in handling the thin foils utilized in focal plane cables is essential.

5.7.2 The materials must be prepared for processing several ways. The thin foil must be carefully cleaned, passivated, and treated for adhesion promotion. The foil is then bonded to the dielectric medium, usually with an adhesive, in a laminating press. (New technologies provide additional possibilities, including sputtered copper and special nickel alloys, and are envisioned as suitable for evaluation in Phase II) For the proposed cables, those laminated will be done for one hour at 350 F at clamping pressures of 200 psi. After removal from the press, the laminate is recleaned and prepared for coating with an ultra- violet (UV) light sensitive material.

5.7.3   The light-sensitive material, commonly referred to as a photoresist, generally comes in two forms: a liquid which can be sprayed, dipped, spread, or spun on, or a dry film which is laminated between heated rollers. A negative-working photoresist will likely be employed (this refers to the effect which UV light has upon the resist). Fine-line features such as those envisioned for the cables would necessitate spin-coating to obtain patterns with adequate resolution. After coating, the resist is precured or stabilized before the next step.

5.7.4 In the imaging proccess, a photomask is produced on an artwork generating device and photographically reduced to its final size. This piece of film, with clear and opaque areas corresponding to the desired final trace pattern, is placed in intimate contact with the sensitized laminate. A vacuum draw-down is employed to assure uniform contact. Exposure to a calibrated UV light source for a controlled time alters the chemistry of the photoresist where the light strikes it through the clear areas of the photomask, creating a latent image on the foil.

5.7.5 The image is developed in appropriate solutions, removing the resist from all areas of the foil except where conductor traces are desired in the final cable.

5.7.6 Chemical baths are formulated and tightly controlled to attack the metal without disturbing dither the remaining photoresist or the dielectric backing. This etching process will generally remove about 0.002" to 0.005" of metal per minute, over the entire surface of the laminate. In production, such a laminate would have several, up to a dozen or so, of the cable patterns.

5.7.7 The remaining photoresist is then removed, and if the cable is to be fully encapsulated, it is returned to the laminating press operation.

While limited fabrication was involved in Phase 1, Phase 2 or a successor program would rely heavily on PTI's expertise in the area of focal plane cable fabrication to produce the baseline evaluation units.

6.0   Test Samples and Results

During the survey preparation and response interval, test samples of a representative focal plane cable were fabricated and subjected to preliminary electrical testing. In order to minimize the measurement error at the point of termination, the circuits were produced in approximately 22 inch lengths. Each cable had an established lengths of 0.008"/0.008" and 0.004"/0.004" conductors and spaces. Exhibit 2 shows artwork from one of these test cables (foreshortened to fit on the report page). These cables were impedance tested in a multilayer configuration at three test frequencies: 60, 1000, and 10,000 Hz. Test data is shown in Exhibit 3.

A sufficient number of these circuits were produced to obtain an indication of the produceability of such a confirguration. The 0.008" region yielded better than a 90% good circuits, while the higher density 0.004" region resulted in a 60% yield.

The test data indicates reasonably good agreement with the model selected, as indicated earlier in the body of this report.

7.0   Proposed Design Parameters

Based upon the survey results and the preliminary test results, each of the two configurations proposed above should have the following parameters as design goals (some of which are mutually exclusive):

1.   DC resistance of less than 100 ohms per foot.
2.   Capacitance trace to trace and trace to shield less than 50pf per foot.
3.   Test geometry with 0.0025", 0.005", and 0.010" traces, each with the same range of spacing. The dielectric thickness should be 0.0005", 0.001". and 0.002", and each cable should be 50cm long. Foil and sputtered shields should be employed on both single and multilayer designs.
4.   Alternative materials with lower dielectric constant should be evaluated, with the recently introduced air-entrained teflon as a prime candidate.

8.0   Conclusions

Analysis of the survey results and preliminary testing indicates that several areas of major technical and budgetary challenge do not justify pursuit of a Phase 2 SBIR contract due to the budgetary limitations of the SBIR program. An inadequately

funded effort would provide only superficial information to the
designers responsible for the interconnections and systems
evaluation associated with LWIR and other cryogenically-based
electro optic systems.

The need for this baseline data appears to be critical. however.
indicating that SDIO should give serious consideration to
requesting proposals from organizations currently involved in
various aspects of the relevant technology.

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12) op. cit.
13) ibid

pti

PHOTON APPLICATION TECHNOLOGY, INC.

FOCAL PLANE ARRAY INTERFACE SURVEY
SEPTEMBER, 1983

RETURN TO _____
FILE _____

1. Do you personally oversee or have involvement in programs utilizing II, LWIR, IR Laser, Starlight, or other EO systems in which cryogenic heat loading, capacitive signal loading, high-density termination, and RFI/EMI/EMP considerations would benefit from improved focal plane array (FPA) interconnect technology?
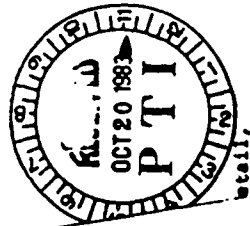
   YES

2. Do you feel that there is a need for such an effort, if not for programs in which you have direct involvement, for other programs of which you are aware?

   YES

3. Beyond (or instead of) developing broad materials and performance characterizations for the FPA geometries and environments, what areas would be of particular interest or future value to you?

   LOW COST, HIGH RELIABILITY INTERCONNECTION/TERMINATION
   (MASS TERMINATION AND/OR CONNECTORIZATION)

4. If such a program were funded would you be interested in assisting in developing the "shopping list" of desirable attributes for focal plane array interface/interconnect devices?

   YES

5. Do any of your FPA needs involve VHSIC integration which would benefit from appropriate interconnect technology development?

   No (NOT VHSIC)

Thank you for your time and participation. Please ... to add comment ... is optional.
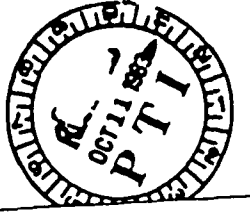
PHOTOFAB. TECH.,INC.
DERRY,N.H. 03038

Part I

A. Electrical Properties   Rating 0 - 5   Specification
                                                                Value

   1.   Capacitance/Delectric Constant

   2.   Insulation Resistance

   3.   Disipation Factor

   4.   Conductor Resistance

B. Thermal Properties

   1.   Thermal Conductance

   2.   Temperature cycling

   3.   Additional comments

C. Mechanical Properties

   1.   Out gassing

   2.   Flex requirements

   3.   Peel strength

   4.   Dimensional stability

   5.   Additional comments

D. Each of the following is known to have an effect on the performance of the FPA system. Briefly comment on each of the following as it applies to the design and performance of the interconnect device and its impact on the overall mission requirement.

   1.   Out gassing of materials used in the vacuum portion of the system.

   2.   Thermal impedence of the FPA interconnect device and the resulting impact on system performance or lifetime.

   3.   The geometry and circuit density at the FPA connection as well as at the processor termination.

4. The method used to connect the flex cable to the FPA assembly and to the processor.

5. Encapsulation of part or all of the sub-assembly.

What other material properties, design requirements, assembly requirements, manufacturing processes, mission requirements, etc., do you feel are or will be important in the design of current and future focal plane cable interconnections?

Do you have a current design or performance issue which you would like to discuss further?

Part II

1. Langmiur's equation ($dw/dt = 0.439 A \sqrt{M/T} \, P_v$) is the starting point to predict the outgassing rate of materials exposed to high vacuum. Have you found this or other models useful to predict the outgassing properties of materials used in FPA systems?

2. Some space specifications required less than 1% TML and less than 0.1% CVCM. Do you have data which would indicate that these levels are acceptable or unacceptable for FPA sytems? If not, what level of outgassing would be acceptable?

3. In your experience with IR systems, what are the primary and secondary detrimental effects of outgassing?

4. Acrylics and epoxies are commonly employed in focal plane cables used inside the dewar. Outgassed products from these systems could consist mainly of low molecular weight acrylic or epoxy molecules from incomplete cure, or they could be the result of processing aids, such as antifoams, surfactants, thickening agents, etc. Have you found useful published data which identifies the chemical nature of the products of outgassing? Are certain chemical functional groups (ester, acrylic, epoxy, urethane, etc.) particularly deterimental to system performance? If yes, would you identify them?

5. Chemical composition and the extent of chemical reactions can be affected by the lot to lot variations of raw materials and the normal day to day processing variations. Have you observed variations of system performance or system lifetime which could be related to such variations?

6. Two major factors associated with outgassing are believed to be critical: condensates which absorb in the spectral region of interest, and volatiles which degrade the vacuum. Regarding vacuum degradation, have you found any of the classical models useful to relate the thermal transport properties of the degraded vacuum to the volatile content of the system? If yes, what model do you use?

7. Do you or your facility have the capability to do volatile content measurements? If so, are you satisfied that the results are useful for your purposes?

8. What technique do you currently use to connect the flexible circuit to the devices at each end? Do you see this termination technique changing in the future? If yes, how?

9. Electrical properties of adhesives can be significant in wide bandwidth systems utilizing fast pulse risetimes. Is dielectric constant, dispation factor, volume resistivity, or some other factor a major, significant, or a minor concern?

10. Thermal cycling induced creep was demonstrated during the development of the HOE cable set. The test procedure involved repeated shock immersion of the cable in liquid nitrogen. Have you observed changes in system performance which were caused by thermal cycling? Do you use a test method to evaluate the effects of thermal cycling?

11. Several of the interface geometry capabilities applicable to focal plane arrays are detailed in IPC-TP-506 (enclosed). What geometries do you see in the future and what density of I/O terminations will be necessary to achieve the desire results?

12. Solder is a common method to connect flexible cables to connectors. Due to size limitations this may not be true in the future. What do you anticipate will be the requirement or method of the attachment of the interconnecting flex cable to the focal plane array and to the processor?

13. Thermal conductance of focal plane cables plays a major role in the thermal budget of sensor systems. The unidirectional steady-state heat flow is related to the thermal gradient by the Fourier-Biot equation: $Q/A = -kdT/dx$ where Q is the rate of heat flow through area A with a temperature gradient dT/dx and k is the thermal conductivity. Have you found this equation or others to be useful to calculate thermal conductance? If yes, how do you handle the fact that the "constants" used vary with temperature? Do you take into thermal conductance calculations both the conductor and the insulation materials?

14. Thermal conductivity has a direct relationship to the electrical resistivity characterized by the Wiedimann-Franz-Lorenz law: $k/\sigma = LK$ where k is thermal conductivity, σ is the electrical conductivity, L is the Lorenz number and K is the absolute temperature. Obviously if thermal loading is to be reduced a compromise must be made in electrical conductivity. Do you use these relationships in making design trade offs? Do you have any data on mechanical designs or electrical/thermal trace restrictions in order to reduce these effects?

15. Capacitance is give by: $C = 2.7 \, w \, \epsilon \, / \, s \, \{1 + s \, / \, \Pi \, w \, [1 + 2.303 \log (2 \pi / s)]\}$ where C is the plate capacitance, ϵ is the dielectric constant, w is the trace width and s is the spacing between trace and shield. However, this equation is limited to line width above 0.020". What equation do you use to calculate distributed capacitance? Do you use these models when developing design specifications for FFA cable assemblies?
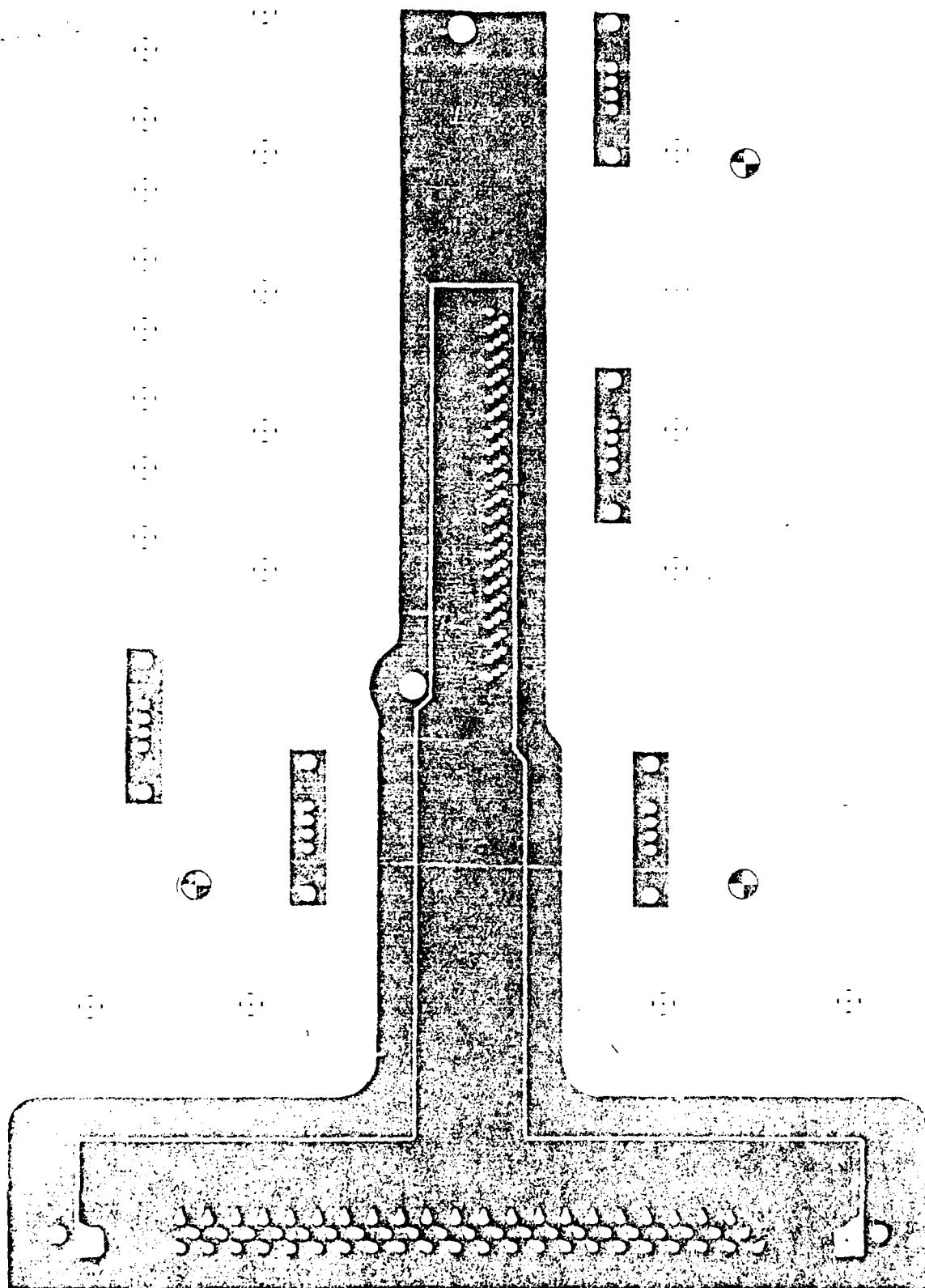
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Exhibit 1

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