Required Features and Performance Summary,
Proof-of-Principle Radiometer System Design

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Table of Contents

1.0 Defining the Instrument .......................................................3
  1.1 Features, Housings ..........................................................4
  1.2 Features, Controller Panels..............................................5
2.0 Environment ........................................................................6
3.0 Optimization .........................................................................7
4.0 Performance Criteria .............................................................8
5.0 References ............................................................................9
6.0 Copyright Notice ....................................................................9
**System Design Outline**

This series of documents reasons through the requirements for the POP-OMD before starting the detailed design. They result in a table of technical specifications, a table of environmental limits, and a list of required features.

**Verification Procedure**: The Proof-of-Principle Opto-Mechanical Detector verifies analytic predictions for mechanical gain, gap spacing control via feedback, and photon noise suppression. An experiment which will accomplish this is laid out in detail. The experiment tells what features and performance the POP-OMD must have to provide verification.

**Required Features**: The experiment requires certain hardware features. Others are required to make the instrument easy to use and understand. What environmental range must be accommodated? Gather these requirements together as specifications.

**OMD Design Simulation**: With the required sensitivity and features known, what is the simplest OMD that will work? Use the OMD simulation program to determine the MEA design parameters. Some specifications and features required of the Controller will result.

**Functional Block Diagram**: Begin the Controller circuitry design by identifying the electronic functions required and how they connect. The block diagram functions, MEA requirements, verification experiment performance, features, and environment will produce the specifications for the function blocks.

**Gap Feedback Loop**: The feedback loop which holds the gap at the quiescent setting requires time constants measured in months. Can system level analysis show such loops to be feasible? If not, another approach must be found.

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**1.0 Defining the Instrument**

The system-level specifications define what the instrument does, what level it performs at, what conditions it works under, and what accommodations it has for the user. Documents that discuss ways to implement the definition come later in the design sequence.

The system-level specifications are non-technical requirements such as a client for the design would request. They are the essential first step in defining the device to be built.

[Years of design contracting have demonstrated that the most practical system-level specifications are non-technical. They answer the question, "What do you wish to accomplish?", which purposely avoids details of how it might be done. Any effort to inject "expert" design...
Required Features Summary

advice has been vigorously rejected. Consequently, the contract specifications accepted for an instrument look the same whether from an experienced electronics engineer or a non-expert. Non-technical system specifications for the Controller electronics will be shown sufficient to determine all technical decisions in the design.

In this case, the user wishes to experimentally verify three aspects of the MEA's performance that have been predicted analytically. The first step in the detailed design devised an experiment which could test the claims using accepted scientific methods.

The experiment design provided minimal specifications for an OMD that could successfully carry out the experiment. The engineering details of that instrument were determined using the OMD simulator.

The next step produces detailed system specifications for the electronics, based on a combination of non-technical user requests and technical requirements from the experiment design and OMD simulation.

1.1 Features, Housings

The experimental setup of Figure 1, Ref A "Verification Procedure Summary" shows the POP-OMD as a small box positioned to align with the infrared beam from the blackbody. The control circuitry will be too bulky to fit in an easily positioned box. Instead, the instrument is divided into at least two boxes connected by a flexible cable.

The electronic design must provide the following features for performance verification and confirmation of analytic models:

<table>
<thead>
<tr>
<th>SYMBOL KEY</th>
</tr>
</thead>
<tbody>
<tr>
<td>□</td>
</tr>
<tr>
<td>✔</td>
</tr>
<tr>
<td>⚫</td>
</tr>
<tr>
<td>❉</td>
</tr>
</tbody>
</table>

Sensor housing: physical requirements

- Small enough for easy mounting and positioning
  - Controller cabinet for remaining components
- Cable connects the housing to the cabinet
  - Minimum electronic components
    - For few cable wires, flexibility, small diameter, few pins
- Sealed window
  - For air current noise suppression
- Optical bench mounting option
  - Adapts to standard translation stages
  - Heat sinking to optical table or mounting rail
Sensor housing: verification requirements
- Removable opaque cap
  - light-tight fit
  - blackened inside surface
    - for NEP (noise-equivalent-power) measurement
- spectral filter
  - irradiation calculation

Sensor housing: diagnostic instrumentation
- thermal feedback monitor
- thermal resistance confirmation via air pressure change
  - airtight
    - hold vacuum and partial pressures
  - vacuum pump barb
    - vacuum pump to produce reduced pressures
  - air pressure sensor (vacuum)
    - calculate gap and stack thermal resistance from pressure
- Electro-Optic Enhancement (EOE) feedback source
  - self-test irradiation source
    - for frequency and linearity testing
  - confirm EOE ability to expand bandwidth
    - user request

Cable
- flexible and light weight
  - user request
- field replaceable
  - for changing cable length or repair
    - user request
- locking connector at Controller
  - strain relief
- Sensor housing end mates to connector
  - strain relief
  - vacuum-sealed feed-through
    - thermal resistance diagnostics

Controller: physical
- in shielded cabinet
  - meet EMI standards
  - provide panels to mount controls, indicators, connectors
- power supply shares cabinet
  - compact
    - setup ease, although noise and heat require more design work
1.2 Features, Controller Panels

The Sensor Housing contains the MEA, Blumlein Bridge, and gap control actuator - a thermoelectric heater/cooler perhaps.

The Controller Cabinet contains the power supply, bridge driver, signal processing, control loops, input/output connections, and user controls.

- **Power connector**
  - ON/OFF switch
  - 120Vac or 240Vac switch

- **Sensor cable connector**

- **Output connector**
  - BNC connector, not grounded to panel
  - front and rear panel connectors

- **Power indicator light**
  - confirms AC power through circuit protector
  - confirms regulators working

- **Ready-to-operate visual indicator**

- **Ready-to-operate signal**
  - BNC connector, not grounded to panel
  - for activating other equipment

- **Bandwidth expansion selector switch (US Patent 5574287)**
  - narrow
    - provides highest S/N ratio
  - medium
    - provides highest noiseless bandwidth expansion
  - wide
    - exchanges SNR for rise time

- **Test signal input**
  - BNC connector, not grounded to panel
    - for driving internally simulated IR source

- **Remote temperature readout connector**

- **Remote air pressure readout connector**
2.0 Environment

The instrument's interface with the world is its environment. This broader interpretation includes power, cabinet space, Internet connection, transportation, and other limitations in addition to the traditional air temperature, vibration, humidity, etc.

The POP-OMD's Verification Procedure is performed in a laboratory. The test verifies MEA concepts, not the prowess of the Controller and other support equipment. To minimize any effect of their shortcomings, the environmental ranges are kept to a practical minimum.

Table 1 defines conditions which assure independence from the environment. (The parameter ranges in the Controller design specifications are likely to be wider.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Nom</th>
<th>Max</th>
<th>Units</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating temperature</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Nominal AC line voltage</td>
<td>115</td>
<td>118</td>
<td>120</td>
<td>Vrms</td>
<td>1</td>
</tr>
<tr>
<td>AC Variation from nominal</td>
<td>-3.0</td>
<td>+3.0</td>
<td></td>
<td>%</td>
<td>2</td>
</tr>
<tr>
<td>AC line voltage frequency</td>
<td>48</td>
<td>62</td>
<td></td>
<td>Hz</td>
<td></td>
</tr>
<tr>
<td>AC line noise, 0.1Hz to 100KHz</td>
<td></td>
<td></td>
<td>-66</td>
<td>dbc</td>
<td>3</td>
</tr>
<tr>
<td>Seismic acceleration, 0.1Hz to 10.0Hz</td>
<td></td>
<td></td>
<td>1.0e-7</td>
<td>m/s²</td>
<td></td>
</tr>
<tr>
<td>Heat sink thermal resistance</td>
<td></td>
<td></td>
<td>1.0</td>
<td>°C/W</td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td>non-condensing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Verification experiment environment

1. Nominal voltage varies with locality and supplier
2. Ferromagnetic constant voltage transformer is suggested
3. 60mVrms/√Hz at 120Vrms line voltage

3.0 Optimization

The prioritized optimization list determines the choice when several solutions or components satisfy the technical requirements. The list submitted for our imagined user is:

1. construction ease
2. available parts
3. cost
4. higher performance
5. extended capability

The laboratory equipment, assembly equipment, and assembly help at the current facility is very limited. Manual assembly by an older assembler requires larger parts and less crowding. The top consideration intends to avoid delays caused by difficult assembly or lack of specialized equipment.

If some choices are left after construction ease is considered, they are rated on availability. Production parts are preferred to custom built, even at the expense of a larger performance margin. Parts in laboratory stock that meet specifications are used even if more recent parts offer some advantages.

The first two optimizations most often result in a single choice, but if not, lower out-of-pocket cost can be used as the tie breaker.

Higher performance and extended capability will rarely be reached, but they are reminders of criteria that might be given higher priority in other applications. Some other examples are: lowest power, highest reliability, lowest production cost, lowest weight, shortest development time, etc.

Optimization only applies when several choices all meet the technical requirements in the specifications.

4.0 Performance Criteria

The Verification Procedure measures NEP and its derivative, D-star. How will this number confirm the the performance predictions have been met?

Gap feedback loop: The feedback loop must be working for the POP-OMD to produce an irradiation response. If it has not balanced the Blumlein bridge, the output will be locked at the positive or negative supply limit, unable to show any signal induced variation.

MEA gain: The POP-OMD relies on 1100X gain from the MEA to bring the signal to a viewable level. If the signal amplitude is significantly less than predicted, the MEA gain is suspect.

Photon noise suppression: The photon-noise-limited D-star is $2.7 \times 10^{10}$ Jones for a detector viewing a 300°K background with near 1.0 emissivity. Beating this limit by at least a factor of 2.0 is offered as sufficient proof that the POP-OMD includes a feature to suppress photon noise without affecting the signal. However, the measurement's lower error bracket interval must be added to the limit to assure that experimental errors have not made the device appear better than it is.
Ref B calculates the error brackets for the Verification Procedure. They are ±24% with 95% confidence. Consequently, the measured D-star must be greater or equal to \(2.7 \times 10^9 \times 2 \times 1.24 = 6.7 \times 10^{10}\) Jones.

A conservative POP-OMD design which just meets the criterion is simulated in Ref C. However, the design does not preclude reducing the gap and increasing the bridge drive. With a factor of 2 changes for both parameters, the D-star would reach \(3.14 \times 10^{11}\) Jones.

5.0 References


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