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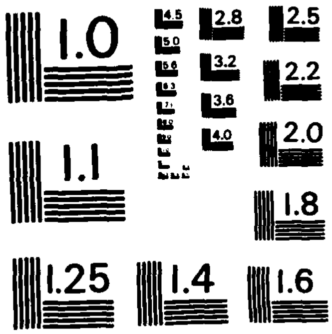


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ARRAY POSITIONING
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SAIC/85-1077

26 June 1985

Contract No. N00014-85-C-0084




Prepared
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Prepared
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# REPORT DOCUMENTATION PAGE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The measurement of acoustic signals with large, line arrays which use free suspended hydrophones, must be concerned with the location of the hydrophone if certain array measurements are to be accurate. This report discusses location error issues and suggests a hydrophone location technique and an array design to meet the test objectives and data requirements.

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# ARRAY POSITIONING REQUIREMENTS

## 1. Background

The Ruby Array of RANGEX-85-1 is designed to estimate the degradation of the present and future BQQ-5 system due to environmental effects in the Arctic. Errors in array element positioning greater than .1 wavelength may cause degradation of array performance which is indistinguishable from environmental effects. As the Ruby array will be required to operate up to 350 Hz, this creates an element positioning requirement of 1.35 feet.

In the Arctic environment, ocean currents can be expected to deflect hydrophones of the Ruby array, which are suspended at 100 feet, by more than 1.35 feet. However the acoustical effects of the mispositioning of array phones can be compensated for if their position can be measured to this tolerance. Two system concepts for array element position measurements have been designed by Joe Collins that can provide the required accuracy. The first is a simple concept for a relatively benign environment, designed as a quick response for the RANGEX-85-1 experiment. The second is a more sophisticated system that provides separate channels for timing signals, continuous monitoring of phone positions, and allows for complex motions of the array phones. This report summarizes both designs for use in future exercises as required.

## 2. Measurement Objectives

A series of acoustic measurements involving the RANGEX-85-1 arrays have been planned, all operating in the frequency range below 350 Hz. A total of 33 hydrophones are closely spaced in 3 independent arrays, sharing common phones in some cases. The array configuration, as of mid-February 1985 is shown in Figure 1. The three "pingers" to aid in positioning the phones are indicated by their X-Y coordinates.

The line arrays, Array X, Array Y and the vertical line array (co-located at the intersection of the X and Y arrays), are designed to provide directional measurements of the signal and noise as well as spatial and temporal coherence measurements. Signal power level at the beamformer output and time spread measured at the beamformer output are most sensitive to errors in the relative position of the array phones.

The uncertainty in phone locations is related to the acoustic measurements as follows:

Table 1.

| Function | Consequence |
|---|---|
| • Beam power output (signal) | Error in beam power measurement, $\tilde{P}(0)=[e^{-\sigma_\phi^2}+\frac{1}{N}(1-e^{-\sigma_\phi^2})]P(0)$, where: $\sigma_\phi = \frac{2\pi F_o \sigma_x}{c_o\sqrt{SNR}}$, $F_o$ = frequency of interest, $\sigma_x$ = RMS phone displacement in the direction of the beam, |

Table 1 (Continued)

| Function | Consequence |
| --- | --- |
| | $c_o$ = ambient sound speed,<br>SNR = signal-to-noise ratio in dB,<br>N = number of phones in the array,<br>P(0) = design power response of the beamformer, on-axis,<br>$\tilde{P}(0)$ = actual power response of the beamformer, on-axis |
| • Time spread (signal)/ frequency coherence | Error in time spread, directly proportional to RMS position error,<br>$\sigma_t = \sigma_x/c_o$,<br>where: $\sigma_t$ = additional apparent time spread,<br>$\sigma_x$ = RMS phone displacement in the direction of the source,<br>$c_o$ = ambient sound speed |
| • Frequency spread (signal)/ error in time coherence | Little or no impact. |
| • Angle spread (signal)/ spatial coherence | Little or no error in measuring spatial coherence at these frequencies. |

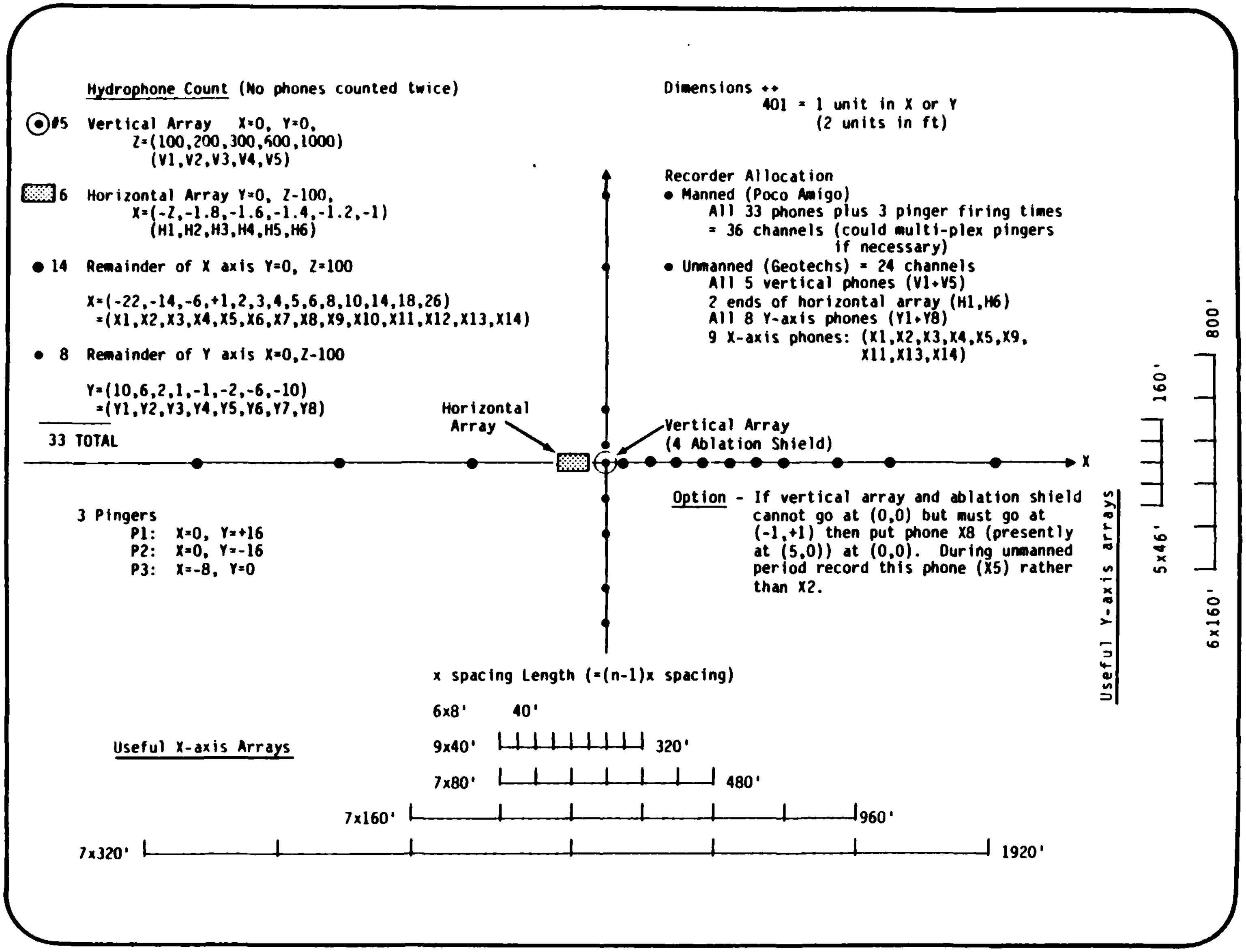


Figure 1. Array Configurations (RANGEX 85-1)

The design objective is to reduce measurement errors by identifying phone position so that corrections can be made before beamforming operation. The "pinger" signals are intended to reduce phone location uncertainty to levels whereby the array measurements of environment on acoustics are not swamped by phone position problems.

## 3. Participants

For information purposes, the following individuals were involved in defining the instrumentation and hydrophone selections for the RANGEX-85-1. They also helped in defining options available for the phone location design, so that existing equipment could be utilized fully. The list of contributing individuals includes:

Table 2.

| | | | |
|---|---|---|---|
| Jerry Santos | NUSC - Newport | | (401)841-3368 |
| Dick Manocke | NUSC - Newport | | (401)841-3933 |
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| Beau Buck | PRL | Ice Man | (805)684-0441 |
| Jim Lastinger | NRL/Orlando | Phone Test | (305)859-5120 |
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| Larry Ivey | NRL/Orlando | Transducer | (305)859-5120 |
| Ken Dial | NORDA | Instrumentation | (601)688-4907 |
| Norm Gholson | Neptune | Instruments | (601)799-2449 |
| Joe Collins | SAIC | System Design | (703)827-4746 |

## 4. System Performance Requirement

### 4.1 Time Resolution/Accuracy Requirements

The maximum frequency of interest is 350 Hz. At the expected sound speed of $c_o$= 4723'/sec, the acoustic wavelength is

13.5', with a period of 2.9 msec. It is desirable to be able to "measure" phone locations to 0.1λ or 0.29 msec; at 350 Hz this requires a resolution of 1.35' in space. Values of time resolution between 0.29 (0.1λ) and 0.36 msec (0.12λ) will be acceptable for the measurements being made. (This is equivalent to phase measurements of 36° to 45° at 350 Hz.)

## 4.2 Performance Analysis

The pulse selected is 1 msec in duration to ensure adequate signal level for the expected transmitter source level and to provide the necessary time resolution; center frequency if the pulse is to be 1.2 kHz which is compatible with the other instrumentation. The arrival time of the pinger pulse is estimated by observing the onset of the pulse; the accuracy of this estimate is not adequate by itself and will require pulse averaging. When the signal-to-noise ratio is about 20 dB or more, the pulse arrival time can be estimated to better than .1 msec, as shown in the following example:

Example: 60 ft Max Depth of J9

For the case where the SNR is $\geq$ 20 dB the time resolution for the 1-msec pulse can be expected to reliably approach 0.1 msec. This is shown by the following for the high SNR case:

$$\Delta t = \frac{1}{BW \left(\frac{E_T}{N_O}\right)^{1/2}}$$

where $\Delta t$ = RMS error - sec

BW = Bandwidth of pulse - Hz $\left(\frac{1}{1\ \text{msec}}\right)$

$$\frac{E_T}{N_o} = SNR$$

$E_T$ = Total Energy

$N_o$ = Noise Spectrum Level

In addition, ping averaging can be used to further reduce the time error ($\Delta t$) as $\sqrt{n}$, where n = number of pulses. For n=10 (the design criteria), $\Delta t$ is reduced by another factor of 3. Therefore, the combination of a 1-msec pulse, a large SNR and n-pulse averaging will provide a reliable time measurement of better than 0.1 msec, an operating accuracy better than the resolution needed.

The measurement geometry is shown in Figure 2, highlighting the end hydrophones, which have the worst case geometry. Assuming a 0.1 msec measurement for each of the three transmitters, the resultant RMS uncertainty is less than 0.14 msec, which results in a measurement uncertainty of .66 feet, well within the acceptable error defined earlier.

The geometry in Figure 2 also provides the basis for the worst-case multipath analysis. The receiver is at a 100-ft depth and the transmitter at 60 feet. With a maximum source-receiver distance of 1150' (the worst case), a multipath arrival reflected from the ice will be 2.2 msec behind the direct path pulse, which is more than adequate separation.

## 5. System Design

### 5.1 The Basic Design

The basic design will measure the distance from each pinger to the phones as well as the relative position of

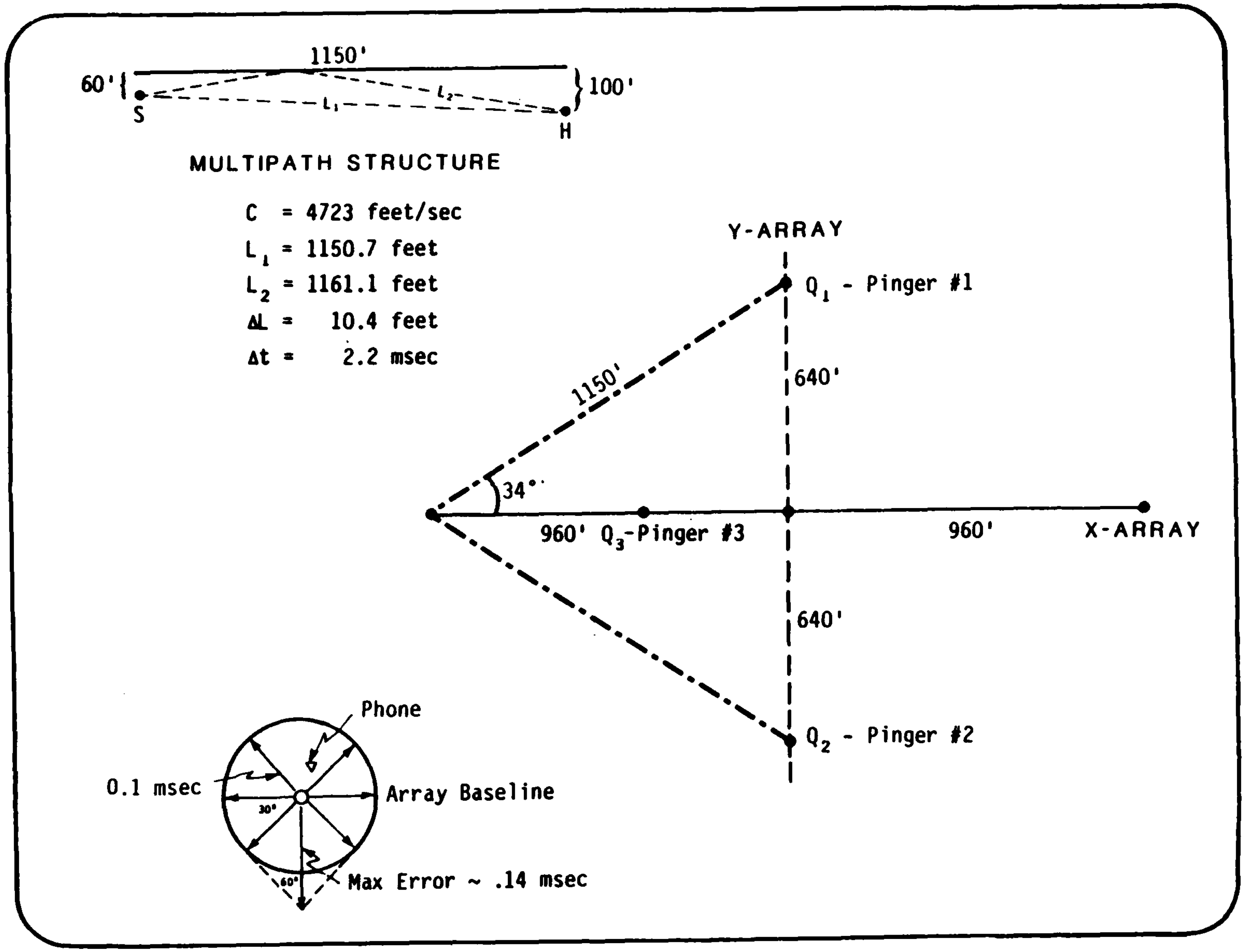


Figure 2. Configuration for Monitoring Array Shape

each phone to the "array". The key unknown is whether hydrophone motion in the form of a "watch-circle" is set up due to the expected currents. Prior arctic current data suggests that the currents are relatively low and stable. If the speed of hydrophone motion is as expected, measurements with the proposed system will be adequate.

### 5.2 The Preferred System Design

The preferred system design is shown in Figure 3. In this approach, the pinger pulses are isolated from the data by sharp low-pass filtering. Thus phone location data can be collected on a continuous basis, even during data transmission. The minimum spacing between pinger pulses is then limited by self-noise considerations due to ice and bottom reverberation. A five-second space between pulses should allow enough separation.

### 5.3 RANGEX-85-1: Simplified Design

The simplified system design is shown in Figure 4. Noise and signal levels are shown for reference and the pulse input levels are shown. The 17-dB SNR assumes average ambient conditions. Contributions from submarine signatures to the noise level should be negligible in the frequency band of the pinger system.

In this design, the pinger pulses are not isolated from the data. For this reason hydrophone location data cannot be monitored continuously during periods of data collection. It is recommended that every fifteen minutes during the collection of data a set of ten pings from each projector are recorded. The planned cycle of pings is shown in Figure 5.

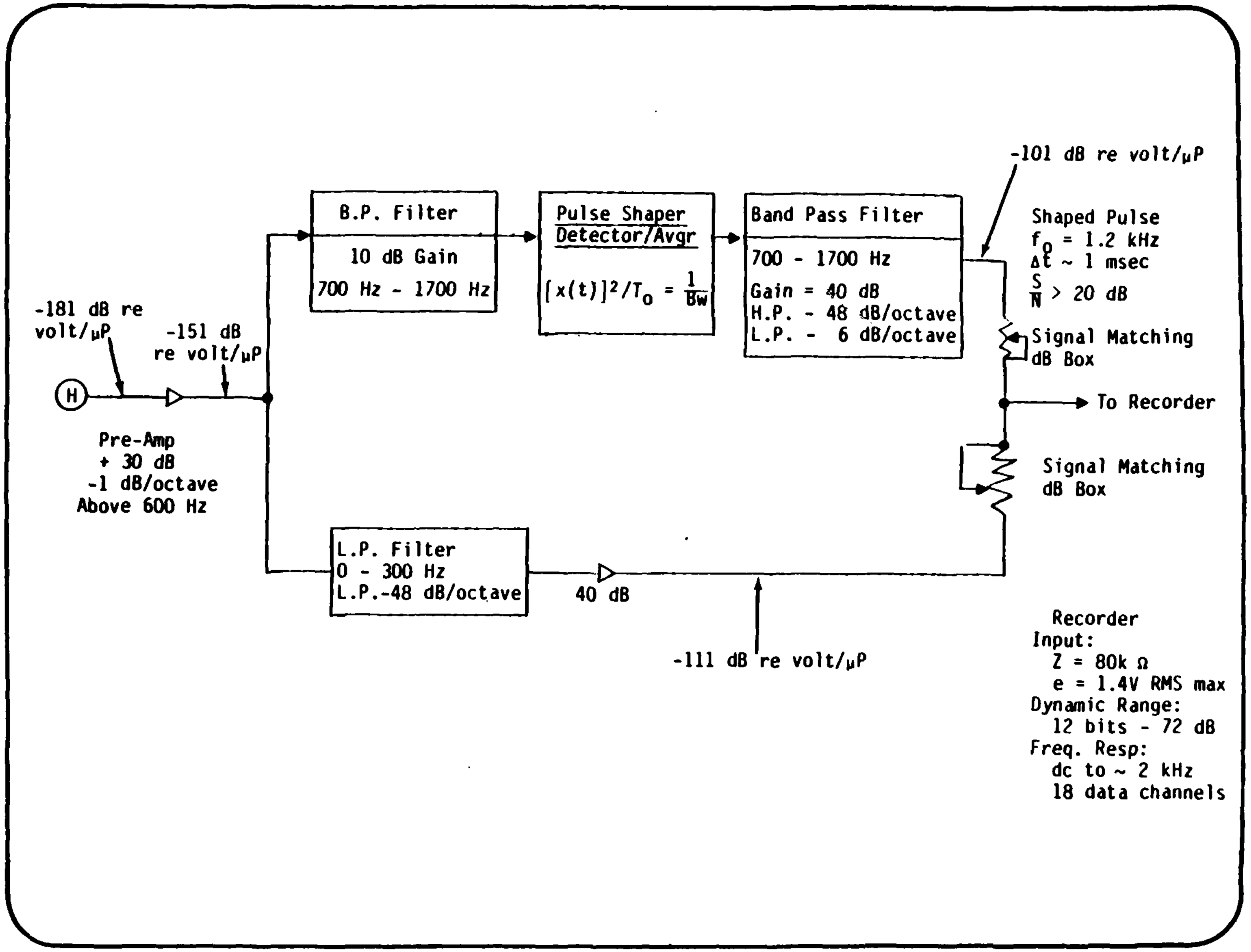


Figure 3. Preferred System Design

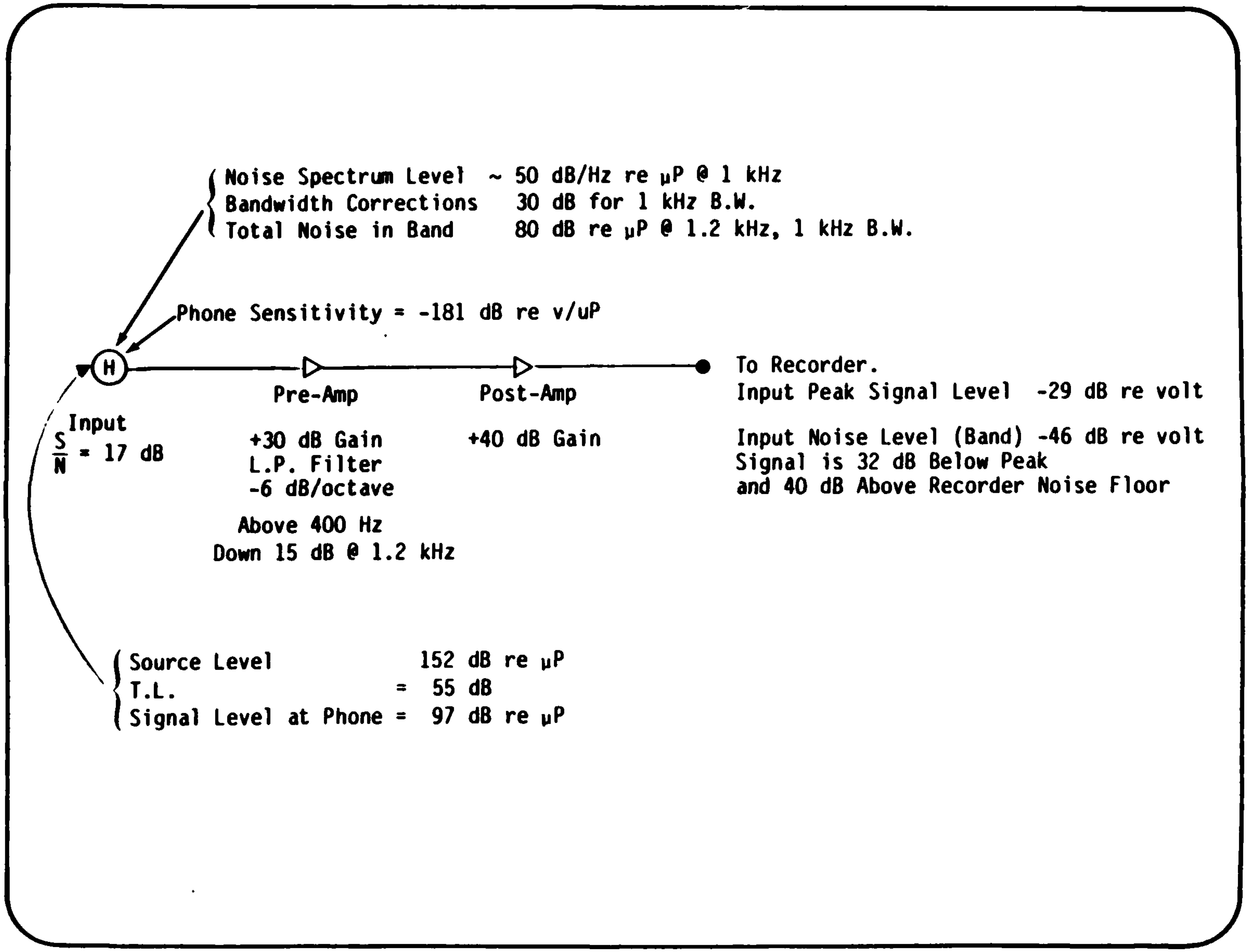


Figure 4. The Simplified System

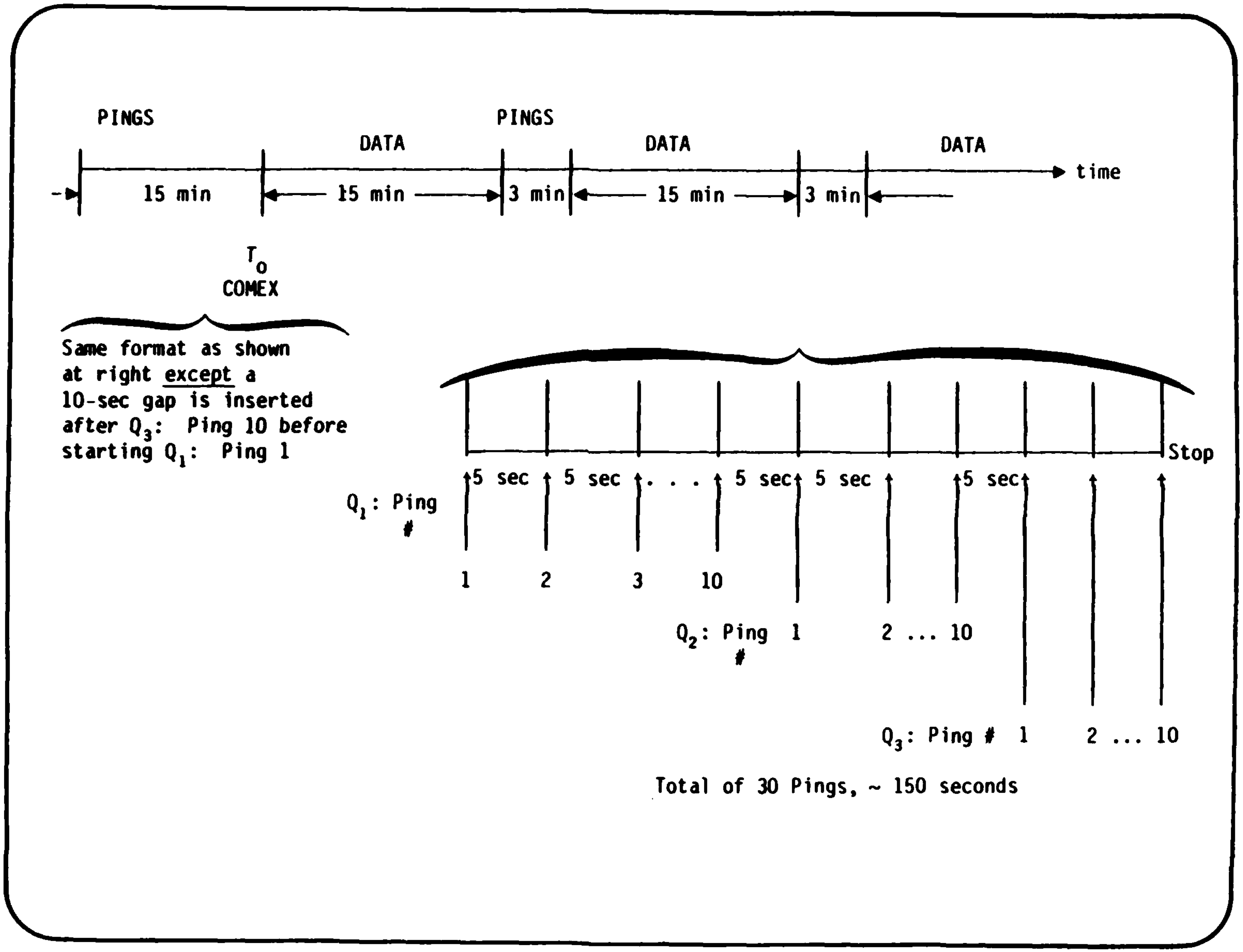


Figure 5. Proposed Ping Cycle

To determine if a watch circle does exist plus its magnitude and periodicity, a sequence of pings from each projector are planned for fifteen minutes prior to event COMEX.

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