TECHNICAL REPORT ON A PROTOTYPE BOUNDARY LAYER INSTRUMENTATION SYSTEM

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Section 1 - Introduction

This report is the final part of a three-part Final Report on the Boundary Layer Instrumentation System produced under Task Order 3 of NOAA Contract E-127-69(N).

- Part One considers the scientific requirements of boundary layer observations for the GARP Atlantic Tropical Experiment.
- Part Two is a specification of a prototype Boundary Layer Instrumentation System (BLIS) which satisfies these scientific requirements.
- The present, final section, is a technical description and justification of the proposed BLIS. It also describes or suggests alternative schemes and systems.

The Boundary Layer Instrumentation System (BLIS) includes up to five Boundary Layer Instrument Packages (BLIP's), an aerodynamically shaped balloon, a tether line onto which the BLIP's are fastened, and a winch located on the deck of a ship. The system is illustrated in Figure 1.

The Boundary Layer Instrument Packages telemeter meteorological parameters - wind speed, wind direction, pressure, wet and dry bulb temperatures, and possibly radio altitude - to a Shipboard Data Acquisition System.

The BLIS will be deployed by a grid of ships to obtain meteorological data from the ocean boundary layer during the GARP Atlantic Tropical Experiment (GATE). The scientific requirements of the BLIS are discussed in Part One of this Final Report (ref. 13). This report, therefore, begins with a discussion of BLIP sensors which satisfy these scientific requirements.

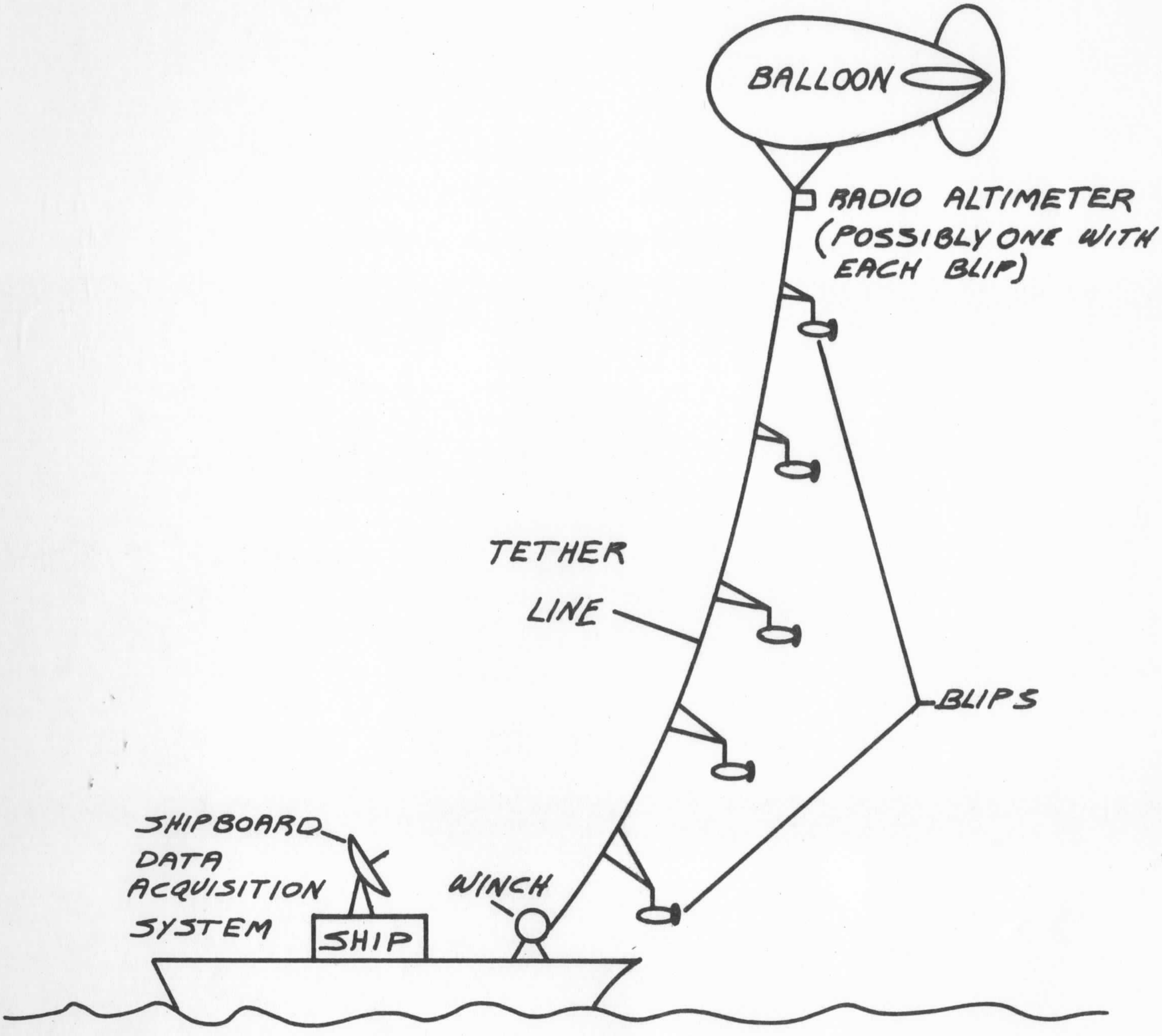


FIGURE 1 THE BLIS CONFIGURATION

Section 2 - Sensors

2.1 Wind Speed and Wind Direction

Wind speed and wind direction are the most important boundary layer measurements of all those specified in the scientific requirements. The WINDAV wind speed and wind direction indicator (ref. 1) was built specifically for boundary layer wind measurements by SSEC in 1968; and was used successfully on the BOMEX boundary layer package. The WINDAV is capable of satisfying the GATE scientific requirements; and, therefore, will be used as the BLIS wind speed and wind direction sensor also.

The difference between the BOMEX wind measurements and the BLIS measurements is in the method of raw data handling. The BOMEX package telemetered the WINDAV sine wave and reed switch closure directly to the ship. This not only required two FM subcarrier channels operating continuously; but, in addition, it required a considerable data processing effort in order to obtain the data with high accuracy. In contrast, BLIS will be a narrowband PCM time-multiplexed system. Therefore, a method is needed for obtaining two PCM words (wind speed and wind direction) from the WINDAV sine wave and reed switch closure. This topic is covered in the telemetry section of this report.

2.2 Temperature

BLIS, like BOMEX, will use a psychrometer for humidity measurements. An analysis was undertaken to see if there is something better than the psychrometer for GATE humidity measurements. There is not. Virtually all of the humidity measuring techniques (including the psychrometer if not properly designed) became degraded when exposed to salt contamination. A discussion of most of the various schemes can be found in References 2 and 3. This report shall concern itself only with the psychrometer.

Tanner (ref. 4) has shown that an accurate measurement of the wet and dry bulb temperature difference ($T_d - T_w$) is more important than the measurement of either T_d or T_w, and $T_d - T_w$. Tanner measured temperature differences directly with thermocouples. However, thermocouples have very low sensitivity. Better sensitivity can be obtained by using thermistors in a bridge arrangement to determine $T_d - T_w$.

The BLIS scientific requirements call for a temperature accuracy of better than 0.1°C. If, in addition, the wet and dry bulb thermistor characteristics are selected to match (i.e., thermistor errors track), then T_d and T_w can be measured separately, and the calculated difference $T_d - T_w$ will be in error by no more than 0.1°C. Wexler (Ref. 5) has published the following table showing error in relative humidity (%) due to errors in depression.

Temp. (°C)					Error in Depression
-20	-10	0	10	20	
5	3	2	1	1	0.1 °C
11	6	4	3	2	0.2 °C

Table 1: Humidity Error due to Depression Error

Thus it is seen that if T_d and T_w are measured to 0.1°C accuracy, and if the separate errors track, then the error in relative humidity over the temperature range of interest ($>0^{\circ}C$) will be less than 2% RH. This meets the accuracy requirement for humidity.

Measuring temperature to 0.1°C accuracy with thermistors is difficult. It will require stable thermistors which are aged and then individually calibrated.

The psychrometer is currently specified as being shielded from direct solar radiation. An alternative scheme, which deserves additional analysis, is to use unshielded thermistors; but in addition, to have additional white and black thermistors with known absorptivities to calibrate out the radiation effects. This method has certain problems (e.g. changes in absorptivity due to salt spray, effect of wet-bulb wick) which must be considered. If the method can be perfected, it would allow a substantial BLIP weight reduction by eliminating the need for a shield, and improve the ventilation of the wet bulb as well.

2.3 Radio (Geometric) Altitude

It is highly desirable that the BLIS measure both the pressure and the geometric (radio) altitude at each BLIP with great accuracy. In order to satisfy the scientific requirements (ref. 13) with respect to the determination of the horizontal pressure gradients, ships on a 260 km grid must be capable of measuring boundary layer pressure with an error of not more than ±0.1 mb, and radio altitude with an error of not more than ±2 meters.

If independent pressure and radio altitude measurements were available, one could, in addition to measuring horizontal pressure gradients, separate the static and dynamic components of pressure.

If, however, weight, power or cost considerations preclude the measurement of one of these parameters, it is most desirable to include radio altitude as the parameter to be measured by the BLIS. This is so, because if the BLIP radio altitude, the surface pressure, and the vertical (virtual) temperature profile are known, then the pressure at the altitude of the BLIP can be computed with the hypsometric equation. It is more accurate to calculate pressure altitude in this way than it is to calculate altitude from pressure measurements.

If a radio altimeter is not used on the BLIP, then the performance of the pressure device can be relaxed considerably. The pressure device would then not measure pressure gradients, but would serve only as an altimeter. The height of the pressure surface would be calculated from the pressure using the hypsometric equation. However, this assumes hydrostatic equilibrium, which is not valid during strong convection.

We do not recommend relaxing the accuracy requirement of the pressure sensor. Even if a BLIS were used without an altimeter, it would be wise to preserve the high accuracy of the pressure measurement in order to: (1) allow for future growth of the BLIS to include an altimeter with each BLIP, or (2) allow for the possibility of using a single altimeter located at the balloon. In this second case accurate geometric altitude of each BLIP would be computed, given the geometric altitude of the balloon, the wind profile, the tether line tension, and the spacing of the BLIP's on the untensioned line.

Therefore, the pressure measurement system which is proposed for BLIS is of high accuracy (± 0.1 mb) to be compatible with altimeter accuracy. However, the Boundary Layer Instrumentation System, as proposed in this report, does not include a radio altimeter as an integral part of the BLIP. It is expected, however, that an add-on altimeter will be developed for the BLIS.

A radio altimeter is currently available which operates with less than ±2 meters error (ref. 12). However, its minimum useable altitude is greater than that required for the boundary layer. The present 400 MHz altimeter must be converted to operate at about 2 GHz, where the minimum altitude is 45 meters.

2.4 Pressure

As mentioned in the preceding section, the scientific requirements with respect to the determination of horizontal pressure gradients impose an error limit on the pressure measurement of not more than 0.1 mb.

A study of various transduction methods resulted in the selection of the classical aneroid as the BLIS pressure sensor. However, the hysteresis and loading of the mechanical linkages and baroswitch rule out the usual radiosonde aneroid transducer for BLIS. An improvement in accuracy over the conventional radiosonde can be made only if an electrical, rather than mechanical, pickup is used on the aneroid. In this case, then, the important concern is the inherent accuracy of the aneroid capsule itself. This is considered it detail by Fink in reference 2. Fink tested several German and U. S. aneroid capsules, including those made by Bendix Aviation, Molded Insulation Co. (now VIZ), and Johnson Service Co. No Vaisala aneroids were tested, although they claim 0.1 mb accuracy.

The best aneroid capsules were those from the radiosonde type VIZ-1095. The following is a summary of the measured values for these capsules.

(a) The average value of hysteresis, A, is 0.3 mb. However, this average is for a very small sample size; and accordingly has a large variance. For example, one capsule showed a value of A = 0. In addition, the hysteresis test was applied over a wide altitude range which is not characteristic of the relatively small pressure changes which will be experienced in the boundary layer application. This hysteresis error is due to the imperfect elastic properties of the aneroid, and should not be confused with backlash and friction errors of a standard radiosonde. Backlash and friction hysteresis are results of the mechanical linkages to the aneroid.

(b) The average value of calibration uncertainty, U, at the indicated pressures of 800, 100 and 10 mb are:

$$U_{800} = \pm 0.05 \text{ mb}$$

$$U_{100} = \pm 0.04 \text{ mb}$$

$$U_{10} = \pm 0.04 \text{ mb}$$

These numbers indicate the average random uncertainty between single measured values and the true value.

(c) The temperature coefficient, T, has the following values at the noted pressures.

T_{800} = -0.05 to +0.02 mb/°C

T_{400} = 0.0 to +0.01 mb/°C

T_{100} = +0.01 to +0.02 mb/°C

T_{10} = +.01 to +.02 mb/°C

These numbers indicate how much the pressure measurement varies from the true value when the pressure is held constant and the temperature of the aneroid is changed by 1°C.

(d) The average values of short term after-effect, K, (also called drift, or time-effect) are:

K_{800} = +0.05 mb

K_{400} = +0.03 mb

K_{100} = .00 mb

The after-effect decreases to zero after 24 hours at a fixed pressure.

(e) The values for relaxation, E, are given below for the stated pressures:

E_{800} = 0.025 mb per cycle

E_{400} = 0.02 mb per cycle

E_{100} = 0.015 mb per cycle

E_{10} = 0.01 mb per cycle

The dimensions of E denote that the relaxation adds with each cycling of the aneroid through its full pressure range. After 20 cycles the surface pressure (800 mb) reading will have changed by 20 x .025 = 0.5 mb.

If it is assumed all of these error sources to be independent, random errors, then the accuracy (standard deviation) of the aneroid could be no better than:

$$\sigma = \left\{A^2 + U^2 + (T \cdot \Delta T)^2 + K^2 + E^2\right\}^{\frac{1}{2}}$$

where ΔT is the change in temperature from the calibration temperature. Assume $\Delta T = 20^\circ C$ during any single measurement period. Further assume that the true pressure is 800 mb. Then the standard deviation, σ, of the pressure measurement is 1.04 mb.

The temperature error is the largest single error; but this can be removed if we first measure the temperature coefficient of the aneroid. Therefore, neglecting this error, the standard deviation is 0.31 mb. Most of this error is due to the hysteresis error, A. However, since the hysteresis error has a large variance, it is not always certain that will always be only 0.31 mb. Since one of the aneroids tested by Fink had A = 0 mb, it will be assumed that by selecting aneroid capsules individually for BLIS packages, a typical value for A will be less than 0.1 mb.

The conclusion is that by individual selection of aneroid capsules, by careful calibration of them, and by careful measurement of the aneroid temperature, it should be possible to measure pressure to about 0.1 mb accuracy. This is, however, a lower limit to the accuracy that is possible.

The French Laboratoire de Météorologie Dynamique is developing a pressure transduction technique whereby a wire (about 10 cm long) is attached between a very soft, many-sectioned aneroid capsule and a fixed frame. The tension in the wire is proportional to atmospheric pressure (irrespective of the relative dialation of the wire or the supporting frame due to temperature changes). The tension in the wire, in turn, determines the resonant frequency of the line. With suitable electronics and magnetic drivers, the wire can act as the resonant frequency - determining device in an oscillator.

The device, according to the French, is "very worth looking into" for BLIS; and they in fact are doing so. No information is available on system sensitivity, accuracy, or weight.

2.5 Sensor Time Constants

The thermistor time constants should be at least as long as twice the sampling period in order to avoid aliasing errors. If sampling occurs once every 15 seconds, then time constants of at least 30 seconds are necessary. Fifty to seventy seconds is a better figure since it results in the sampling rate being faster than the Nyquist sampling rate.

If the BLIS temperature measurements are to be used to study turbulent fluctuations, as is indeed envisioned by NOAA, then a faster sample rate is necessary. However, wind speed and wind direction should still be sampled once every 13.3 seconds or less (alternatively, wind speed and wind direction can be sampled at a faster rate, but in the data processing only 13.3 second sample rates are used). The desired thermistor time constants are obtained by selecting a thermistor with a certain mass.

Pressure variability is much slower than any anticipated sampling rates. Therefore no special control of pressure sensor time constants is needed. However, it is important to cancel the effect of dynamic pressure fluctuations caused by wind turbulence. This can be accomplished with a properly designed tube outlet from the aneroid chamber, or with a porous filter between the aneroid chamber and the outside air.

Section 3 - BLIP Electrical System

The BLIP electrical system consists of two main sections, the telemetry system and the power supply. Both are discussed in this chapter of the report. The telemetry system is further broken down into description of the various subsystems.

3.1 The BLIP Telemetry System

The required performance of the BLIP is very high, comparable to that expected from a piece of laboratory equipment. The BLIP must be lightweight, low-powered, and operate in a severe environment including rain.

The method of obtaining this performance is the liberal use of reference signals and auxillary data. As mentioned in the Section 2.4, one can get high performance pressure measurements by measuring the temperature of the pressure capsule and applying the appropriate corrections in the data processing. Thus, while the telemetry system seems complicated, it turns out to be an economical way to obtain high performance.

A block diagram of the telemetry system is shown in Figure 2. The basic principles of operation are as follows. The sensor outputs and the calibration reference signals are time multiplexed electronically, and converted to digital words with specialized analog-to-digital converters. The digital words are parallel-loaded into a shift register and read out serially. The individual bits of the shift register output are formated and then used to modulate a narrow band FM transmitter.

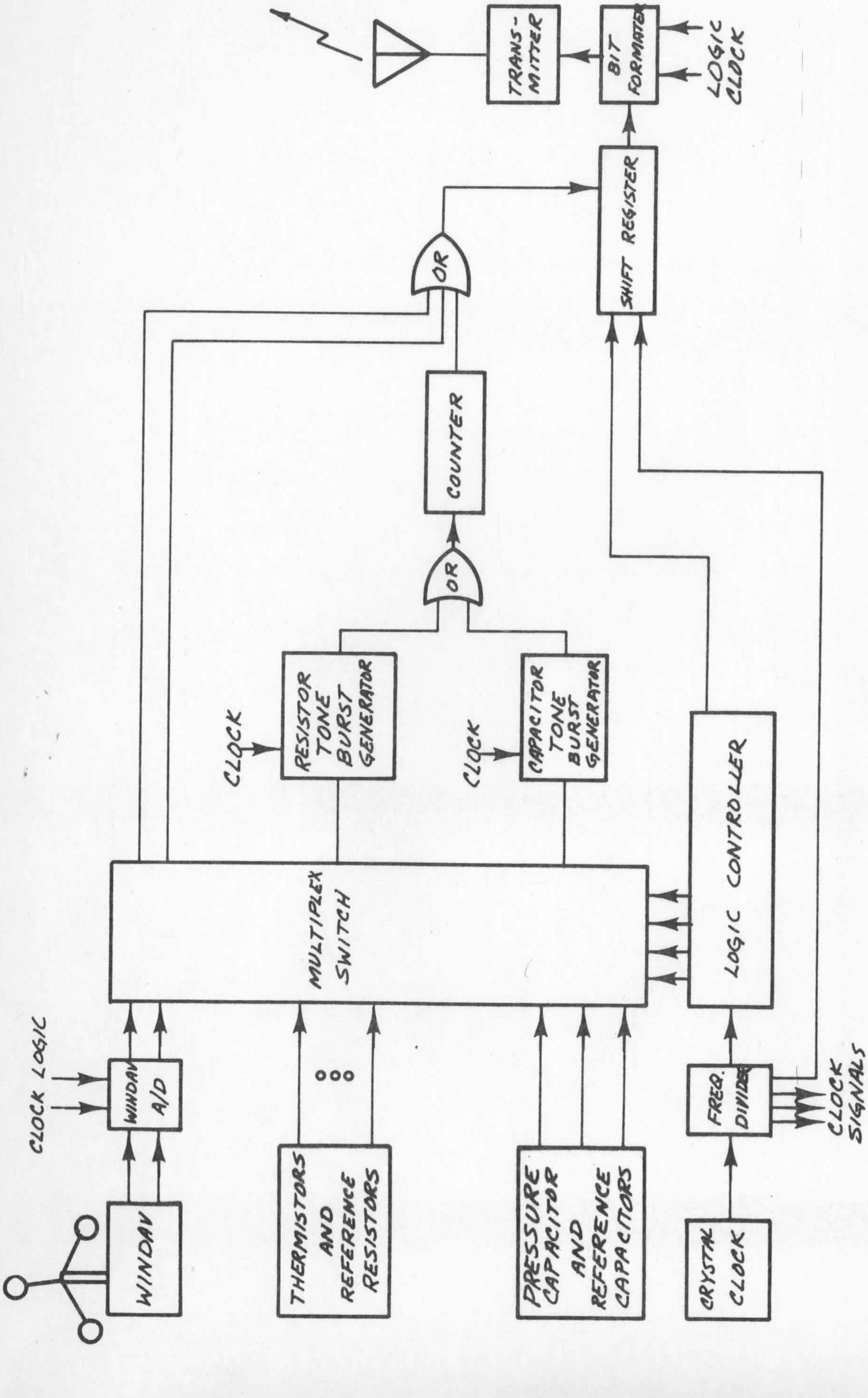


FIGURE 2 BLIP TELEMETRY SYSTEM BLOCK DIAGRAM

The BLIP signal is received and recorded by the Shipboard Data Acquisition Acquisition System. A pulse code modulation (PCM) system is desirable for BLIS for several reasons:

(1) With a fixed transmitter power, the performance will be degraded less by noise in the data link than will the performance of analog systems. This is a result of the fact that the received energy per bit of information is higher with PCM. Another way of looking at this is that for a given error rate (S/N), PCM requires less power.

(2) For the information rates of interest to BLIS, the bandwidth of a PCM-FM system can be very small. An analog FM system would have to have a rather large bandwidth to handle the BLIS accuracy (resolution) requirements. The narrow bandwidth of PCM is of vital importance in a shipboard EMI environment.

(3) PCM is compatible with digital computers for data processing. This is only a minor advantage, since suitable A/D interfacing could be built between a receiver and a computer (or tape recorder). However, the PCM circuitry does not substantially affect the power or weight budgets of the BLIP, so that the inclusion of A/D interfacing at this early stage in the data link is warranted in view of (1) and (2) above.

3.1.1 Analog-to-Digital Converters

Two separate and distinct analog-to-digital (A/D) converters are proposed for BLIS. One is required for the wind measurements. While it may seem desirable to multiplex all signals into a single A/D converter, the wind information is (1) very important, and (2) in a form not easily adaptable to this concept.

Similarly, the temperature and pressure signals are differnt. One is a resistance change, and the other is a capacitance change. Therefore different tone burst generators (gated oscillators) are proposed, but a common counter and logic is used to convert into digital form.

It is conceivable that additional commonality might be possible, resulting in further simplification. This should be considered, but *not at the price of reduced performance*.

A discription of the two analog-to-digital converters are given in the next four sections.

3.1.2 Wind Speed and Wind Direction Processing

The WINDAV sine wave and reed switch closure must be converted to digital words related to wind speed and wind direction. The technique which is outlined in the specification is shown in Figure 3. The WINDAV

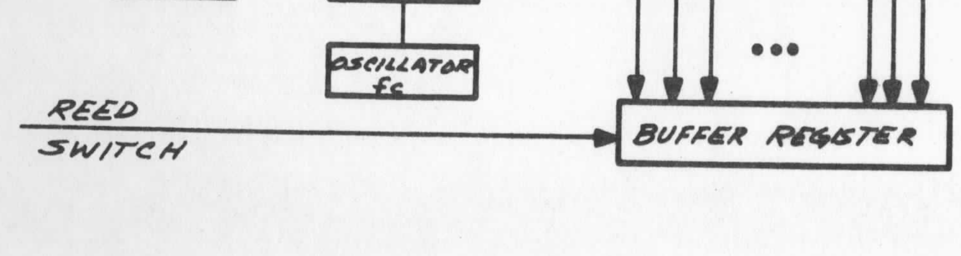


FIGURE 3 COUNTER TECHNIQUE FOR WINDAV PROCESSING

sine wave is hard-limited to form a square wave and applied to a logic block. The logic block forms a pulse whose length is one WINDAV period; and uses this pulse to gate an oscillator with frequency f_c into a counter. The count accumulates for one WINDAV cycle (call this count N_1), and is stored, by command of the logic block, in a buffer register. In addition, when the reed switch closes, a count, N_2, is stored in another buffer register. These counts remain in the buffer register until they are updated on the next WINDAV cycle. The binary words, N_1 and N_2, which are stored in the buffer registers are telemetered to the ship sequentially.

It can be shown (Ref. 1) that the wind speed, V, is related to WINDAV rotational frequency by:

$$V = kw$$

Thus, the WINDAV period, T, is:

$$T = \frac{1}{w} = \frac{k}{V}$$

The count N_1 is equal to $f_c T$, so that wind speed is given by:

$$V = \frac{k f_c}{N_1}$$

Wind direction, relative to east, is given by:

$$\phi = 360 \cdot \left(\frac{N_2}{N_1}\right)$$

It should be noted that, although wind speed and wind direction measurements are updated every WINDAV cycle (a rate which depends on the wind speed), they are read out only once every 15 seconds. It should also be noted that the counter in Figure 3 is being used continuously.

Hence, a separate counter is needed for the A/D conversion of the other sensor signals.

The advantages of this wind speed and wind direction processing technique are: (1) it is simple in terms of parts count compared to the other techniques which were considered, and (2) it uses mostly digital circuitry, and consequently can have very low power consumption.

Other Systems Considered

Several other techniques were considered. One technique is to replace the reed switch with (1) a small bar magnet attached to the tip of the WINDAV rotor shaft, and (2) a second Sony magneto-diode near the bar magnet. As the magnet turns, a sine wave is produced in the second Sony diode with a phase difference compared to the first diode which is proportional to wind direction. Both sine waves are sampled at greater than the Nyquist sampling rate, and converted to a digital word with a voltage (or current) A/D converter. The digital words constitute the desired PCM signal which is transmitted to the ship. During data processing, a computer reconstructs the sine waves by some optimal curve-fitting algorithm, and then measures the frequency and phases of the two sine waves. This technique requires the estimation of the sine waves' frequency, phase angles and amplitudes. The technique has the advantage that its sampling rates are on the order (10 Hz) of the other sensor sampling rates. The disadvantage is that the data processing, especially the estimation of sine wave amplitudes, is difficult when high accuracy is required.

Another technique is illustrated in Figure 4. The system is basically a phase-locked loop (PLL) which phase locks to the WINDAV sine wave. The voltage-controlled oscillator (VCO) runs at 360 times the input frequency and is divided down (÷360) before being phase-compared with the input. The individual stages of the frequency divider give a binary output word proportional to instantaneous phase. The divider is synchronized to give an all-zero output word at the positive zero-crossing of the input; and is read out on command of the reed switch closure. This read-out gives wind direction. Wind speed must be obtained by one of the other means described in this section.

The input frequency varies between 0.075 and 2.25 Hertz. Because of this wide range, the lowpass filter of the PLL must have an adaptive cutoff frequency, so that only the difference-frequency component of the phase detector output is allowed to pass.

Thus, it is seen that the phase-locked loop system, although sound theoretically, is complicated in terms of hardware. Another disadvantage of this system is that the PLL would have a long acquisition time (unlock time) at slow wind speeds.

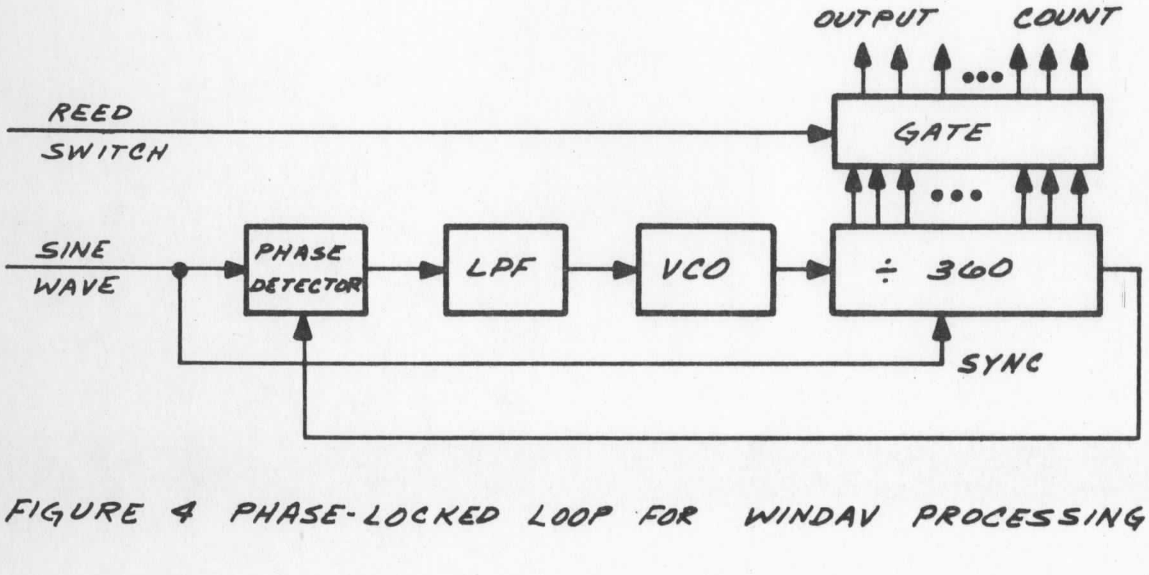


FIGURE 4 PHASE-LOCKED LOOP FOR WINDAV PROCESSING

A final technique is illustrated in Figure 5. The operation of this system is most easily described by reference to waveforms of Figure 6. The outputs, waveforms F and H, are (theoretically) the average values of pulse trains E and G, respectively.

In actuality F and H have ripple. The ripple in waveforms F and H should be less than the required resolution of the measurement. The ripple is adjusted by changing the low pass filter time constant. An analysis of the ripple as a function of input waveform parameters and time constant, RC, shows that the ripple is equal to:

$$V_2 - V_1 = \left\{ \frac{\exp(-T_1/RC) + \exp(-T_2/RC) - \exp(-T/RC) - 1}{\exp(-T/RC) - 1} \right\} V'$$

where the symbols are defined in Figure 7.

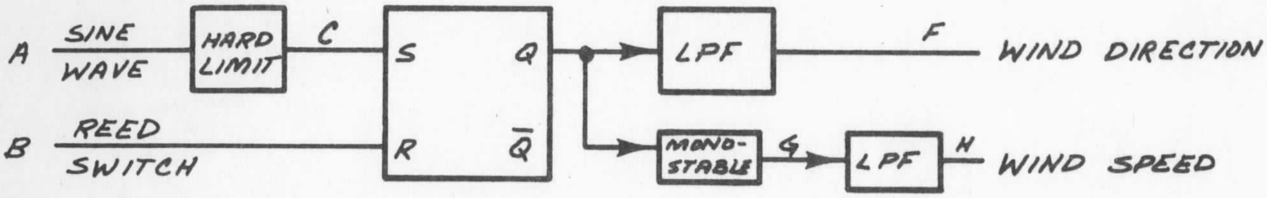


FIGURE 5 ANALOG AVERAGING TECHNIQUE FOR WINDAV PROCESSING

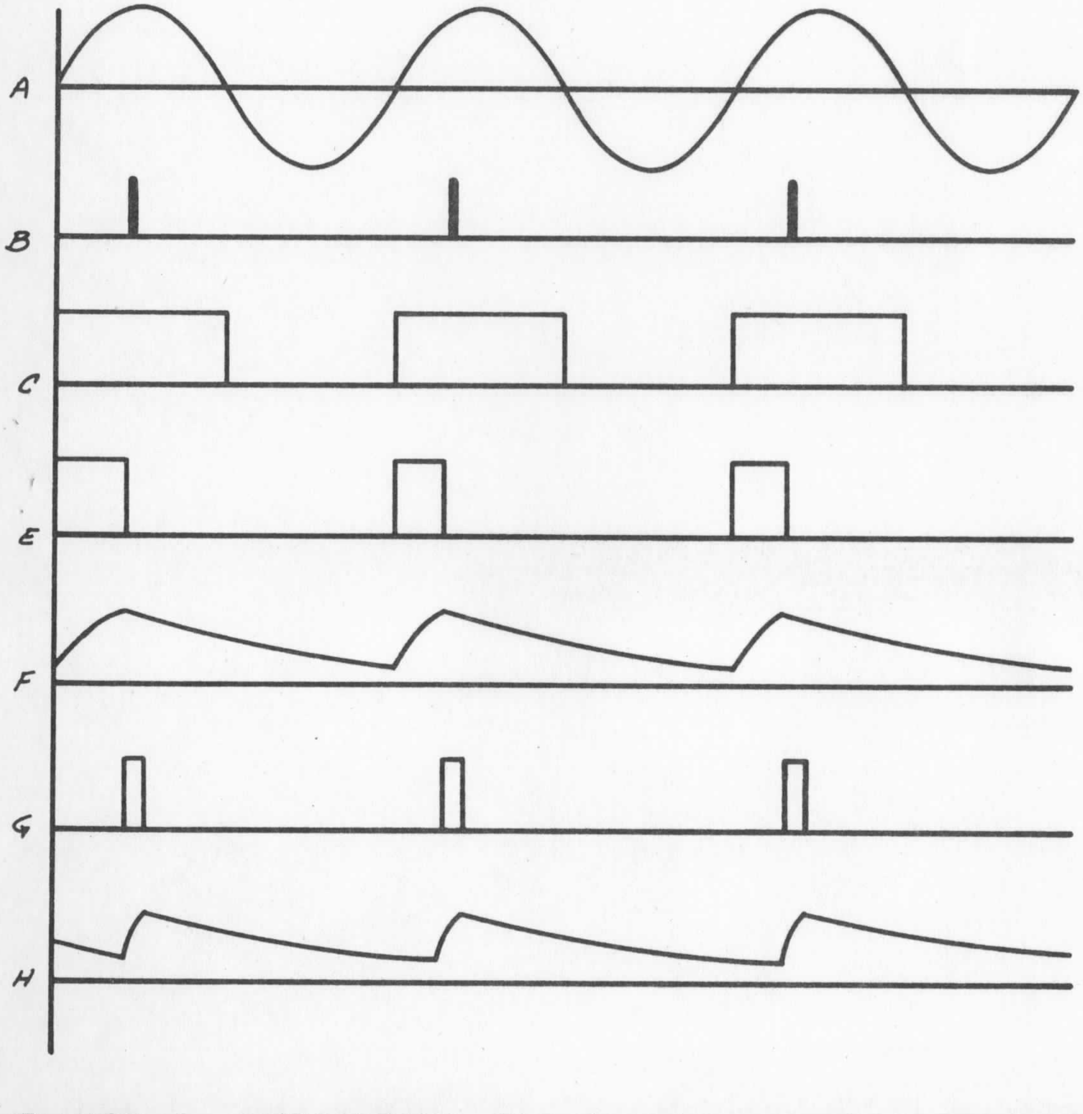


FIGURE 6 WAVEFORMS FOR ANALOG WINDAV PROCESSING

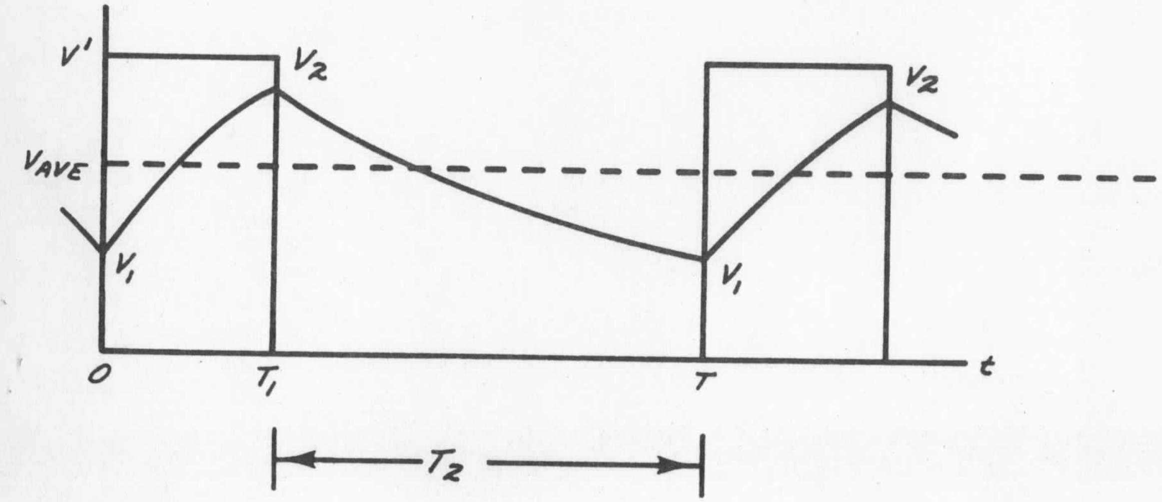


FIGURE 7 RIPPLE ANALYSIS WAVEFORM

As a typical example, if $V' = 6$ volts, then it is necessary to resolve $6/360 = 16.7$ mv to resolve one degree in wind direction; and it is necessary to resolve $6/30 = 0.2$ volts to resolve 0.5 m/s in wind speed. Suppose that $T_1 = 0.44$ seconds and $T_2 = 13.3$ seconds. Then to keep the ripple less than 0.2 volts requires that the time constant be greater than 14 seconds. For one degree wind direction resolution, suppose that $T = 13.3$ seconds and $T_1 = 13.3/2 = 6.67$ seconds. Then to keep the ripple less than 16.7 mw requires that the time constant be greater than 20 minutes. These two examples describe worst case conditions; that is, conditions which result in maximum ripple.

These filtered voltage waveforms are converted into digital words by an A/D converter.

A theoretical voltage-vs.-wind direction characteristic for this system is shown in Figure 8 (solid lines). When taking averages there can exist a "modulo-360° ambiguity" in wind direction. This ambiguity causes a serious problem under certain conditions. Suppose the wind direction is turbulent about 360 degrees; that is, suppose at various instants the true wind directions are those in column one of Table 2 on the following page.

The straight average of these values (or the average value of the voltages corresponding to these values) is 181.9°, almost exactly opposite the true average value. One solution to this problem is to include a second reed switech on the WINDAV shaft, positioned 180 from the first reed switch. A second electronic processor, as per Figure 5, would also be needed. This second phase angle measurement has a characteristic shown in dashed lines in

Wind Direction	"Processed" Wind Direction
1°	1°
360°	0°
359°	-1°
2°	2°
1°	1°
358°	-2°
0°	0°
359°	-1°
1°	1°
358°	-2°

Table 1: Wind Direction Sample Values

Figure 8. Now, whenever an ambiguity exists in one measurement (as detected by suitable logic), an unabmiguous reading can be obtained from the second measurement. Note that the second reed switch measurement does not give any new information; it simply removes an ambiguity. As such it is wasteful of power and telemetry channel space.

The ambiguity can be removed without resorting to an additional telemetry channel. The technique is as follows. When a potentially ambiguous situation is detected on a sample-to-sample basis, 360 degrees are subtracted from all angles greater than 180°, and all angles less than 180° are not altered. The "processed" wind directions are given in column 2 of the Table 2. The straight average of the processed wind directions is -0.1. Since the sign is negative, 360 degrees are added, giving 359.9°. If the sign of the average was positive, no addition of 360 degrees would be necessary.

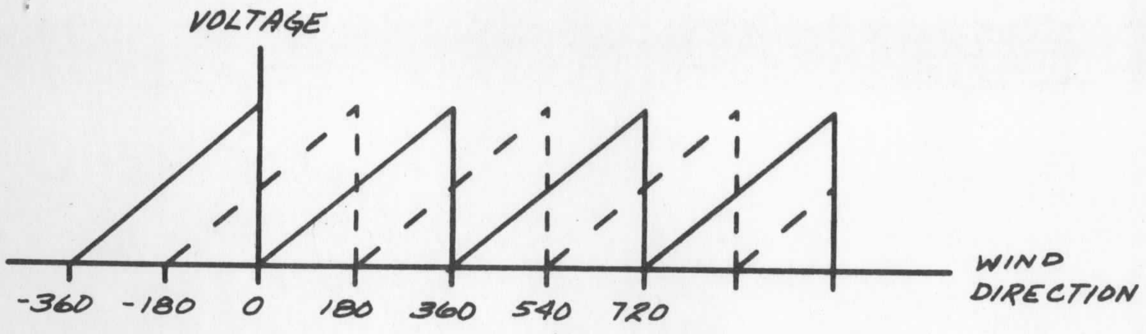


FIGURE 8 VOLTAGE -VS- WIND DIRECTION CHARACTERISTIC

Although the three alternative WINDAV processing techniques described above will work satisfactorily, they were rejected for use in BLIS because they are either too complicated, or they require complicated data processing.

3.1.3 - Temperature and Pressure Processing

The analog-to-digital converter used to process the pressure (capacitive) and temperature(resistive) sensor signals has three main sections: (1) a tone burst generator for resistive sensors, (2) a tone burst generator for capacitive sensors, and (3) a counter with associated logic. One of the tone burst generators (depending on which is selected by the multiplex switch) produces a stream of pulses which are accumulated in the counter. The binary count of the number of pulses in the counter at the end of the counting period is the desired digital version of the sensor signal at the input of the A/D converter.

In the case of the resistive tone burst generator, the tone burst is always at a known frequency, but its duration is variable depending on the sensor resistance. This tone burst generator is described in detail in section 3.1.4.

In the case of the capacitive tone burst generator, the tone burst always lasts for a known duration, but the frequency is variable depending on the sensor capacitance. This tone burst generator is described in detail in section 3.1.5.

Efforts are being made to develop a suitable pressure-to-resistance transducer. This would eliminate the capacitance tone burst generator and greatly simplify the BLIP electronics. However, it must be emphasized again that any such simplification must be accomplished without degrading system performance.

3.1.4 Resistive Tone Burst Generator

The thermistors used for temperature sensing change resistance with temperature. These resistance measurements are converted into digital words with the tone burst generator-counter technique described in the previous section. The resistive tone burst generator is shown in Figure 9 and works in the following manner.

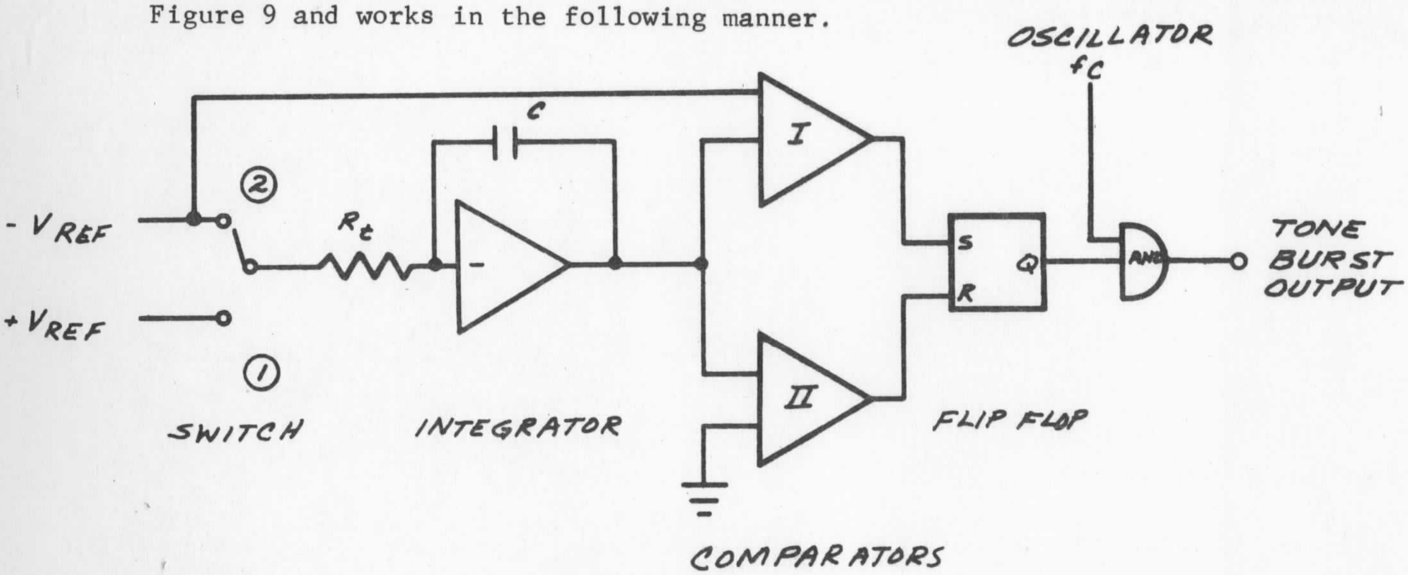


FIGURE 9 THERMISTOR A/D CONVERTER

The solid state switch is initially in position 1, so that e_{out} is "reset" to a negative value, V_{reset} (-4 volts). When the switch is switched to position 2, the integrator begins to integrate positively. The output voltage is:

$$e_{out} = \frac{V_{ref}}{R_t C} t - V_{reset}$$

where V_{ref} is approximately 1.5 volts, R_t is the thermistor (50-100K) and C is the integrator capacitor. At the time T_1, e_{out} goes through $-V_{ref}$

volts, and comparator I switches, setting the flip-flop. Time T1 is given by the expression:

$$T_1 = \left(\frac{V_{reset}}{V_{ref}} - 1 \right) R_t C$$

At time T_2 the output voltage goes through zero, comparator II switches, and the flip-flop is reset. Time T_2 is given by the expression:

$$T_2 = \left(\frac{V_{reset}}{V_{ref}} \right) R_t C$$

The flip-flop output, Q, is a pulse with duration $\Delta T = T_2 - T_1$. That is

$$\Delta T = T_2 - T_1 = R_t C$$

Thus a conversion of resistance (R_t) to time period (ΔT) is accomplished. The flip-flop pulse gates on a continuously running oscillator (derived from the clock) of known frequency. This is the desired tone burst. Note that V_{ref} does not appear in the expression for ΔT. This tone burst scheme is, therefore, independent of reference voltage. This is confirmed experimentally. Variations in capacitance, C, will cause an error; however, this error can be removed (in the data processing) by switching highly stable high and low reference resistors into the circuit in place of the thermistor, and telemetering these known calibration values to the ship. The multiplex switch which switches the calibration resistors and the thermistors into the tone burst generator is not shown in Figure 9.

3.1.5 Capacitive Tone Burst Generator

The BLIS will use a capacitive pressure transducer. A capacitive transducer works on the principle that pressure moves one plate of

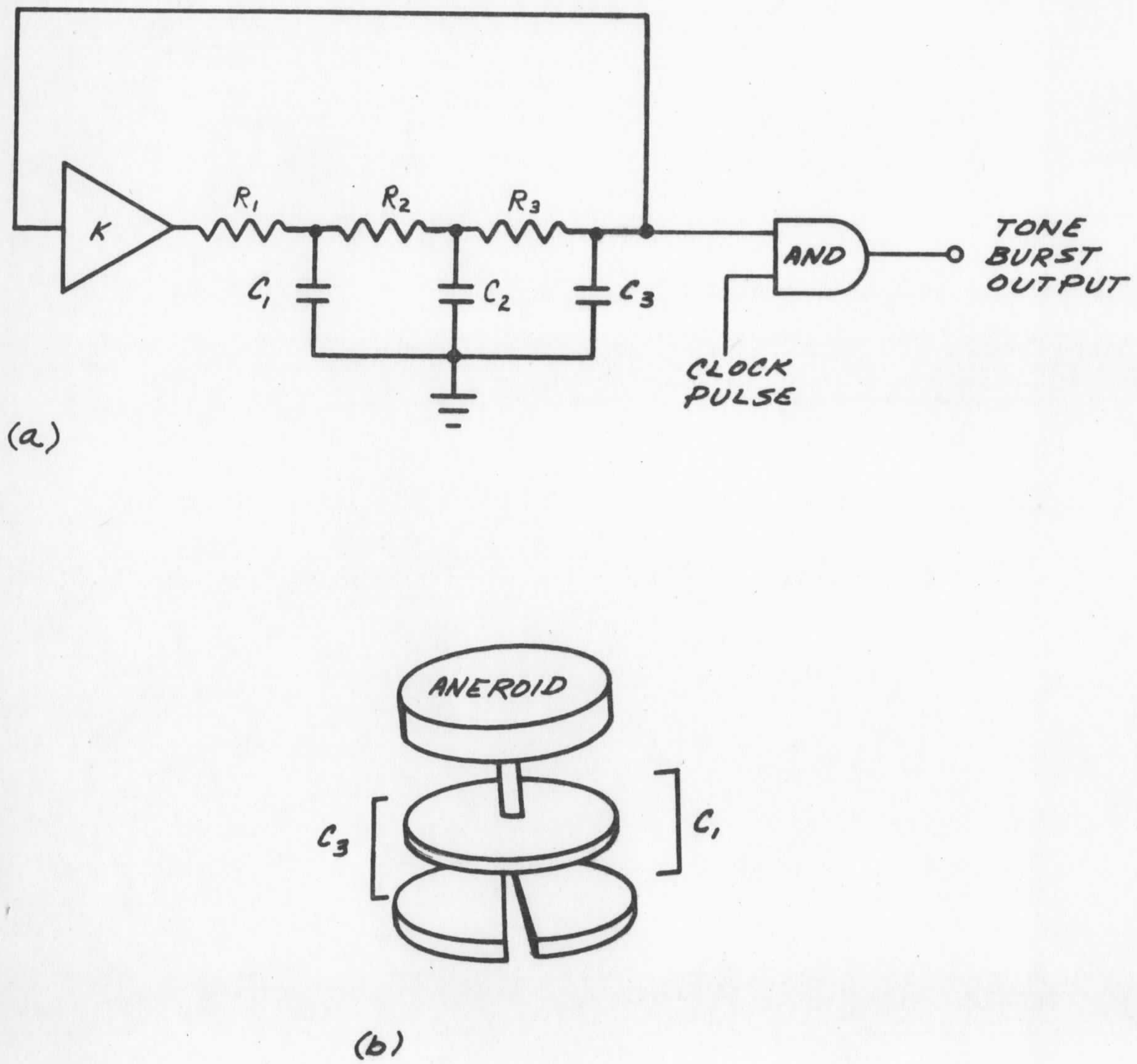


FIGURE 10 CAPACITIVE TONE BURST GENERATOR

a capacitor relative to another, thus converting pressure into a capacitance value. The capacitance value is then used to generate a tone burst, which in turn is fed into a counter as described in Section 3.1.3.

The tone burst generator proposed for BLIS is shown in Figure 10a, and works in the following manner.

The capacitive transducer (Figure 10b) is used as the frequency-determining element in a phase shift oscillator. The oscillator output is, therefore, a continous sine wave whose frequency is related to pressure. The oscillator output must be converted into a tone burst. This is accomplished by gating the oscillator into a counter for a precise time period determined by a crystal clock. The relationship between the pressure and the total number of counts produced by the capacitive tone burst generator is derived below.

The linear displacement, d, of the aneroid varies linearly with the range of pressures in the boundary layer. Therefore the capacitance of the transducer is:

$$C = \frac{K_o}{d} = \frac{K_1}{P_o + P}$$

where K_o and K_1 are constants depending on the construction of the capacitor and aneroid, and Po is the reference pressure.

The frequency, f, of the oscillator is given by

$$f = \frac{1}{(R_1 R_2 R_3 C_2)^{1/3}\, C^{2/3}}$$

where $C_1 = C_2 = C$, and the other terms are defined in Figure 10a. Combining these two equations gives:

$$f = K_2 (p_o + p)^{2/3}$$

where K_2 is another constant. Finally, the total number, N, of pulses generated by the oscillator in known time, ΔT , is

$$N = f \cdot \Delta T = K (p_o + p)^{2/3}$$

where K is a constant.

Note that the count is not linear with pressure. The count can be made linear with pressure by changing the configuration of the capacitive transducer (Fig. 10b) so that it contains three capacitors (C_1, C_2 and C_3 of Figure 10a) instead of just two.

For the high precision needed for BLIS pressure measurement, the slight nonlinearity of the aneroid displacement-vs-pressure characteristic will have to be included in the processing of the telemetry data to obtain pressure accurately. This is most easily included by producing individual pressure-vs-frequency calibration curves for each transducer-phase shift oscillator combination.

In Figure 10a note that the capacitors and resistors are interchanged from the normal phase-shift oscillator, so that all the capacitors have a common ground. As seen in Figure 10b, capacitors C_1 and C_3 are variable with pressure. A breadboard circuit has a sensitivity of 120 Hz/micron. The aneroid capsule under consideration (VIZ 1160-10) has a sensitivity of 7.6 micron/mb. Thus the overall sensitivity is about 920 Hz/mb. The oscillator operates in the 30 KHz range.

The advantage of the phase shift oscillator scheme is that the oscillator frequency is relatively insensitive to voltage amplitude fluctuations, and is completely insensitive to d.c. drift problems since it is an a.c. measuring scheme.

The aneroid capsule is required to <u>accurately</u> determine displacement (related to pressure) as small as 0.7 microns (0.1 mb). If the aneroid-capacitor assembly is made of metal, the capacitor plate spacing will change with 1°C temperature fluctuations the same order of magnitude as with a 0.1 mb pressure change. For example, for the mount used in SSEC experiments, and shown in Figure 11, the 5 cm supports would change by 0.72 microns/°C if they were made of steel. Quartz tubes can withstand a 30°C change for the same linear expansion. Therefore the SSEC mount contains three hollow quartz tubes.

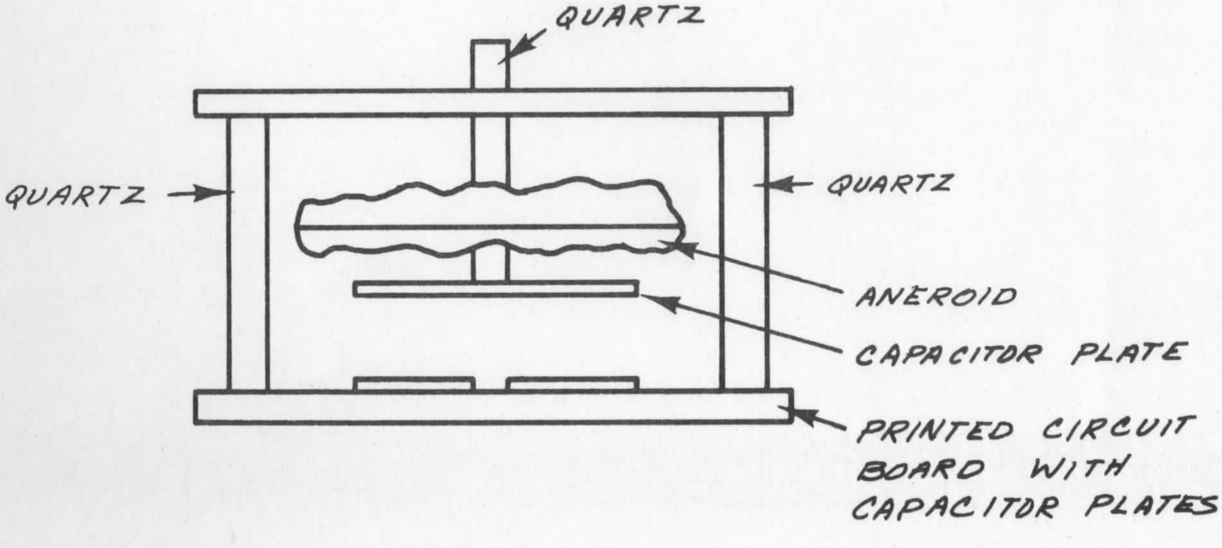


FIGURE 11 SSEC CAPACITIVE PRESSURE TRANSDUCER

In the proposed BLIP it will be necessary to telemeter the aneroid temperature in order to compensate for the temperature coefficient of the aneroid capsule. However, it is evident that one could also compensate for the thermal expansion of the aneroid mount also. Therefore quartz tubes are not necessary.

3.1.6 Multiplex Switch

Eleven meteorological and "engineering" parameters must be time multiplexed. They are:

1. wet bulb temperature
2. dry bulb temperature
3. aneroid temperature
4. electronics package temperature
5. pressure
6. wind speed count
7. wind direction count
8. high resistance reference
9. low resistance reference
10. high capacitance reference
11. low capacitive reference

In terms of digital design it is no more complicated to have 16 channels, rather than 11. The five remaining channels allow for future expansion. In particular if unshielded thermistors are used for the psychrometer, additional black and white thermistor measurements will have to be made. Furthermore, if a net radiometer (Ref. 7) is to be added, an additional two thermistor channels will be needed.

Another possibility is as follows. It may be desirable from a scientific viewpoint to transmit temperatures and pressure twice during a single data frame. This would mean that one of the extra channels should be allocated to a capacitive transducer (pressure), and two other channels allocated to resistive transducers (wet and dry bulbs).

In view of these possibilities, it seems reasonable to have 16 channels; and, of the five extra channels, four should be allocated to resistance measurements and one to the capacitive measurements.

The multiplexer is actually 3 separate switching arrays; one to switch thermistors into the resistive tone burst generator, one to switch capacitors into the capacitive tone burst generator, and one to switch the WINDAV counts into the output shift register. The WINDAV and resistance switches are rather straight-forward design problems. However, the capacitance switch is more difficult, because the capacitances being switched (<30pf) can be on the same order of magnitude as stray capacitances.

Further design may indicate that miniature (DIP-style), low-power, reed relays may be needed to do this capacitor switching; although every effort should be made to avoid this solution. If such a solution were necessary, the time required for reliable switching of the reed switches would be the limiting factor on the data rates.

The multiplex switch designed at SSEC is an array of field effect transistors which are switched on, one at a time, by digital logic signals. It is currently expected that the BLIP multiplex switches will also be discrete. MOS integrated circuit multiplex switches have been investigated (and one type tested) to determine their suitability in BLIS. Those currently available require large drain and source voltages (about 15 to 20 volts) for accurate analog switching. However, new products are constantly being introduced; and should a suitable switch appear on the market, it would be advantageous to use an integrated multiplex switch.

3.1.7 Crystal Clock

All timing and logic sequencing is derived from an onboard crystal clock. The clock frequency is approximately 78 KHZ. The (ideal) exact frequency such that the sixth division by two yields a frequency (about 1229 Hz) which just fills the 14-bit WINDAV counter during one cycle (13 1/3 seconds) of the WINDAV at the lowest wind speed desired (0.5 m/s). A stability of 0.005 percent over the 0-50^{o}C temperature range is possible with commercially available crystals, and insures that errors due to clock drift are almost two orders of magnitude less than the 0.1 percent system accuracy requirement.

The crystal oscillator is expected to use a field effect device, most probably a COS/MOS inverter, as the amplifying section of the oscillator. Design considerations and procedures are described in reference 8.

The frequency divider chain following the oscillator, as well as all control and sequencing logic, will also be RCA COS/MOS devices. The estimated power consumption of all digital circuitry for BLIS is less than 250 microwatts.

3.1.8 Bit and Frame Formats

The individual PCM bits must be transmitted along with a clock signal, so that bit synchronization can be achieved at the receiver. The waveforms shown in Figure 12 combine the bit value (0 or 1) with the clock. A simple circuit for this job is shown in Figure 13. This circuit uses less than 5 mw.

The bit format proposed by General Electric is more complicated requires almost twice the bandwidth for a given data bit rate; but it does offer a somewhat better immunity to burst noise. The GE bit format obeys the following rules:

(1) each data bit is divided into four equal sections. The first and third sections are always zero.

(2) the second and fourth sections are non-zero; and are the same polarity if the bit is a logical one, and opposite polarity if the bit is a logical zero.

(3) the second section "sub-bit" has the opposite polarity of the fourth section "sub-bit" of the previous bit.

A circuit to generate the GE data format is shown in Figure 14. The clock has twice the frequency of the clock in the SSEC data formater. The power consumption is essentially the same in both circuits.

The receiver must also be able to identify the beginning of a telemetry frame if it is to perform demultiplexing. Therefore the BLIP must transmit a uniquely identifiable frame sync signal. The present General Electric Shipboard Data Acquisition System envisions the sync signal to be a uniquely idenfifiable as the data frame sync

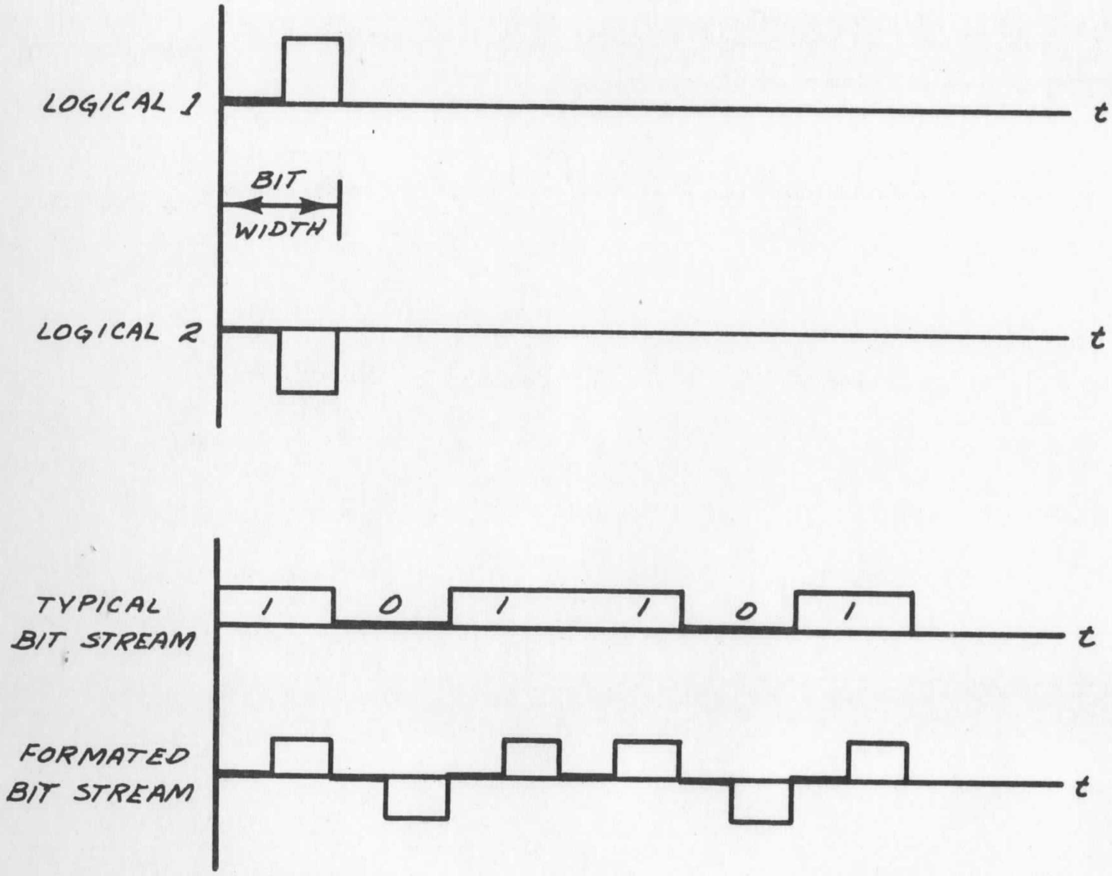


FIGURE 12 BLIP BIT FORMAT

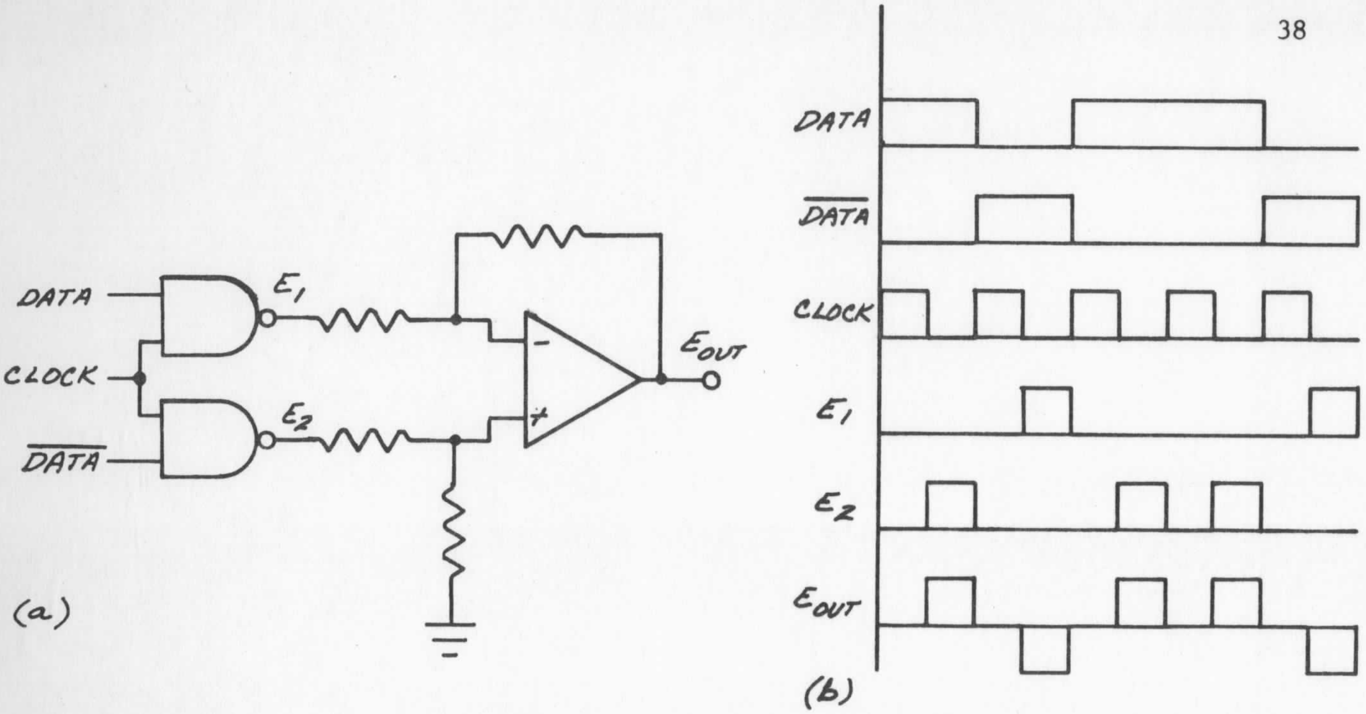


FIGURE 13 DATA BIT FORMATER CIRCUIT AND WAVEFORMS

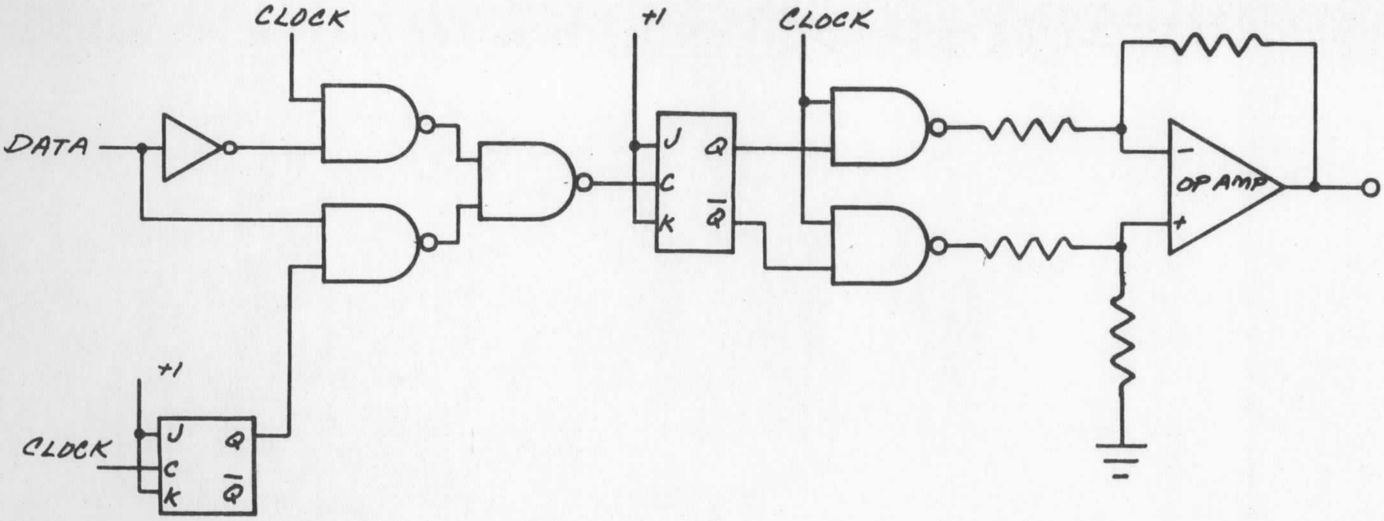


FIGURE 14 BIT FORMATER CIRCUIT FOR G.E. BIT FORMAT

code. Therefore the demultiplexer could synchronize incorrectly on a frame-to-frame basis. The identification of the proposed sync frame code requires a correlator at the receiver, and consequently requires a relatively long "acquisition" time before the frames are synchronized.

A simpler and faster synchronization procedure is to transmit a sync pulse as shown in Figure 15. The beginning of a frame is detected by integrating the demodulated bit stream (resetting the integrator with every negative-going edge) and threshold detecting the sync pulse. When the threshold detector triggers, it sets a flag, making it known that the frame begins at the trailing edge of that sync pulse.

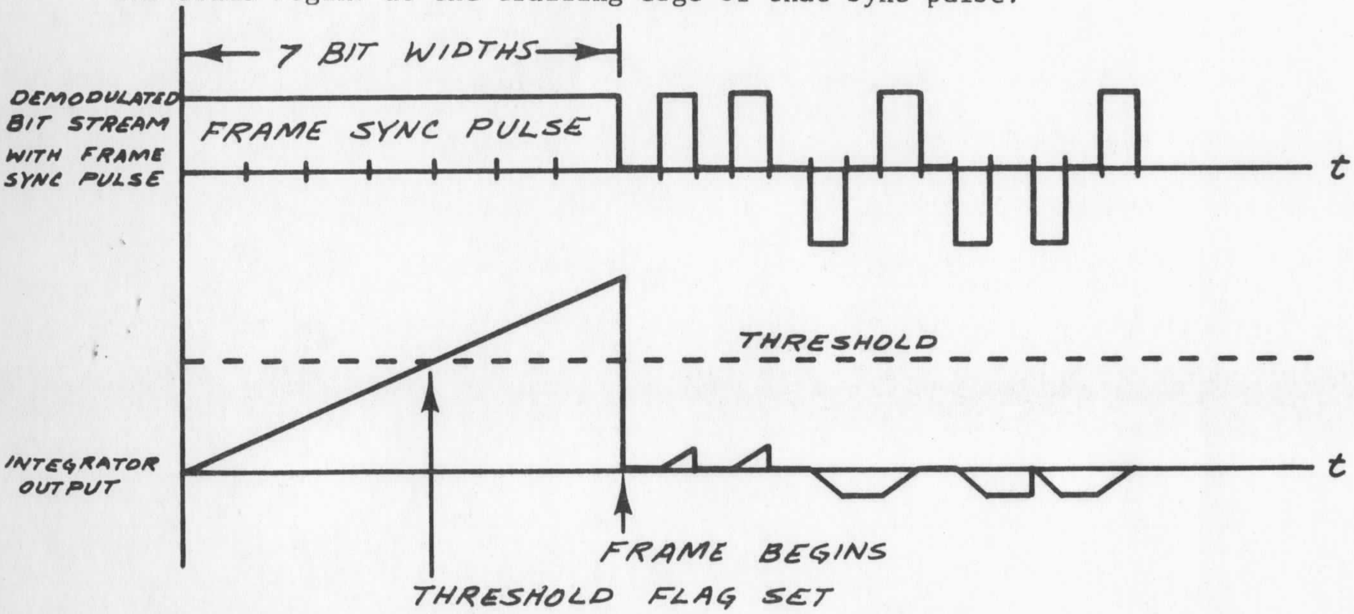


FIGURE 15 FRAME SYNC METHOD

Note that the frame sync pulse is seven bit widths long, and that it has no clock signal superimposed on it (as the bit stream does). This lack of a clock is unimportant, however, since there is no bit decoding being performed during frame sync (as there is in the GE system). It is, in fact, precisely this absence of the clock signal which given the frame sync pulse its uniqueness, and hence its easy identifiability.

Following the frame sync pulse is a seven bit BLIP identifier word. This allows for 128 unique identifier names.

Following the BLIP identifier are the 16 data channels. Each channel is 14 bits long. This figure is obtained in the following manner. It is a requirement to measure wind speeds from 0.5 m/s to 15 m/s. This corresponds to a WINDAV frequency range of 0.075 Hz to 2.25 Hz. It is also a requirement to measure wind direction to one degree accuracy. Referring to the discussion on WINDAV processing, it is evident that the counter clock frequency, fc, must be at least fc = 360 x 2.25 = 810 Hz . Any frequency less than this would result in a wind direction <u>resolution</u> (and hence accuracy) greater than 1^o at the highest wind speed. With a clock frequency of 810 Hz, the largest count which would accumulate in the WINDAV counter is 810/0.075 = 10800 . To reach a count of this size requires a 14-stage binary counter. Note that 0.075 Hz corresponds to a period of 13.3 seconds for one WINDAV revolution with a 0.5 m/s wind speed. This means that wind speed and wind direction should be telemetered no more often than once every 13.3 seconds. Alternatively, if samples of temperature and pressure are desired more often, the frame telemetry rate could be increased; but the wind speed and wind direction should be sent as blanks, except once every 15 seconds.

In the proposed BLIS system there is a 1229 Hz (approximately) clock signal available. This provides the necessary resolution (>810 Hz) and the maximum count (1229/0.075 = 16383) is still a 14-bit word.

Because 14 bits are required for wind speed and wind direction, 14 bits should be used for all the other data channels also. This makes the overall system simpler, especially in view of the fact that the ultra-low powered RCA COS/MOS digital integrated circuit family contains a 7-stage binary counter. It is expected, therefore, that the RCA COS/MOS family will be the logic used in the BLIP electronics. In view of this, it is now evident why the frame sync pulse and the BLIP identifier words are specified as being seven bits long each.

3.1.9 Modulator and Transmitter

The transmitter designed by SSEC uses a 50 MHz (3rd overtone) crystal oscillator with a power output of 30 mw into 50 ohms. The oscillator uses 12 volts (which is obtained from across the entire ± 6 volt supply), and draws 4.5 ma. The oscillator frequency is pulled with a varactor diode, which is coupled to the data formater output.

The oscillator output drives a passive X8 varactor frequency multiplier. Output is 5 mw into 50 ohms at a nominal frequency of 400 MHz. Overall efficiency is 9.3 percent; but further design (mounting on PC board, eliminating stray capacitances, etc.) should boost the overall efficiency to better than 10 percent.

Better efficiency (perhaps as high as 50 percent) could be obtained using on LC-oscillator. However, the electronics would not be simpler, and frequency stability would not be as good. The high frequency stability of the SSEC oscillator relaxes the performance requirements of the telemetry receiver. More importantly, an LC oscillator would be much more susceptible to undersirable frequency modulation due to the loading of the rotating WINDAV cups. This can be eliminated by using a buffer stage; however, this increases complexity and reduces the overall efficiency. The isolation on the SSEC oscillator-multiplier is such that the final tank circuit can be detuned by as much as 50 MHz without noticeable shift in the output frequency.

The five milliwatt output power was determined as per the following conservative power budget analysis.

5 mw transmitter	+7 dbm
transmitter antenna gain	0 db
2000 m transmission loss	-32 db
estimated system loss	-10 db
receiver antenna gain	0 db
minimum received power	-35 dbm

Table 3: Transmission Power Budget

The -35 dbm received power level corresponds to a minimum received rms voltage level of -70 dbm. Since telemetry receivers with -90 dbm sensitivity are common, we have gain (20 db voltage) to spare if 5 mw is transmitted.

Section 3.2 BLIP Power Supply

One should not consider the power supply requirement independently of the balloon. From the viewpoint of minimizing BLIS operational problems and reducing the risk of damage to the balloon and BLIP's, it is desirable to have as long a flight time as possible. But this means the power supply will be heavy, requiring a larger balloon, which in turn increases operational problems. Power supply weight could be reduced by including a radio-controlled switch on each BLIP to control the duty cycle of BLIP operation. This feature would have value only if a balloon with very low gas leakage is available. There is no question that a controllable duty cycle would allow greatly extended duration with little or no increase in weight or loss in value of the data due to its sampled nature. The system design should allow this feature to be added later.

A realistic flight time for a balloon, based on published leak rates, appears to be 48 hours. Therefore the BLIP power supply should be capable of supplying the power required by the BLIP electronics for at least 48 hours also.

The power required by a BLIP has been estimated (based on measurements and calculations) to be 191 mw of regulated power. The preliminary power budget is shown in Table 4.

Transmitter	50 mw
Multiplex Switch	5 mw
Resistive Tone Burst Gen.	35 mw
Phase Shift Oscillator	65 mw
Crystal Clock	5 mw
WINDAV	25 mw
Bit Formater	5 mw
Logic	1 mw
Total Power	191 mw

Table 4: Preliminary Power Budget

The power estimates in Table 4 are based on a bipolar six volt supply. This voltage was selected because it is compatible with RCA COS/MOS digital logic, with most of the new micropower operational amplifiers, and with 400 MHz varactor operation. Increasing the voltage above this would not yield improved performance, but would increase power consumption.

A balanced 191 mw load from a ± 6 volt supply means that 15.9 ma of current is drawn from the supply. For 48 hours of operation this requires a power supply with a capacity of 762 mah.

Two types of batteries, mercury and silver, are possible candidates for BLIS power sources. Both of these cells have very flat voltage-vs-time discharge curves (see Figure 15 for single cell curves). This is important because an electronic regulator is not needed if the battery voltage remains constant during discharge. The voltage stability for mercury cells over the 48 hour span can be better than 5 percent without an electronic regulator.

Other reasons for selecting mercury and silver cells for the power supply are that they have: (1) a higher capacity-to-weight ratio than other battery power, sources, (2) good temperature characteristics, and (3) long shelf life.

Both mercury and silver cells operate well at $50^{o}C$; however, mercury cells suffer a severe loss of capacity at about $4.5^{o}C$ ($40^{o}F$), and at $0^{o}C$ ($32^{o}F$) the mercury cell gives very little service. Figure 16 illustrates the temperature-vs.-lifetime characteristics of mercury cells. It is proposed, therefore, that mercury cells be used for all normal BLIS work; but if low temperature work is anticipated, silver cells (which exhibit good low temperature characteristics) be used.

The open circuit voltage of silver cells is 1.6 volts, as compared to 1.35 volts for mercury cells. The battery packs could consist of 10 mercury cells or 8 silver cells. The battery voltages would be ± 6.75 volts for the mercury battery and ± 6.40 volts for the silver battery. The BLIP electronics must be capable of handling these two different voltages. In addition, the BLIP mechanical design must be such as to preserve the BLIP center of gravity with either type of battery.

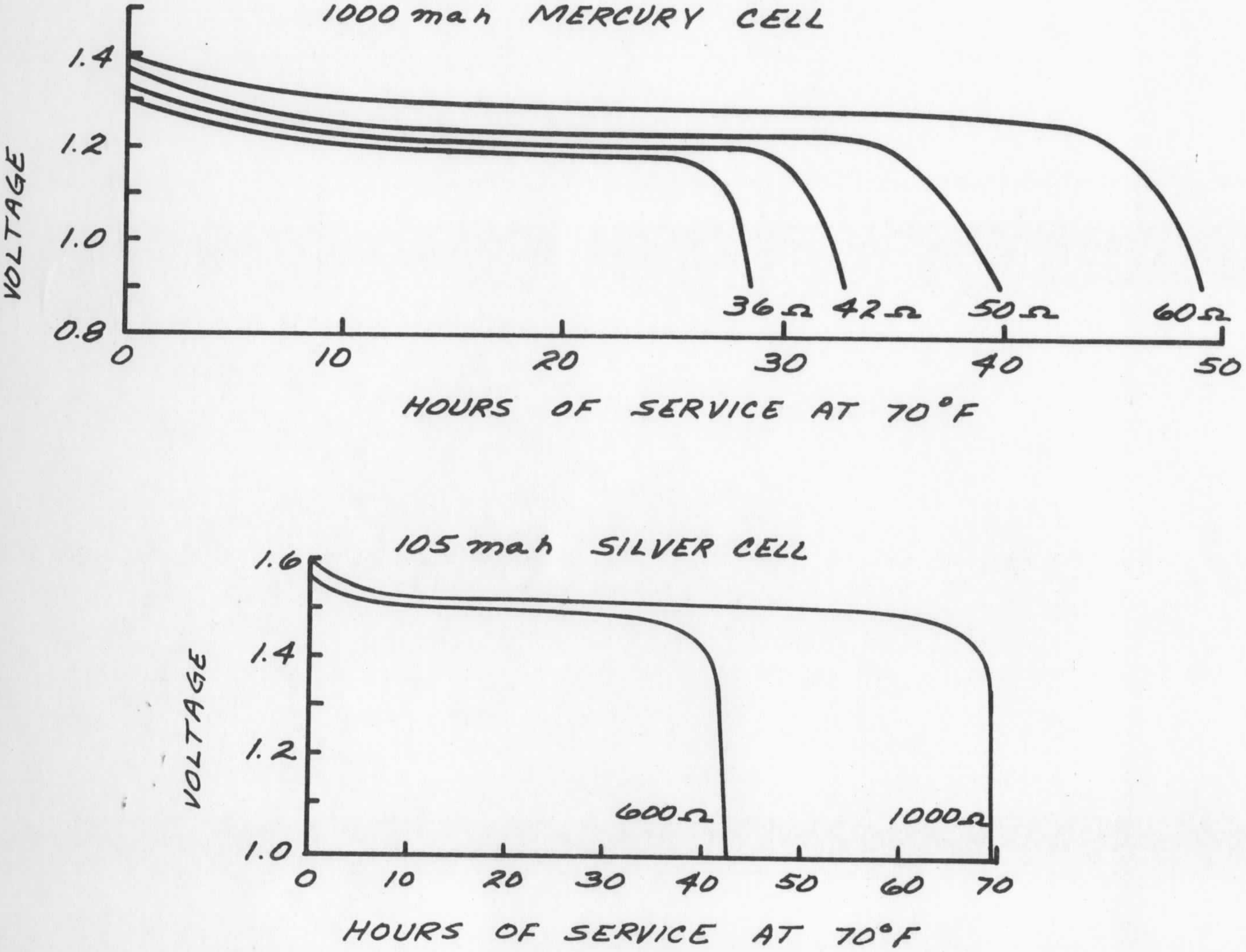
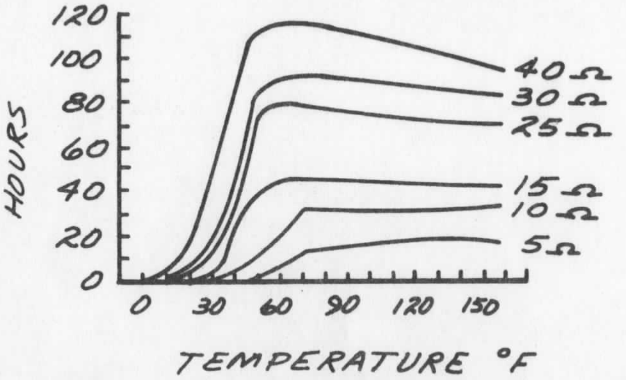
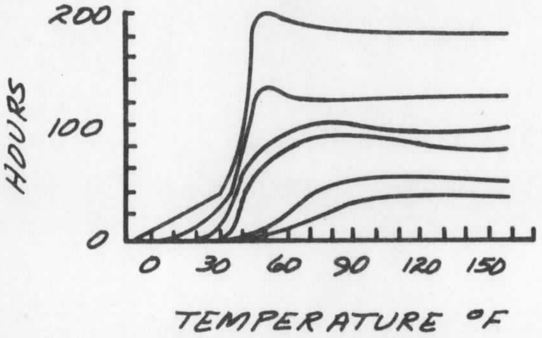


FIGURE 16 VOLTAGE -VS- TIME CURVES FOR MERCURY AND SILVER CELLS



LIFE vs. TEMP. (EVEREADY TYPE E12 3600 mah)



LIFE vs TEMP. (EVEREADY TYPE E4 3400 mah)

FIGURE 17 LIFETIME vs TEMPERATURE CHARACTERISTIC FOR MERCURY CELL

Section 4 Mechanical Design of the BLIP

The BOMEX boundary layer package had several serious shortcomings. In particular, it was heavy, rather delicate, and very difficult to handle and service. These shortcomings must be avoided in the BLIS.

In order to minimize the amount of handling by the ship crews, BLIS flight times must be long (48 hours versus the four hour typical BOMEX flight time). Obviously, BLIS expendables--helium, batteries and psychrometer water--all must last at least 48 hours, and must be easily and quickly replenishable. Operational simplicity and ruggedness must also be reflected in BLIP design details--e.g. flexible antennas and quick-disconnects on the BLIP's and tether lines.

Furthermore, because there will be up to five packages on the tether line, it is imperative that each BLIP be lightweight. A lightweight BLIP means that the balloon used need not be large, and hence the balloon deployment and topping-off problems can be minimized.

It is expected that the weight of the BLIP can be held to below 730 grams, including batteries and psychrometer water. A preliminary weight budget is given in Table 5. The prototype BLIP may very well be lighter than this estimate, especially with respect to the electronic circuit weights.

Batteries	160 gm
Temp. sensors	20 gm
Pressure	60 gm
WINDAV	60 gm
Transmitter	80 gm
Other electronics	100 gm
Packaging	250 gm
TOTAL	730 gm

Table 5: Weight Budget for BLIP

Because packages will be distributed along the entire length of the tether line, the BOMEX A-frame concept, wherein the instruments are rigidly attached to the frame, will not work satisfactorily. This is because the tether line is not vertical for its entire length, and hence a BOMEX-type package will not keep the rotational plane of the WINDAV cups horizontal. Figure 18 illustrates this.

It is a requirement that the WINDAV should rotate no more than eight degrees from the horizontal in order to keep the cosine error in wind speed to less than one percent.

A possible solution to this problem is to have the BLIS suspended from a frame, as shown in Figure 19, by a swivel (possibly as simple as those used for fishing lines). The basic mechanical configuration of the BLIP might consist of: (1) a rigid frame which is fastened to the tether line, and (2) an instrument package which is fastened to the frame with a quick-disconnect mechanism. This arrangement allows the operator to mount the BLIP onto the line without exposing the BLIP instruments to damage (as, for example, from the ship's pitching or rolling) for long periods of time. The point of suspension on the BLIP should be at the center of pressure and above the center of gravity of the package, so that wind forces only cause the BLIP to translate (not rotate) with respect to the frame. A dashpot may be needed on the swivel to prevent unwanted BLIP swaying due to ship motion and wind turbulence.

The feasibility of this concept has not been verified experimentally yet. The shape of the BLIP is Figure 19 does not represent a proposed design, it merely shows the broad design concept. The actual BLIP shape is a subject for future detailed analysis and design, and depends to a large extent on experimental work and wind tunnel testing.

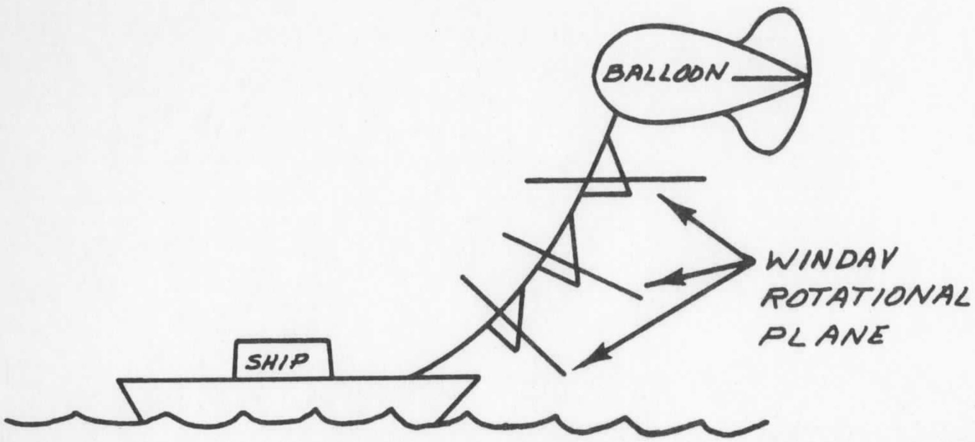


FIGURE 18 COSINE-ERROR PROBLEM WITH BOMEX-TYPE BLIP

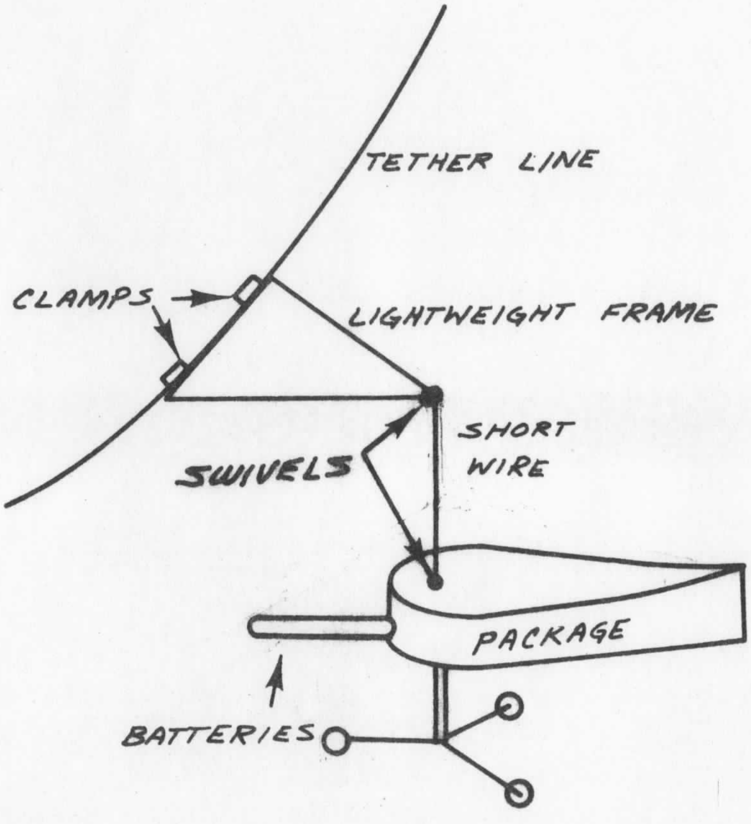


FIGURE 19 GENERAL BLIP MECHANICAL DESIGN CONCEPT

Section 5 Balloon

The BOMEX boundary layer experiment used the Jalbert Aerology Laboratory, Inc., J-8 balloon. This balloon is not satisfactory for GATE. Based on the BOMEX experience, on published literature (refs. 9, 10, 11), and on personal conversations with Domina Jalbert, it is proposed that a balloon similar to the Jalbert J-9 be used for GATE. A chart comparing the J-8 and J-0 appears below.

	max dia. (ft.)	length (ft.)	free lift (lb.) at sea level with helium	vol. (ft.^{3})
J-8	10'	28'8"	23/27	1500
J-9	12'	33'	46	2100

Table 6 Comparison of Jalbert Balloon Characteristics

Note that in terms of physical dimensions the J-9 is not significantly larger than the J-8.

The main reason for recommending the J-9 (or a balloon with similar specifications by a different manufacturer) is that the J-8 is incapable of reaching 1500 meters altitude with five BLIP packages, and a tether line of sufficient strength, and any static electricity elimination system.

The weight of the tether line uses the largest percentage of the available free lift. Jalbert recommends that the cable have a safety factor of 4, meaning that a J-8 needs approximately 500 pound test line, and a J-9 requires approximately 800 pound test line. These figures dictate that cable weights be about 3.9 pounds/1000 feet for the J-8, and 5.7 pounds/1000 feet for the J-9. Six thousand feet of 500 pound test cable weighs 23.5 pounds, which leaves no lift for instrument packages. Six thousand feet of 800 pound test cable for the J-9 weighs 34 pounds, leaving 12 pounds of free lift.

The J-9 balloon will also generate about 75 pounds of dynamic life with a 7.5 m/s wind speed. With this extra lift, which will usually be present but cannot be depended upon, there should be no problem with reaching 1500 meters altitude with the BLIP's.

A balloon will expand 15 percent over its sea level size at 1300 meters. The Jalbert "accordian" dialation device on the J-9 is designed to allow a 12 1/2 percent change in volume. Therefore the Jalbert J-9 will have to be modified slightly to be able to operate at 1500 meters.

Jalbert has stated that a J-9 will easily hold enough gas to stay aloft for 48 hours. The top half of the J-9 is built of a heavier fabric than the J-8 (permeability to hydrogen is 5 $1/m^2/24$ hr. maximum verses 8 $1/m^2/24$ hrs. maximum). If we assume that the permeability varies with the square root of the molecular weight of the gas, then these figures are halved for helium. The J-9 has a surface area of approximately 100 m^2, so that the J-9 will leak about 325 liters of helium in 24 hours. The J-9 volume is 2100 $ft.^3$, or 60,000 liters. Based on these figures, the balloon will lose a maximum of about 10 percent of its gas during a 48 hour flight. This amounts to a loss of 4.5 pounds of free lift at sea level, so that after 48 hours of operation there is still 7.5 pounds of free lift for BLIP's. This is barely enough lift for five packages. It should be emphasized that these figures are based on the maximum diffusion rates for the balloon fabrics.

The above analysis assumes that gas is lost only by diffusion through the balloon skin. Leakage through bad seams and pin holes will cause the leakage rate to be higher, but no data is available on this type of leakage. Presumably this problem can be minimized, because Jalbert's balloon specification (ref. 9) states that, "the completed balloon envelope shall have no greater leakage rate than the leakage rate of the fabric employed in its construction." Jalbert also claims that the balloons are capable of performing to specification for a year or more. This is confirmed by life-time estimates in reference 11.

Special emphasis is given to Jalbert balloons in this report only because information about these is readily available (they are the only "off-the-shelf" balloons available). This is not to be construed as a recommendation of Jalbert balloons to the exclusion of others. In fact, it has been shown in the previous paragraphs that the Jalbert J-9 is marginal for the 48 hour flights.

An optimum choice might well be a Jalbert-style balloon made of Mylar-Dacron-polyurethane fabric (Mylar film laminated to a Dacron cloth and coated with a pigmented polyurethane elastomer for ultraviolet protection). This envelope material has a lower permeability to helium than the Nylon-neoprene fabric, and more importantly, weighs about 2/3 as much for comparable ultimate tensile strengths. The advantages of this fabric are twofold: (1) the lower permeability means the static lift would remain more nearly constant throughout the 48 hour flight, and (2) the lower weight for a similarly-sized balloon would make available about 10 additional pounds of lift. Alternatively, a smaller balloon could be used. The disadvantage of this envelope material is that the balloon would require somewhat more careful handling during launch because the tear strengths of the Mylar-Dacron-polyurethane fabric is only about half that of the Nylon-neoprene fabric.

In any event, it is evident that careful quality control in selecting the balloon fabric, and in constructing and handling the balloon is necessary in order to have a 48 hour flight without the necessity of topping off the balloon.

The balloon should have a long hose attached to the balloon, so that the balloon can be topped off without bringing the balloon onto the deck of the ship. BOMEX balloons had about sixty feet of soft rubber surgical tubing, and results were entirely satisfactory.

Section 6--Tether Line

According to Jalbert's recommendation of a tether line safety factor of four, BLIS requires 800 pound test line. Obviously, the lightest weight line which meets this requirement, and which can withstand the environmental problems which are expected during GATE, is the recommended cable.

Much work still remains in determining a suitable tether line. The main problem is that of currents caused by atmospheric electricity melting the line. Several possibilities for solving this problem have been suggested. The most suitable at this time seems to be a wax-coated nylon line. This solution, suggested by Professor Charles Moore of the University of New Mexico, depends on the fact that the wax coating prevents salt water from collecting between the individual fibers of the tether line. This gives the line a uniformly bad conductance.

This is in contrast to the other solution to the problem - that of using a uniformly good conductor. Two possibilities have been suggested. A steel cable, or a nylon cable which is treated with a conductive coating, or which charge dissipators distributed along its length. The steel cable has several disadvantages: (1) it is unsafe to operators during electrical storms, (2) a kink in the cable will weaken it fatally, and (3) it would require a complicated system of taking up slack and paying out line as the ship pitched. Nylon line has the disadvantages of (1) requiring special treatment to make it somewhat conductive, and (2) not knowing the exact height of the packages because of the elastic motion of the line due to the motion of the ship. The nylon cable does, however, weigh considerably less than steel cable. An untreated 800 pound test line made of nylon weights about 5.7 pounds/1000 feet. Strand-compacted steel music wire (800 pound test) weighs about 14 pounds/1000 feet.

Further study and experiments must be conducted to arrive at a suitable tether line. Reference 11 contains a great deal of information on tether lines.

Section 7--Winch

The purpose of the winch is to pull in and pay out the tether line. The specification describes a possible configuration for a BLIS winch. Those winch requirements are also listed below. The exact design of the winch depends on the type of tether line used. Since this is not yet known, and may not be decided upon until after sea trials of several types, it is desirable to make all winch parameters which depend on the cable adjustable, or at least capable of handling all types and sizes of cables which would reasonably be used by BLIS. Such parameters include storage drum size, capstan tension control, level wind mechanism rate, pulley sheave size, and storage drum line tension. These and other design details of winches are considered in reference 11.

The winch should have the following features:

> A fairlead or similar mechanism for pulling-in and paying-out line at vertical angles of 0-90° and for azimuth angles of 0-360°C.
>
> A motor-driven capstan for the purpose of limiting tension in the tether line during pull-in. The motor should be a dc

variable-speed reversible motor. The capstan drive should be reversible for paying out; but in this mode the motor need act only as a torquer (to counteract the inertial load of the capstan), not as a power drive.

A drum for storing the tether line. The drum should store at least 2000 meters of line. The drum should have a dc reversible motor acting as a torquer to wind line onto the drum during pull-in, and acting as a brake during pay-out. The tension in the line on the drum during pull-in should be adjustable up to twenty pounds of force.

A mechanism to distribute the line evenly on the drum. This device should be adjustable to handle tether lines of from 0.100 inches to 0.250 inches in diameter.

A counter which measures the amount of line off of the drum. The counter should read out in meters. The meter should measure untensioned line length to within ± 5 percent accuracy.

Ratchet-equiped hand cranks attached to the capstan and to the drum through clutches, in the event of an electrical power failure.

An electrical control system which allows both manual and automatic operation of the winch. In the automatic mode the equipment should be capable of cycling through ascent and descent patterns of the type described in reference 13. The automatic sequences should be programmable by means of panel controls of (1) the length of line to be payed-out by the winch (0-2000m), (2) the winch pull-in rate (0-2 m/s), (3) the length of line to be pulled in by the winch (0-2000m), (4) the holding time interval between winchings (0-24 hours), and (5) the number of winching intervals per cycle (0-10). The control system should have an automatic stop and a warning indication when an incompatible winching sequence has been programmed.

Reference 11 gives a list of winch manufacturers which have either made tethered balloon winches already, or which have standard winches suitable for tethered balloon use. From a cost viewpoint, it would be advantageous to modify an existing winch design to meet the BLIS requirements.

Section 8 Growth Possibilities

The experience with tethered balloons gained during BOMEX shows that the operational aspects of this activity to be fairly complex especially for a shipboard environment. Balloon handling on deck for example is a major problem. Furthermore, the opportunities for complete loss of the system are many. The BOMEX experience shows that the safest place for the unwieldy balloon is in the sky, not on-board the ship. Fortunately this is where it ought to be when collecting data also. Data collection, as such, ought not to be a burdensome activity, especially with a system proposed in this document.

Balloon handling is a major headache and also represents the situation of greatest jeopardy. Clearly there is an urgent need to extend the lifetime of balloon flight and to remove from the system any other factors which limit the time between service.

These are:

1. Balloon gas leakage
2. Battery lifetime
3. Wet bulb water supply

The limit now appears to be balloon leakage. As this is reduced, battery lifetime becomes limiting but this can be extended by radio controlled duty cycle reduction. Finally, one should seek alternate ways to obtaining humidity information to eliminate the need for the wet bulb water supply. The package design should be such that these options are kept open for further increase in flight duration.

Section 9 - References

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