AD-780 064

THE DESIGN OF A SECOND GENERATION YAWSONDE

William H. Mermagen, et al

Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

April 1974

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AD-780064

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
BRL Memorandum Report No. 2368		

4. TITLE (and Subtitle)
THE DESIGN OF A SECOND GENERATION YAWSONDE

5. TYPE OF REPORT & PERIOD COVERED
Final

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
William H. Mermagen
Wallace H. Clay

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
USA Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland 21005

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
RDT&E 1T061102A33D

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army Materiel Command
5001 Eisenhower Avenue
Alexandria, Virginia 22304

12. REPORT DATE
APRIL 1974

13. NUMBER OF PAGES
33

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Amplifier
Yawsonde
Solar Cell
High-g Telemetry
Integrated Circuit
Projectile Instrumentation
Circuit Design

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

Improvements have been incorporated into existing yawsonde telemeters to facilitate ground reduction of extensive quantities of data. The main area of improvement has been in the design of the amplifier so that solar pulses of constant amplitude and constant width can be transmitted to ground receiving stations. The new amplifier design makes it possible to reduce the solar pulse data on board the projectile itself providing solar aspect angle as a function of time of flight in binary coded form at the transmitter. Such on-board, real

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract (continued)
time motional data could be used in a command/control system to enhance the accuracy of artillery fire.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Preceding page blank

I. INTRODUCTION

Yawsondes have been extensively used during the past eight years to measure the in-flight motional behavior of a variety of cannon-launched projectiles[1,2,3]. First developed by Amery and his colleagues[4], the projectile yawsonde has undergone miniaturization and modification until it now is housed entirely in the confines of an artillery fuze. Adaptations of Amery's original design have made it possible to measure the pitching, yawing, and rolling motion of artillery shell as well as fin-stabilized projectiles with slow roll rates.

A yawsonde is a device which measures the angle between the axis of a projectile and a vector directed from the projectile toward the sun. While this definition is not exact or complete, it will serve for the discussion of this paper. Since the yawsonde measures an aspect angle between missile and solar vector, the actual motional behavior of the missile with respect to the flight path must be inferred, usually through a complex numerical reduction and fitting procedure[5,6]. A complete reduction of yawsonde data is not necessary, however, in order to visualize gross features of the motion of the projectile. A simple plot of solar aspect angle versus time of flight can provide useful details about the precessional, nutational, and rolling motion of the projectile.

---

1. *W. H. Mermagen, "Projectile High-G Telemetry for Long Range Dynamics Measurements," Proceedings of the International Telemetering Conference, Vol. VII, September 1971, pp. 500-513.*

2. *W. H. Mermagen, "Measurements of the Dynamical Behavior of Projectiles Over Long Flight Paths," Journal of Spacecraft and Rockets, Vol. 8, No. 4, April 1971, pp. 380-385.*

3. *W. R. Hazeltine, "Yawing Motion of 5.0" MK41 Projectile Studied by Means of Yaw Sondes," Naval Weapons Center Report NWC TP 4779, August 1969, AD 862065.*

4. *I. O. F. Amery, "Flight Behavior of Projectiles. Yaw Telemetry Trial. 4.5" Naval Shell. Malta, April, 1967," Royal Armament Research and Development Establishment Memorandum 9/68, November 1968.*

5. *G. T. Chapman and D. B. Kirk, "A Method for Extracting Aerodynamic Coefficients from Free Flight Data," AIAA Journal, Vol. 8, No. 4, April 1970.*

6. *R. H. Whyte and W. H. Mermagen, "A Method for Obtaining Aerodynamic Coefficients from Yawsonde and Radar Data," Journal of Spacecraft and Rockets, Vol. 10, No. 6, June 1973.*

Preceding page blank

In the early stages of yawsonde development, circuit elements were chosen for their ability to survive high accelerations experienced in gun launches. Circuit design was kept simple to increase the probability of a successful flight. During the past several years, the electronics manufacturers have provided the market with a variety of microminiature and integrated circuit electronics which have proven capable of withstanding high-g environments. These circuit elements and complete subassemblies are now being incorporated into more sophisticated on-board telemetry devices such as yawsondes.

Although yawsondes have provided useful data on a number of projectiles of interest to the Army, many of the results were degraded by radio-frequency interference, poor resolution, data dropout, and inaccuracies in calibration and data reduction. The problems associated with data reduction and calibration have been somewhat solved[7] and the design of a two-slit sonde has increased resolution. The problems of rf interference and data dropout remain. A potential solution to the rfi and dropout problems lies in the possibility of reducing the raw yawsonde data on board the projectile.

In this paper the general characteristics of a yawsonde will be reviewed. The need for an improved yawsonde design will be shown with substantial emphasis on the amplifier circuit as the key to a successful design. Finally, results of improved design will be shown and an on-board data reduction system will be described.

II. THE YAWSONDE

A yawsonde is a device which produces information about the pitching and yawing motion of a missile or projectile. Yawsondes can be accelerometers, magnetometers, solar aspect sensors, or similar devices. In this paper, the discussion will be limited to solar aspect sensors or solar yawsondes. The data from yawsondes are transmitted to ground receiving stations via a telemetry link. The telemeter design is determined by the characteristics of the yawsonde instrument and sensing cells. A detailed analysis of the yawsonde is described elsewhere[7]. Here we wish to briefly mention the main features of the instrument.

At present there are two basic solar yawsonde designs. One is an adaptation of the original British design by the Harry Diamond Laboratories (HDL) and the other is a design produced at the Ballistic Research Laboratories (BRL). The HDL sonde uses a silicon photovoltaic cell, masked in a V configuration, behind a pinhole aperture located on the surface of the projectile. The BRL yawsonde uses a number of slits

7. *W. H. Clay, "A Precision Yawsonde Calibration Technique," Ballistic Research Laboratories Memorandum Report No. 2263, January 1973, AD 758158.*

mounted with tilted fields of view on the surface of the projectile. Each slit illuminates a separate photovoltaic cell. Both systems require that the projectile be spinning at a nearly constant roll rate in order to make a sensible measurement. Both systems produce roll rate data from the spin of the shell. Although the improvements detailed in this paper could certainly apply to the HDL sonde, the main discussion will be restricted to the BRL two or three slit solar yawsonde.

Figure 1 shows a schematic of the BRL yawsonde. The two slits form a V in space. As the projectile rotates about its axis in flight, each field of view in turn intercepts the sun. The solar cell associated with each slit produces a voltage when illuminated and since the slit sweeps past the sun, the output is in the form of a series of pulses. The repetition rate of pulses from one cell is related to the rolling motion of the projectile. The phase relationship between pulses from both cells can be shown to be a function of the angle between the axis of the projectile and a vector directed from the projectile to the sun. This angle, called the solar aspect angle, changes with trajectory curvature and with the pitching and yawing motion of the shell.

The data from a yawsonde, then, consists of a succession of pulses whose phase relationship is a function of aspect angle and whose period is a function of roll rate. The data pulses can be made to modulate a transmitter directly or, as is done in the BRL sonde, an FM/FM transmission mode can be used to reduce noise. After the data have been recorded on the ground, the data tapes are played back through a discriminator into a hybrid computer for preliminary reduction. The computer is not a mere convenience but is essential because of the high pulse repetition rate and the volume of data to be processed. A typical artillery shell flight produces from 6,000 to 10,000 yawsonde pulses. The phases of all these pulses must be measured. The present hybrid computer reduction requires considerable operator skill since the data are often contaminated with noise or spurious pulses. The hybrid computer output is a digital tape for further processing on high speed digital computers. This tape contains pulse phase and spin data.

One of the major problems with the hybrid computer reduction is due to the fluctuations in pulse amplitude and also occasional signal dropout and spurious pulses. These factors have made it essential to improve the existing yawsonde circuit design to provide for constant amplitude pulses. A second generation sonde could be designed to provide on-board data reduction so that signal dropout would mean only a brief loss of data rather than a time consuming piecemeal reduction on the computer. A sample pulse train from the present yawsonde as well as the reduced solar aspect angle versus time is shown in Figure 2. Figure 3 shows the yawsonde telemeter in block diagram form. The amplifier and the photovoltaic cell are the items which require careful modification and improvement. The voltage-controlled oscillator (VCO) and radio-frequency oscillator (RFO) are quite reliable and well proven items in the high-g inventory.

A. Sunsensor Design

The signals which provide data about the behavior of the projectile come from silicon photovoltaic cells mounted in slit fixtures as shown in Figure 4. The slit fixture is designed with mirrored side walls so that the cell will be illuminated even at extreme angles of solar incidence. If the sun is in the plane of the slit, within ± 45 degrees from the normal, the cell is fully illuminated and a maximum output of up to 0.4 volts can be obtained. From 45 degrees to 150 degrees of solar incidence, multiple reflections off the mirrored walls will occur and the cell will be illuminated with light of varying intensity. Thus, in order to obtain illumination over a wide field of view, variations in intensity must be accomodated.

The silicon cell is a variable impedance device. The dark resistance is about 40 kΩ and the impedance decreases to several hundred ohms under full illumination. Risetimes less than one microsecond are characteristic of the cell when properly matched to an amplifier. The impedance of the cell will vary from one lot to the next. The solar cell is quite brittle and must be encapsulated in a clear potting compound to enable it to survive high accelerations. The optical transmissivity of the potting material affects the solar cell output and response. Matching cells for yawsondes is usually required to assure equal amplitude pulses from both cells under the same lighting conditions.

B. Amplifier Design

The silicon solar cell design cannot be easily changed. The single crucial element subject to change in the yawsonde then becomes the amplifier. Even if the output of the solar cell were constant and maximum overall conditions of aspect angle, amplification would still be needed in order to drive the subsequent IRIG voltage-controlled oscillator. Since fluctuations in cell output exist, high gain amplification is needed to assure reasonable voltages at the VCO when the illumination of the cell is weak. The first yawsonde amplifier design for the BRL sonde was made in 1967 using then available high-g tested components. The limitations of the solar cell were taken into account by rather simple expedients. The amplifier has, however, functioned to provide useful data until recent requirements made redesign essential.

1. The current design of the yawsonde solar cell amplifier is shown in Figure 5. A photograph of the yawsonde assembly is shown in Figure 6. Amplification is done by a type 712 integrated circuit operational amplifier. This device requires external frequency

compensation and an asymmetric power supply. The op-amp is operated as a difference amplifier with the solar cells coupled to the inverting and non-inverting inputs. Low value resistors (150 ohms) are used to shunt the solar cells so that the variable impedances of the cells will not adversely affect the amplifier. In this loaded down configuration, the cell outputs are tens of millivolts and the amplifier has to be set to a gain of 1000 or more to provide sufficient signals to drive the VCO.

Reasonable amplitude pulses can be obtained with this amplifier over most of the trajectory of a projectile if the sun is correctly positioned in the sky. The amplitude of the pulses from one cell may differ from that of the other cell and the amplitude of either set may vary due to lighting conditions. The shapes of the pulses may also differ. These variations and fluctuations cause serious difficulties in data reduction at the ground station. Therefore, consideration was given to the redesign of the amplifier so that the yawsonde would put out constant amplitude pulses with reproducible risetimes over a wide variety of aspect angle and lighting conditions.

A first approach to solve this problem might be to remove the 150 ohm shunt resistors and to operate the amplifier at saturation so that even millivolt signals from the solar cells would produce volts at the amplifier output. This simple fix, however, leads to a variable gain amplifier. The gain is determined by the ratio of the feedback impedance to the total impedance between inverting input and ground. This includes the impedance of the signal source. Since the impedance of the solar cell varies inversely with light intensity, a variable amplifier results so that precisely at those conditions where maximum gain is needed (low light levels) a lowest gain is achieved. A more sophisticated redesign was therefore indicated.

The criteria for an improved sunsensor amplifier depend on the characteristics of the solar cell and the desired pulse shapes. In the first place, the amplifier should not load down the solar cells. This criterion would eliminate the inconsistent results due to cell to cell variability. Secondly, the amplifier should have ample gain so that the output is saturated at some minimum input level consistent with the most pessimistic illumination condition. A saturated output would permit automatic handling of the data pulses, whether on board the projectile or on the ground. Thirdly, an internally compensated, integrated circuit, operational amplifier should be used. A variety of feedback systems could then be used without affecting amplifier stability. Finally, the amplifier should work from a symmetric power supply for ease in circuit design and assembly of the yawsonde system. Of course the amplifier must be able to survive the high-g gun launch environment.

2. Several redesign attempts were made with different operational amplifiers. The first is shown in Figure 7. A type L144CJ op-amp was used. This device contains three independent amplifiers in a standard

DIP package. Internal compensation is provided for and a symmetric power supply is used. The design concept was to use a three-stage dc amplifier in the one IC with the first stage as a buffer between the solar cells and the amplifying stages. The first stage would be close to unity gain and act as an impedance matching device. The next two stages would provide the clipped output pulses. The overall gain of the system was 300. The input leads of the two solar cells were arranged so that the amplifier would sum the signals and provide pulses of alternating polarity.

Three yawsondes using this first redesign amplifier were fired on board M107, 155mm artillery projectiles at the N.A.S.A. facility at Wallops Island, Virginia. The results of firings showed a square wave yawsonde signal rather than the expected alternating pulses. The amplitude of the square wave was the saturation voltage of the amplifier and the frequency of the square wave was the roll rate of the projectile. It was not possible to determine the exact cause of the problem but it was felt, at the time, that the recovery time of the overdriven op-amp might be too long.

A second redesign attempt was made using the circuit shown in Figure 8. The same L144CJ op-amp was used with only a single stage of amplification. Both cells were coupled to the non-inverting input in such a manner as to obtain alternating polarity pulses. A high pass filter was used at the cell input with the 3 db point set a 1 Hz. The purpose of the filter was to block any slowly varying background light signals which might occur (it was thought) during the flight. Since the 10 kΩ filter resistor did load the cells down somewhat, the overall gain was increased to 400. In this design, the cells were not connected to the gain loop and it was hoped that a constant gain amplifier would result.

Two yawsonde rounds using 155mm projectiles and the second redesign amplifier were fired at Wallops Island. Again a square wave output was observed over the entire flight. Again the frequency corresponded to the roll rate of the projectile. At this point it was decided to change the operational amplifier for a third redesign. A type 741, single stage, internally compensated IC operational amplifier was used with an arrangement of components shown in Figure 9. The configuration of the amplifier was identical to that of the second redesign (Figure 8) except that it was now operated in the ac mode by putting a capacitor in the gain circuit. The gain was reduced to 100 and the high pass filter resistor increased to 300 kΩ with a 3 db point at 75 Hz.

Once again the trip to Wallops Island was made with two yawsondes using the third redesign amplifier. The results were similar to the first two redesigns with a significant difference, however. The waveform from one flight was not a square wave over the entire flight. Toward the end of the flight one could see some pulses beginning to appear. Two additional yawsondes had been fired with the original circuit on board as a control. Part of the pulse trains from the original circuit and from the third redesign are shown in Figure 10 for comparison. It is interesting to note that the data from the original sondes consist of pulses riding on what seems to be a sinusoidal waveform. Comparing these pulses with the pulses from the third redesign firings suggests that the square wave data received in prior tests was due to an over-amplification of the sinusoidal interpulse baseline. If this sinusoidal interpulse baseline existed on previous flights, then the amplifier gains would have been sufficient to produce saturation with this sinusoid alone. The solar pulses, of course, would have been far beyond saturation. The immediate question, then, had to do with the origin of the sine wave and it was suggested that the sinusoidal variation was due to background radiation.

3. The effect of background radiation due to sky and earth had never been taken into account since it was assumed that the intensity of the sun would mask all other effects. The effect of background radiation was indeed smaller than the effect of the sun but was not negligible, particularly with the original circuit design. Moreover, the assumption that the background would vary slowly over the flight was untrue. Certainly the difference between sky and earth, if discernible, would cause a variation at the same rate as the roll rate of the projectile. Such a variation would be sinusoidal.

In prior designs the solar cells had always been coupled to the amplifier with reversed polarity leads to provide positive and negative pulses at the output. In such a configuration, the signals from the two cells will subtract from each other. If the cells are installed 180° apart on the projectile circumference, the background signals should be 180° out of phase. The individual cell signal amplitudes and the difference amplitude for background radiation are shown in Figure 11. The waveforms are idealized but the amplitudes were measured at 80 mV for skylight and 20 mV for reflection from the earth. The difference between the outputs of the cells appears as a sine wave input to the amplifier with a ± 60 mV fluctuation. The original amplifier design loaded the cells down so that voltage outputs up to 80 mV did not produce a great deal of output from the amplifier in comparison to the 400 mV produced by the sun (see Figure 10). The three redesigns, however, left the solar cells unloaded. With gains in the order of 300 to 400, the output of the amplifier would always be at saturation for input amplitudes greater than 20 mV. As a result, the solar pulses were not detectable due to the enormously magnified background radiation.

III. THE SECOND GENERATION AMPLIFIER

A number of promising designs for a second generation yawsonde amplifier can be suggested on the basis of the preceding discussion. The two designs outlined in the following paragraphs have been successfully tested at Wallops Island.

A. Single Polarity Amplifier

A single polarity amplifier can eliminate the background radiation problem. If the leads from the solar cells are so arranged that they add the outputs rather than subtracting them, then the result of background radiation should be a constant amplitude level. This dc input to the amplifier is readily eliminated by using an ac amplifier design similar to the design shown in Figure 9. The resultant amplifier circuit is shown in Figure 12. The essential difference is the polarity of the cell leads. A single yawsonde using this circuit was fired at Wallops Island and a data train of positive pulses, saturated in amplitude, was the result. No effects due to background radiation were noticeable. A sample of the data from this flight is shown in Figure 14a.

B. Differentiating Input Amplifier

A differentiating input amplifier can be used with the cell output leads either adding or subtracting. The use of a differentiating input gives the advantage of producing fast rising pulses of narrow width while at the same time eliminating the relatively slow variations due to background. The differentiating input, however, produces overshoot and a limiting circuit must be incorporated into the amplifier output as shown in Figure 13. The circuit shows that cells arranged so that the signals will add thus requiring only a single overshoot limiter. A slightly more complicated arrangement of limiters would be required if alternating polarity outputs were desired. A yawsonde using the circuit of Figure 13 was flown at Wallops Island and produced the results shown in Figure 14b. It should be noted that the pulses are fast rising with no background effect. Additional tests are now being conducted with both the single polarity and the differentiating input amplifiers to determine which one will be used in the next generation yawsonde.

IV. A SECOND GENERATION YAWSONDE

The redesign of the yawsonde amplifier has produced an instrument which generates data pulses with sharp risetimes and constant amplitudes since the amplifier gain is set so that minimum input signals will saturate the output. The reduction of data from such yawsondes should be greatly simplified for the hybrid computer. Unfortunately, the amplifier redesign has not solved the problem of rf interference or data loss due to signal dropout. Even if transmitter power were increased to overcome noise interference, there would still exist data dropout due to antenna pattern variations or firing conditions such that the sun is not in view over portions of the flight. Sporadic data is still quite difficult to reduce on the hybrid computer. If it were possible to telemeter the measured solar aspect angle rather than a data pulse train, then gaps in the data would mearely represent an incomplete flight history rather than an unmanageable reduction chore.

In-flight data reduction has the added advantage of producing real time information about the behavior of the shell. Such data might make it possible to accomplish mid-course adjustments to the motion of the projectile and thereby enhance the accuracy of artillery fire.

It has become technically feasible to reduce yawsonde data on board the projectile with the availability of IC computer circuits in conventional DIP packages. A variety of such circuits have been tested at up to 40,000 g and have functioned successfully after test. The design of a circuit to reduce the data on board requires the availability of uniform and precise pulses for measurement purposes. Thus, the on-board data reduction system consists of signal conditioning circuits and pulse measuring and transmitting circuits.

A. Signal Conditioning

Signal conditioning of the data pulses would be done in the manner shown in Figure 15. The output of the redesigned amplifier is used to drive a flip-flop. The normal and the inverted outputs of the flip-flop are coupled to two inputs of a NAND gate. As the amplifier solar cell pulses arrive at the flip-flop, they change the output state (either high to low, or low to high). Alternate inputs to the NAND gate will then go high or low depending on which pulse has triggered the flip-flop. When either input to the NAND gate goes low, the output of the NAND gate goes high and remains in a high state for a length of time proportional to the RC time constant at the input. The result of a train of sunsensor pulses is an output from the NAND gate of a train of constant amplitude, constant duration pulses which are synchronized with the sunsensor pulses. For the usual yawsonde application, the pulse duration would be set at about 200 microseconds. For a completely on-board reduction system, the pulse widths would be set to about one microsecond. As shown in Figure 15, the first tests of the signal conditioning circuits would be done with a parallel output from the amplifier to drive a separate VCO. This would allow a comparison between the data pulses derived from the signal conditioner and the ones derived just from the amplifier.

B. The On-Board Data Reduction System

The on-board data reduction system proposed for tests later this year is shown in block diagram form in Figure 16. The circuit components are all digital IC's using COS/MOS type logic. The digital IC's use very little power, can be operated over a voltage range from 3 to 15 Vdc and have been tested at the high accelerations experienced in gun launches.

The on-board circuits are designed to measure the time interval between pulses generated by the solar cells. Two time intervals are measured, one between pulses from the same cell (roll rate) and the other between pulses from different cells (related to aspect angle). The amplified and conditioned sunsensor pulse train is a source of control pulses for the digital circuits. A 14-stage binary counter counts clock pulses from a 1-MHz internal clock. The conditioned sunsensor pulses are used to initiate parallel transfer of the count or state of the counter to a 16-stage shift register. The system is so designed that the pulse from one sunsensor will allow the state of the counter to be read by the shift register without disturbing the count. The pulse from the second sunsensor will be used to read the count in the binary counter and then will reset the counter for the next data interval.

After the parallel data shift from the counter to the shift register takes place, a second internal clock serially shifts the data out of the shift register into the telemeter circuits for transmission to ground stations. The data input to the telemeter is in the form of a series of 14 bit binary words, each word representing a time interval between sunsensor pulses. These binary words can be read and directly related, through calibration, to the spin and solar aspect angle data required from the yawsonde. Further sophistication could be provided so that the solar aspect angle would be available on board the projectile, if needed for control purposes.

V. CONCLUSIONS

A number of methods for improving yawsonde data have been described and the results of actual flight tests have shown these methods to be promising. A second generation yawsonde which will provide enhanced pulse data for hybrid computer reduction has been designed and flight tests are currently being undertaken. The circuits for accomplishing on-board data reduction have been g-tested and the design of an on-board reduction system has been accomplished. Further tests of this system will be made on actual projectiles once the selection of amplifier and signal-conditioner has been completed.

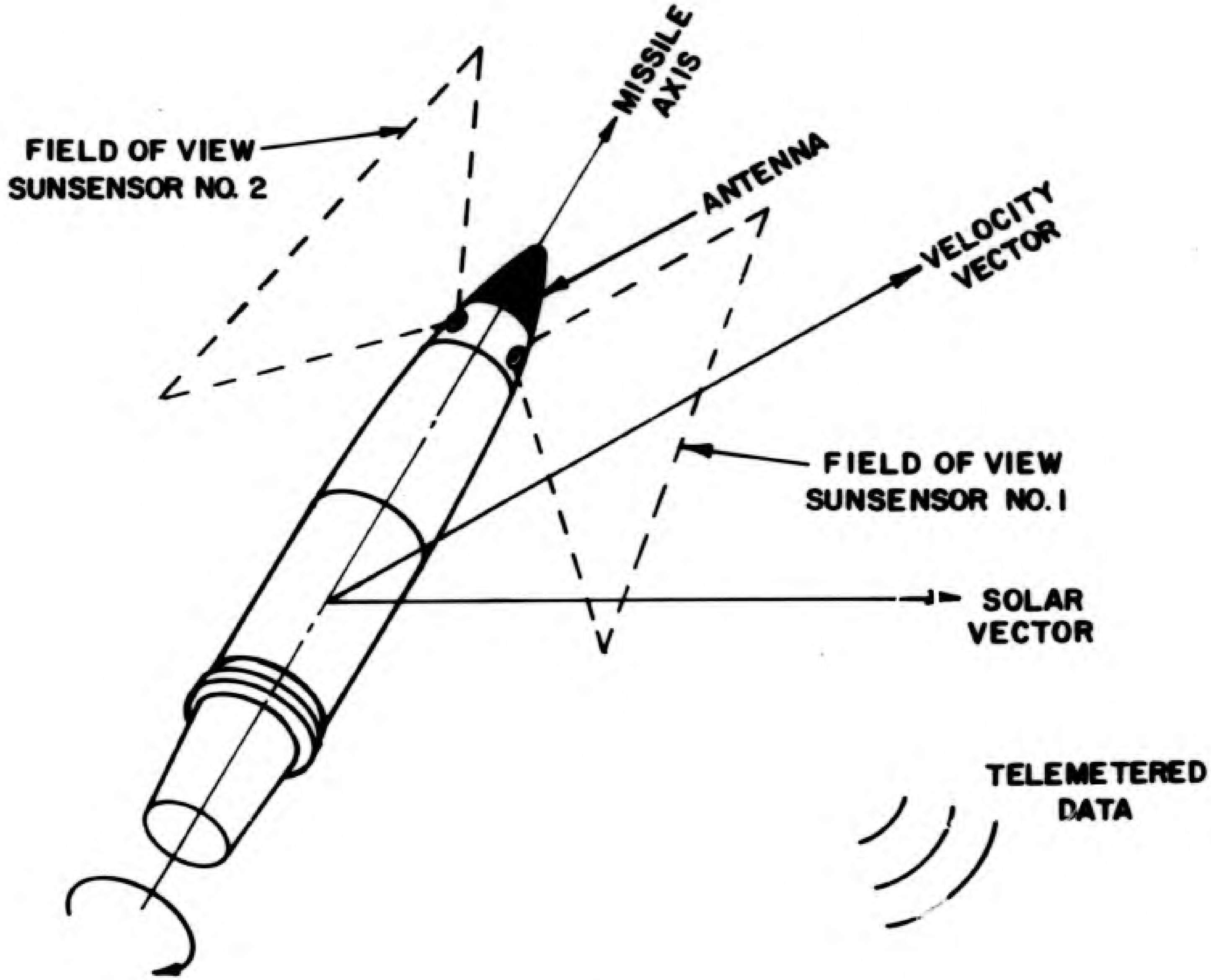


Figure 1. A Schematic of the BRL Yawsonde

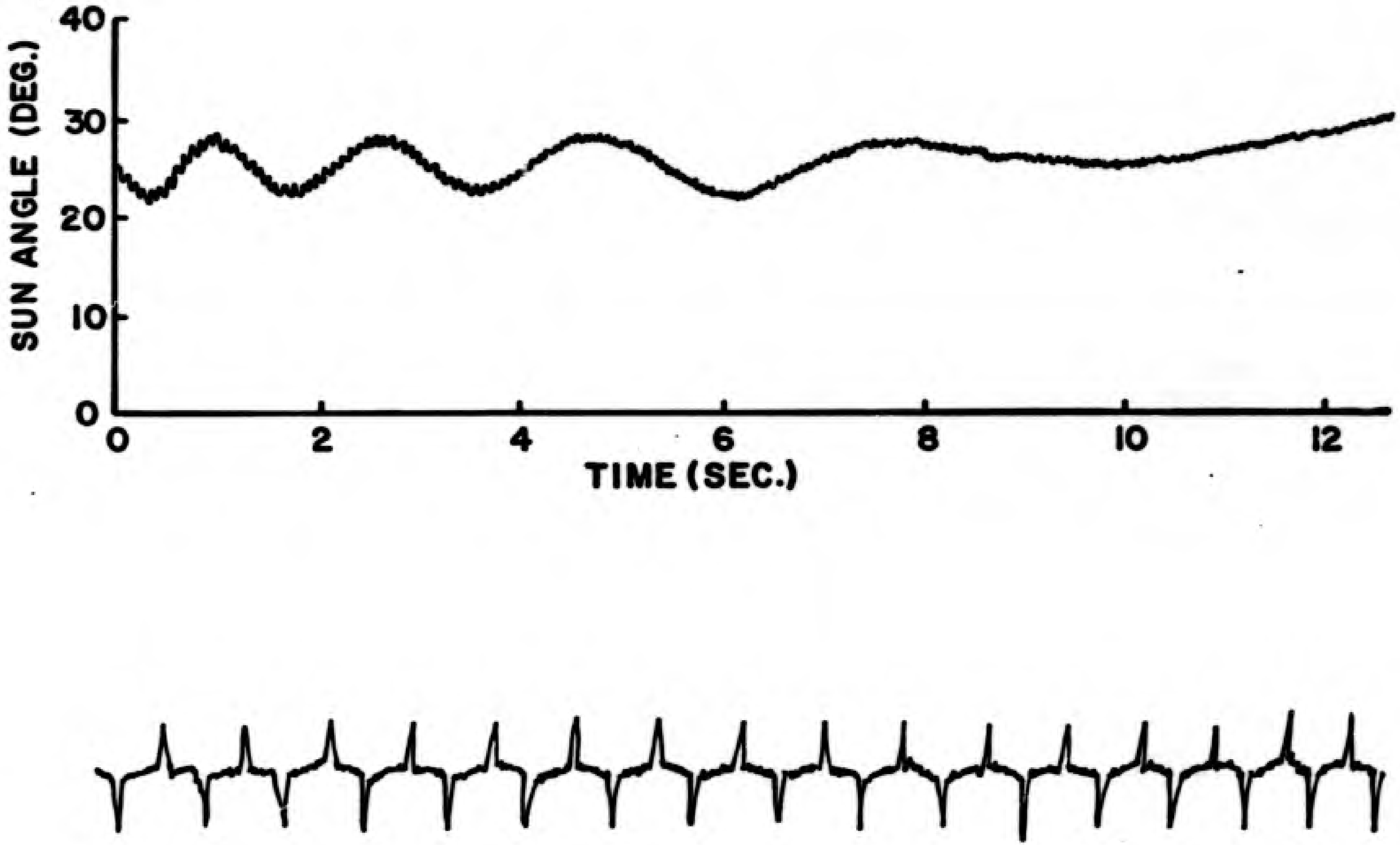


Figure 2. A Sample Yawsonde Pulse Train (bottom) and the Reduced Solar Aspect Angle (top)

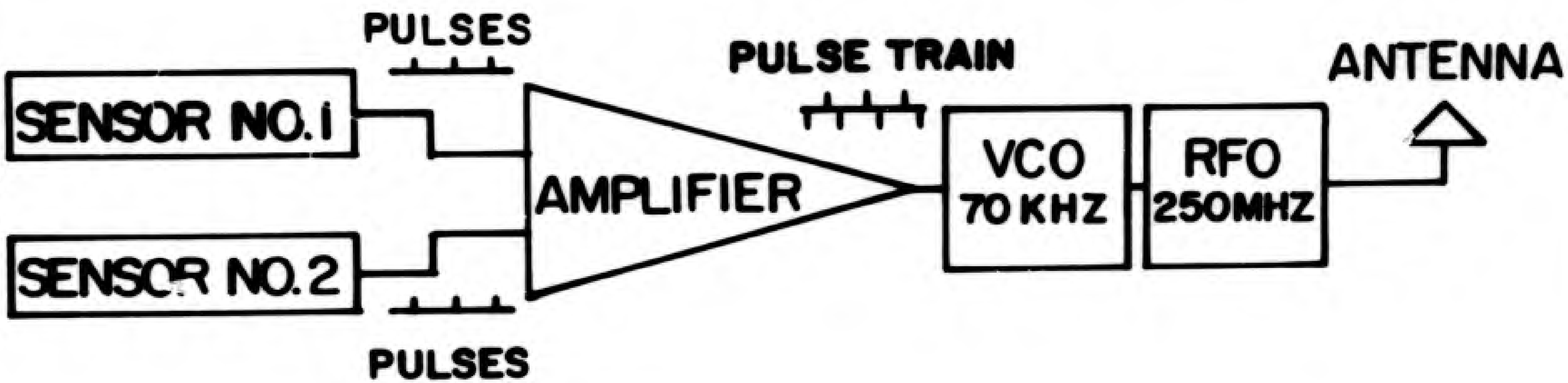
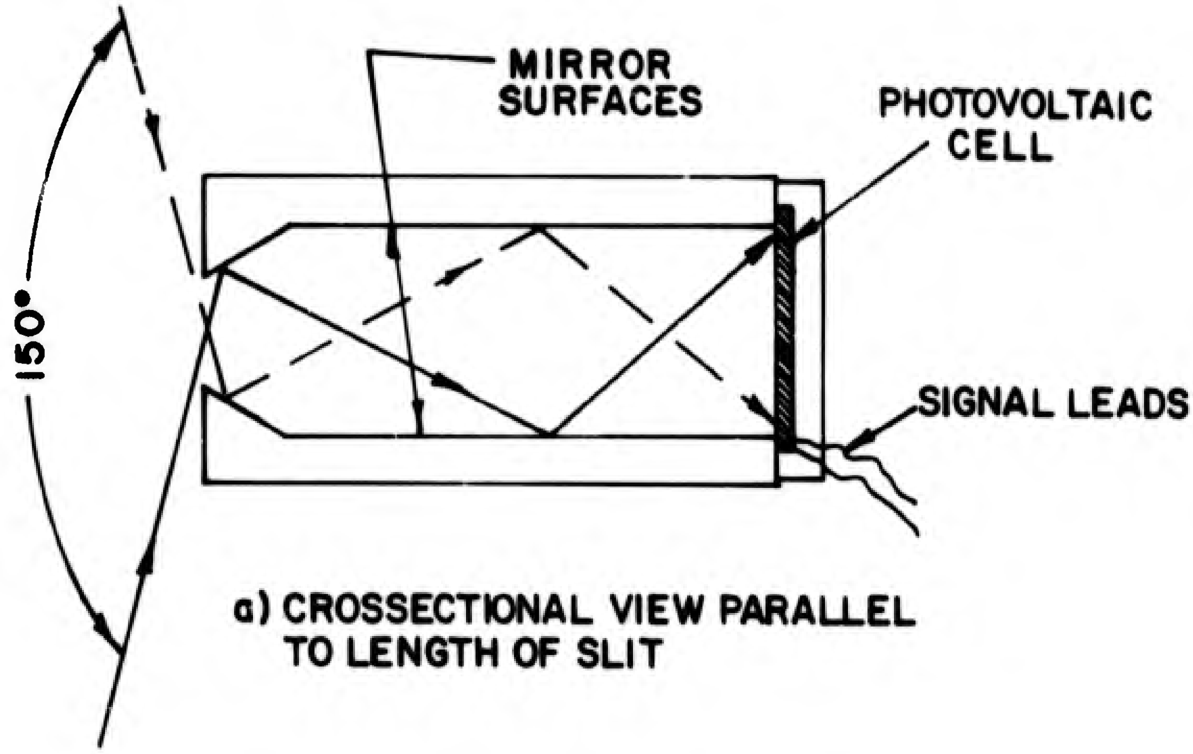


Figure 3. A Block Diagram of the Current BRL Yawsonde Electronics



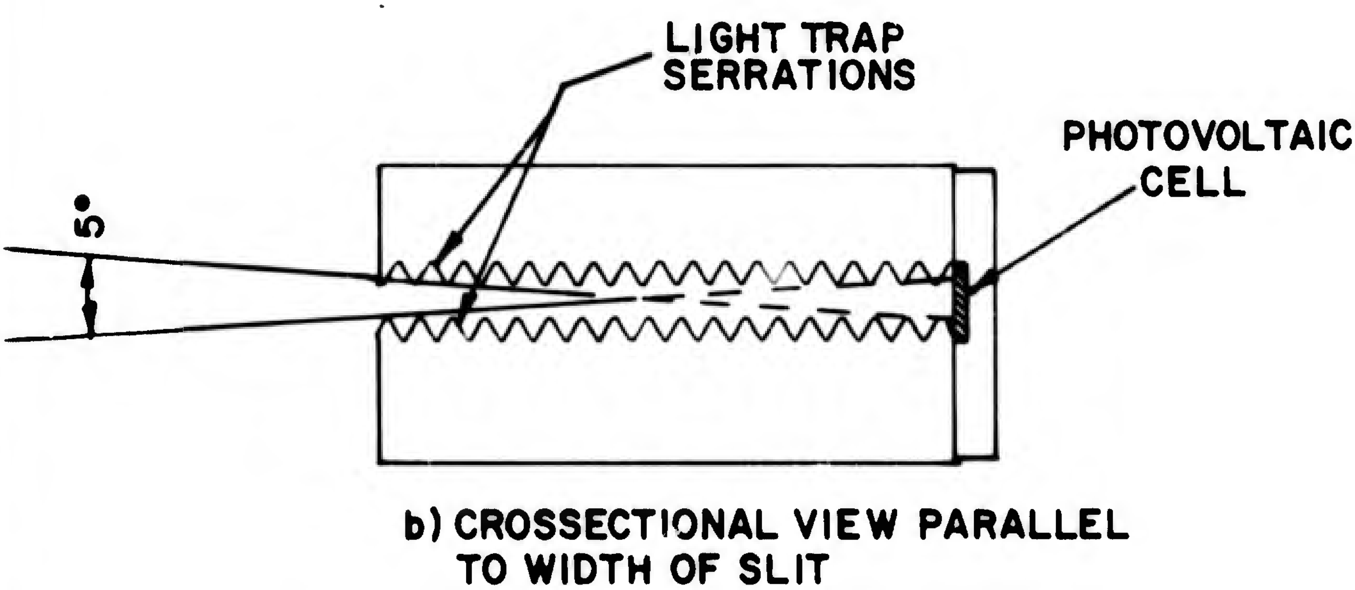


Figure 4. A Schematic of the Solar Cell and Slit Geometry

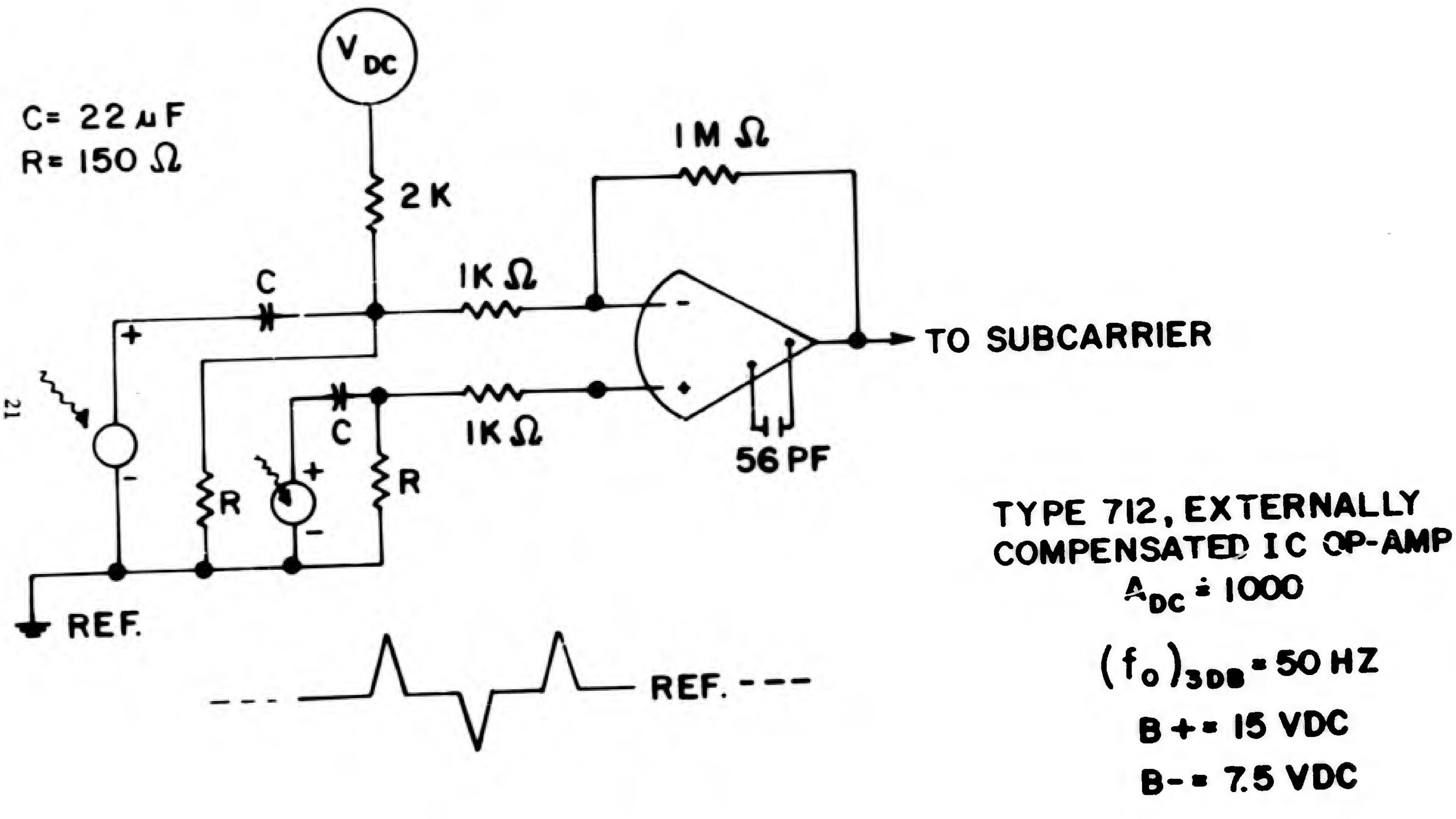


Figure 5. Circuit Diagram of the Current Yawsonde Amplifier - An ac Amplifier with Differential Input

Figure 6. The Components of the Nose-Fuse Yawsonde

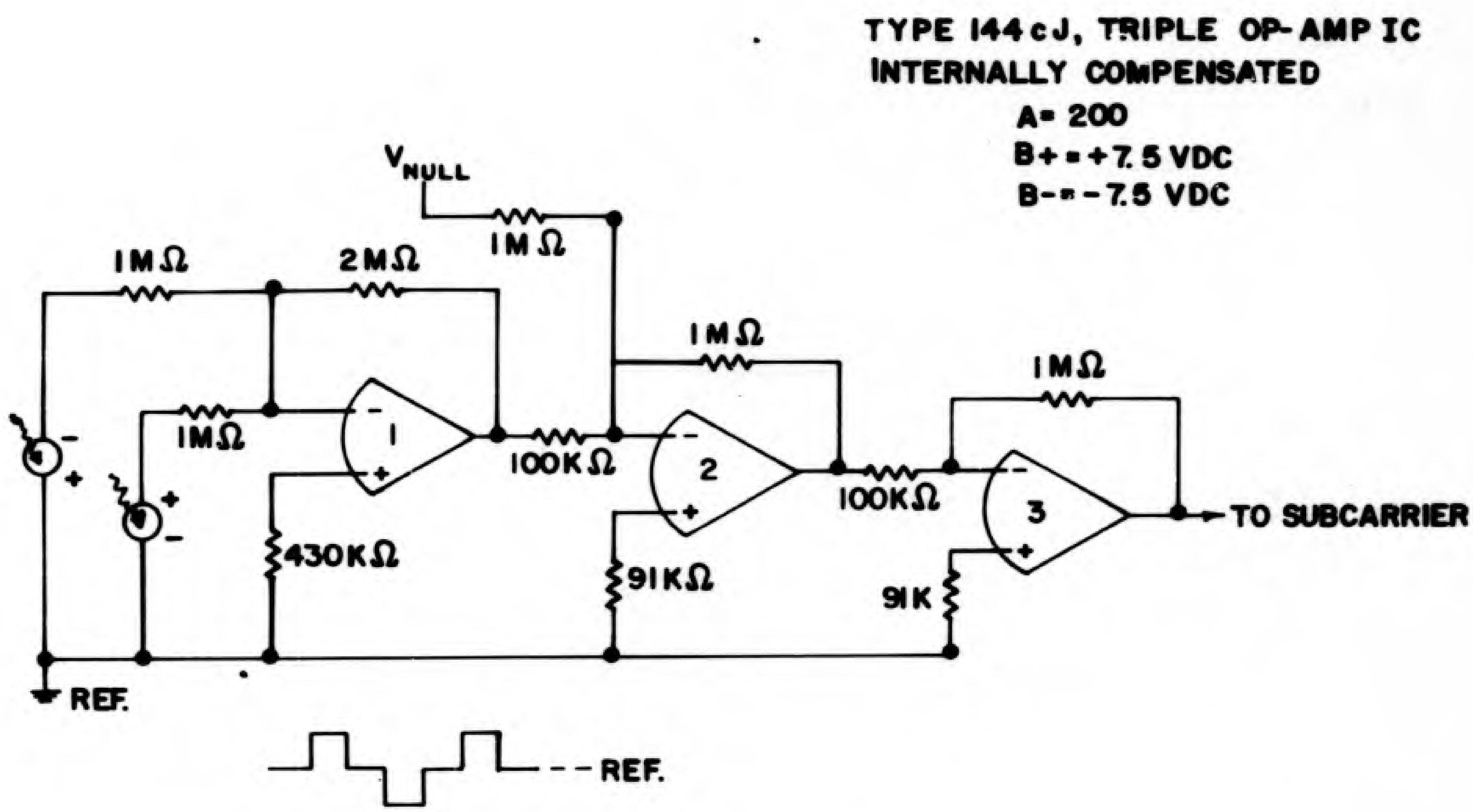


Figure 7. Circuit Diagram of the First Amplifier Redesign Attempt - A 3-Stage, dc Amplifier

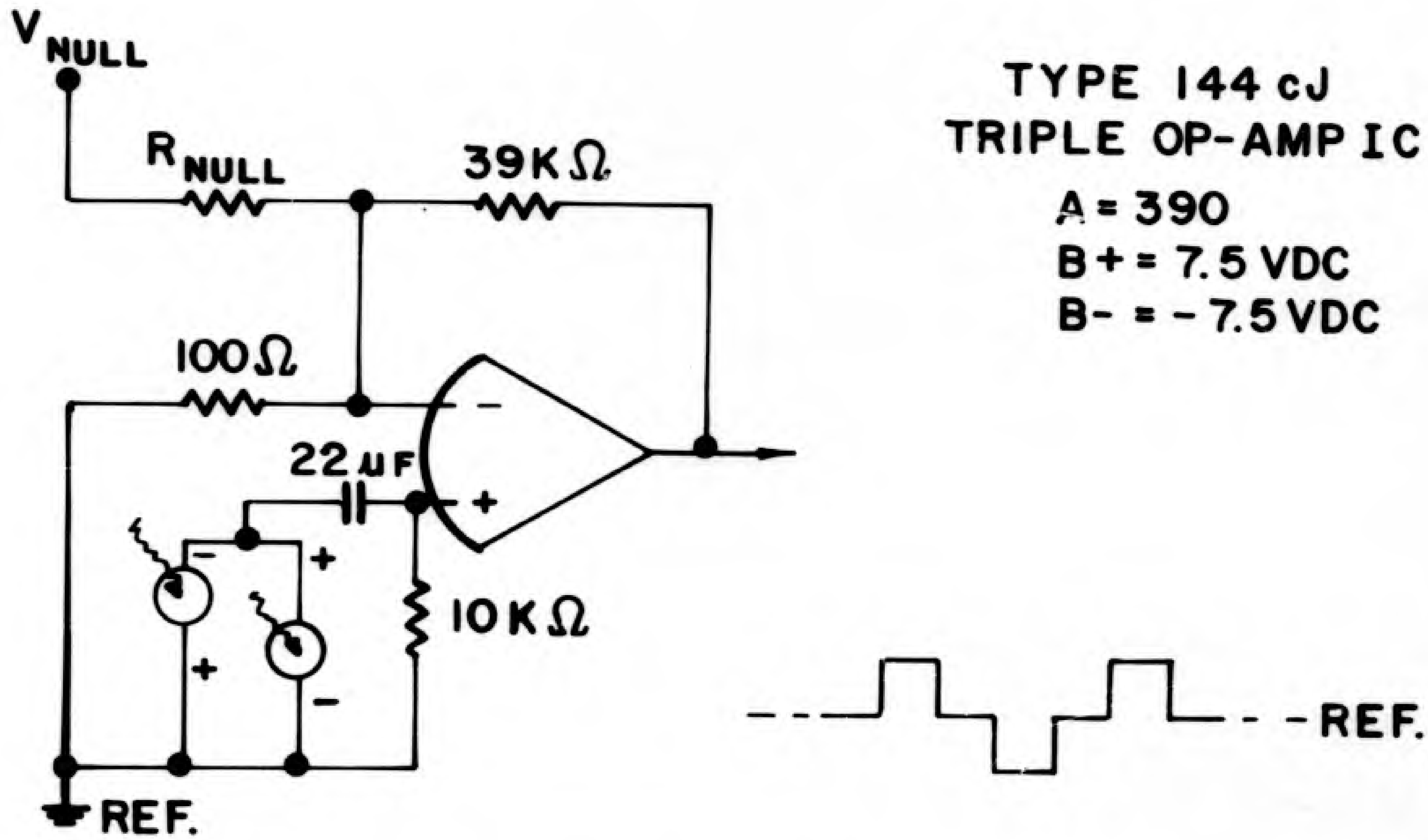


Figure 8. Circuit Diagram of the Second Amplifier Redesign Attempt - An ac-Coupled, dc Amplifier

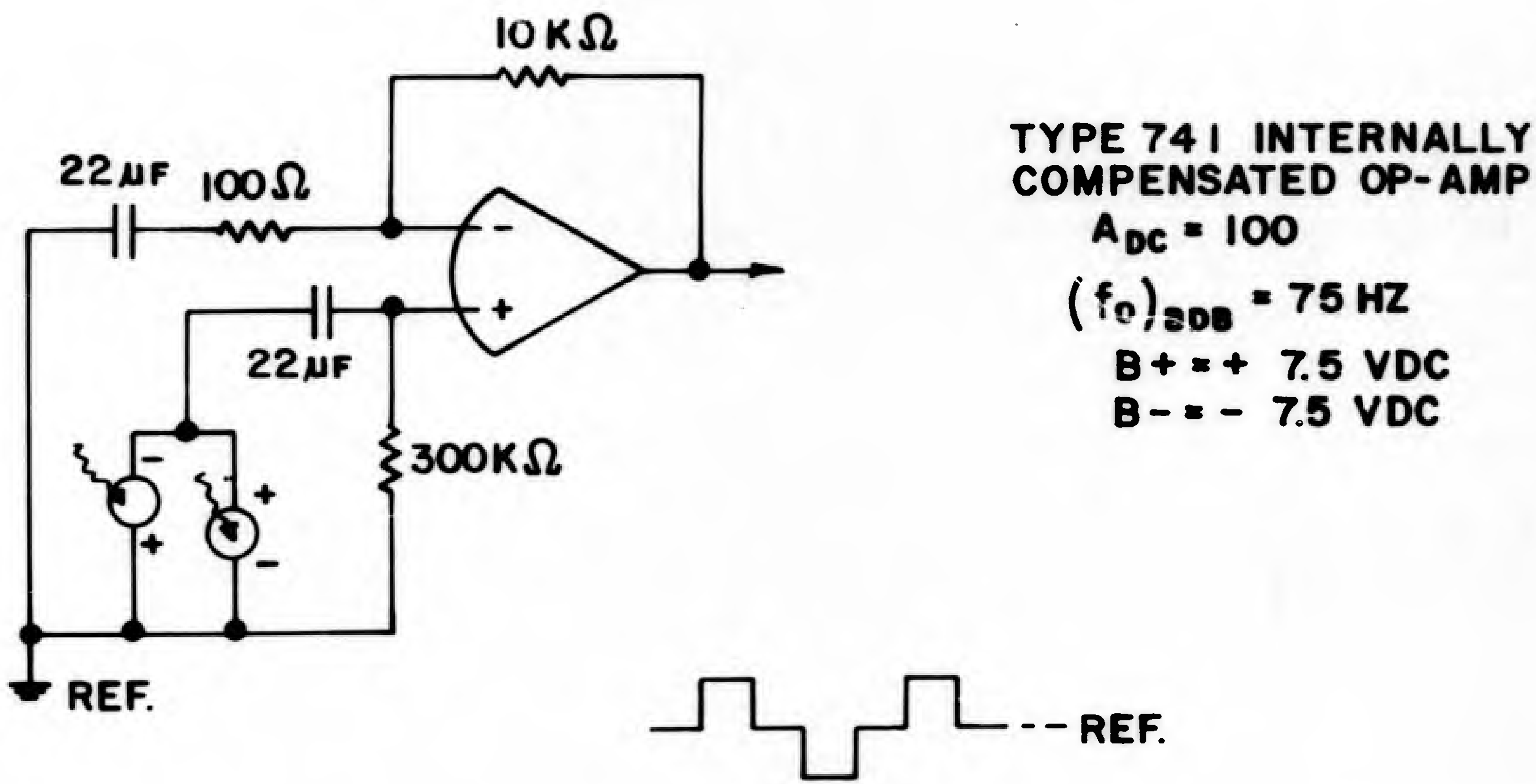


Figure 9. Circuit Diagram of the Third Amplifier Redesign Attempt - An ac-Coupled, ac Amplifier

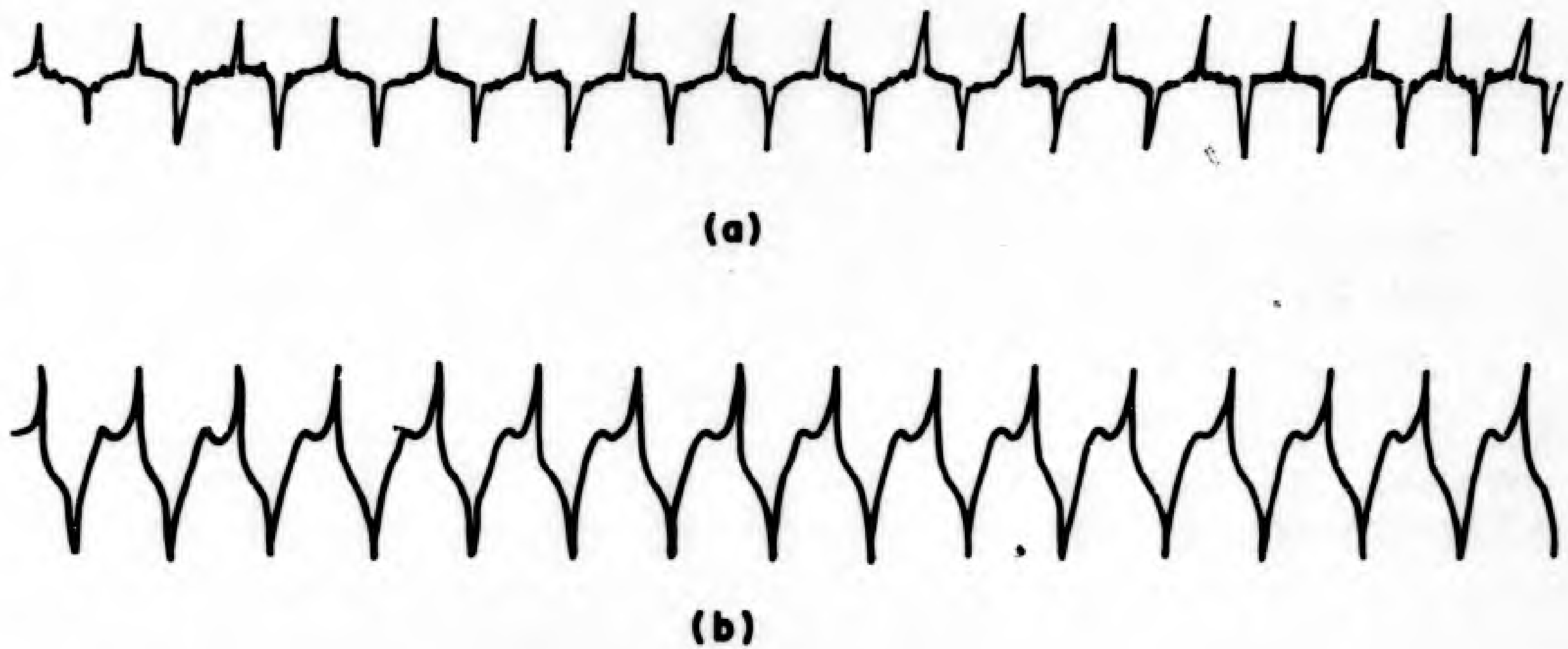


Figure 10. (a) Solar Cell Pulses from Original Circuit
(b) Solar Cell Pulses from the Third Redesign Circuit

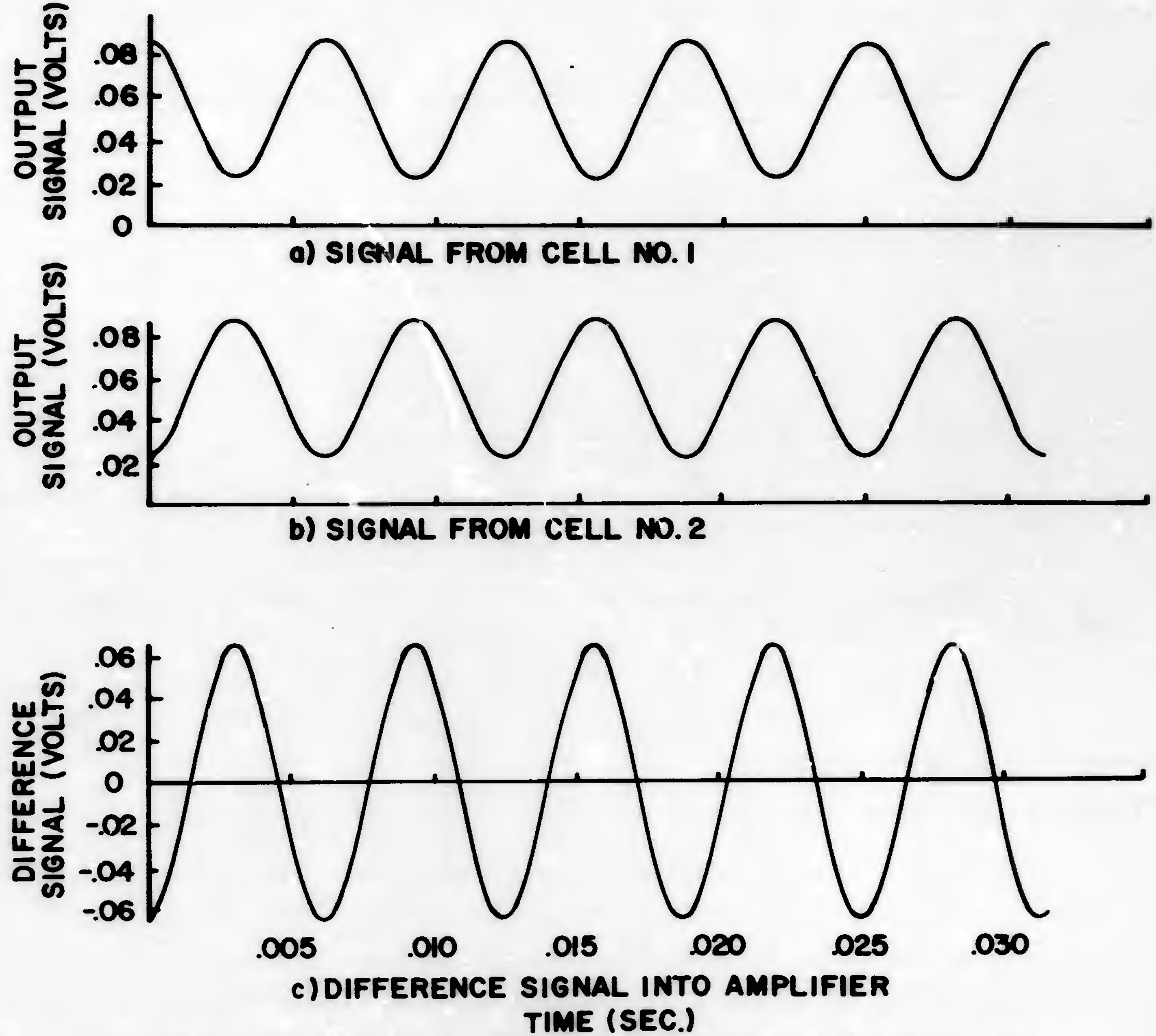


Figure 11. Idealized Waveforms from Each Cell Due to Background and the Combined Signal into the Amplifier

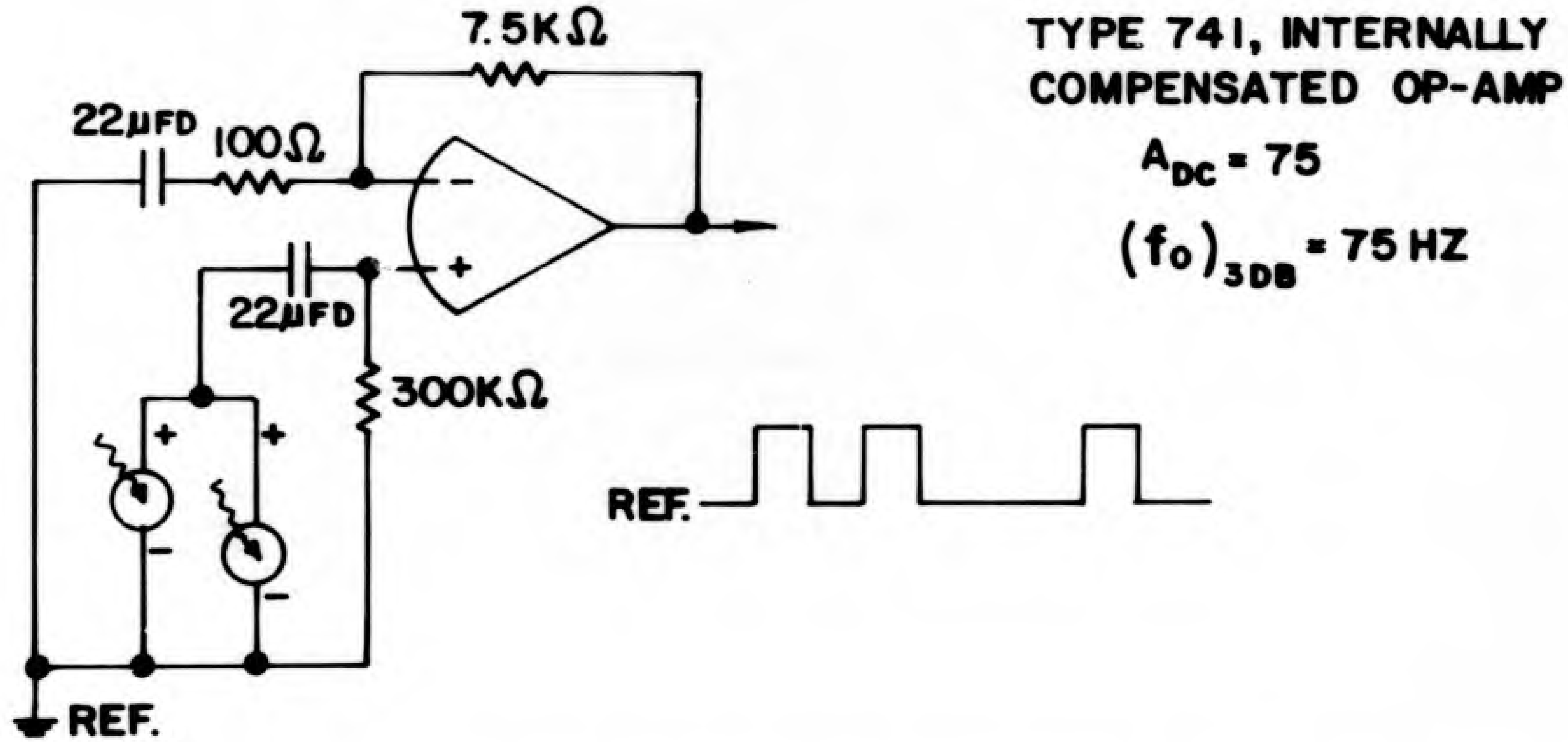


Figure 12. An Amplifier Design that Produces Output Pulses of the Same Polarity

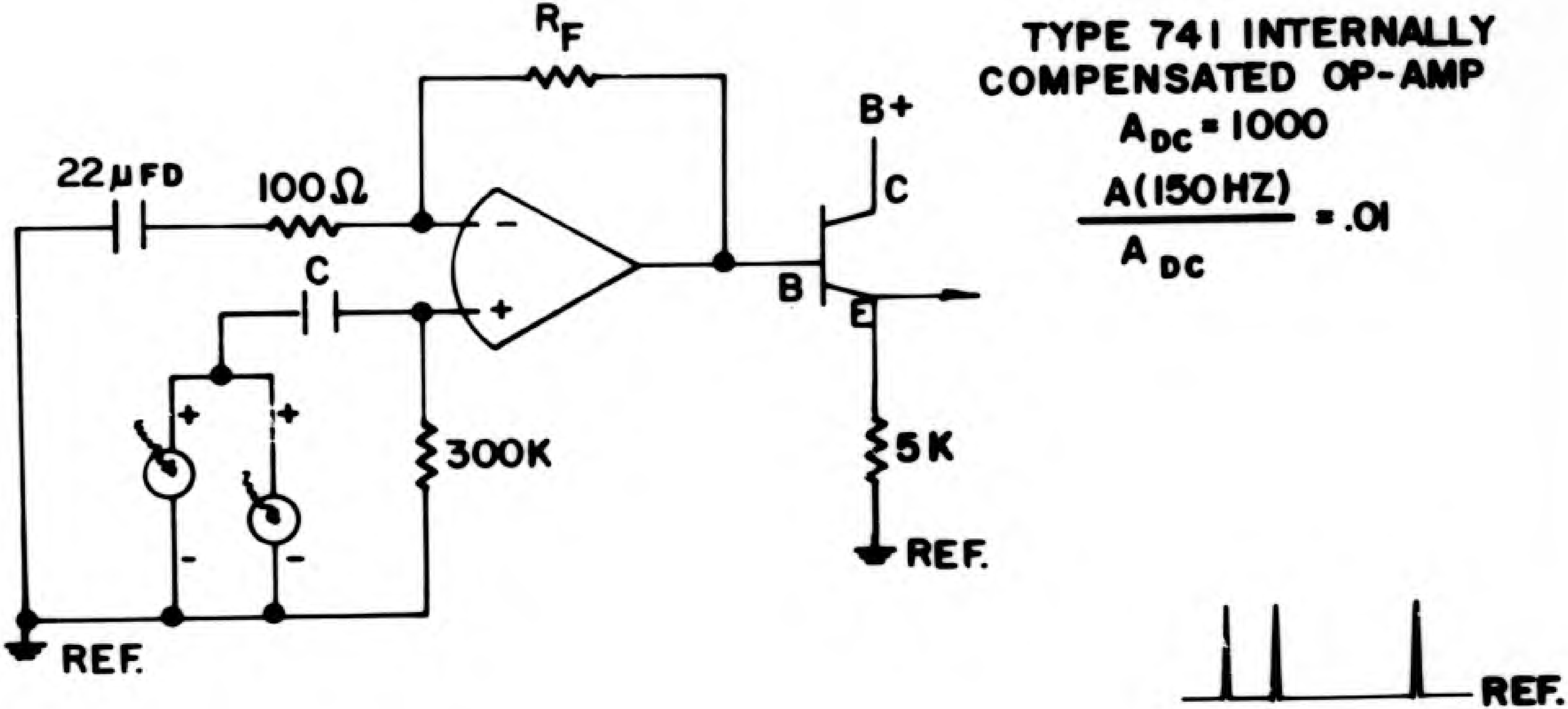


Figure 13. An Amplifier Design with Differentiated Input Pulses

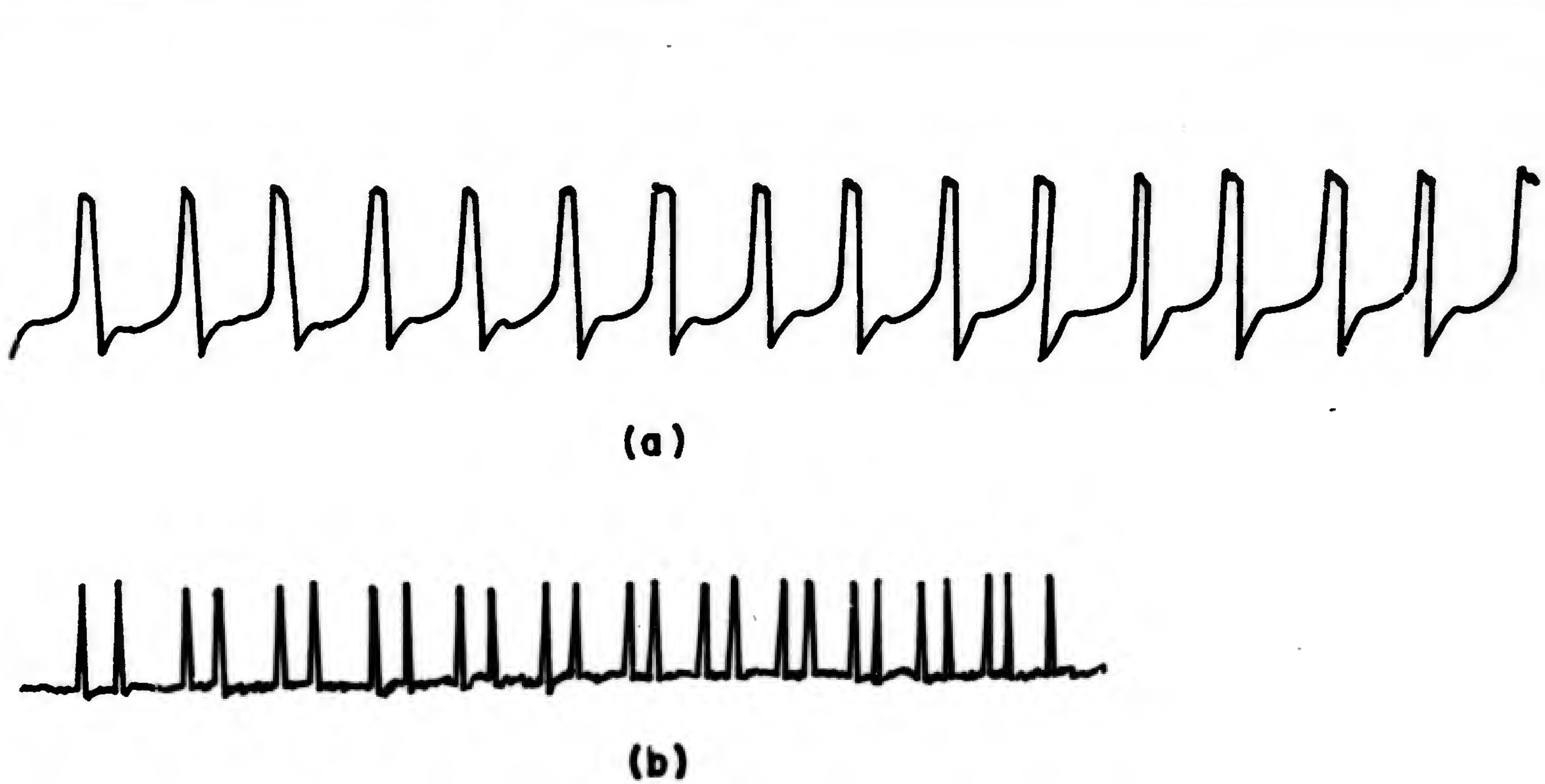


Figure 14. (a) Data Pulses from a Yawsonde with a Single Polarity Output
(b) Data Pulses from a Yawsonde with a Differentiated Input

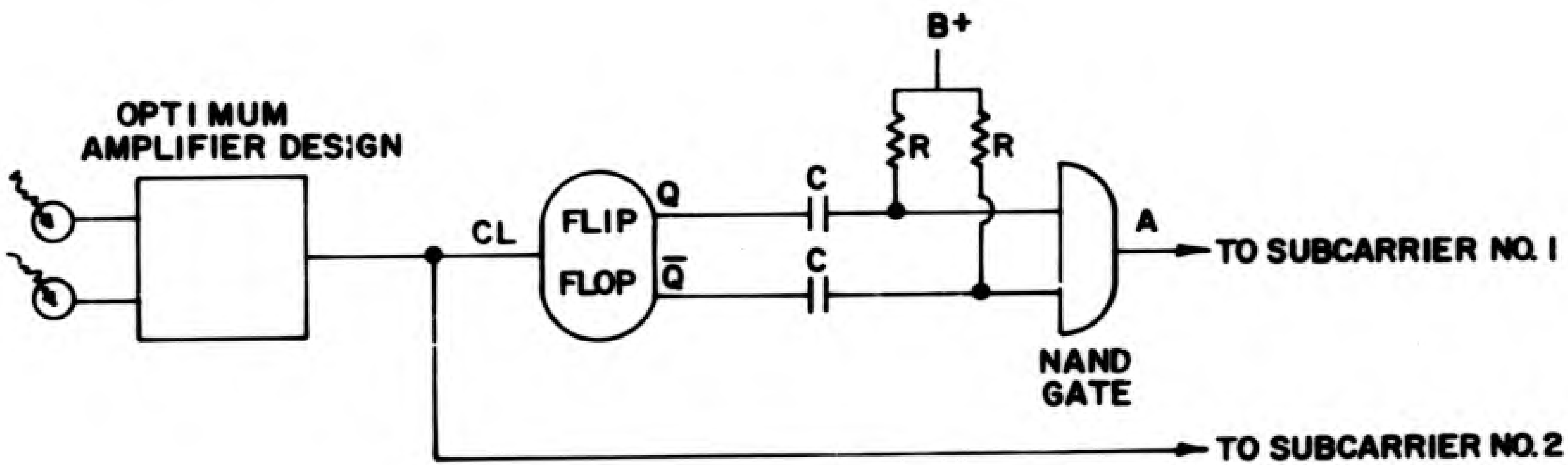


Figure 15. A Signal Conditioning Circuit for Use on Improved Yawsondes or for On-Board Data Reduction Circuits

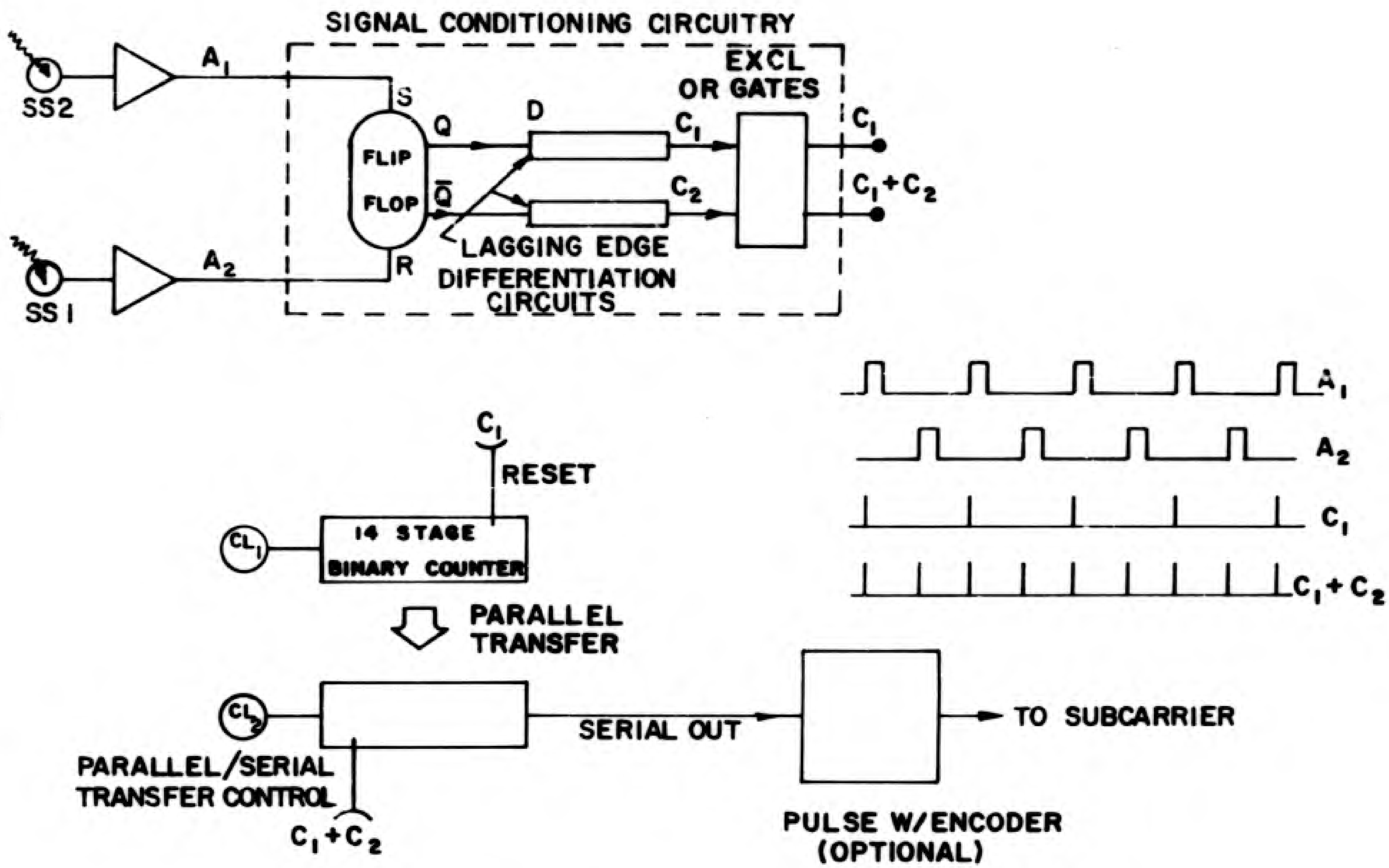


Figure 16. A Block Diagram of a Proposed On-Board Data Reduction System

REFERENCES

1. W. H. Mermagen, "Projectile High-G Telemetry for Long Range Dynamics Measurements," Proceedings of the International Telemetering Conference, Vol. VII, September 1971, pp. 500-513.

2. W. H. Mermagen, "Measurements of the Dynamical Behavior of Projectiles Over Long Flight Paths," *Journal of Spacecraft and Rockets*, Vol. 8, No. 4, April 1971, pp. 380-385.

3. W. R. Hazeltine, "Yawing Motion of 5.0" MK41 Projectile Studied by Means of Yaw Sondes," Naval Weapons Center Report NWC TP 4779, August 1969, AD 862065.

4. I. O. F. Amery, "Flight Behavior of Projectiles. Yaw Telemetry Trial. 4.5" Naval Shell. Malta, April, 1967," Royal Armament Research and Development Establishment Memorandum 9/68, November 1968.

5. G. T. Chapman and D. B. Kirk, "A Method for Extracting Aerodynamic Coefficients from Free Flight Data," *AIAA Journal*, Vol. 8, No. 4, April 1970.

6. R. H. Whyte and W. H. Mermagen, "A Method for Obtaining Aerodynamic Coefficients from Yawsonde and Radar Data," *Journal of Spacecraft and Rockets*, Vol. 10, No. 6, June 1973.

7. W. H. Clay, "A Precision Yawsonde Calibration Technique," Ballistic Research Laboratories Memorandum Report No. 2263, January 1973, AD 758158.