7-92

1992

PRELIMINARY SERVICE MANUAL

NELLCOR® N-180 PULSE OXIMETER

Caution: Federal law (U.S.) restricts this device to sale by or on order of a physician.

Nellcor Incorporated
25495 Whitesell Street
Hayward, California 94545 U.S.A.
510 887-5858
1-800-NELLCOR

023219B-0292

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Introduction

1.1 INTRODUCTION

This manual contains information for servicing the *NELLCOR* N-180 pulse oximeter. This manual is intended for use by individuals who have a technical background in analog and digital electronics. Service of this product must be done by qualified service personnel.

Before servicing the N-180, read the operator's manual carefully for a thorough understanding of operation.

1.2 OVERVIEW

The N-180 pulse oximeter measures functional oxygen saturation of arterial hemoglobin (SpO_2), and pulse rate. The N-180 monitors SpO_2 and pulse rate continuously and noninvasively, with measurements updated at each pulse beat. An internal AC power supply provides isolated power for operating the monitor and charging its internal batteries. In addition, the N-180 provides a digital output for external data recording devices.

1.3 FEATURES

The N-180 provides immediate use after power-up, without need for operator calibration or configuration. It offers:

- Automatic self-test and error messages.
- Automatic oximetry calibration.
- Visible and audible oximetry displays.
- An early warning system that provides an audible indicator for both SpO_2 and pulse rate: a tone signals each pulse and its pitch varies with changes in SpO_2.
- Operator-configured audible oximetry alarms, with default alarm limits preset for adults or neonates. Pulse rate and oxygen saturation displays change from green to red during an alarm condition.
- Battery operation up to 6 hours.

The N-180 provides the operator with the capability to tailor the system for specific clinical applications. Capabilities include:

- Audible alarms that can be silenced temporarily or disabled; the alarm tone has adjustable volume.
- Three oximetry operating modes that change measurement averaging time to suit varied clinical applications.

1.4 NOTES, CAUTIONS, AND WARNINGS

This manual uses three terms that are important for proper operation of the monitor:

1.4.1 *Warning*

A warning precedes an action that may result in injury to, or death of, the patient or user. Warnings are highlighted in boldface type, with a border.

1.4.2 *Caution*

A caution precedes an action that may result in damage to, or malfunction of, the monitor. Cautions are highlighted in boldface type.

1.4.3 *Note*

A note gives information that requires special attention by the reader.

Section 2
Principles of Operation

2.1 INTRODUCTION

The N-180 is based on the principles of spectrophotometry and plethysmography. It includes an electro-optical sensor and a microprocessor-based monitor. The sensor has two low-voltage light-emitting diodes (LEDs) as light sources and one photodiode as a photodetector. One LED emits red light (nominal 660 nm wavelength) and the other emits infrared (nominal 920 nm). When the light from the LEDs passes through the sensor site, part of the light is absorbed. The photodetector measures the light that passes through, which is a measure of red and infrared absorption.

With each heartbeat, a pulse of oxygenated arterial blood flows to the sensor site. Oxygenated hemoglobin differs from deoxygenated hemoglobin in its relative red and infrared absorption, and the N-180 measures red and infrared absorption to determine the percentage of functional hemoglobin that is saturated with oxygen.

Light absorption that is measured when pulsatile blood is not present reflects absorption by tissue and nonpulsatile blood—absorption that does not change substantially during the pulse. This is analogous to the reference measurement of a spectrophotometer. Absorption is also measured when pulsatile, arterial blood is in the tissue. The N-180 then corrects this measurement for absorption when the pulsatile blood is not present. The ratio of the corrected absorption at each wavelength determines SpO_2.

2.2 AUTOMATIC CALIBRATION

The oximetry subsystem incorporates automatic calibration mechanisms. It is automatically calibrated each time it is turned on, at periodic intervals thereafter, and whenever a new sensor is connected. Also, the intensity of the sensor's LEDs is adjusted automatically to compensate for differences in tissue thickness.

Each sensor is calibrated when manufactured: the effective mean wavelength of the red LED is determined and encoded by a calibration resistor in the sensor plug. The instrument's software reads this calibration resistor to determine the appropriate calibration coefficients for the measurements obtained by that sensor.

2.3 FUNCTIONAL VERSUS FRACTIONAL SATURATION

Because the N-180 measures functional SpO_2, it may produce measurements that differ from those of instruments that measure fractional SpO_2. Functional SpO_2 is oxygenated hemoglobin expressed as a percentage of the hemoglobin that is capable of transporting oxygen. Because the N-180 uses two wavelengths, it measures oxygenated and deoxygenated hemoglobin, yielding functional SpO_2. It does not detect dysfunctional hemoglobin, such as carboxyhemoglobin or methemoglobin.

In contrast, some laboratory instruments such as the Instrumentation Laboratory 282 CO-Oximeter report fractional SpO_2—oxygenated hemoglobin expressed as a percentage of all measured hemoglobin, whether or not that hemoglobin is available for oxygen transport. Measured dysfunctional hemoglobins are included.

Consequently, to compare N-180 measurements directly with those of another instrument, that other instrument must measure functional SpO2. If it measures fractional SpO2, those measurements can be converted using the following equation:

$$\text{functional saturation} = \text{fractional saturation} \times \frac{100}{100-(\%\ \text{carboxyhemoglobin} + \%\text{methemoglobin})}$$

2.4 Measured versus Calculated Saturation

When SpO2 is calculated from a blood gas measurement of the partial pressure of arterial oxygen (PaO2), the calculated value may differ from the N-180 SpO2 measurement. This is because the calculated SpO2 may not have been corrected for the effects of variables that shift the relationship between PaO2 and SpO2 (see Figure 2-1): temperature, pH, the partial pressure of carbon dioxide (PaCO2), and the concentrations of 2,3-DPG and fetal hemoglobin.

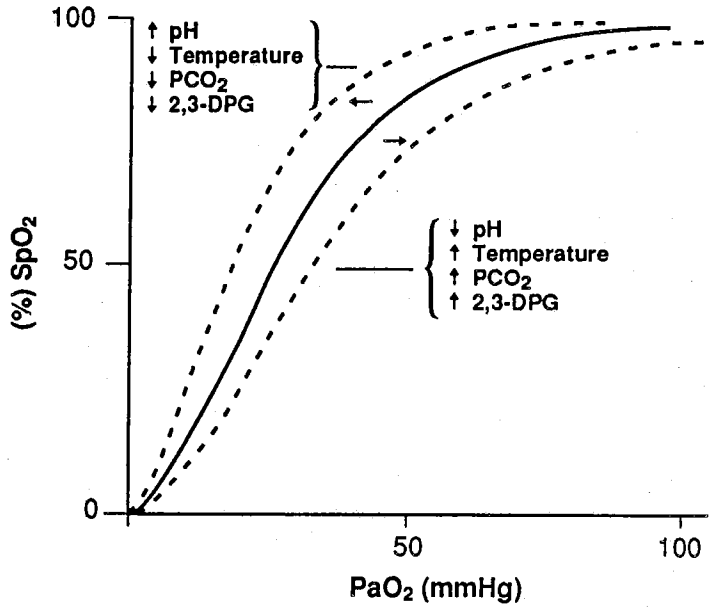

Figure 2-1: Oxyhemoglobin Dissociation Curve

Section 3
Circuit Analysis

3.1 INTRODUCTION

This section provides qualified service personnel with a detailed explanation of circuit operation for the *NELLCOR* N-180 pulse oximeter, hereinafter called the monitor. The text includes illustrations supporting discussions of circuit operation. Section 8, "Schematic Diagrams," contains circuit diagrams providing greater detail. The section is divided into two major parts:

3.2 Block Diagram Analysis
3.3 Detailed Circuit Analysis

Note: Active low logic signals are designated by a forward slash after the signal name (e.g., SIGNAL/).

3.2 BLOCK DIAGRAM ANALYSIS

The following discussion is an overview of the N-180 and identifies major assembly blocks. A detailed discussion of major functional blocks is given in paragraph 3.3 The N-180's circuits are divided into the following subassemblies:

3.2.1 Oximetry Module
3.2.2 Front Panel Assembly
3.2.3 CPU PCB
3.2.4 AC Power and Control
3.2.5 Battery Pack

Refer to Figure 3-1, "N-180 Block Diagram," for the physical relationship of these circuit blocks.

3.2.1 *Oximetry Module*

The oximetry module drives the oxygen transducer and conditions the signal derived from the patient. This signal, referred to as the "SAT" signal, is conditioned and used to derive saturation percentage and pulse rate values presented on the monitor. This information is serially coupled to the processing circuits on the CPU PCB for display and external output conditioning.

The following discussion is given as an overview of the oximetry module and identifies major circuit blocks. A more detailed discussion of each block is given in paragraph 3.3. The circuits of the oximetry module can be divided into the following major functional blocks:

3.2.1.1 LED Driver
3.2.1.2 Sensor Assembly
3.2.1.3 Input Amplifier and Synchronous Detector
3.2.1.4 Filters/Amplifiers
3.2.1.5 A:D Conversion
3.2.1.6 Support Circuits

Refer to Figure 3-2, "Oximetry Module Block Diagram," for the logical relationship of these circuit blocks.

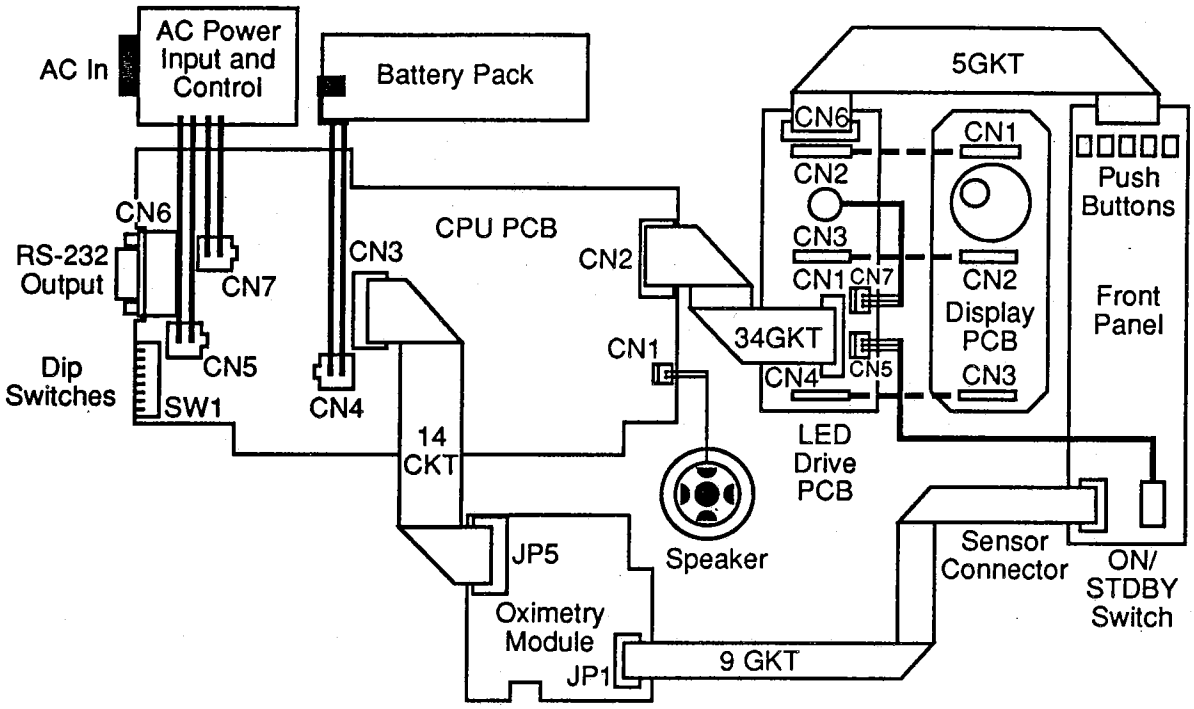

Figure 3-1: N-180 Block Diagram

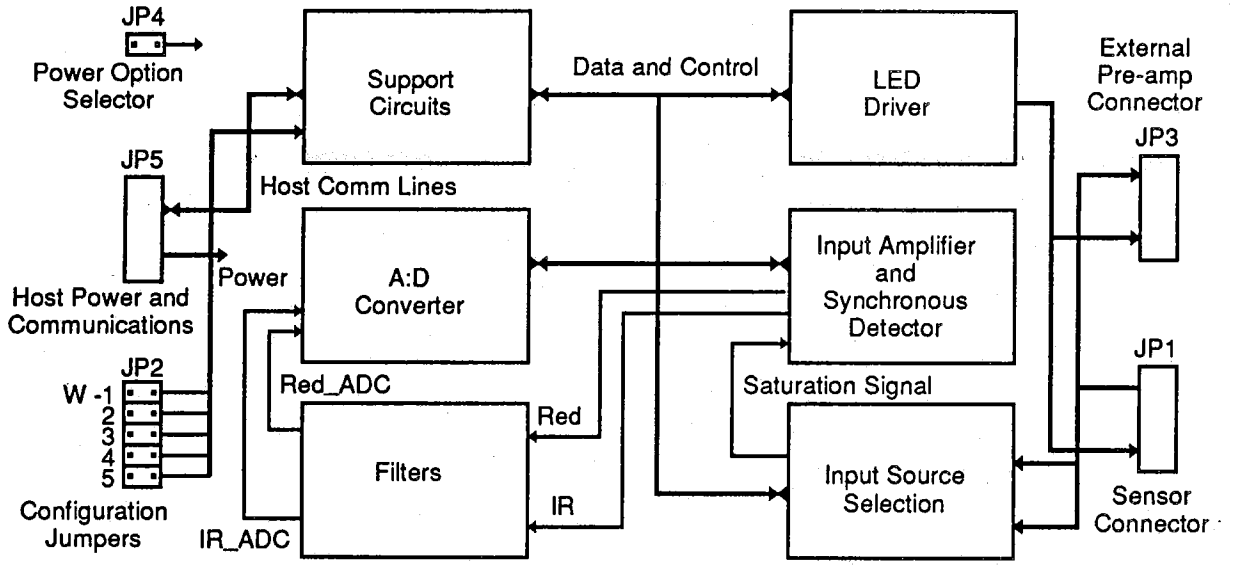

Figure 3-2: Oximetry Module Block Diagram

3.2.1.1 LED Driver

Circuits in this block develop LED drive signals as well as control current switching to ensure the necessary LED sequences to develop an oxygen saturation signal at the measurement site.

3.2.1.2 Sensor Assembly

Refer to Section 2, "Principles of Operation," for additional details about Nellcor sensor operation.

Oxygen saturation data signal is developed using a *NELLCOR* oxygen transducer at the selected patient site. Sensor LEDs generate alternate infrared and red light pulses at the measurement site. A photodiode in the transducer responds to the physiologically modulated emergent light energy from the site. The photodiode SAT signal is coupled into the module via the monitor's front-panel sensor connector.

3.2.1.3 Input Amplifier and Synchronous Detector

The SAT signal is conditioned by the input amplifier and the synchronous detector to provide signal gain and reduce or eliminate the effects of ambient interference (such things as motion artifacts, ambient light, and spurious electrical noise). The final analog conditioning of the SAT signal is accomplished by circuits in the filter block.

3.2.1.4 Filters/Amplifiers

The module includes two separate active filter channels, IR and red. These low-pass filter/amplifier circuits and associated gating circuits recover the patient's pulse waveform from the multiplexed SAT signal. The next step is to digitize these pulse waveforms in the A:D converter circuit block.

3.2.1.5 A:D Conversion

The A:D conversion block digitizes the two pulse waveforms obtained from examining the measurement site with IR and red light. Sensor calibration information is also digitized for use in the saturation calculation algorithms.

3.2.1.6 Support Circuits

Support circuits include the following:

- Processor Circuits
- Power

- **Processor Circuits**

Oximetry module operations are controlled by an 80C552 microcontroller with supporting hardware and software. The software also provides a diagnostic program to assist in determining module status.

- **Power**

Module power is supplied by the CPU PCB. See paragraph 3.3, "Detailed Circuit Analysis," for more information about module power requirements.

3.2.2 *Front Panel Assembly*

The front panel assembly includes the LED Driver PCB, LED Display PCB, front panel user interface points (push buttons, control knob, sensor input connector, and ON/STDBY switch).

3.2.3 *CPU PCB*

The CPU PCB includes the monitor processor, power supply, battery charger, audio generator, and the necessary interfaces to interconnect and power all system subassemblies.

3.2.4 *AC Power Input and Control*

The AC power input and control assembly includes the AC input receptacle, AC mains switch, fuses, interference filter, and power transformer.

3.2.5 *Battery Pack*

The battery pack is self-contained and connects directly to the CPU PCB via a special connector.

3.3 DETAILED CIRCUIT ANALYSIS

This section discusses the major functional circuit blocks of the N-180 in detail. The purpose is to provide qualified service personnel with the necessary information to understand monitor operation sufficiently to locate and repair malfunctions. The discussions address circuits in the order of logical troubleshooting methods using signal flow analysis where possible. Support circuits and components such as the microprocessor and power circuits are addressed last, or as they apply as support functions.

The following index assists in locating a specific area of interest:

Functional circuit block diagrams may employ a technique whereby some components are either absent from the circuit or grouped into functional sub-blocks. This is intended to give the reader a quick understanding of overall circuit operation. These simplified diagrams are similar in layout to the detailed schematics. This approach facilitates signal tracing to the component level when necessary.

Note: Depending on the manufacture date of any particular N-180 there may be differences in the circuits. If there are questions regarding differences, call Nellcor's Technical Services Department or your Nellcor representative.

3.3.1 *Oximetry Module*

The oximetry module is a self-contained assembly that provides oxygen transducer power, conditions the resulting SAT signal, and calculates the patient's oxygen saturation and pulse rate from the measured data. The saturation percentage, pulse rate, and other pertinent information are transmitted to the N-180 CPU PCB for display, alarm, and interface processing.

The following index assists in locating a specific area of interest:

Refer to the Oximetry Module schematic diagram (sheet 1 of 7) for details on the electronic relationship of these blocks.

3.3.1.1 LED Driver

Refer to Figure 3-3 "Oximetry Module LED Driver Circuit," and the Oximetry Module schematic diagram (sheet 2 of 7) for additional detail during the following discussion.

SAT signal development requires the measurement site to be illuminated with specific light wavelengths. The Nellcor system uses two light sources, IR and red. These LED sources are an integral part of each *NELLCOR* oxygen transducer. The LEDs are alternately pulsed on and off under control of the system microprocessor. The LED control circuit is discussed below.

The LED drive voltages are developed by dual DAC U1. Initially, both DACs in U1 are instructed via the DACBUS to develop approximately 0.5 VDC on their respective outputs (pins 4 and 18) coincident with the time period each LED is selected. The microprocessor alternately closes FET switches U4A/U4B via control lines IRLED/ (U4 pin 16) and REDLED/ (U4 pin 1). This results in samples of the DAC outputs being ORed or multiplexed at U4 pins 3 and 15.

The frequency of each control signal (IRLED/ and REDLED/) is 1355.3 Hz, with a 25% duty cycle. When both DAC outputs are multiplexed at U4 (pins 3 and 15) a four-phase LED drive signal with a frequency of 2710.6 Hz is created. The LED drive signal is summed with a negative 5 V coupled though voltage divider R2, R3, and R4. This results in the LED drive having a negative voltage. This negative voltage ensures that LED Driver U3A's output is zero during the times when no LED is being selected by either control line. This is necessary to counter any normal offsets that may be present in U3A.

Typically, the LED drive signal has a peak-to-peak value of 0.5 V with the lower boundary at 0 V.

Initially, both LED drive levels are maximum (0.5 V), but may be reduced as the processor adjusts each of the individual LED intensities to compensate for measurement site lighting variables. High background ambient light/energy and/or translucent measurement sites (such found in neonates) may cause a reduction in overall LED intensity.

As mentioned previously, the LEDs operate in a four-phase sequence. Each phase has a time period of 182 µs.

Phase 1	IR LED on
Phase 2	Both LEDs off
Phase 3	Red LED on
Phase 4	Both LEDs off

LED drive current switching is accomplished by Q1 through Q6 and the control lines, IRLED and REDLED. Figure 3-3 illustrates the relationship of these components and their association with the red (R) and IR (I) LEDs in the sensor (the LEDs are shown as they appear electrically in the circuit without the interconnection diagram). The numbers 2 and 3 on either side of the back-to-back LEDs indicate pin numbers in the sensor connector.

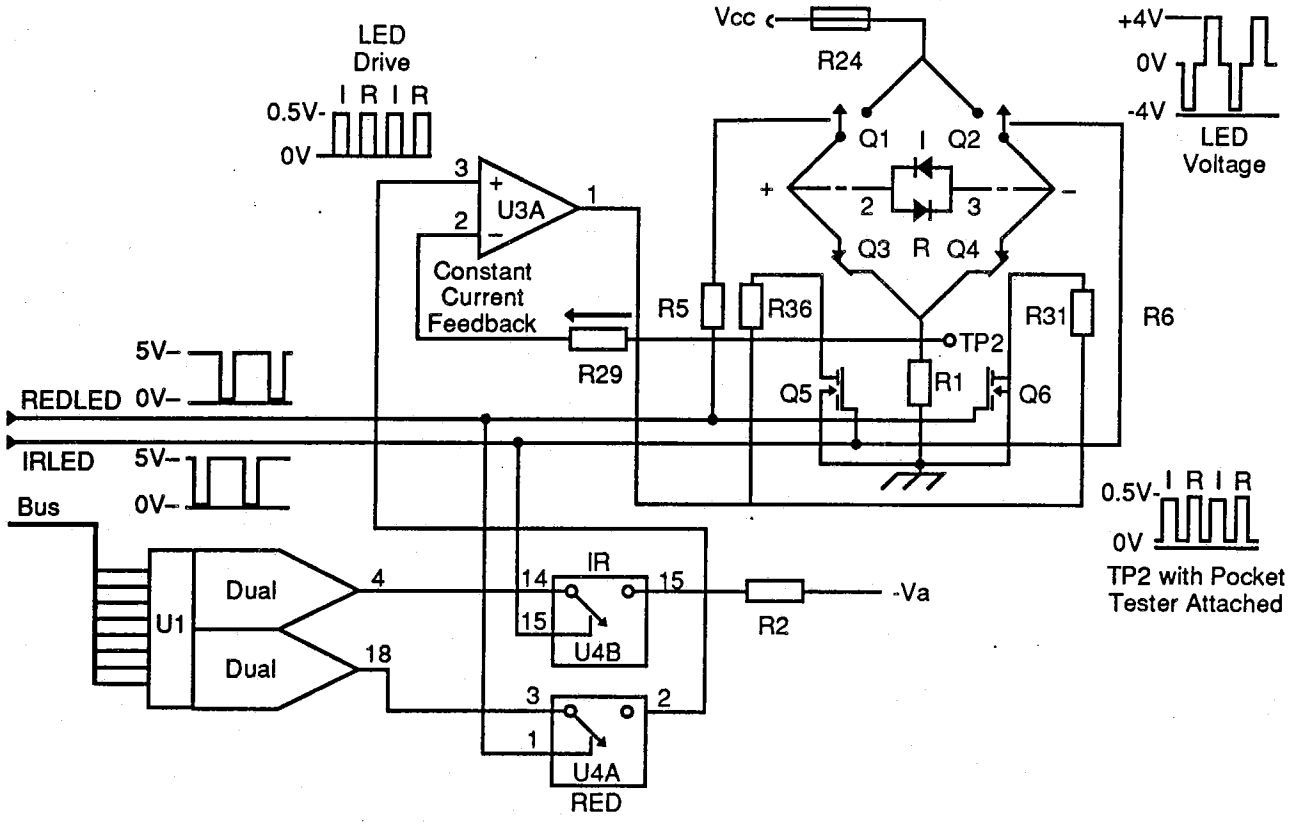

Figure 3-3: Oximetry Module LED Driver Circuit

The four-phase LED drive signal is presented to U3A. The resulting drive potential is coupled equally to both sides of the bridge circuit via R31 to Q4 and R36 to Q3. Control inputs IRLED and REDLED are pulsed low to cause their respective LEDs to light. When both lines are a logic high, all bridge transducers are turned off. Q1 and Q2 are reverse-biased directly by the control inputs via R5 and R6. Q3 and Q4 are reverse-biased by conduction of Q5 and Q6, which are being forward-biased by the control lines.

The IR LED (I) is lighted when control signal IRLED/ is pulsed low. Q5 turns off, allowing Q3 to respond to the drive level from U3A, and Q2 is turned on. The resulting current flow is from ground through R1, Q3, IR LED, Q2, and to Vcc. The red LED (R) is lighted when control signal REDLED/ is pulsed low. Q6 turns off, allowing Q4 to respond to the drive level from U3A, and Q6 is turned on. The resulting current flow is from ground through R1, Q4, red LED, Q1 Vcc. The LED back-to-back configuration ensures that the proper LED lights.

LED intensity is critical. Intensity variations during LED on time caused by any source other than blood oxygen levels can distort the SAT signal. The LED driver is a current regulator. Its purpose is to keep the voltage at TP2 exactly the same as the input voltage to the circuit (U3A, pin 3). This is accomplished by using the voltage voltage developed across R1 as a constant current feedback to driver U3A. This circuit has a very high rejection of power supply changes that could cause intensity changes.

3.3.1.2 Input Source Selection Circuits

Refer to Figure 3-4, "Oximetry Module Input Source Selection Circuits" and the Oximetry Module schematic diagram (sheet 3 of 7) for additional detail during the following discussion.

The SAT signal is developed by the photodiode in the *NELLCOR* sensor, responding to the emergent red and IR light at the measurement site. The emergent light intensity is a direct result of the four-phase controlled LED cycling, the patient's oxygen saturation, and the pulse changes occurring at the site.

The time-multiplexed, intensity-modulated photodiode current is coupled into the oximetry module via JP1 (pins 1 and 4) to the high-impedance input of U8, which performs current-to-voltage conversion for the photodiode current. The non-inverting input of U8 is biased by R38/R44 to 8.57 V. This results in the output of U8 having an 8.57 V maximum positive offset in the absence of any light or energy on the photodiode. This bias prevents a no-light condition from clamping U8 at +15 V. The presence of light or energy from any source causes U8's output to move in a negative direction.

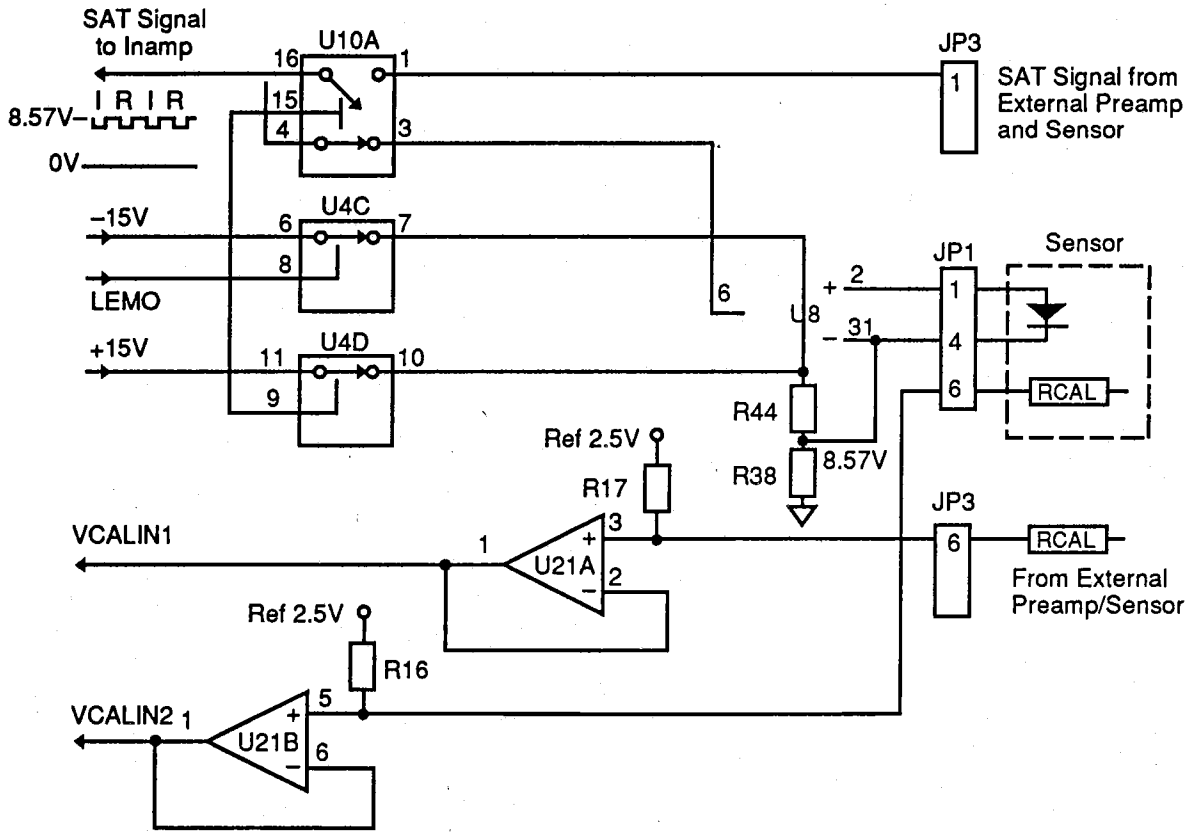

Figure 3-4: Oximetry Module Input Source Selection Circuits

An undistorted saturation signal at the input amplifier is essentially a square wave (the actual amplitudes may vary between the IR and red phases) with a frequency of 2710.6 Hz. The square wave peak-to-peak amplitude is proportional to LED emergent light intensity, plus any artifact with a frequency above DC. The DC offset (negative from the +8.57 V bias point) is dependent on steady-state background light or energy. Peak-to-peak amplitude changes in the signal are dependent on the measurement site oxygen saturation, pulse amplitude, and non-steady-state artifact energy.

The remainder of this discussion assumes that a *NELLCOR* PT-2500 pulse oximeter module tester (pocket tester) is connected to the module input in place of a normal patient sensor. This establishes a consistent set of values for discussion and comparison. The PT-2500 conditions the LED drive voltage and simulates the sensor photodiode output for an average adult with an oxygen saturation percentage of 81% ±1 digit (80% to 82%) and a pulse rate of 40 ±1 bpm (39 to 41 bpm). Note that pocket tester pulse rate is dependent on LED switching rate and will be different on other Nellcor pulse oximeter models.

The simulated SAT signal from the pocket tester is coupled to the monitor SAT conditioning circuits via the sensor input to JP1 (pins 1 and 4) on the oximetry module circuit board. After conditioning by current-to-voltage converter U8, the signal has the following characteristics:

DC offset:	approximately +8.5 V
Frequency:	2710.6 Hz
Modulation:	maximum peak-to-peak amplitude, approximately 0.02 V frequency, 0.666 Hz (40 cycles/minute)

Simply stated, a SAT signal produced by the PT-2500 is a low-amplitude, multiplexed carrier at 2710.6 Hz, modulated by an extremely low-amplitude 0.666 Hz square wave, changing amplitude approximately 20 mV.

The only additional oxygen saturation input requirement is the wavelength of the red LED. This number is derived from the RCAL resistor value located in the sensor or PT-2500. When a sensor is connected to the monitor, the RCAL resistor connects between JP1 pin 6 and ground to become part of a voltage divider with R16 on the PCB. Power for this divider is a 2.5 V reference developed in the module. This calibration voltage (VCALIN2) is communicated to the oximetry module microprocessor via buffer U21B.

Returning to the analysis of the oximetry module where U8 is used as the preamplifier, note that the SAT signal is coupled through U10A to the next conditioning stage, input amplifier, and synchronous detector.

3.3.1.3 Input Amplifier and Synchronous Detector

Refer to Figure 3-5, "Oximetry Module Input Amplifier, Synchronous Detector, and Filter/Amplifiers," and the Oximetry Module schematic diagram (sheet 4 of 7) for additional detail during the following discussion.

The SAT signal must be monitored continuously and controlled to prevent excessively high LED intensities or the combination of LED intensity and/or background light/energy from overloading the photodiode in the sensor. However, LED intensity must be kept as high as possible to ensure optimal signal-to-noise figures. The task of compensating for excessive light is accomplished by U7 and associated components, which monitor the SAT signal while it is still DC-coupled.

Initially LED intensity is set at maximum safe level (50 mA) upon monitor power-up. If the total of the LED energy and/or external light energy is excessive, the DC offset at the output of U8 could be enough to drive the SAT signal amplitude envelope into the negative region of U8's operating range. To prevent the amplitude from exceeding U8's negative supply voltage, U7 is employed to monitor the negative excursion of the SAT signal.

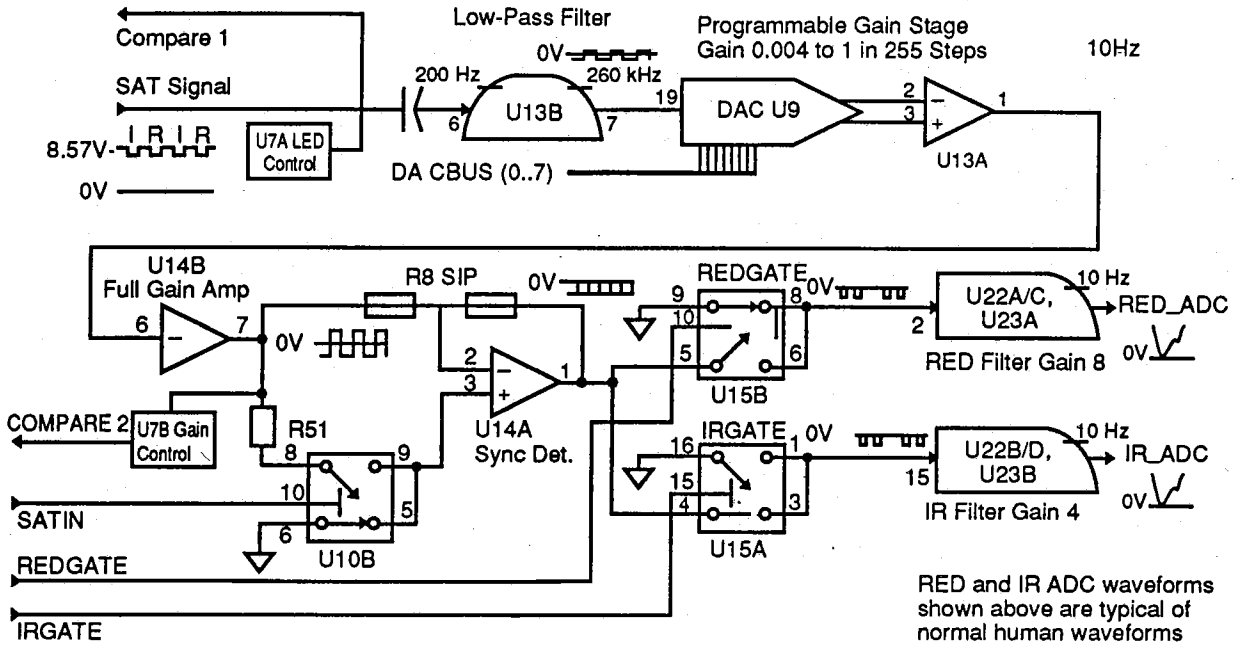

Figure 3-5: Oximetry Module Input Amplifier, Synchronous Detector, and Filter/Amplifiers

U7A is a negative peak detector that produces a DC output proportional to the maximum negative excursion of the SAT signal pulses. If negative excursions of the saturation signal exceeds –10 V (indicating that the patient module current-to-voltage converter stage output is approaching its negative supply voltage of –15 V), the microprocessor that is monitoring the output of U7A (COMPARE1) initiates action to reduce the output of the dual DAC that controls LED intensity. The microprocessor may reduce current through only one of the LEDs if necessary.

The result of the above-mentioned microprocessor action is that the pulse amplitude of the 2710.6 Hz saturation signal, during the time periods of the offending LED, will be reduced.

After the LED intensity control requirements are accomplished, the SAT signal is coupled through C55. This coupling removes the offset effect of DC or steady-state ambient energy artifact. The signal is then coupled to U13B, a bandpass filter with a gain of one, low-frequency roll-off at 200 Hz, and high-frequency roll-off at 260 kHz. The filter passes the SAT signal (2710.6 Hz) and effectively removes noise on either side of the SAT signal frequency.

The signal is then introduced to a programmable gain circuit, which consists of 8-bit DAC U9 and operational amplifier U13A. The DAC is configured so that its internal impedance ladder is in series with the operational amplifier feedback loop. Amplifier gain is controlled by microprocessor adjustment of the DAC impedance over 255 discrete steps. The maximum gain of the circuit is one. The minimum gain is 1/255 or 0.004.

The signal is then coupled to full-gain amplifier U14B, which has a gain of 51. The output of U14B is used by the microprocessor as the sense point to determine input channel gain requirements. U7B is employed to monitor the amplified SAT signal at the output of the input amplifier.

U7B is a positive peak detector that produces a DC output proportional to the positive excursion of the amplified SAT signal pulses. If the positive excursions of the saturation signal exceed +10 V (indicating excessive amplifier gain), the microprocessor, which is monitoring the output of U7B (COMPARE2) initiates action to reduce the programmable stage's gain. The microprocessor may reduce current through only one of the LEDs if necessary.

The SAT signal is then coupled to the synchronous detector. The signal is still in its original multiplexed format and essentially a square wave at 2710.6 Hz. The peak-to-peak amplitude of alternate voltage excursions represents the emergent light from one of the LEDs (IR or red). Amplitude changes or modulation of this signal represent the effect of the patient's saturation and pulse activity at the measurement site.

Synchronous detection conditions the SAT signal in a manner such that subsequent filtering can reclaim the patient's pulse waveform component relatively free of artifact and interference. U10B, U14A, and associated resistors comprise the synchronous detector. The detector is an operational amplifier configured so that it can operate as two different circuits: an inverting amplifier, and a voltage follower. When the positive input of U14A is grounded by U10B, the device is an inverting amplifier with a gain of one. When this input is not grounded, the device becomes a voltage follower with a gain of one.

The microprocessor controls U10B via the SATIN line, and closes the switch during phases 1 and 3 of the four-phase clock mentioned in the LED drive discussion. The result is that the voltage values represented by the IR and red LED on times are inverted by the detector. The voltage values represented by the LED off times (phases 2 and 4) are permitted to pass through the detector at their original voltage level and polarity. The output of the synchronous detector is applied to a bus coupled to the inputs of the IR and red filter/amplifier channels.

3.3.1.4 Filters/Amplifiers

There are three circuits in the demodulation (filtering) block:

- Gating
- IR Filter/amplifier
- Red Filter/amplifier

- **Gating**

Refer to Figure 3-5 and the Oximetry Module schematic diagram (sheets 4 and 5 of 7) for additional details during this discussion.

FET switches U15A/B are employed to separate the IR information in the SAT signal from the red information. Phases 1 and 3 constitute the IR and red on time segments, and phases 2 and 4, the IR and red off time segments. The gate control inputs (IRGATE and REDGATE) to U15A/B are processor-controlled and operate in time sequence with the four-phase LED drive control. The switch pairs in each gate operate exclusively so that the filter/amplifier input does not see an open circuit when switches to the signal input bus are open.

During the time period that phases 1 and 2 of the 2710.6 Hz saturation signal (IR ON and IR OFF) follow one another on the bus, the processor strobes U15A twice. The first strobe pulse comes 112 µs after the beginning of phase 1 and continues for 70 µs, or to the end of phase 1. This gates the last 70 µs of IR ON signal level into the IR filter/amplifier. The next gate strobe pulse comes 112 µs after the beginning of phase 2 and continues for 70 µs, or to the end of phase 2. This gates the last 70 µs of IR OFF signal level into the IR filter/amplifier.

During the time that phases 3 and 4 of the 2710.6 Hz saturation signal follow one another on the bus, the microprocessor strobes U15B twice. The first strobe pulse comes 112 µs after the beginning of phase 3 and continues for 70 µs, or to the end of phase 3. This gates the last 70 µs of RED ON signal level into the red filter/amplifier. The second gate control pulse comes 112 µs after the beginning of phase 4 and continues for 70 µs or to the end of phase 4. This gates the last 70 µs of RED OFF signal level into the red filter/amplifier.

The reason for gating only the last 70 µs of each phase into the filter/amplifier is to eliminate possible artifacts occurring during the first 112 µs of the phase due to sensor photodiode settling time. Photodiodes exhibit an exponential change when the energy from a sudden LED state change is experienced. Using only the last 70 µs of the photodiode output, after the diode has settled, excludes this potential error from the measurement.

- **IR Filter/Amplifier**

Refer to Figure 3-5 and the Oximetry Module schematic diagram (sheet 5 of 7) for additional details during this discussion.

The IR filter/amplifier circuit is an active low-pass type with a 3 dB roll-off point at approximately 10 Hz and a total gain of four. The filter cannot track the high-frequency LED pulse input, but does respond to the low-frequency patient pulse modulation, reproducing the patient's pulse waveform at the filter/amplifier output. The IR filter/amplifier pulse waveform output is coupled to the A:D Converter.

The input signal to the IR filter/amplifier, as explained above, is two 70 µs pulses separated by a 112 µs space (phases 1 and 2). The next two phases (3 and 4) are gated into the red filter/amplifier in the same manner. This leaves a 476 µs period until the next pair of IR pulses is gated into the IR filter/amplifier. The overall pulse amplitudes are proportional to the emergent light at the measurement site. The individual pulse pair amplitudes are a function of the low-frequency patient pulse modulation and artifacts at the measurement site.

These pulse pairs are coupled to the first of two identical filter/amplifier stages, each having a gain of approximately two. The signal is then coupled to the last stage, which has a gain of one. The DC offset of the resulting low-frequency patient pulse waveform is proportional due to the average LED intensity at the measurement site. The peak-to-peak amplitude of the patient's pulse waveform is a result of the factors expressed in the Beers-Lambert Law, which is used to calculate oxygen saturation (density, dimension, and color).

The patient's pulse waveform at the IR filter/amplifier output, labeled IR, must always be at a positive voltage level, because the next step is to digitize the waveform in the A:D circuits. To ensure that the waveform does not move to a negative level, the final amplifier stage input has a + 2.5 mV input, which guarantees a minimum positive offset of 0.05 V at the output.

- **Red Filter/Amplifier**

Refer to Figure 3-5 and the Oximetry Module schematic diagram (sheet 5 of 7) for additional details during this discussion.

The red filter/amplifier circuit is an active low-pass type with a –3 dB roll-off point at approximately 10 Hz and a total gain of four. The filter cannot track the high frequency LED pulse input, but does respond to the low frequency patient pulse modulation, reproducing the patient's pulse waveform at the filter/amplifier output. The red filter/amplifier pulse waveform output is coupled to the A:D Converter. The input signal to the red filter/amplifier, as explained previously, is two 70 µs pulses separated by a 112 µs space (phases 3 and 4). The next two phases (1 and 2) are gated into the IR filter/amplifier in the same manner. This leaves a 476 µs time space until the next pair of red pulses are gated into the red filter/amplifier. The overall pulse amplitudes are proportional to the emergent light at the measurement site. The individual pulse pair amplitudes are a function of the low frequency patient pulse modulation and artifact at the measurement site.

These pulse pairs are coupled to the first of two identical filter/amplifier stages, each having a gain of approximately two. The signal is then coupled to the last stage having a gain of two. The DC offset of the

resulting low frequency patient pulse waveform is proportional due to the LED intensity at the measurement site. The peak-to-peak amplitude of the patient's pulse waveform is a result of the factors expressed in the Beers-Lambert Law is used to calculate oxygen saturation.

The pulse waveform at the red filter/amplifier output, labeled RED, must be at a positive voltage level, because the next step is to digitize the waveform in the measurement system. To ensure that the waveform does not move into a negative voltage region, the final amplifier stage input has a +2.5 mV input, which guarantees a minimum positive offset of 0.50 V at the output.

3.3.1.5 Control Signals

Refer to Figure 3-5 and the Oximetry Module schematic diagram (sheets 4 and 7 of 7) for additional details during the following discussion.

The SpO2 measurement process is controlled by several logic lines from microcontroller U5. The various control signals are listed and defined below:

IRGATE/ is a result of microcontroller output PWM1/ ANDed with output CMT1. IRGATE/ controls the transmission of the IR on and off levels into the IR Filter/amplifier.

IRLED/ from microcontroller output CMSR4. IRLED/ controls the selection of the LED drive level at U4B and the direction of current applied to the sensor LEDs.

REDGATE/ is a result of microcontroller output PWM1/ ANDed with output CMT0. REDGATE/ controls the transmission of the red on and off levels into the red filter/amplifier.

REDLED/ from microcontroller output CMSR5. REDLED/controls the selection of the LED drive level at U4A and the current direction applied to the sensor LEDs.

SATIN from microcontroller output CMSR3. SATIN controls synchronous detector action through U10B.

3.3.1.6 A:D Conversion

Refer to Figure 3-6, "Oximetry Module A:D Conversion Circuits," and the Oximetry Module schematic diagram (sheet 6 of 7) for additional details during this discussion.

A:D conversion is accomplished by a dual-channel device (U20) that produces a multiplexed serial output. Channel 1 (AIN1) accommodates either VCAL1 voltage or the analog pulse waveform from the red filter/amplifier channel. Channel 2 (AIN2) accommodates either VCAL2 voltage or the analog pulse waveform from the IR Filter/amplifier channel. These selections are determined by the configuration of quad FET switch U24A,B,C,D. FET switching is controlled by logic signal RESISTORS.

U20's output bit stream multiplexing is determined by logic signal ADCCHN, which determines the channel present on the ADCDATA line. The ADCDATA line is coupled directly to microcontroller U5 for conditioning prior to transmission to the instrument display processing circuits.

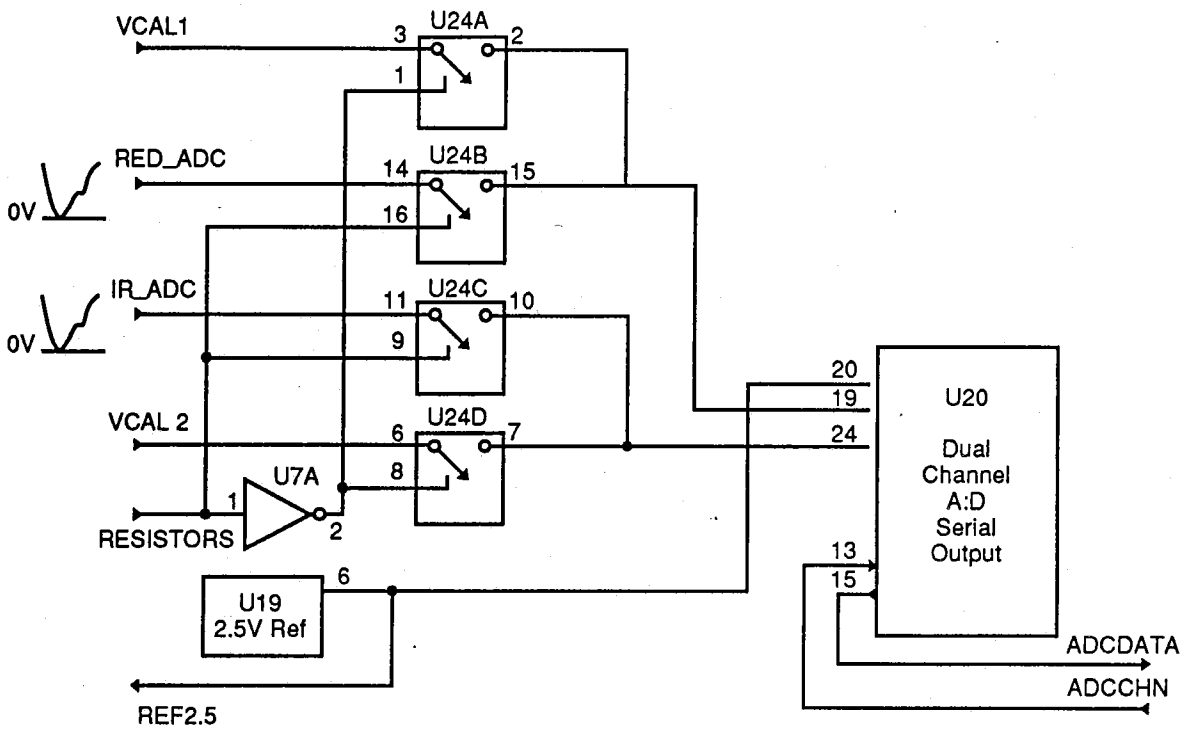

Figure 3-6: Oximetry Module A:D Conversion Circuits

3.3.1.7 Support Circuits

Support circuits include the following:

- Communications
- Processor Circuits
- Power

- **Communications**

Refer to Figure 3-7, "Oximetry Module Support Circuits," and the Oximetry Module schematic diagram (sheet 7 of 7) for additional details during the following discussion.

Other than supply voltages provided to the oximetry module from the power supply, there are five data signals present at the module connection to the instrument. These signals are:

CTS — clear to send is a logic signal (active low) transmitted to the oximetry module by the instrument to suspend data transmission from the module.

RESET — is an input (active low) from the processor to effect a reset in the saturation module.

RXD — is the receive data line to the saturation module.

TXD — is the transmitted data line from the saturation module.

The communication data link is bidirectional-asynchronous serial. Transmissions are checked for errors and the presence of an error is considered to be evidence of a hardware problem. No transmission retry capability is included.

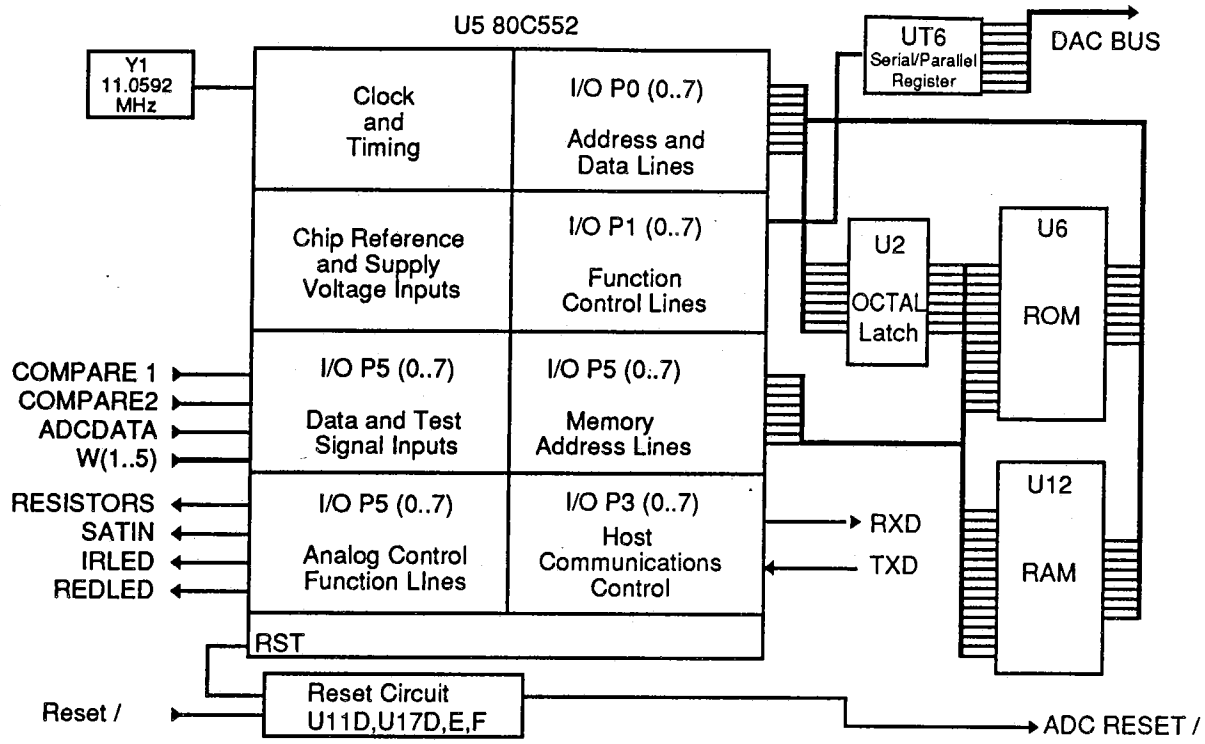

Figure 3-7: Oximetry Module Support Circuits

3.3.1.8 Processor Circuits

Refer to Figure 3-7 and the CPU PCB schematic diagram (sheet 1 of 4) for additional details during the following discussion.

Module support circuits consist of 80C522 microcontroller U5, ROM U6, and RAM U12, all served by octal latch U2. U16, a serial-to-parallel shift register, converts serial data to parallel data for the DACBUS.

The system operates using an 11 MHz crystal-controlled oscillator. Sections U11 and U17 perform reset and buffer functions for the communication link.

3.3.2 *Oximetry Module Communication Circuit*

Refer to Figure 3-8 "Oximetry Module Communication Circuit," and the CPU PCB schematic diagram (sheets 1 and 3 of 4) for additional information during the following discussion.

The oximetry module communication interface is in the form of a bidirectional, TTL level data link operating at 9600 baud. Processor U9 controls this data link via its I/O "A." Output signals TXA1, RTS1/, and RESET/ are buffered and sent to the oximetry module by gates U7A, C, and D. Connector CN3, on the CPU PCB, provides a power and data connection interface for the module.

3.3.3 *User Interface Circuits*

User interface circuits include the front-panel display circuits, front- and rear-panel input devices (push buttons, switches, control knob, etc.), and the rear panel external RS-232 output port. This subsection discusses the following circuit blocks:

3.3.3.1 Display Circuits
3.3.3.2 User Input Circuits
3.3.3.3 External Output Port

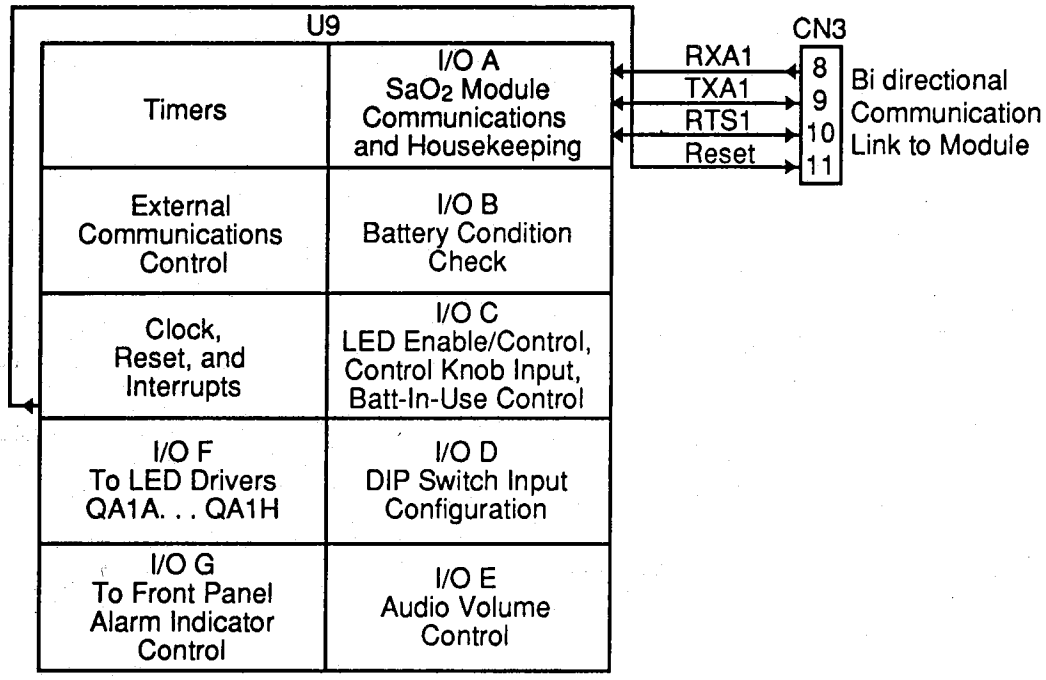

Figure 3-8: Oximetry Module Communication Circuit

3.3.3.1 Display Circuits

Refer to Figure 3-9 "N-180 Display Circuits," and the CPU PCB schematic diagram (sheets 1, 2, and 4 of 4) for additional information during the following discussion.

N-180 display data and control originate at processor U9 I/Os. Drive levels are sourced by I/O "F," buffered by QA1 on the CPU PCB, and coupled to the Display Driver PCB via CN2/CN1. LED enable and address information is sourced from I/O "C" and coupled to the Display Driver PCB in the same manner.

Address data is decoded by U1A and U2A on the Display Driver PCB and coupled with the drive information to the LED Display PCB via connectors CN1, CN2, and CN3.

The LED Display PCB consists of LED modules placed so that they provide the necessary display information.