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A System for Telemetering Low-Frequency Data from Active Volcanoes

by

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INTRODUCTION

Low-frequency measurements of parameters such as ground tilt, gas concentrations, magnetic field variations, etc. have been shown to be useful tools in assessing volcanic activity (Dzurisin et al. (1983), McGee et al. (1987), Johnston et al. (1980)). Telemetering such measurements to central receiving sites provides near real-time information as to the status of a volcano when personal observation or on-site data collection is impossible due to high hazards or inclement weather. The low-frequency telemetry system described here works largely the same as that described by Roger et al. (1976). Individual field transmitters accept up to 16 analog inputs. These inputs are digitized and the data transmitted via VHF/UHF radio links to a central receiving site at preselected intervals. Since the time scale for significant changes in low-frequency measurements ranges from hours to months or longer, 10 minute transmit intervals are usually adequate (Roger et al., 1976). This allows the transmitter to be in a low-power sleep state most of the time since, transmissions typically take less than 10 seconds. This not only conserves power but also allows numerous transmitters to share the same radio and audio frequencies. Each transmitter in turn activates itself, transmits its data, and goes back to sleep, allowing the other transmitters to send their data. The transmissions are received by a common radio and sent to a battery-powered lap computer for decoding and data storage.

SYSTEM CONSIDERATIONS

A major problem with any telemetry system involving multiple transmitters and a single receiver is transmission collisions. If two transmitters try to transmit data at the same time, they interfere with each other and no data is received. Three solutions to this problem are: 1) assigning time slots for each transmitter, 2) polling each transmitter from the central receiving site, and 3) having each transmitter transmit randomly. The first two solutions have major drawbacks. Assigning time slots requires either very stable crystal oscillators, or frequent resetting of each transmitter's clock to prevent them from drifting into another time slot. Either way is expensive. Polling each transmitter involves sending a signal from the receiver to each individual field transmitter telling it to wake up and send data. Though an attractive solution, this increases power consumption at the transmitter (a radio receiver must be on to receive the wake-up call) and doubles the complexity of the radio network.

Transmitting randomly is the preferred solution. It increases neither complexity, nor power consumption, nor cost. By using inexpensive oscillators, the transmission interval, though nominally set for 10 minutes, will actually vary from 8 to 12 minutes. Transmission collisions will occur, but unlike the assigned slot system where once stations overlap, they stay that way for a long period (due to their transmit intervals being essentially the same), with a random transmission system, stations will overlap for 1 transmission, but not the next as their transmit intervals are slightly different. The sample rate is set high enough so that losing an occasional data point is not considered a problem. The drawback to such a system is that it can become overcrowded with collisions ocurring too often. Transmitting the data at 50 baud, the system described here can adequately handle 20 different parameters at 10 minute transmit intervals. Increasing the baud rate to 300 could allow probably as many as 60 parameters to be transmitted, but new software for the receiver would have to be written to accept the quicker transmissions.

If either the polling or assigned time slot solutions are still desired, a spare circuit board slot on the transmitter board allows their implementation.

DESIGN CRITERIA

Telemetering data from active volcanoes presents special problems. Typically, the field sites are in hazardous areas, accessable only by helicopter or foot. Weather conditions range from tropical monsoons to freezing rain. Weather and ash can render solar panels ineffective. In many instances, the equipment is installed with the knowledge that it will be soon destroyed. Because of these reasons, a variety of different sensors will tend to congregate around any established telemetry site. Hence, the ideal telemetry transmitter should have low power consumption, be easily carried, able to accept outputs from multiple sensors, and inexpensive.

IMPROVEMENTS OVER EXISTING SYSTEMS

Though most low-data-rate telemetry transmitters are relatively small and light weight, the peripherial gear (yagi antennas, masts, and large banks of batteries) needed by them tend to be heavy and unwieldy. By using 4 watt radio transmitters with quarter-wave whip antennas and minimizing power consumption, these peripherials have been eliminated. The entire unit, including radio and batteries, is housed in a single steel water-tight container, 36 cm diameter by 45 cm high (excluding antenna). With enough batteries to power the unit for 1 year at a 10 minute sample rate, the package weighs about 30 kilograms. If a lower powered radio can be used, such as 100 milliwatts, the weight would be reduced (because fewer batteries are needed) to about 10 kilograms and a smaller container could be used.

Custom circuitry for the receiver was eliminated by transmitting the data in standard RS-232C format on standard Bell 103 modem frequencies. The output of the radio receiver is hooked directly into the modem port of a Radio Shack Model #100 lap computer. A resident high level language (BASIC) and a variety of peripherials available for the #100 provide maximum flexibility in data storage, display, and access, at minimum expense.

THEORY OF OPERATION

The transmitter consists of 10 blocks; the clock, the voltage regulators, the transmission control logic, the analog multiplexor, the analog to digital converter (A/D), the channel ID counter, the number-of-channels-transmitted counter, the universal asychronous receiver transmitter (UART), the modem, and the radio (see figure A). To conserve power, the transmitter is normally in a sleep state, with only power applied to the clock and perhaps the multiplexor. At switch selectable intervals, the clock enables the voltage regulators, and the transmitter control logic begins the data transmission sequence. Counters indicating the initial analog input to be selected for digitizing and the channel ID are preset (the channel ID is a number (0-255) sent along with the data to indicate from which analog input of which transmitter the data came). The selected analog input is then digitized.

The radio, which had been off to prevent radio frequency interference during the A/D conversion, is now turned on (or keyed). The digitized data along with its channel ID is converted to serial RS-232C format by the UART.

This serial data is converted by the modem to Bell 103 audio tones which are transmitted by the radio. At the completion of the data transmission, the radio is turned off and a counter that keeps track of the number of channels transmitted is incremented along with the analog input select and the channel ID. If all the channels that were to be transmitted have been transmitted, the voltage regulators are disabled and the transmitter returns to its sleep state awaiting the next wake-up pulse from the clock. If, however, another channel is to be transmitted, the next analog input is digitized and the data transmitted as before. The data transmission sequence continues until the correct number of channels have been transmitted (fig. B).

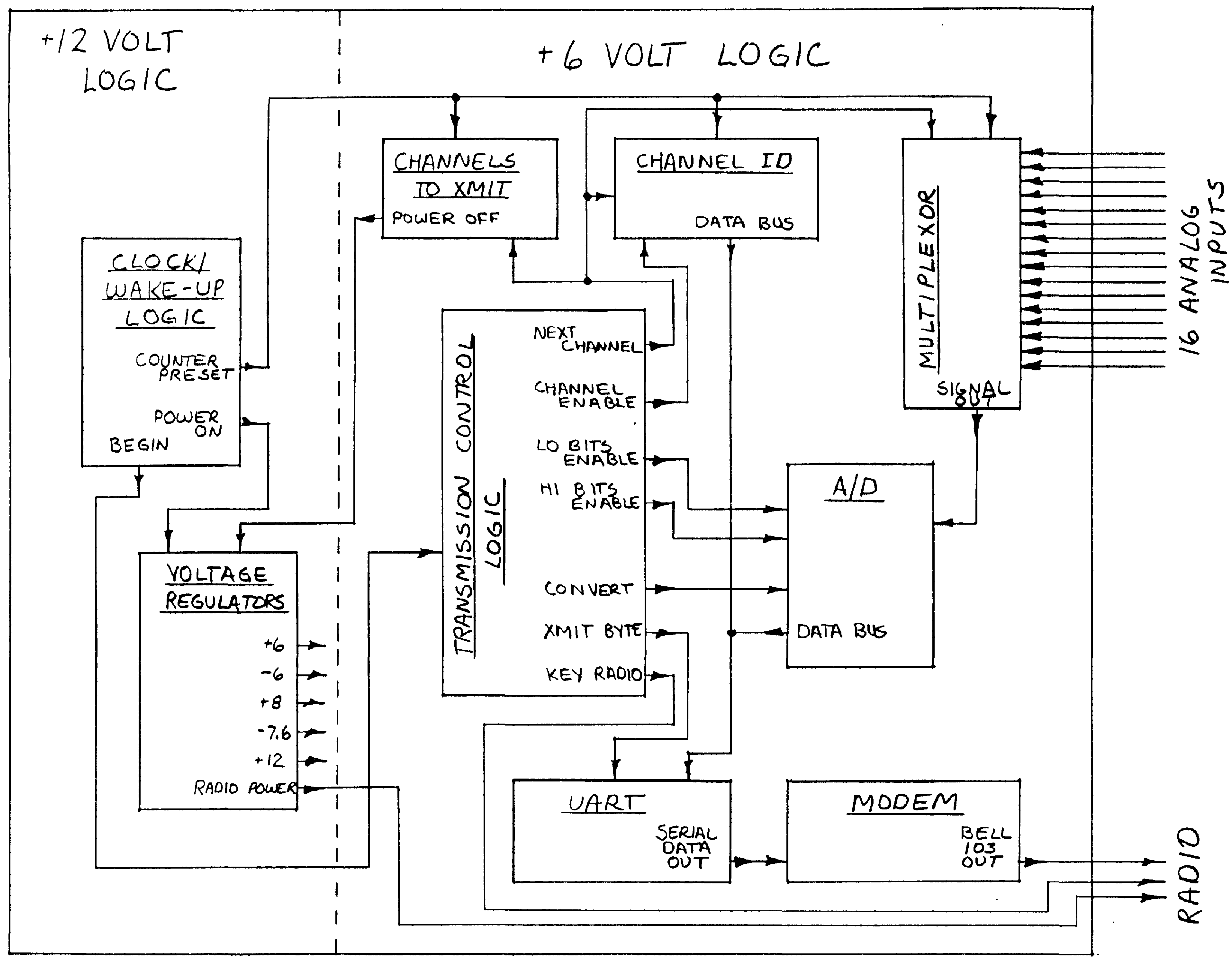
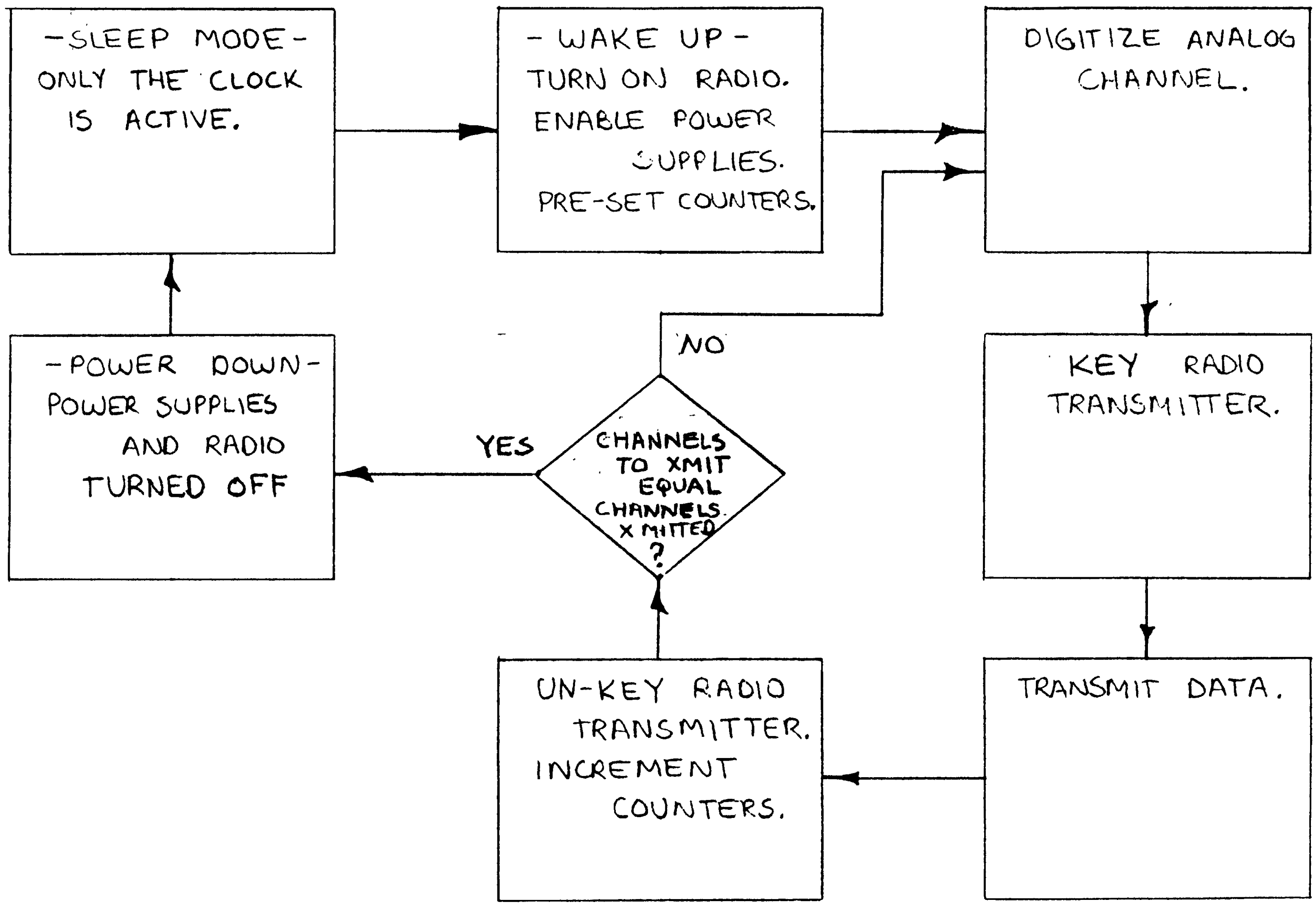


FIGURE A TRANSMITTER BLOCK DIAGRAM



FLOW CHART FOR TRANSMITTER
FIGURE B

DETAILED CIRCUIT DESCRIPTION

CONVENTIONS USED

The convention for designating a specific pin of an IC is to state the IC followed by a dash and the pin number. For example, pin 5 of IC U12 would be U12-5. Frequently gates are designated by both the input and output pins. The inverter whose input is pin 3 of U20 and output is pin 4 would be referred to as gate U20-3/4.

The following terms are used throughout this report:

Transmitter refers to the entire field unit, including the radio transmitter.
Board refers to the circuitry described in detail in this report, i.e. the transmitter minus the radio.
Receiver refers to the both the radio receiever and the computer used to decode the data transmissions.

CLOCK

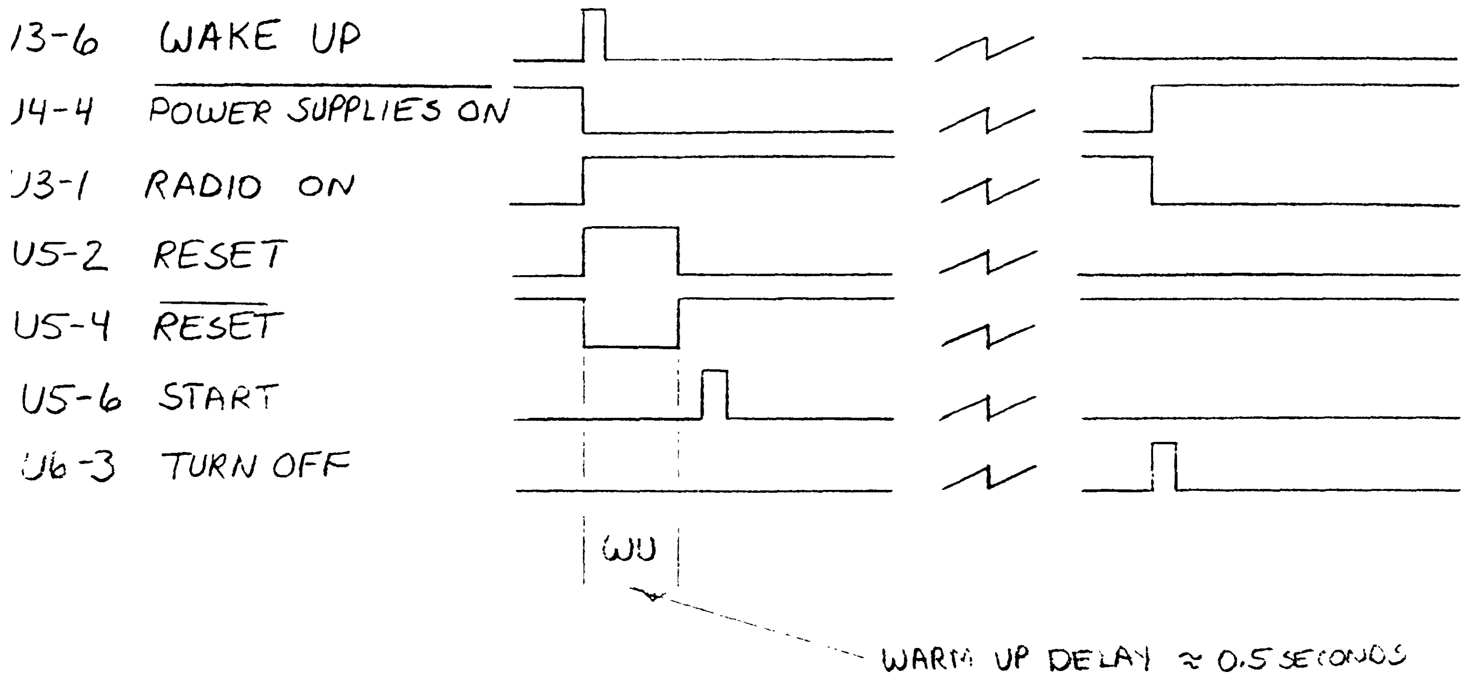
In order to conserve power and allow numerous transmitters to use the same radio and/or audio frequency, the transmitter is normally in a wait state, with only 6 IC's active. These IC's make up the clock and turn-on logic for the rest of the transmitter. They are all powered directly from the +12 volt supply. Current consumption while in the wait state is typically 60 microamps with U32 as the analog multiplexor and 400 microamps with U14 as the multiplexor (see section MULTIPLEXOR/SIGNALS IN for the differences between the two multiplexors).

The clock consists of U1,U2, and S1. U1 (CD4047) is a low power oscillator whose output freqency (typically 2 hz) is determined by R1, R65, and C1. Binary counter U2 (CD4020) divides this frequency down to 9 switch-selectable transmit intervals (via S1). If S1 is set at position 1, transmissions will typically occur about every 36 seconds. At position 2, transmissions will occur at twice the interval of that at position 1 (or typically every 72 seconds). Position 3 will be twice the interval of position 2 (about 144 seconds) and so on. At position 0 no transmissions will be initiated.

SYSTEM TURN-ON

A positive transition at the output of S1 (S1-9/3) is turned into a positive pulse by C2 and R2. This pulse initiates a transmission. It sets the outputs of the 4 R/S latches of U3 (CD4043) high. These latches control the start-up logic and power for the transmitter. U3-1 goes through an inverter (U4-3/4) to enable the ±6 volt and ±8 volt regulators to supply power to the rest of the transmitter. U4-4 also turns on Q1 (VP0300L) to enable the +12 volts switched (+12SW) for powering external sensors and Q2 (IRF511) to power the radio. If the auto-off is enabled, U3-2 will go high and start the auto-off process (see the section on the AUTO-OFF OPTION).

U3-9 (START) controls the initialization logic. This signal goes through schmitt trigger/inverter U-4 (CD40106) to provide the RESET's and GO signals. These are buffered by U5 (CD4050) to the +6 volt logic levels of the rest of the transmitter. The RESETs initialize the ICs in the transmitter



TIMING NOT TO SCALE

POWER UP - POWER DOWN TIMING
FIGURE C

prior to starting the transmission. While U3-9 is high, C4 is charging through R5 and when the trip point is reached at U3-7, U3-9 will go low. RESET will go low, $\overline{\text{RESET}}$ will go high and the transmitter will be ready to start. The GO command (begin transmission) is issued by the low going transition on U3-9. This pulse is delayed by U4-11/10 and U4-13/12 to provide time for the resets to settle before starting the transmissions. See figure C.

VOLTAGE REGULATORS

Voltage regulators U7 and U9 (both ICL7663) are enabled by a low on their pin 5. U7's output of +6 volts is adjusted by R63, and U9's output of +8 volts is adjusted by R64. U8 (ICL7660) converts the +6 volts to -6 volts and U10 (ICL7660) converts +8 volts to -7.6 volts (a required diode on the the output for voltages above 7 volts prevents the output from dropping to a full -8 volts). Besides powering the board, U7 can provide 10 ma at 5.75 volts for external sensor use. U9 can similarly provide 15 ma at 7.8 volts for external sensor use. U8 and U10 can provide 5 ma of current at -5.75 and -7.0 volts. Q1 can provide over 100 ma to power other devices.

MULTIPLEXOR/SIGNALS IN

The transmitter can accept up to 16 single-ended analog inputs. These inputs enter the board via J1. Space is provided to insert Tranzorbs (Z0-Z15) in locations where lightning and other transients are a problem. The inputs then go to J2 which has cuttable jumpers between the inputs and outputs of it. If needed, the jumpers can be cut and a signal conditioning card inserted into J2. Also, if differential input signals are used, a connector similar to J1 can be put on a board with instrumentation amps and inserted into J2. The differential input signals can be converted to single-ended without any modifications to the transmitter.

Either U14 (HI-506-A) or U32 (CD4051) is used as the analog multiplexor. The HI-506-A (not readily available, costs $20) should be used if the analog input signals are present even with the transmitter in its wait state, or more then 8 inputs are being transmitted. It is powered by the +12 volt supply to insure that no analog input signals leak onto the board when it is in a wait state. The CD4051 (readily available, costs $2) can be used if 8 or less signals are to be transmitted and the external sensors are powered only when the transmitter is in its active state. Note that 5k resistors in series with the analog inputs will also protect the 4051 from overvoltage damage and is an alternative to using the HI-506 in applications where the analog input signals are always present.

U13 (CD40193) controls which analog input is selected by the multiplexor. It is configured as a binary up counter so that each time it is incremented, its output causes the multiplexor to choose the next analog input (00-15). The input selection also wraps around', i.e. if 4 analog signals are to be transmitted and the first signal to be sampled is input 14, inputs 14, 15, 00, 01 will be transmitted in that order. The initial input to be sampled is set using switch S6. When $\overline{\text{RESET}}$ is low, the number represented by S6 is loaded into U13 (see the section on PROGRAMMING PROCEDURE). After an input is sampled and its data transmitted, NXT CHNL makes a low to high transition causing U13 to increment by one and the multiplexor to select the next analog input. This continues until all the inputs to be sampled have been transmitted and the transmitter goes into its wait state. Note that this input number can be different from the channel ID (which is determined by S7). The analog input refers to the inputs (00-15) to the transmitter while the channel ID (000-255) is a code that refers to both the analog input and the transmitter.

Before going to the analog-to-digital converter (A/D) the output of the multiplexor is buffered by voltage follower U15 (OP07).

CHANNELS TO TRANSMIT

U11 and U12 count the number of analog signals that have been transmitted and put the transmitter back into its wait state after the programmed limit has been reached. The counters are set to zero by RESET. After each analog input is transmitted the counters are incremented by the low to high transition of NXT CHNL. U11-9 (corresponding to 8 signals to transmit) is connected to the counter enable of U11 (U11-13) and through an inverter (U20-1/2) to the enable of U12 (U12-13). This allows U11 to count up to eight signals transmitted while U12 is disabled, and then U12 counts the next eight. Switching on one of the 16 switches of S4 and S5, selects one of the outputs of the counters. A high on this selected output will go through a logic level shifter (U6-3/2) and put the transmitter back into a wait state by reseting the flip-flop (U3-1) that enables the voltage regulators, the switched +12 volts and the power to the radio. If one analog input is to be transmitted, S4-1 is switched on. For two inputs, S4-2 is switched on and so on up to 8 inputs. For 9-16 inputs, S5 is used, with S5-1 corresponding to 9 inputs to be transmitted and S5-8 to 16 inputs. It is important to realize that only one switch at a time can be on otherwise different outputs of the counters will be shorted.

If no switch on S4 or S5 is on, the transmitter will continue to transmit until power is disconnected or the auto-off circuit (if enabled) puts the transmitter back into its wait state.

AUTO-OFF OPTION

An auto-off circuit is also included that will automatically put the board back into a sleep state after a certain time period. Enabling this feature adds some insurance that the board will not get stuck with the radio on, which would jam transmissions from all the field transmitters. This feature has never been utilized and no long-term testing of it has been performed. Installation of a board in the field with the auto-off enabled should be done only after much testing in the lab. No board as of yet has gotten stuck with the radio on.

To implement this feature, D3 should be replaced with a .01uf capacitor and the auto-off select jumper that normally shorts U3-3 to ground should be cut and rejumpered so that U3-3 is connected to R4. Also, a level shifter gate has to be inserted before the off pulse goes to the reset input U3-15. to do this, two traces will have to be cut and two jumpers added to the board. The trace on the component side of the board between D3 and U3-15 and the trace between U6-5 and U6-7 on the bottom of the board should be cut. Then jumper what was the input to U3-15 to the level-shifter gate U6-5 and its output, U6-4, back to the reset input U3-15. Finally, the appropriate resistor value for R4 must be chosen for the time-out period required. Start with a value of 3meg and experiment until the correct value is determined.

When the board awakes from its sleep state, U3-4 pulses high, setting U3-2 high. C3 is slowly charged from U3-2 via R3 and R4 until the threshold is reached at the reset U3-3 causing U3-2 to return low. This high to low transition is inverted by U4-1/2 and capacitatively coupled via the capacitor that replaced D3 to the same point where the off pulse from switches S4 and S5 is capacitatively coupled. With the two capacitors on the line, the off pulse voltage to U15-3 will only be one half of what it should be. That is why is the signal must first be routed to the level-shifter to get the full signal voltage. This full voltage pulse is then routed back to U3-15 which resets U3-1 low, returning the board to its sleep state.

CHANNEL ID

Binary counters U16 and U17 (both CD40193) determine the channel ID that is transmitted with the data for each analog input. Each analog input for each transmitter has a specific ID (0-255). The receiver uses this ID to determine the analog input and transmitter for each data transmission. A low on RESET (U16-11 and U17-11) loads the channel ID of the first analog input to be transmitted into the counters from S7 (see the section PROGRAMMING PROCEDURE for programming S7). After each input is transmitted, a low to high transition on NXT CHNL increments the counters to the next analog input's channel ID. The outputs of the counters are gated onto the data bus by a low on U18-1 (74C373).

ANALOG-TO-DIGITAL CONVERTER

U22 (ICL7109) is a 12 bit plus sign dual slope integrating analog-to-digital converter (A/D). The output of buffer U15 is connected via R36 to the INPUT HI of the A/D (U22-36). INPUT LO (U22-35) is connected directly to the analog input ground.

Full scale input is twice the reference voltage (U22-36). Normally R62 is adjusted to give the voltage reference U23 (LM236-2.5) an output of +2.500 volts giving the transmitter a full scale input range of ±5 volts. If for some reason a different voltage range is desired, not only does the reference voltage have to change but also C18, C19, and R37 (see an ICL7109 data sheet for details). The maximum conversion rate is 30 conversions/second.

A high pulse on run hold (R/H, U22-26) starts a conversion. While converting, STATUS (U22-2) is high. A high to low transition by STATUS indicates conversion is complete. The output of U22 is gated onto the data bus by lows on U22-18 (LBEN) for the low order data bits and U22-19 (HBEN) for the high order bits.

For best operation, C16, C18, and C19 should be capacitors with low self-adsorption such as polypropylene. Also note that the maximum operating voltage for U22 is +6.2 and -7.0 volts.

TEST SOCKET

A test socket (U33) is provided as a convenience. It contains all the A/D logic and the data bus.

SPARE CARD EDGE CONNECTOR J3

J3 is provided as a spare connector for custom application cards. This connector provides a place for cards performing such tasks as DTMF decoding, alternate FSK frequency generation, threshold detectors, etc.

THE A/D RADIO LOGIC

To allow the analog signal time to settle before doing the A/D conversion, U19-2 (CD4043) delays the conversion command by about 0.5 seconds. A high on either NXT CHNL or GO sets U19-2 high. Approximately 0.5 seconds later C14 will have charged to the point of reseting U19-2 low. This high to low transition goes through schmitt trigger/inverter U20-9/8 (CD40106) and gate U21-1/3 to initiate an A/D conversion. Status (U22-2) is low during the conversion. Upon completion of conversion, status returns high. This low to high transition goes through schmitt trigger/inverter U20-5/6 and sets the 2 R-S latches U19-10 and U19-1 high. The high on U19-1 enables Q3 (IRF 511), shorting the radio's transmit/receive control to ground, putting the radio into transmit mode, and the data for that channel is transmitted. Upon completion of transmission of data for a channel, NXT CHNL goes high, resetting U19-1 low and disabling Q3. U19-10 delays the start transmit (START XMIT) pulse by approximately 0.5 seconds to allow the radios to stabilize. See figure D.

UNIVERSAL ASYCHRONOUS RECEIVER TRANSMITTER

U28 (IM6402), the universal asychronous receiver transmitter (UART) converts the 8 bit parallel data to a standard RS-232C serial stream. It is configured to transmit 8 data bits, an odd parity bit, and 2 stop bits. The baud rate generator (U29, IM4712) and switch S8 allow transmissions at various baud rates (see table 1 for baud rates available). Though rates as high as 9600 are available, the modem (U30) limits the selection to 600 or less. The UART clock (U28-40) frequency is 16x the baud rate. A low on TBRL (U28-23) loads the parallel data into the UART and a low to high transition instructs the UART to begin transmitting. While transmitting, TRE (U28-24) goes low and returns high upon completion.

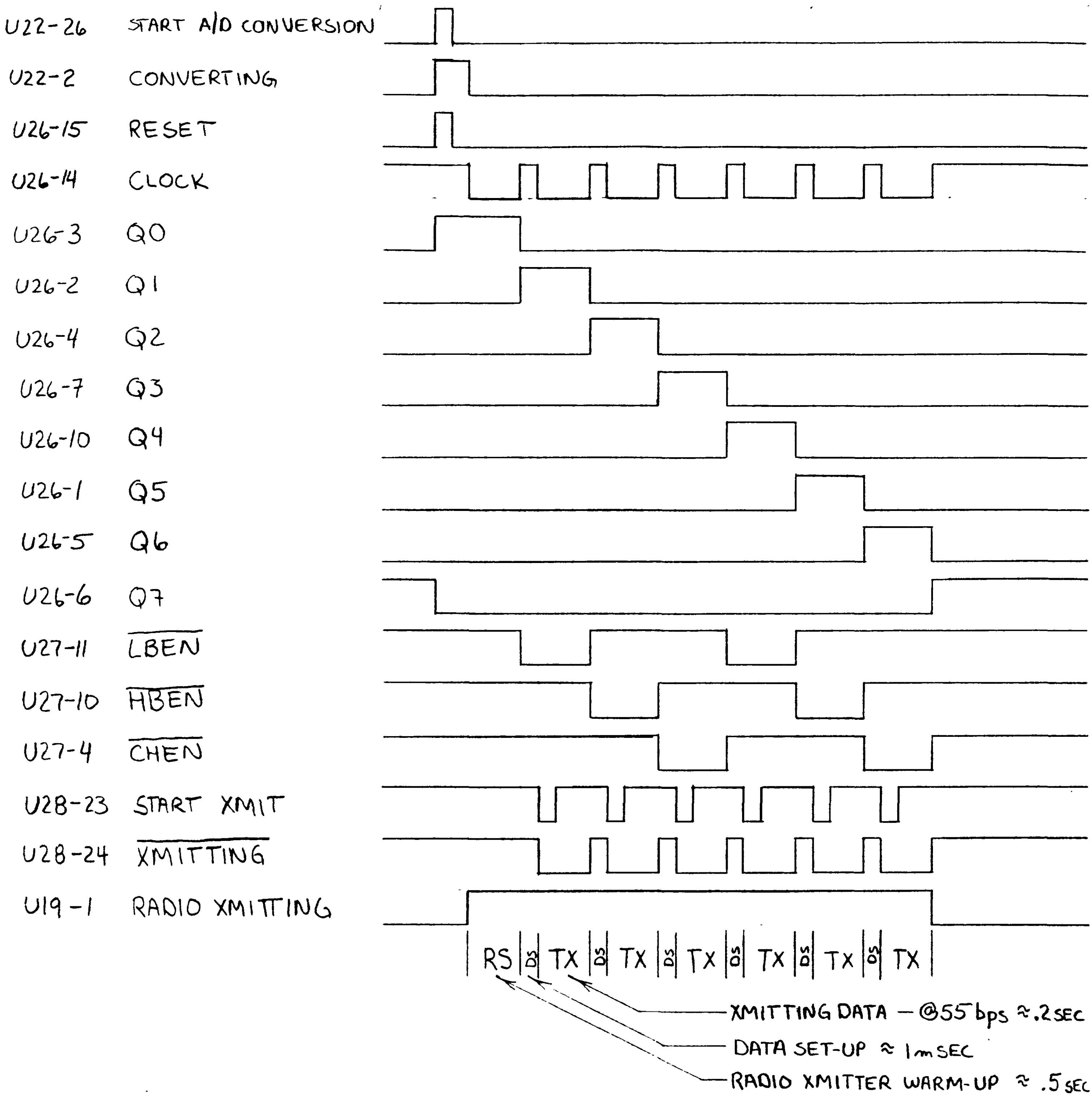
MODEM

A frequency-shift keying (FSK) modem, U30 (MC14412), converts the output of the UART (UART OUT, U28-25) to audio tones. Normally configured for U.S. (or Bell 103) standard originate frequencies (input high is indicated by a tone of 1270 hz, input low 1070 hz), switch S8 allows the use of other standard frequencies (see table 2 for programming instructions).

U31 buffers the output of the modem, and R60 is used to adjust the output amplitude. Though R60 can adjust the output down to the millivolt level required by some radios, it is suggested that a resistor divider (100 and 5k ohms for example) be put as close to the radio as possible in these cases. This lessens the possibility of RF interference problems. The signal is transformer coupled by T1 to the radio input (SIG+OUT and SIG-OUT).

TRANSMISSION FORMAT CONTROL

Data for the analog input is transmitted in 6 eight bit words. The first and fourth word are the low order A/D bits, the 2nd and 5th the high order A/D bits, and the 3rd and 6th the channel ID. The redundancy is used by the receiver as a check for a valid data transmission. A Johnson counter, U26 (CD4017) and NOR gate U27 (CD4001) are used to gate the various bytes onto the data bus. A high from either RESET (U5-6) or R/H (U21-3) on the counter's R/S (U26-15) puts it in its zero state. A low to high transition by START XMIT



TIMING NOT TO SCALE

DATA TRANSMISSION TIMING

FIGURE D

(U20-4) through U24-6/4 to the counters clock (U26-14) increments the counter. Counter output q1 (U26-2) goes high and through U27-13/11 gates the low order A/D bits onto the data bus (LBEN). The next low to high transition on the counter's clock will cause q1 to return low and set q2 (U26-4) high. The high on q2 will (through U27-9/10) gate the high order A/D data bits onto the bus (HBEN). The next time the counter is incremented, q3 (U26-7) will go high and through U27-5/4 gate the channel ID onto the bus (CHEN). This continues until q7 (U26-6, NXT CHNL) goes high and the sequence stops. The high on NXT CHNL increments various counters and starts the process for the next channel to be sampled and transmitted. See fig. D.

The signal incrementing the counter is sent through a delay, U20 (CD40106) and associated components. This is to allow the data bus to stabilize before issuing a transmit command to the UART (U28). LBEN, HBEN, and CHEN are ANDed together by U24 (CD4081) such that if any one is gating data onto the bus, U25-12 (CD4075) is low. This allows the delayed pulse to go through the OR gate and instruct the UART to transmit the data (SEND WORD). If no data is gated onto the bus (as when q7/NXT CHNL is high) U25-12 remains high and the delayed pulse will not get through the gate.

RADIO TO BOARD HOOKUP

Power and controls for a radio are available from the board via J5. S3 switches the positive side of the batteries to the radio. Power ground is switched to the radio by Q2. With the transmitter in its wait state, Q2 is disabled and the radio ground is essentially disconnected from the battery ground. When the transmitter is active, Q2 is enabled, providing a low impedence path between radio ground and battery ground. By switching the ground this way, the radio voltage does not necessarily have to be the same voltage as the transmitter board.

To prevent radio frequency (RF) interference while sampling the analog signals, the radio transmitter is keyed only when data is to be transmitted. Radios normally do this by shorting a control line to ground with a switch. Q3 provides this function. When the radio is to be keyed, Q3 is enabled and provides a low impedence path to ground.

The input signals to the radio are transformer coupled by T1. If the radio uses signal inputs in the millivolt range, it is recommended that a resistor divider be placed as close to the radio as possible to bring the input down to that level. This minimizes RF inteference problems.

PROGRAMMING PROCEDURE

SETTING THE INITIAL ANALOG INPUT TO BE DIGITIZED AND THE INITIAL CHANNEL ID

Set S6 to the binary number of the initial analog input to be digitized (0-15), and S7 to the initial channel ID (0-255). The least significant bit (LSB) is at pin 1. The binary representation of a decimal number is determined as follows:

Binary numbers consist of either ones or zeroes such as 10001 or 1010110. Moving right to left through the number, each place represents a power of 2 starting with 2**0 on the far right and incrementing to 2**1, 2**2, etc. as one moves to the left. The sum of all the powers of 2 for each place times the number in that place is the value for that number. for example, the binary number 0110. moving from right to left:

0*(2**0)+1*(2**1)+1*(2**2)+0*(2**3) or 0+2+4+0 = 6

Another example: 1101

1*(2**0)+0*(2**1)+1*(2**2)+1*(2**3) or 1+0+4+8 = 13

A longer example: 11010101

1*(2**0)+0*(2**1)+1*(2**2)+0*(2**3)+1*(2**4)+0*(2**5)+1*(2**6)+1*(2**7)
or 1+0+4+0+16+0+64+128 = 213

And a table showing the first 15 decimal numbers and their binary equivalent:

00 = 0000	08 = 1000
01 = 0001	09 = 1001
02 = 0010	10 = 1010
03 = 0011	11 = 1011
04 = 0100	12 = 1100
05 = 0101	13 = 1101
06 = 0110	14 = 1110
07 = 0111	15 = 1111

To encode the binary numbers into the slide dip switches S6 and S7, a 1 corresponds to a switch on and a 0 corresponds to a switch off. Pin number one of the switch is the least signifcant bit (LSB) or the right-most position in the binary number.

SETTING THE NUMBER OF CHANNELS TO TRANSMIT

Switches S4 and S5 determine the number of channels to transmit (1-16). Considering them as one long 16 position switch, the left-most switch corresponds to 1 channel to transmit while the right-most to 16 channels. to program switches S4 and S5, first make sure all 16 switches are off. Then count from left to right the number of channels you want transmitted and slide that switch to on. Having more than 1 of these 16 switches on at any one time will cause erratic behavior and possible damage to the unit.

SETTING THE TRANSMIT INTERVAL

The 10 position switch S1 determines the transmit interval. The nominal intervals for each position are as follows:

0 = infinite	5 = 9.6 minutes
1 = 36 seconds	6 = 19.2 "
2 = 1.2 minutes	7 = 38.4 "
3 = 2.4 "	8 = 1.3 hours
4 = 4.8 "	9 = 2.6 "

Longer transmit times can be achieved by increasing the resistance of R1 or the capacitance of C1.

BAUD RATE AND MODEM FREQUENCIES

Tables 1 and 2 give instructions for programming the baud rate and the modem frequencies. Because the Model #100's BASIC interpreter is quite slow, the baud rate is normally set for 50. The modem frequency is normally set for U.S. originate.

S9-1	S9-4	HI	LO	TYPE
OFF	OFF	1270 HZ	1070 HZ	US ORIG.
ON	OFF	1180 HZ	980 HZ	CCITT #1
OFF	ON	2225 HZ	2025 HZ	US ANS.
ON	ON	1850 HZ	1650 HZ	CCITT #2

DATA TRANSMISSION FREQUENCIES

TABLE 1

S8-1	S8-2	S8-3	S8-4	BAUD RATE
ON	OFF	ON	ON	50
OFF	OFF	ON	ON	75
OFF	OFF	OFF	OFF	110
ON	ON	OFF	ON	134.5
ON	OFF	OFF	OFF	150
ON	OFF	ON	OFF	200
OFF	ON	OFF	OFF	300
ON	OFF	OFF	ON	600

BAUD RATE SELECTION

TABLE 2

POWER CONSUMPTION

Because the transmitter only draws 0.4 ma max. in its wait state and 13 ma when active, powering it is not a major problem. Even transmitting all 16 channels every 10 minutes, a 12 volt 20 amp-hour alkaline lantern battery (such as the Duracell ID9260) can power it for a year. The formula for determining average current consumption is:

AVERAGE CURRENT = QUIESCIENT + ((CHNLS * 5 / INTERVAL) * ACTIVE)

where:

QUIESCIENT	=	the quiescent current consumption (.06 ma if U32 is used, 0.4 ma if U14 is used)
CHNLS	=	the number of channels to transmit
5	=	the number of seconds to transmit one channel
INTERVAL	=	the time between transmissions (in seconds)
ACTIVE	=	the active current consumption (13 ma + current drawn by external sensors)

Power for the radio is more of a problem. A typical 4 watt radio draws 900 ma while transmitting, and 20 ma while in receive mode. A single 12 volt 20 amp-hour battery would last only about 2 months if the radio was transmitting 3 channels every 10 minutes. By paralleling more batteries, this time period can be increased to the desired amount. The formula for determining average current consumption for the radio is:

RADIO CURRENT CONSUMPTION =((RCV * 2) + (XMIT * 3)) * CHNLS / INTERVAL

where:

RCV	=	radio current consumption in receive mode
2	=	seconds/channel radio is in receive mode
XMIT	=	radio current consumption in transmit mode
3	=	seconds/channel radio is in transmit mode
CHNLS	=	number of channels to be transmitted
INTERVAL	=	time between transmissions (in seconds)

Be aware that batteries such as alkalines and carbon-zinc do not have flat discharge voltages. That is, the voltage slowly drops as the battery is discharged. This means that though a 12 volt battery may be rated at 10 amp-hours, 5 of those amp-hours may be at voltages below 10 volts and the power output of the radio will fall to an unacceptable level. If the radio can handle 16 volts, it is preferable to power it with 7.5 volt batteries in series/parallel to provide a nominal 15 volt supply.

TEST PROCEDURE

If this is the initial test of the board, install only ICs U1 through U10. If the board has already been completely loaded, do not take out the other ICs but be ready to adjust the +6 volt output (step 4) because a voltage greater than +6.4 volts can destroy the A/D (U22). The test procedure can also be used for troubleshooting. Though the procedure will not isolate the problem to a specific IC, it will usually narrow the search to 2 or 3 ICs.

****
Please note: 90% of all problems are bad solder joints or solder bridges.
****

TEST EQUIPMENT NEEDED

Digital multimeter
Frequency counter
Oscilliscope (preferable dual trace)
12 volt supply (preferable current limited to 1.0 amps)
Digital logic probe
Radio Shack Model #100 computer
Radio receiver
Dummy analog input box

CLOCK, VOLTAGE REGULATORS, AND INITIALIZATION

Set-up

1) Place a current meter on the +12 volt supply. With only ICs U1 through U10 in place the current should never be above 3 ma. With a fully loaded board, the current should not exceed 15 ma. Unless one of the ICs is getting hot (which should give a pretty good idea where the problem is), continue with the testing and hope the problem reveals itself further on.

Procedure

1) Power up the board. Make sure the ICs running off the +12 volt supply are indeed getting +12 volts.
2) Test the clock oscillator output. Hook the scope up to test point CLOCK OSC. A square wave, +12 volts peak-to-peak (PTP), with a frequency of approximately 0.5 hz should be present.
3) Make sure the wake-up pulse is being sent. Set S1 (XMIT INTERVAL SELECT) to position 1. A high pulse should be seen about every 36 seconds at U3-4. With the switch at position 2 the pulse should occur at intervals twice as long as position 1 or every 72 seconds. For position 3 the interval will be twice as long as at position 2 or every 144 seconds, and so on. Time considerations make testing positions 4 through 9 not worth the effort at this time.
4) Adjust the voltage regulators to +6.0 volts and +8.0 volts with R63 and R64 respectively. About -6.0 volts and about -7.4 volts should be present at their checkpoints also.
5) Set S1 back to position 1 to give a wake-up pulse every 36 seconds.
6) The wake-up pulse should set U5-2 high (+6 volts) and U5-4 low for

about 0.5 seconds to reset the counters in the transmitter. At the end of this period, a high pulse should occur at U5-6, causing the transmitter to begin operation.

TRANSMISSION SECTION

Set-up

1) If not already done, turn off power and install the rest of the ICs.
2) Set all dip switches to off except the baud rate select. It should have positions 1,3, and 4 on (50 baud).
3) Insert a current meter on the +12 volt supply. As stated before, if it reads greater than 15 ma, then something is wrong. Unless an IC is getting hot (which isolates the problem), ignore this and hope the source of the problem becomes apparent later on.
4) Attach the voltmeter to the +6 volt supply.

Procedure

1) Apply +12 volts to the board.
2) Wake the transmitter by turning switch S1 one full circle, ending up at position 0. Usually one of the outputs of U2 will be high, and turning S1 all the way around should give the transmitter at least one high pulse to wake it up.
3) Check that the +6 volts is still at +6. Do the same for the +8.0, -6.0 and -7.4 volts.
4) Adjust the +2.500 voltage reference with R62.
5) Check that the UART CLOCK has a frequency of 16 times the baud rate (16*50=800 hz).
6) With the scope, monitor UART out. It should be normally high, with data being sent about every 3 seconds. The data transmission will be a series of lows, lasting about 1.2 seconds, with a return to high. If it is not then a problem exists in the A/D - data transmission logic. Set S1 to postion 1 (so that it initiates a transmission every 36 seconds) and go through the various test points using the detailed circuit description. Good luck.
7) Check the FSK output by hooking the scope up to SIG+ and SIG-. A tone of 1270 hz should be seen with periodic modulations to 1170 hz corresponding to data being transmitted. R66 may need adjusting to bring the amplitude up to a pleasant 0.7 volts PTP.

COUNTERS AND DATA SECTION

Set-up

1) A Radio Shack Model #100 needs to have its modem input hooked up to the SIG+OUT and SIG-OUT of the board. The switches on the left side of the #100 should be in the ACP and ANS positions. The program FLDRCV.BA should be running.
2) Set S1 to postion 1 (to issue wake-up pulses every 36 seconds).
3) S6, S4, S5, and S7 should be all off.
4) Hook up the dummy analog inputs to J1.
Note: if using inputs other than the CVO dummy analog inputs box the data values listed below as examples will not be valid. Each dummy

analog input box will have to be calibrated to determine the correct values for it.

5) Turn on the board.

Procedure

1) At this point, the Radio Shack #100 should be receiving data. This is indicated by a beeping of the #100, and the channel ID, data, voltage, and time being displayed on the screen. The channel numbers should be starting at zero, incrementing by one to 5 or 6 and then restarting at 0. This is happening because the clock is set for a wake-up every 36 seconds, which resets the counters to 0. The data values should be cycling also.
2) Set S1 to position 0 to disable any more wake-up pulses. The channel number should now continue to increment all the way up to 255 where it should rollover to 0 again. The data also should be cycling through the 16 analog inputs. It is not necessary to wait for the full 255 channels to transmit to continue on.
3) Set S1 to position 1. Set S4-1 to on. Now only one channel should be transmitted. Hook up the scope to SIG+OUT and SIG-OUT. A sine wave should appear, transmit one channel, and disappear as the board goes back to its sleep mode.
4) Set S4-1 back to off, and S4-2 to on. Now 2 channels should be transmitted before returning to sleep mode.
5) Now try transmitting 9 channels. S4-2 returns to off and S5-1 goes on. Initially, this will not look any different from the results of step 1. That is because it takes longer than 36 seconds to transmit the 9 channels, and the wake-up pulse is resetting the counters before the 9th channels is transmitted. Set S1 to postion 3 and all 9 channels should be transmitted before returning to sleep.
6) Reset the board to transmit 3 channels every 36 seconds.
7) Set the initial channel ID to 1 (S7-1 on). Now, instead of transmitting channels 0, 1, and 2, the board should be transmitting channels 1,2, and 3.
8) Set the initial channel ID to 9 (S7-1 and S7-4 on). Now channels 9,10, and 11 should be transmitted.
9) Set the initial channel ID back to 0 (all of S7 off).

The following data values will are valid only for the CVO phony input box

10) Note the data being transmitted for each channel. With all S6 off, channel 0 should be about 8165, channel 1 about 7584 and channel 2 about 7004.
11) Set the initial analog input to 1 (S6-1 on). Now the data that was with channel 1 will be with channel 0 and channel 1 will have channel 2's. Channel 2 will have the next analog input or about 6423.
12) Set the initial analog channel to 2 (S6-1 off, S6-2 on). The data should shift again as in step 11.
13) Set the initial analog channel to 15 (all of S6 on). Now, with respect to the original data, channel 2 should have the data that was with channel 1 and channel 1 that which was with channel 0. Channel 0's data should be about 0035.

RADIO POWER AND KEYING

Set-up

1) Hook the radio output of the board to a radio transmitter. Make sure the radio is turned on.
2) Turn on a radio receiver tuned to the same frequency as the transmitter.

Procedure

1) Set the board to transmit 2 channels every 36 seconds. The radio receiver should be outputting a tone for about 0.5 seconds (the radio warm-up time) and then about 1.2 seconds of a modulated tone (the data). A squelch break should follow indicating the transmitter has turned off. Then the second channel should come on and do the same.
2) Hook the output of the receiver to the modem port on the Model #100. Set the #100 up to receive the data (the volume of the receiver may have to be turned to full on). The #100 should display the data as it is transmitted.
3) To check that the mosfets (Q2 and Q3) are turning full on and off, hook the voltmeter to ground and to the middle post of one of them. The voltage should switch back and forth between 0.7 volts of the +supply voltage (indicating the mosfet is off) and within 0.7 volts of ground (the mosfet is on). Then check the other mosfet.

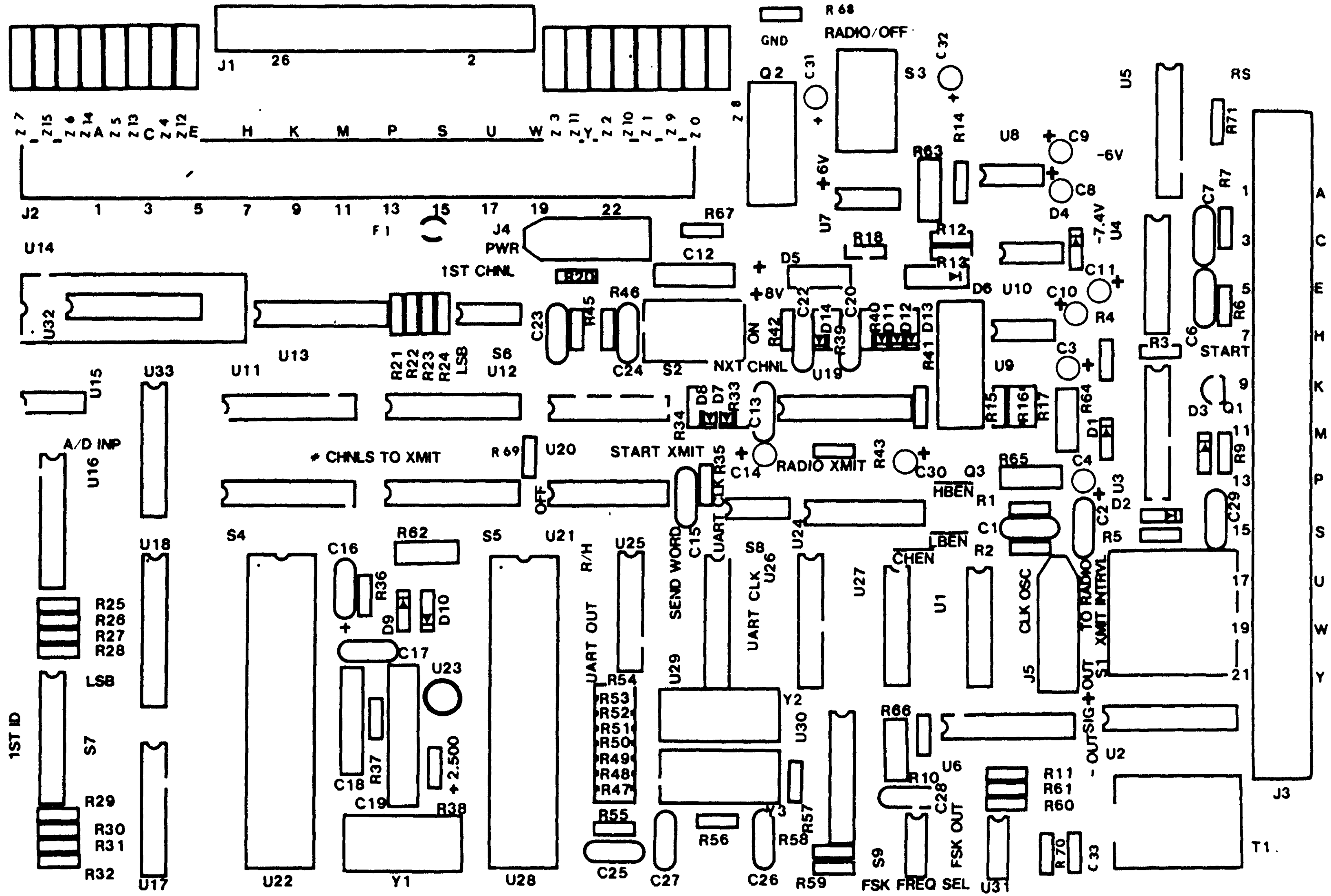
FINAL CHECK

Set-up

1) Use the current meter to monitor the supply current and the scope to monitor the transmissions.
2) Set the transmitter to transmit 2 channels every 36 seconds.
3) Disconnect the radio.

Procedure

1) Check the current consumption when the board is transmitting and when it is sleeping. Sleep mode current consumption should be about 60 microamps with the 8 channels multiplexor installed (U32) or 400 microamps with the 16 channel (U14). Current consumption should be 10-13 mamps when it is transmitting.



SILKSCREE

FIG. E

7

16a

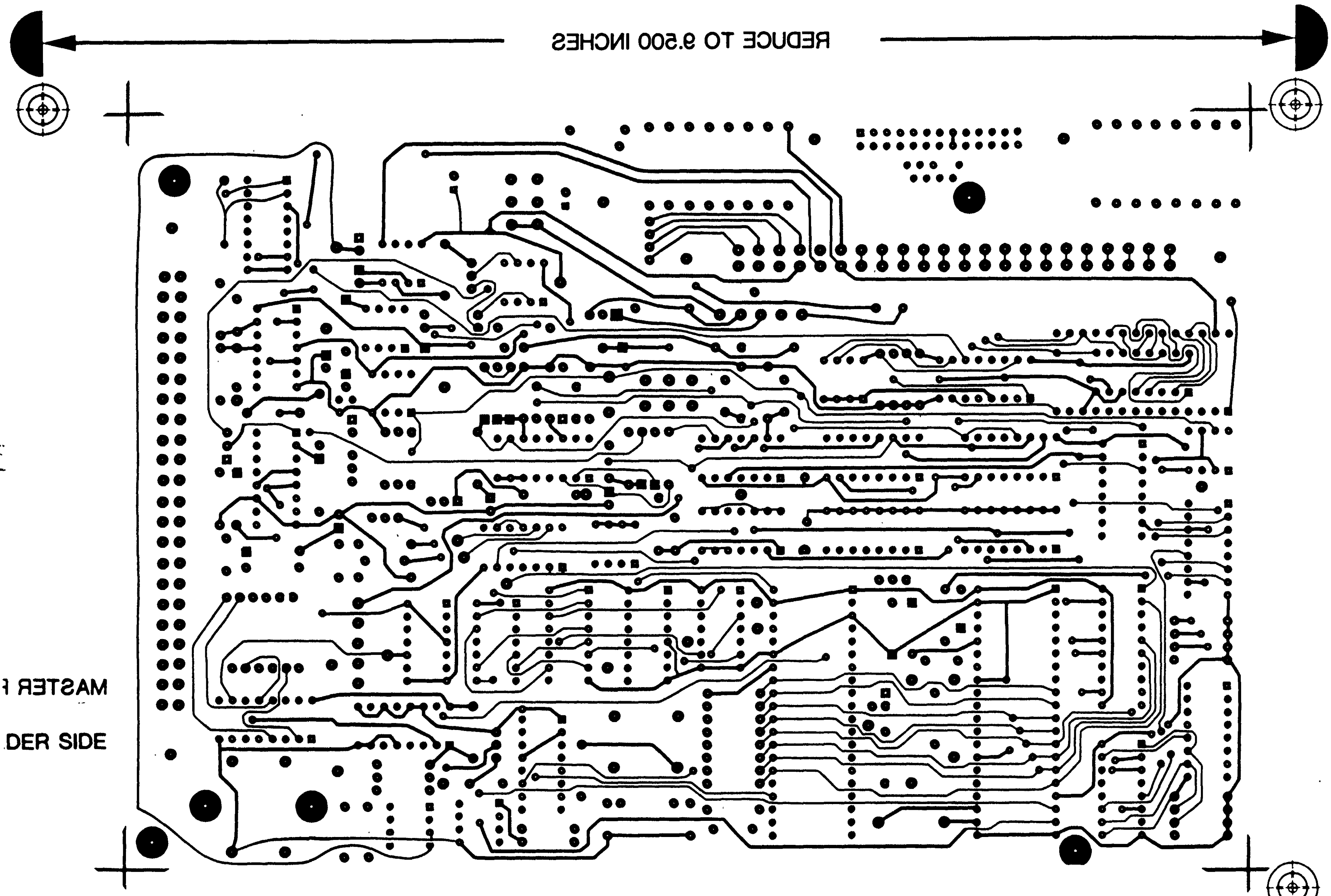


FIG. F

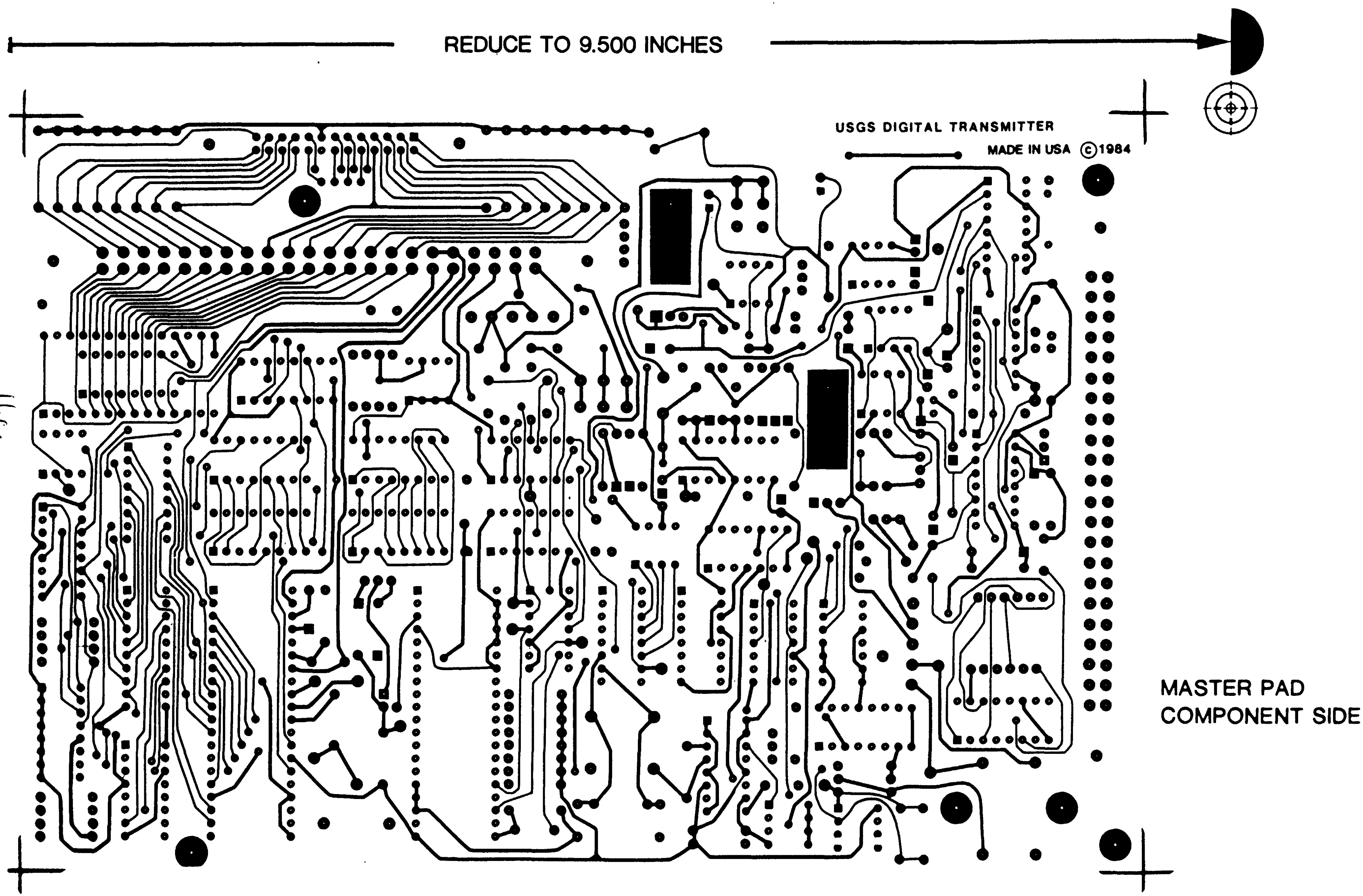

REDUCE TO 9.500 INCHES
USGS DIGITAL TRANSMITTER
MADE IN USA ©1984
MASTER PAD
COMPONENT SIDE

FIG. G

16c

TRANSMITTER SPECIFICATIONS

Power requirements:

Supply voltage	8.7 - 15 volts D.C.
Supply current	
(U32 installed)	70 microamps quiescent
(U14 installed)	400 microamps quiescent
(without radio)	15 ma transmitting

Average current (4 channels transmitting every 10 minutes, U32 installed):
<400 microamps

Analog inputs:

Range	±5 volts
A/D Converter	12 bit plus sign, integrating type
Resolution	1.22 mv
Number of inputs	16 max., single ended

Power output:

Switched +6.0 volts	10 ma	*5.7 volts*
Switched -6.0 volts	5 ma	*5.7 volts*
Switched +8.0 volts	25 ma	*7.8 volts*
Switched -7.4 volts	5 ma	*7.0 volts*
Switched supply voltage	100 ma	

Data out:

Standard RS-232C	8 bit binary (not ASCII), odd parity, 2 stop bits
Baud rate	switch selectable 50 - 9600 (50 standard)
FSK frequencies	switch selectable CITT or Bell 103 standard answer or originate

Each channel's data is transmitted as 6 8-bit bytes: low order data byte, high order byte, channel I.D. byte, and then repeated.

Packaging:

Water-tight steel drum	36 cm. dia. x 45 cm. high

Cost:

Transmitter (w/o radio)	$550 parts
	$200 ? labor
Radio	$300 - $850 VHF 1-5 watt
	$400 VHF 100 mWatt
	$750 UHF 200 mWatt

RECEIVER REQUIREMENTS

Any computer with a Bell 103 modem can be programmed to receive the data directly out of the radio receiver. The data then can be uploaded to a larger computer, sent through a digital/analog board to a chart recorder, stored on cassette tape, etc.

Receiver costs:

Radio Shack Model #100 computer w/32K	$500	
Radio receiver	$300	same as radio transmitter
Disk drive (optional)	$400	
Printer (optional)	$125	

It is important to remember that because the radio transmitters are only on when data is being sent, one radio receiver and Radio Shack Model #100 computer can receive the data from more than one transmitter. A practical limit exists, though, of about 20 channels each transmitting once every 10 minutes. Adding more channels or transmitting more frequently can cause problems as messages from separate transmitters will start to interfere with each other too often.

TEST POINTS

GND	System ground.
CLK OSC	Output of the oscillator U1 (CD4047). Should be a 12 volt, approx. 2 hz square wave.
START	Output of R-S flip-flop U3-9 (CD4043). Goes high (12 volt logic) beginning of transmission to preset all counters. Its high to low transition initiates processing the first channel.
RS	RESET, output of U5-2. RS goes high (6 volt logic) for about 0.5 seconds after a wake up to preset various counters.
+6V	Output of voltage regulator U7-1 (ICL7663). Should be +6.00 volts when transmitter is active.
-6V	Output of voltage inverter U8-5 (ICL7660). Should be -6 volts when transmitter is active.
+8V	Output of voltage regulator U9-1 (ICL7663). Should be +8 volts when transmitter is active.
-7.4V	Output of voltage inverter U10-5 (ICL7660) through D4. Should be about -7.4 volts when transmitter is active.
A/D INP	Analog input to the A/D. Output of the buffer U15-6 (OP07).
R/H	Output of AND gate U21-3. Run/hold for the A/D. A high pulse initiates a conversion by U22 (ICL7109). It also resets the counter U26 (CD4017).
+2.500	Reference voltage (U23) for the A/D. Should be +2.500 volts when the transmitter is active.
START XMIT	Output of inverter U20-4. A low to high transition initiates transmission of data for a channel.
LBEN	Output of OR gate U27-11. Low order data bits from the A/D are gated onto the data bus when this is low.
HBEN	Output of OR gate U27-10. High order data bits from the A/D are gated onto the data bus when this is low.
CHEN	Output of OR gate U27-4. The channel ID is gated onto the data bus when this is low.
SEND WORD	Output of OR gate U25-10. A low pulse here loads the data from the bus into the UART and initiates the transmission of that data.
RADIO XMIT	Output of R-S flip-flop U19-1. A high keys the radio into transmit mode.

UART OUT	Serial data output of the UART (U28-25).
FSK CLK	Output of baud rate generator (U29-10). Should be a square wave with a frequency 16 times the baud rate.
FSK OUT	Buffered sine wave output of the modem (U30-9) and op amp U31-1.
NXT CHNL	Output q7 of U26-6. A low to high transition indicates the data for a channel has been transmitted and the processing for the next channel should begin. It is reset to low by a high on R/H.
SIG-OUT and SIG+OUT	Transformer (T1) coupled output to the radio.
OFF	A high pulse (from either U11 and S4 or U12 and S5) puts the transmitter back into a sleep state.

RECEIVER PROGRAM FOR THE RADIO SHACK MODEL #100

Data can be received by a Radio Shack Model #100 lap computer running the following program - FLDRCV.BA. The transmitted signal is connected to the Model #100 through the modem port. Signal hi goes to pin 4 and signal lo to pin 2. The modem selecter switch should be in the ACP position, and, if the transmitter is transmitting on the normal originate frequencies, the ANSwer/ORiGinate switch should be in the ANS position.

When entering this program into the computer, it is recommended that the comments be left out. This will save time and memory.

FLDRCV.BA

```
90  PRINT "PROGRAM STARTED"
'        declare the arrays to hold the incoming data bytes (DA%) and their
    arrival time (TI%)
91  DIM DA%(6)
92  DIM TI%(6)
93  OS%=VAL(MID$(TIME$,7,2))
'        initialize the arrays to dummy values
94  FOR I=1 TO 6
95  DA%(I)=-1
96  TI%(I)=OS%
97  NEXT I
98  CLOSE
'        open the modem port for 8 bit, even parity, 2 stop bits, and no
    xon/xoff
100 OPEN "MDM:8E2D" FOR INPUT AS 1
'        reset the baud rate to 50.  no guarantees that this will run at
    faster baud rates.
102 OUT 188,0 : OUT 189,76 : OUT 184,195
'        set the modem interrupt
120 ON MDM GOSUB 300
'        N% keeps track of how many of the 6 bytes/transmission we have
    received
122 N%=0
'        the wait for an incoming byte loop
125 MDM ON
130 GOTO 125
'--------------------------------------------------------------------------------
'        we have some data.  first stop the modem interrupt
300 MDM STOP
'        get the incoming byte directly from the communication buffer.  we
    have to do it this since we are sending binary data and a CTRL-Z or end-
    of-file designator may be received and close the communication port.
302 A%=PEEK(((PEEK(65416)+63) MOD 64)+65350)
'        since we grabbed the byte with a PEEK we have to fool the
    communication buffer pointer into thinking we got it in the normal manner
303 POKE 65414,0
'        check for parity or framing errors
306 IF INP(208)>241 THEN GOTO 485
```

```
'       increment the pointer to our incoming data arrays and put the byte
    into the proper position
310 N%=N%+1
311 DA%(N%)=A%
'       record the time it was received (seconds only)
320 TI%(N%)=VAL(MID$(TIME$,7,2))
'       the entire message must fit into a two second window.  check that by
    subtracting the current seconds from that of the first byte received in
    the message.
325 DU%=TI%(N%)-TI%(1)
326 IF DU%>2 THEN GOTO 700
'       allow for the fact that the seconds go 58, 59, 00, 01 at each minute.
350 IF DU%>-58 AND DU%<0 THEN GOTO 700
'       if we haven't gotten all six bytes yet, go back and wait for the
    rest.
390 IF N%<6 THEN RETURN
'       we have six bytes so we test for the redundancy.  byte 1 must equal
    byte 4, byte 2 must equal byte 5 and byte 3 must equal byte 6.
400 IF DA%(1) <> DA%(4) THEN GOTO 700
410 IF DA%(2) <> DA%(5) THEN GOTO 700
420 IF DA%(3) <> DA%(6) THEN GOTO 700
'       also byte 2 is always greater than 192
425 IF DA%(2) <192 THEN GOTO 700
'       its valid data!  extract the data out of the message.  see a data
    sheet for the ICL7109 a/d to see the data format in the bytes.
440 DA%(0)=DA%(5)-INT(DA%(5)/16)*16
450 DA%(2)=DA%(4)+DA%(0)*256
460 DA%(5)=DA%(5)-INT(DA%(5)/64)*64
470 IF DA%(5) >=32 THEN DA%(2)=DA%(2)+4097 ELSE DA%(2)=4096-DA%(2)
'       that done, beep and print it on the screen.
474 BEEP
480 PRINT USING "CH=### DATA=#### VOLTS=+#.###          ";DA%(6),DA%(2),
(DA%(2)-4097)*.00122, TIME$
'       reset the pointer into the arrays and return.
485 N%=0
490 RETURN
'------------------------------------------------------------------------------
'       if the timing is off or the bytes don't match up we throw out the
    first byte and move the others down 1 in the arrays.
700 FOR I=1 TO N%
710 DA%(I-1)=DA%(I)
715 TI%(I-1)=TI%(I)
720 NEXT I
'       move the pointer down one and return.
730 N%=N%-1
740 RETURN
'------------------------------------------------------------------------------
```

PARTS LIST

The following prices are only rough estimates and some may reflect quantity discounts. Pin-for-pin equivalent components from other manufacturers may be substituted.

PART NO.	PART		COMMENTS	PRICE
C1	ceramic disk	.1uF		.10
C2	"	.01uF		.10
C3-4	electrolytic	10uF		.40 ea
C5	not used			
C6	ceramic disk	.1uF		.10
C7	ceramic disk	.01uF		.10
C8-11	electrolytic	10uF		.40 ea
C12	"	15uF		1.14
C13	ceramic disk	47pF		.10
C14	electrolytic	10uF		.40 ea
C15	ceramic disk	.01uF		.10
C16	polyprop.	1uF	Electrocube 935B1B105K	1.99
C17	ceramic disk	.01uF		.10
C18	polyprop.	.22uF	Electrocube 935B1B224K	1.28
C19	"	.47uF	Electrocube 935B1B474K	1.49
C20	ceramic disk	.01uF		.10
C21	not used			
C22	ceramic disk	.01uF		.10
C23-24	"	.001uF		.10 ea
C25	tantalum	1uF		.30
C26-27	ceramic disk	56pF		.10 ea
C28	"	.01uF		.10
C29	not used			
C30	electrolytic	10uF		.40
C31-32	"	22uF		.40 ea
C33	ceramic disk	.01uF		.10

PART NO.	PART		COMMENTS	PRICE
R1	resistor	750K	1/4 watt 5% carbon	.02
R2	"	100K	"	.02
R3	"	200K	"	.02
R4	"	*	selects auto off time	.02
R5-7	"	100K	1/4 watt 5% carbon	.02 ea
R8	not used			
R9	resistor	100K	"	.02
R10	"	3M	"	.02
R11	"	1M	"	.02
R12	"	20	"	.02
R13	"	360K	"	.02
R14	"	100K	"	.02
R15	"	20	"	.02
R16	"	510K	"	.02
R17	"	100K	"	.02
R18	shorted			
R19	not used			
R20	resistor	1M	"	.02
R21-34	"	100K	"	.02 ea
R34	"	150K	"	.02
R35	"	100K	"	.02
R36	"	1M	1/4 watt 1% RN60C	.02
R37	"	250K	"	.02
R38	"	2.4K	1/4 watt 5% carbon	.02
R39	"	100K	"	.02
R40	"	1M	"	.02
R41	"	150K	"	.02
R42	"	100K	"	.02
R43	shorted			
R44	not used			
R45-53	resistor	100K	"	.02 ea
R54	not used			
R55	resistor	100K	"	.02
R56	"	10M	"	.02
R57	"	15M	"	.02
R58-59	"	100K	"	.02 ea
R60-61	"	*	selects VCO output range	.02 ea
R62-64	pot	10K	Spectrol 64W103	1.18 ea
R65	"	100K	" 64W104	1.18
R66	"	10K	" 64W103	1.18
R67	resistor	100K	1/4 watt 5% carbon	.02
R68	"	100	"	.02
R69	"	100K	"	.02
R70	"	20K	"	.02
R71	"	100K	"	.02

PART NO.	PART	COMMENTS	PRICE
D1-4	diode	IN914	.03 ea
D5	Tranzorb	Gen Semi #1.5KE18CA	2.00
D6	diode	Motorola IN5400 (3 amp)	.30
D7	"	IN914	.03 ea
D8	not used		
D9-D14	diode	IN914	.03 ea

PART NO.	PART	COMMENTS	PRICE
Z0-15	Tranzorb	Gen Semi #1.5KE7.5CA (optional)	2.10 ea

PART NO.	PART	COMMENTS	PRICE
Q1	mosfet	Siliconix VP0300L	1.07
Q2-Q3	"	Motorola IRF511	1.42 ea

PART NO.	PART	COMMENTS	PRICE
S1	10 position switch		7.00
S2-3	DPDT switch	Sprague QSP 1410	.60 ea
S4-5	8 pos DIP switch	C&K BD08	.65 ea
S6	4 pos DIP switch	" BD04	.65
S7	8 pos DIP switch	" BD08	.65
S8-9	4 pos DIP switch	" BD04	.65 ea

PART NO.	PART	COMMENTS	PRICE
Y1	crystal 3.5795M	US Crystal Corp	3.00
Y2	" 2.4576M	"	3.00
Y3	" 1.0M	"	12.79
T1	transformer	600 ohm primary/secondary impedance	10.00

PART NO.	PART	COMMENTS	PRICE
U1	CD4047BE	National	1.04
U2	CD4020BE	"	.88
U3	CD4043BE	"	.58
U4	CD40106BE	"	.50
U5	CD4050BCN	"	.72
U6	MC14504BCP	Motorola	1.10
U7	ICL7663CPA	Intersil	4.60
U8	ICL7660CPA	"	3.00
U9	ICL7663CPA	"	4.60
U10	ICL7660CPA	"	3.00
U11-12	MC14017BCP	Motorola	.65
U13	MM74C193N	National	2.00
U14	HI-506-A	Harris (optioned w/U32)	45.02
U15	OP07CZ	PMI	4.20
U16-17	MM74C193N	National	2.00 ea
U18	MM74C373N	"	1.00
U19	CD4043BE	"	.58
U20	CD40106BE	"	.84
U21	MC14081BCP	Motorola	.23
U22	ICL7109IJL	Intersil (ext. temp.)	29.70
U23	LM236H-2.5	National (ext. temp.)	5.75
U24	MC4081BCP	Motorola	.23
U25	CD4075BCN	National	.40
U26	MC14017BCP	Motorola	.65
U27	CD4001BCN	National	.29
U28	IM6402IPL	Intersil	5.20
U29	IM4712IPE	"	11.73
U30	MC14412FP	Motorola	4.60
U31	TL022CP	Texas Inst.	3.00
U32	CD4051BF	National (optioned w/U14)	1.06

PART NO.	PART	COMMENTS	PRICE
J1	I/O connector	A P 925225-26-R	3.45
	I/O cable/conn	A P 924003-36-R	5.15
J2	44 pin edge connector		5.00
J3	"	spare board connector	5.00
	8 pin DIP socket	Augat 508-AG37D (9 total)	.75 ea
	14 "	" 514-AG37D (7 total)	1.16 ea
	16 "	" 516-AG37D (18 total)	1.30 ea
	20 "	" 520-AG37D (1 total)	2.14
	28 "	" 528-AG37D (1 total)	1.50
	40 "	" 540-AG37D (2 total)	2.10 ea

PART NO.	PART	COMMENTS	PRICE
	circuit board		30.00
	9.0 gallon steel drum		20.00
	BNC bulkhead mount		10.00
	BNC crimp plug		10.00
	10 pin fmale recpt		5.00 ea
	10 pin male plugs		15.00 ea
	5 pin fmale recpt		15.00 ea
	5 pin male plug		15.00 ea
	5 pin conn kit	Waldom/Molex	5.00
	misc. nuts and bolts (4-40)		5.00
	12 volt battery		10.00 ea
	wire		4.00
	radio		200.00 - 600.00
	antenna		15.00 - 200.00
	coax cable		5.00