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COSPAS/SARSAT 406-MHz Emergency Beacon Digital Controller

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SUMMARY

The digital control portion of a low-cost 406-MHz COSPAS/SARSAT emergency beacon has been designed and breadboarded at the NASA Lewis Research Center. This report discusses the requirements and design tradeoffs of the digital controller and describes the hardware and software design. The detailed hardware and software design is available to United States citizens or companies.

INTRODUCTION

In the 1970's, NASA began experimenting with Doppler tracking for locating terrestrial transmissions. In 1976, the search and rescue satellite program became an international effort involving the United States, Canada, and France. By 1980, the Soviet Union became involved, thus creating the COSPAS[1]/SARSAT[2] program. This program is divided into two emergency beacon detection systems: one system designed for interaction with aircraft and the other system designed for interaction with satellites. Both systems are currently operational (ref. 1).

Emergency transmitters designed for interaction with aircraft were developed first. These transmitters have also been used with satellites. A beacon with a characteristic audio signal transmitted at 121.5 or 243 MHz can be located to within 20 km (12 mi). However, these emergency transmitters must be within a 3220-km (2000-mi) radius of a ground terminal in order to be received.

A major problem with the 121.5/243-MHz transmitters has been the large number of "false alarms" caused by unintentional activation and by equipment failure. Presently, the only way to track down false alarms is to send out a rescue force to investigate. This can become quite expensive.

A second system, using 406-MHz transmission, has been designed specifically for use with satellites. This system provides the following improvements over the 121.5/243-MHz system: global monitoring, location determination to within 5 km (3.1 miles), and a beacon-specific message. Because each beacon-specific message contains a user identification code, false alarms can be quickly tracked by contacting the beacon user. If the user can be contacted, the transmission is obviously a false alarm.

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[1]COSPAS is the Space System for Search of Vessels in Distress (translation from Russian).
[2]SARSAT is the Search and Rescue Satellite-Aided Tracking System.

Three classes of 406-MHz emergency beacons exist: the emergency locator transmitters (ELT's), emergency position indicating radio beacons (EPIRB's), and personal locator beacons (PLB's). ELT's and EPIRB's are readily available. PLB's are available only on a limited basis. Presently, each class of emergency beacon must meet the same operational and environmental specifications. ELT's are packaged for use on aircraft (i.e., manual or crash activation), EPIRB's are packaged for use on maritime vessels (i.e., waterproof, floats, manual or water activation), and PLB's are packaged for use by campers, backpackers, and recreational boaters (i.e., small and easy to carry).

NASA is attempting to stimulate technological advances in a number of areas in order to reduce dramatically the cost of the 406-MHz beacons. Since April 1986 the minimum cost for an EPIRB or ELT has been approximately US$1500. This is considered too high to mandate that all commercial shipping, large recreational boats, and aircraft carry 406-MHz beacons. NASA would like to bring the cost down to US$300 to US$500 per unit in production quantities.

The 406-MHz beacon can be divided into seven subsystems: digital controller, ultrastable oscillator, oscillator-multiplier chain, modulator, amplifier, antenna, and battery (fig. 1). The items that require technology advancements in order to meet the international specifications and remain low in cost are the oscillator, modulator, amplifier, and battery. The digital controller has been developed using present technology. A discussion of the digital controller design follows.

REQUIREMENTS

The following are general requirements for the 406-MHz beacon digital controller. It must be able to

(1) Control power to the oscillator and amplifier

(2) Turn the 121.5-MHz beacon ON/OFF

(3) Generate both long and short messages with the characteristics illustrated in tables I to III

(4) Generate 21 Bose-Chaudhuri-Hocquenghem (BCH) error-correcting bits by using a BCH (82,61) code

(5) Transmit the carrier for 160 msec ±1 percent

(6) Transmit the message in a Biphase-L format at a bit rate of 400 bps ±1 percent (fig. 2)

(7) Transmit the message every 50 sec with a jitter of ±2.5 sec to avoid the synchronization of any two transmitters

(8) Provide asynchronous communication capability through an RS-232-type port

(9) Provide self-test capability

(10) Determine whether the beacon was activated manually or automatically

(11) Determine emergency code (tables IV and V)

Detailed requirements for the 406-MHz emergency beacon are described in reference 2.

HARDWARE DESIGN

The general guidelines for the overall beacon, including the digital controller, were low cost, low parts count, and, if possible, low power, because the beacon is powered by a battery. Upon reviewing the operational requirements and formulating a sales and licensing scenario, a simple three-chip design was developed using an 80C51 microcontroller, a 256x4 PROM, and a 1Kx4 PROM (fig. 3).

The 80C51 microcontroller has 4K of on-board PROM, 128 bytes of on-board RAM, two internal timers, and a transmit and receive port for asynchronous communications. It also meets the 406-MHz beacon temperature requirements. The 4K of PROM and 128 bytes of RAM are more than adequate to hold the software. One timer is used to generate the transmission bit rate while the other timer generates the asynchronous communication baud rate. The 80C51 provides the necessary signals for reading the two PROM's as well as providing up to 24 input/output ports and 2 external interrupts (figs. 4 and 5, and ref. 3).

The 256x4 PROM is used for storing beacon-specific data (i.e., user ID, country code, etc.). Having the beacon-specific information stored on a PROM allows for easy, inexpensive programming of individual beacons.

The 1Kx4 PROM is used to encode switch settings which specify the emergency code. Having the PROM encode the switch settings allows the switch to be simple and inexpensive, thus increasing the reliability of the overall circuit. Also, by using a PROM, the same circuit can generate any 4-bit emergency code.

In order to eliminate the need for extra integrated circuits (IC's), the hardware design has an unusual addressing implementation. In order to eliminate the need for multiplexing the PROM enable signal, both PROM's are always read together. Each PROM uses a 4-bit-wide data bus. Two PROM's are put in parallel to form an 8-bit data bus compatible with the 80C51. The 80C51 addressing system expects the lower 8 of 16 address bits to be latched during each read/write cycle because the lower 8 address bits and the data bus are multiplexed. In order to eliminate an IC for latching, the beacon-specific data PROM is addressed using the upper 8 address bits.

SOFTWARE DESIGN

The main program consists of an interrupt handling routine and the following major modules: initialization of the CPU, RS-232 communications, message generation, Biphase-L transmission, and jitter delay (fig. 6). The main program and the RS-232 communication module are written in a high-level language

(Intel's PLM). Because of the extremely detailed byte and bit manipulation involved in the remaining modules, they are written in assembly language.

COMMUNICATION MODULE

The communication module is written for asynchronous RS-232 communications at 110 baud. In order to simplify the proof of concept software, all critical timing modules were written around a machine cycle time of 1 msec, which requires a 12-MHz crystal (ref. 3). Because the communication module was implemented last and all previous timing was based on a 12-MHz crystal, the 110-baud rate was the only standard rate that could be generated by the 80C51 baud-rate generator circuits. The baud rate could easily be modified by changing the oscillator and slightly modifying the software. A commercially manufactured 406-MHz emergency beacon would probably operate at 1200, 4800, or 9600 baud (refs. 4 to 6).

The following are valid commands: ECHO, TEST, RUN, and LONGITUDE and LATITUDE. The ECHO command causes the ECHO flag bit to toggle. The ECHO bit indicates whether or not the system should echo characters back to the terminal or the computer. ECHO is used mainly to debug the communications and to allow for operation with a terminal that does not echo characters to itself. The RUN command causes the RUN flag bit to be set. A RUN bit, when set, terminates the communications routine allowing message generation and transmission to begin. The TEST command initiates three separate tests: the 80C51 test, the data PROM test, and the switch PROM test. The 80C51 and data PROM tests are checksum tests. A calculated checksum is compared with the expected checksum that is stored in the last location of the 80C51 ROM and the last two locations of the data PROM. If the test is successful, a test flag bit is set. The switch data PROM is tested by placing the switch in the test position and comparing the value read with the expected value. A checksum test cannot be performed on the switch PROM because this PROM cannot be addressed from the 80C51. Upon completion of the test, the 80C51 returns an ASCII value to the computer or terminal (table VI). The LONGITUDE and LATITUDE command is used to enter longitude and latitude information into the 80C51 (table VII). Execution of the LONGITUDE and LATITUDE command causes the longitude and latitude information to be properly formatted and stored in the long message portion of the 80C51 RAM.

Use of the RS-232 communication port requires a 5-V power line to minimize the drain on the beacon's battery. Immediately after the beacon is powered on, the external power input is tested. If external power is being supplied, the communication module is called; otherwise, the communication module is bypassed and message generation and transmission begin. The two ways of exiting the communication loop are by executing a RUN command or by removing the external power. When the external power (RS-232 connector) is removed, the battery power takes over. Removing the external power causes an external interrupt which sets the RUN flag bit, thereby causing an exit from the communication module.

MESSAGE GENERATOR MODULE

The message generator module performs two major functions: first, it generates the 21 BCH error-correcting bits, and second, it places the beacon-specific information and emergency code information into the proper locations within the first 112 bits of the message. The BCH encoding routine is performed before the full 112-bit message is formatted. This is done to conserve RAM by utilizing bits 1 to 24 for temporary storage. After the 21 BCH encoding bits are generated, the short message is easily constructed using general assembly code commands (i.e., SHIFT, ROTATE, AND, OR, XOR, and others).

The BCH (82,61) is a shortened form of the BCH (127,106) triple error-correcting code (refs. 7 to 9). Since the BCH code is a cyclical code, it can be easily implemented in hardware by using a 21-bit shift register (fig. 7) or in software by using software-implemented shift registers. Shift registers of any length can be generated in software by using ROTATE with CARRY commands acting on previously reserved contiguous bytes of RAM. The BCH (82,61) encoding algorithm (fig. 8) uses the following two software-implemented shift registers: a 61-bit data register and a 21-bit code word register. Before entering the BCH encoding loop, a storage register is initialized to a count of 62. The loop counter is decremented and tested for zero. After all 61 data bits have passed through the encoder, the loop counter is zero, signifying that the encoding is complete. If the loop counter is not zero, the information in the data register is rotated so that bit 0 becomes bit 60, bit 1 becomes bit 0, etc. After rotating the data register, data bit 60 and code bit 20 are exclusive-ORed and saved as a temporary code bit. The code register is shifted so that code bit 19 becomes code bit 20, code bit 18 becomes code bit 19, etc. The temporary code bit becomes code bit 0. Since 0 exclusive-ORed with any constant is that constant, if the temporary code bit is 0, then program execution returns to the beginning of the BCH encoding loop. If the temporary code bit is 1, the 21-bit code word is exclusive-ORed with the BCH encoding polynomial before returning to the beginning of the BCH encoding loop. Table VIII shows an example of the BCH encoding algorithm for the three data bits.

BIPHASE-L TRANSMISSION MODULE

The Biphase-L transmission module controls three modulator signals that determine the phase of the transmit RF signal: 0 rad for the carrier, +1.1 rad, and -1.1 rad (fig. 2). The module is composed of a message rotation loop and four separate delay loops that account for carrier and bit rate timing adjustments (fig. 9). The program first tests for a long or short message format. If a short message is to be transmitted, the end-of-message address is set for a 14-byte message, and the loop counter value for the third delay loop is set to compensate for rotation of a 14-byte message. If a long message is to be transmitted, the end-of-message address is set for an 18-byte message, and the loop counter value for the third delay loop is set to compensate for rotation of an 18-byte message. After initializing the end-of-message address and the loop counter value used in the third delay loop, the carrier is turned ON, and the first delay loop is executed. This delay loop adjusts for 160 msec minus the amount of time it takes to rotate the message and begin the Biphase-L transmission loop. Note that the ±1 percent variance in the carrier specification means the delay loop does not have to compensate for long or short message rotation. The message transmission loop is entered while the carrier is still being transmitted. The message transmission loop begins by testing to see if the entire message has been transmitted. If it has not, the entire message is rotated so that the last message bit becomes the second last message, continuing until the second message bit becomes the first message bit, and the first message bit becomes the last message bit. The first message bit is also transmitted for half the bit time (1.250 msec) by setting either the +1.1- or the

-1.1-rad control line, depending on whether the first message bit is 1 or 0, respectively. The timing for this is controlled by the second delay loop. The Biphase-L transmission is implemented by toggling the +1.1- and -1.1-rad control lines and transmitting the second half of the first message bit. The third delay loop is executed next. This delay loop compensates for the 1.250 msec transmission time minus the time it takes to test for the end of the message and to rotate through either the long or short message. Note that both the long and the short message must be accounted for in the third delay loop because there is not enough margin in the transmission time specifications to ignore the extra four rotations necessary for long messages. After the third delay loop is completed, the program returns to the beginning of the transmission loop where the end-of-message test is executed. Even though the end-of-message test may indicate that the entire message was transmitted, the last half of the last bit of the message is still being transmitted. Therefore, a fourth delay loop is necessary to compensate for the 1.250 msec minus the end-of-message test and the time it takes to terminate transmission.

JITTER DELAY MODULE

The jitter delay module (fig. 10) terminates message transmission, controls the power to the amplifier, modulator, and homing beacon (if one exists), and creates a 47.5- to 52.5-sec delay between message transmissions. Upon entering the jitter delay module, the message transmission is terminated, the amplifier and modulator power are both turned OFF, and the homing beacon is turned ON. The amplifier and modulator power are turned ON and the homing beacon is turned OFF before exiting this module. The 47.5- to 52.5-sec delay is created by generating a 47.5-sec delay and a 0- to 5-sec delay using the routine shown in figure 11. The 0- to 5-sec random jitter is created by using an address pointer to sequence from byte 4 through 14 of the transmission message (the beacon-specific information) and loading the timing-loop counter with the byte of information pointed to by the address pointer.

ADDITIONAL COMMENTS

Since the present 406-MHz beacon batteries are sized to accommodate the power drain of the RF amplifier, the power drain of the digital circuits is insignificant. Because this may not be the case in the future, the digital controller is implemented with power conservation in mind. All timing delays are implemented using the internal timers available on the 80C51 and the software-initiated "idle mode" capability of the 80C51. When in the idle mode, the 80C51 CPU is inactive while at the same time the on-chip peripherals and counters remain active. The idle mode terminates when any enabled interrupt is received or by a hardware reset. In the case of the timing delays, the idle mode terminates when the internal counter overflows. A detailed discussion of the idle mode is available from reference 3.

The 406-MHz distress beacon software design has been written specifically for the User Protocol message format (table III). The software can easily be modified to accommodate the Maritime/Location protocol (table II) with almost all modification residing in the communication routines.

For a number of reasons, it appears rather impractical that the communication routines would be used in the present 406-MHz environment when the User

Protocol format is used. First, the communication routines are necessary only when the long message format is used. For the User Protocol, the long message contains longitude and latitude information that is redundant information because the longitude and latitude are being determined by the satellite through the use of Doppler tracking. Second, if the capability exists to input longitude and latitude information into an EPIRB or ELT over an asynchronous communication link during an emergency, the capability most probably also exists to simply radio for help. Third, EPIRB's, in particular, would be much more expensive to manufacture when asynchronous communication capability is included. The increased expense would be associated almost entirely with the connector. The connector would have to be reliable, withstand corrosion, and be able to separate easily and reliably from the EPIRB when the vessel is sinking. Also, some additional circuitry would be required in order to switch between external power and battery power.

An EPIRB that uses the Maritime/Locator Protocol must have asynchronous communication capability because the user-specific data portion of the message contains the longitude and latitude information, and the long message portion of the message contains the time, course, and speed of the vessel. All of this information must be provided from an external source through the asynchronous communication port.

In the future, geostationary satellites may be used for detection of emergency beacons. The advantage of the geostationary satellites over the presently used polar-orbiting satellites is that geostationary satellites offer continuous immediate global coverage, whereas polar-orbiting satellites receive emergency transmission for only 15 min every few hours. If geostationary satellites are used for detection of emergency beacons, asynchronous communication capability would be required. Geostationary satellites do not perceive Doppler shift as do polar-orbiting satellites; therefore, it is necessary for an emergency beacon to transmit its location to a geostationary satellite.

CONCLUDING REMARKS

The digital control portion for a 406-MHz emergency beacon has been designed, breadboarded, and tested. The hardware was designed to have a low parts count and to be simple, reliable, and inexpensive. The hardware and three major software routines (BCH encoding, Biphase-L transmission, and Jitter Delay) are generic to any 406-MHz beacon. Although the software was designed to use the User Protocol format, it can easily be modified to accommodate any existing or future message formats.

The work described in this paper was performed in support of the SARSAT program at the NASA Lewis Research Center in cooperation with the NASA Goddard Space Flight Center. Questions and comments concerning the digital control design should be addressed to the NASA Lewis Research Center, Space Electronics Division. Questions and comments concerning the COSPAS/SARSAT program should be addressed to the NASA Goddard Space Flight Center.

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TABLE I. - GENERAL 406-MHz MESSAGE FORMAT

[From ref. 2.]

Bit location	Number of bits	Message	Additional information
1-15	15	Bit synchronization	15 "1" bits in all beacons
16-24	9	Frame synchronization	000101111 in all beacons
25-85	61	Protected data field	Bits 25 to 112 (or to optional 144) form the unique code in each beacon
86-106	21	Error-correcting code	
107-112	6	National use or emergency code	
113-144	32	Long message data (optional)	

TABLE II. - UNIQUE DATA IN 406-MHz MESSAGE FOR MARITIME/LOCATOR PROTOCOL

[From ref. 2.]

Bit location	Number of bits	Message	Additional information
25	1	Format flag	"0" for short message and "1" for long message format
26	1	Protocol flag	Set to "0" for this format
27-36	10	Country code	Binary equivalent of appropriate 3-digit decimal number
37-56	20	Maritime identification digit	
57-85	29	Latitude and longitude	Shown in deg and min
86-106	21	BCH error-correcting code	
107	1	National use or emergency code flag	"0" for national use and "1" for emergency code
108	1	Automanual activation	"0" for manual activation and "1" for automatic activation
109-112	4	National use or emergency code	Four user-settable bits for national use or for emergency codes
113-144	32	Long message data (optional)	Optional data giving time and velocity of vessel

TABLE III. - UNIQUE DATA IN 406-MHz MESSAGE FOR 8 POSSIBLE USER PROTOCOLS

[From ref. 2.]

Bit location	Number of bits	Message	Additional information
25	1	Format flag	"0" for short message and "1" for long message format
26	1	Protocol flag	Set to "1" for this format
27-36	10	Country code	Binary equivalent of appropriate 3-digit decimal number
37-39	3	User protocol	Specifies orbitography, aviation, maritime, serialized or test format (plus three spare formats)
40-83	44	Data	
84-85	2	Homing signal	Specifies which auxiliary homing frequency is incorporated in the beacon
86-106	21	BCH error-correcting code	
107	1	National use or emergency code flag	"0" for national use and "1" for emergency code
108	1	Automanual activation	"0" for manual activation and "1" for automatic activation
109-112	4	National use or emergency code	Four user-settable bits for national use or for emergency codes
113-144	32	Long message data (optional)	Optional data giving latitude and longitude of beacon in deg and min

TABLE IV. - INTERNATIONAL MARITIME ORGANIZATION (IMO) EMERGENCY CODES

[From ref. 2.]

Code	Definition
0000	Undesignated
0001	Fire or explosion
0010	Flooding
0011	Collision
0100	Grounding
0101	Listing, in danger of capsizing
0110	Sinking
0111	Disabled and adrift
1000	Abandoning ship
1001	Undesignated
1010	↓
1011	↓
1100	↓
1101	↓
1110	↓
1111	Test

TABLE V. - EMERGENCY CODES FOR NONMARITIME USERS[a]

[From ref. 2.]

Bit	Description
109	No fire, 0, or fire, 1
110	No medical help, 0, or medical help, 1
111	Not disabled, 0, or disabled, 1
112	Spare, 0

[a]Orbitography, aviation, and others.

TABLE VI. - THREE TESTS PERFORMED AND ASCII VALUE DETERMINED

ASCII Value	Test results		
	Switch PROM	Data PROM	80C51
0	Failed	Failed	Failed
1	↓	Failed	Passed
2	↓	Passed	Failed
3	↓	Passed	Passed
4	Passed	Failed	Failed
5	↓	Failed	Passed
6	↓	Passed	Failed
7	↓	Passed	Passed

TABLE VII. - COMMAND FORMAT FOR ENTERING LONGITUDE AND LATITUDE

```
L XX XX X XXX XX X
  |  |  |  |  |  |___ E/W  East or West
  |  |  |  |  |______ Minutes longitude
  |  |  |  |_________ Degrees longitude
  |  |  |____________ N/S  North or South
  |  |_______________ Minutes latitude
  |__________________ Degrees latitude
```

TABLE VIII. - BCH (82,61) ENCODING ALGORITHM FOR THREE DATA BITS

Operation	Data bit							Code bit																					
	0	1	2	...	58	59	60	TB[a]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Initialize code word	1	0	1	...	X	X	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rotate data word	0	1	X	...	X	X	1	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D60 XOR C20	0	1	X	...	X	X	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shift code word	0	1	X	...	X	X	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Code word XOR polynomial[b]	0	1	X	...	X	X	1	1	1	1	0	0	0	1	1	1	1	0	0	1	1	0	1	1	0	1	1	0	0
Rotate data word	1	X	X	...	X	1	0	1	1	1	0	0	0	1	1	1	1	0	0	1	1	0	1	1	0	1	1	0	0
D60 XOR C20	1	X	X	...	X	1	0	0	1	1	0	0	0	1	1	1	1	0	0	1	1	0	1	1	0	1	1	0	0
Shift code word	1	X	X	...	X	1	0	0	0	1	1	0	0	0	1	1	1	1	0	0	1	1	0	1	1	0	1	1	0
Skip XOR operation	.	.	.	...	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rotate code word	X	X	X	...	1	0	1	0	0	1	1	0	0	0	1	1	1	1	0	0	1	1	0	1	1	0	1	1	0
D60 XOR C20	X	X	X	...	1	0	1	1	0	1	1	0	0	0	1	1	1	1	0	0	1	1	0	1	1	0	1	1	0
Shift code word	X	X	X	...	1	0	1	1	1	0	1	1	0	0	0	1	1	1	1	0	0	1	1	0	1	1	0	1	1
Code XOR polynomial	X	X	X	...	1	0	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1	1	0	1	1	0	1	1	1

[a]TB, temporary bit.
[b]BCH encoding polynomial $= 1 + x^1 + x^5 + x^6 + x^7 + x^8 + x^{11} + x^{12} + x^{14} + x^{15} + x^{17} + x^{18} + x^{21}$.

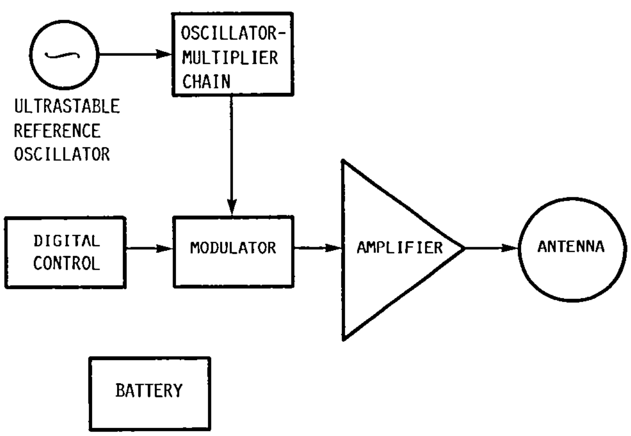

FIGURE 1. - COSPAS/SARSAT 406-MHz DISTRESS BEACON COMPONENTS.

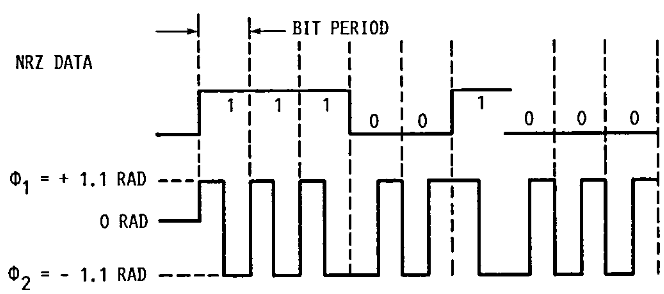

FIGURE 2. - DATA ENCODING AND MODULATION SENSE (REF. 2).

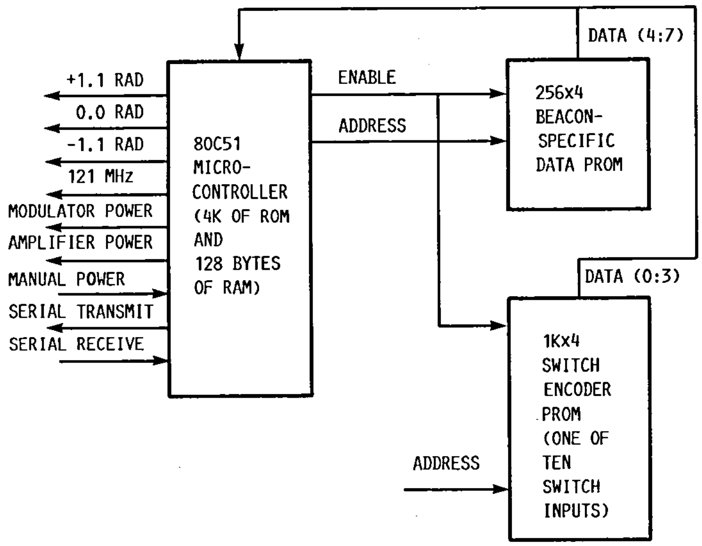

FIGURE 3. - THREE-CHIP DESIGN FOR 406-MHz EMERGENCY BEACON.

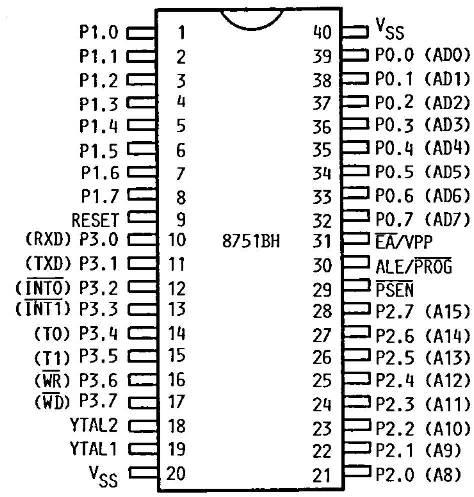

FIGURE 4. - CONNECTION DIAGRAM OF 80C51 MICROCONTROLLER (REF. 3). DIAGRAM IS FOR PIN REFERENCE ONLY. PACKAGE SIZES ARE NOT TO SCALE.

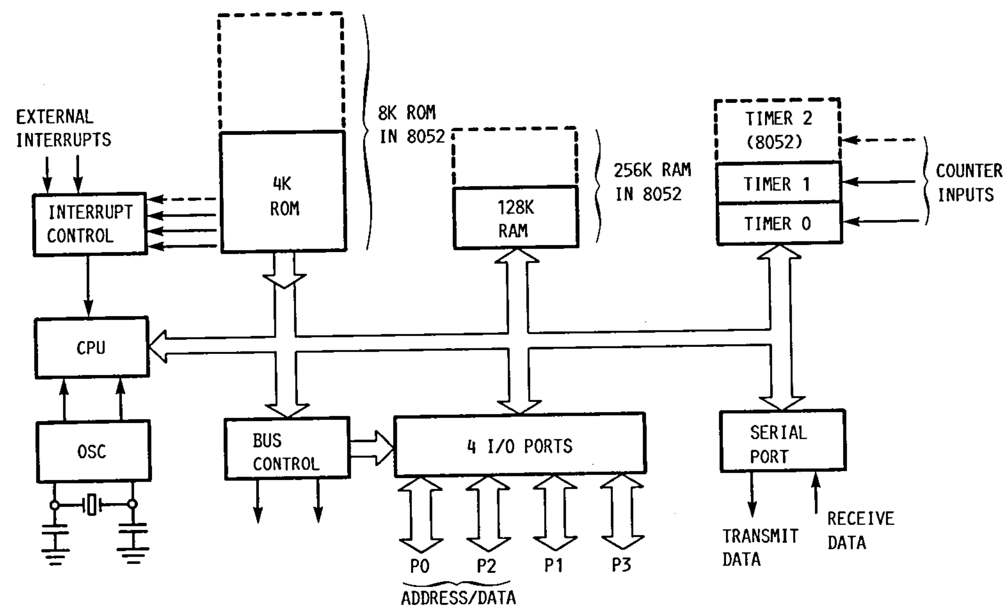

FIGURE 5. - ARCHITECTURAL BLOCK DIAGRAM OF 80C51 MICROCONTROLLER (REF. 3).

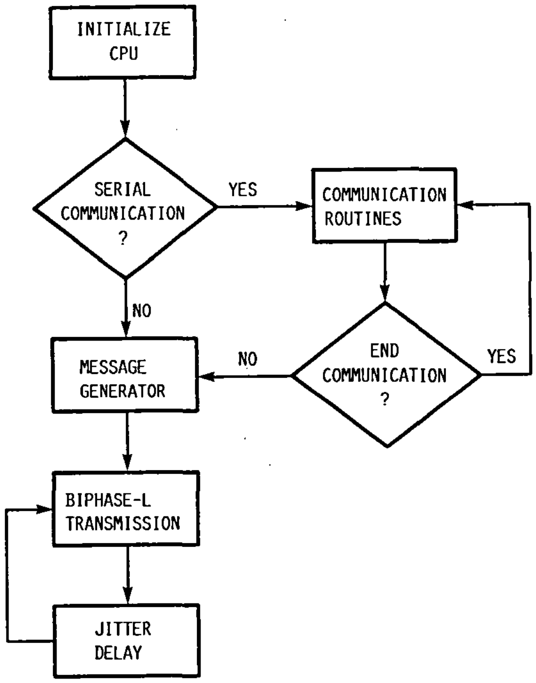

FIGURE 6. - MAJOR MODULES AND INTERRUPT ROUTINE OF MAIN PROGRAM.

$$G(X) = 1 + X^1 + X^5 + X^6 + X^7 + X^8 + X^{11} + X^{12} + X^{14} + X^{15} + X^{17} + X^{18} + X^{21}$$

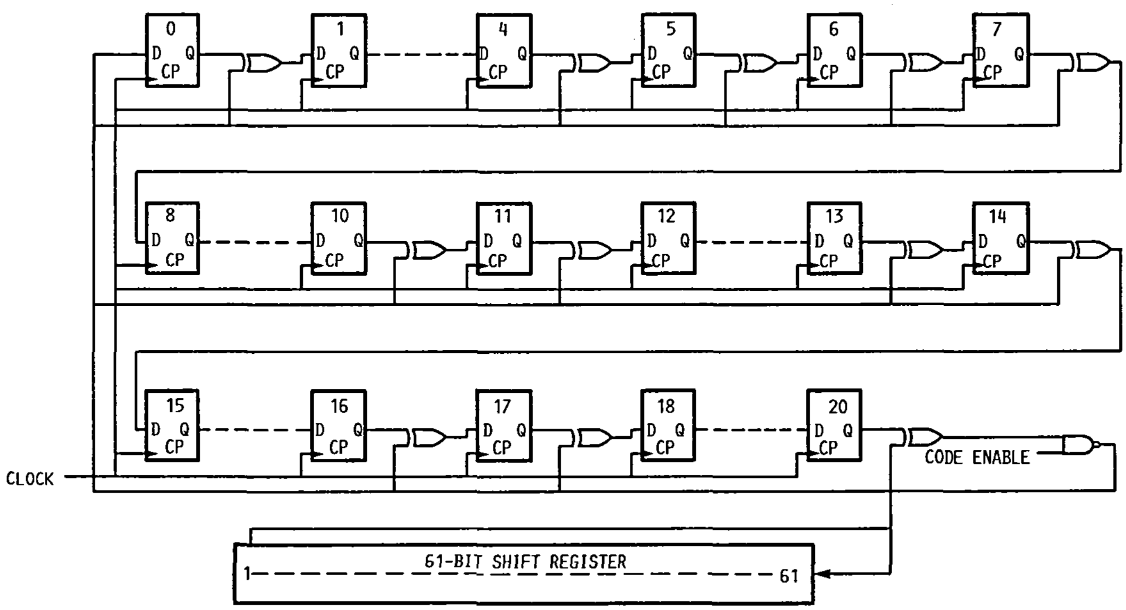

FIGURE 7. - BCH (127, 106) ENCODER.

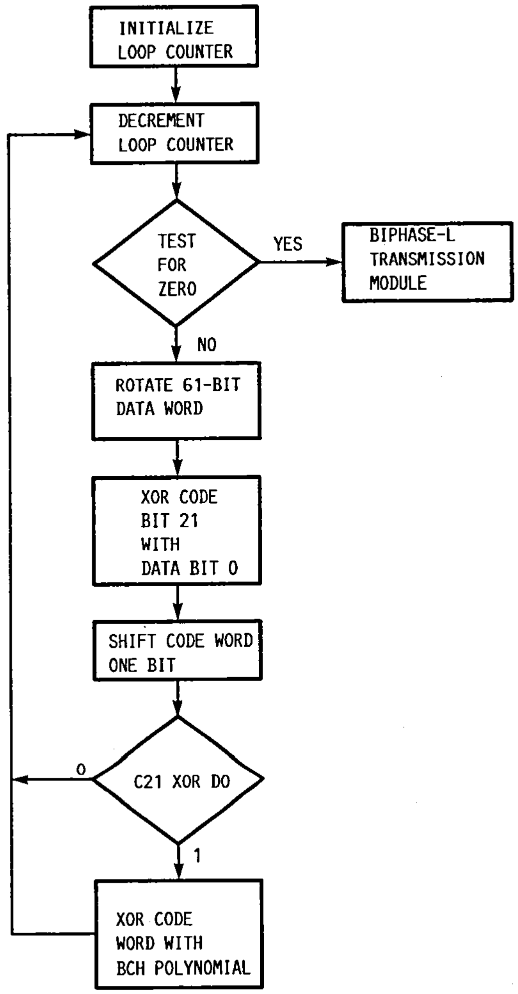

FIGURE 8. - BLOCK DIAGRAM OF BCH (82, 61) ENCODING ALGORITHM.

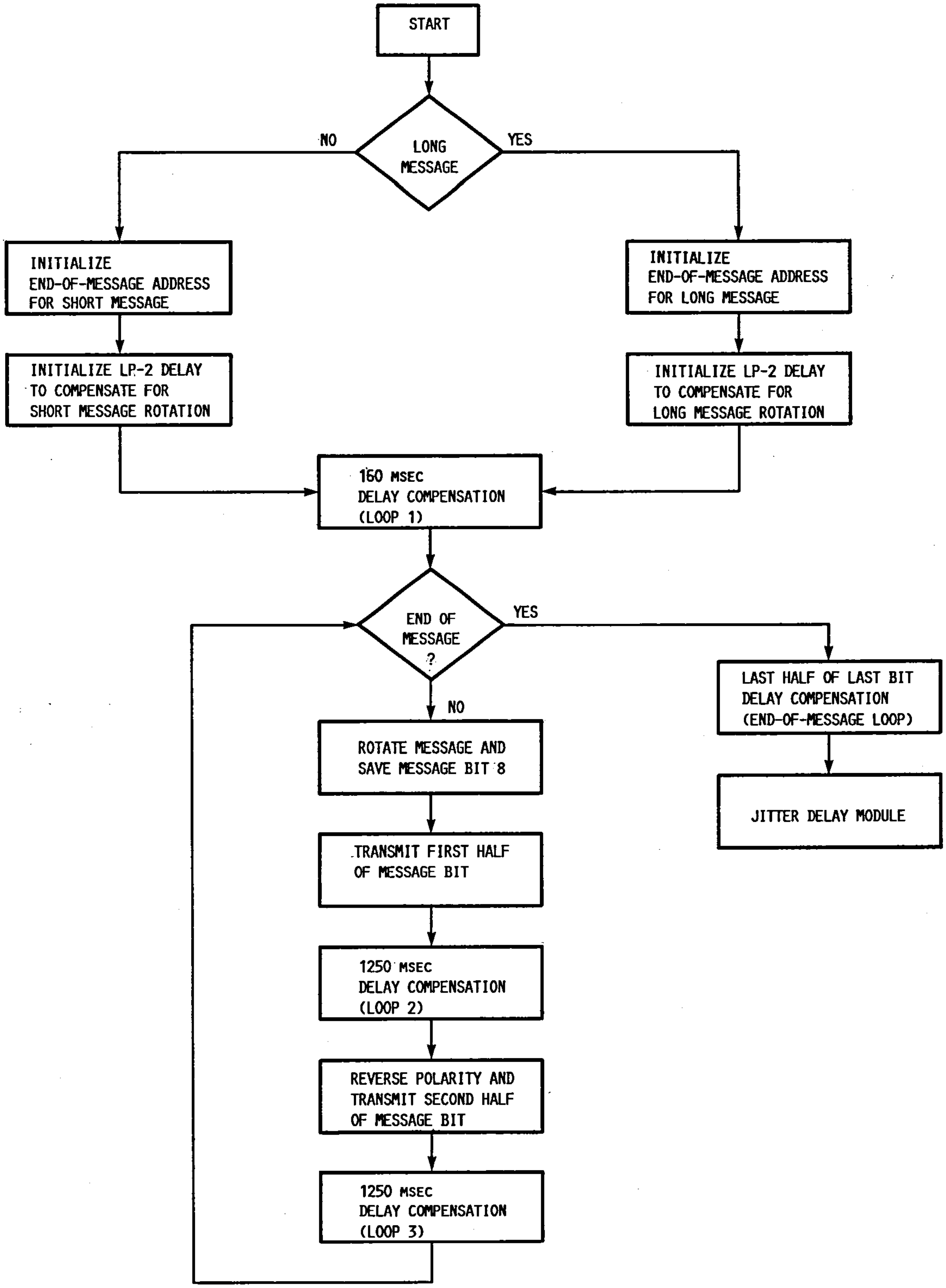

FIGURE 9. - TRANSMISSION MODULE DELAY LOOPS FOR MAKING TIMING ADJUSTMENTS.

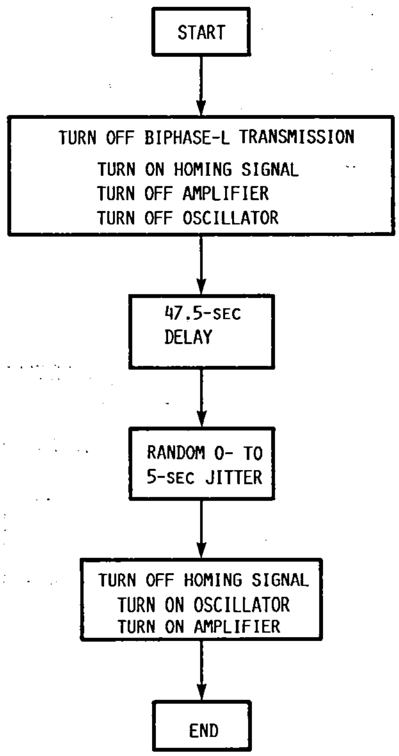

FIGURE 10. - JITTER DELAY MODULE.

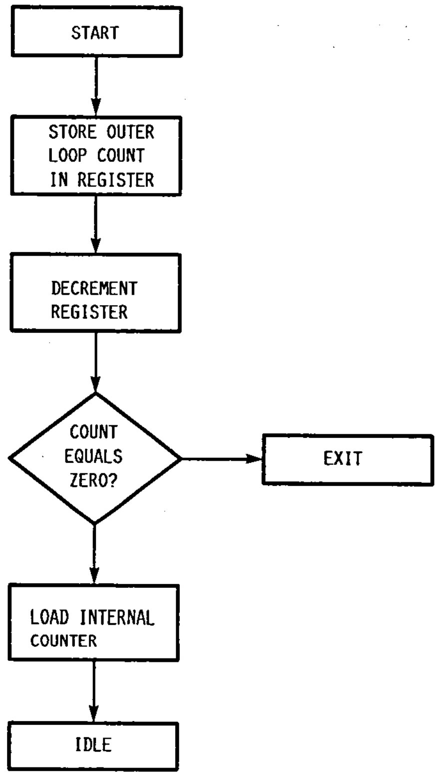

FIGURE 11. - JITTER DELAY MODULE ROUTINE FOR CREATING DELAY BETWEEN MESSAGE TRANSMISSIONS.

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15. Supplementary Notes

16. Abstract

The digital control portion of a low-cost 406-MHz COSPAS/SARSAT emergency beacon has been designed and breadboarded at the NASA Lewis Research Center. This report discusses the requirements and design tradeoffs of the digital controller and describes the hardware and software design. The detailed hardware and software design is available to United States citizens or companies.

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