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TITLE- Up-Data to the CSM, LM and S-IVB/IU - Space Vehicle Description and Processing Delays

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ABSTRACT

The basic operations associated with up-data demodulation, decoding, computer processing, and telemetry transmission are described for the Command Module, Lunar Module, and the S-IVB Instrument Unit. Areas where these space vehicles show commonality and differences are discussed. Particular emphasis is placed on the space vehicle's inherent delay in processing an up-data message and presenting its status on the telemetry link to the Manned Space Flight Network.

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FROM: W. J. Benden

TM: 68-2034-9

TECHNICAL MEMORANDUM

I. INTRODUCTION

Up-data is the term used to describe the digital information sent from the Manned Space Flight Network (MSFN) sites on Earth to the Apollo Command Service Module (CSM), Lunar Module (LM) and the Launch Vehicle Instrument Unit (S-IVB/IU). The Apollo Up-Data Link (UDL) has evolved from the Gemini Digital Command System.

A. Brief History

Both the Gemini and the Apollo systems use digital codes in contrast to the multiple tone system used in the Mercury Project. Project Mercury employed the command system that was used at most of the missile test facilities within the United States. In this system, a UHF carrier was frequency modulated with a combination of twenty discrete IRIG subcarrier tones. Project Mercury was restricted to use no more than thirteen tones during launch, and fifteen during orbit. These restrictions were imposed to avoid possible interference with the Range Safety operations and to avoid the poor modulation characteristics of the higher subcarrier tones (see Reference 1). As the Mercury program evolved, the command requirements steadily increased until it became evident that the Mercury command system was approaching the limit of its capability to support manned space flight. During the later Mercury flights, it was decided that the follow-on Gemini flights should use a digital command system. The digital command system, having a growth potential greater than that for the tone system, would also be able to support the Apollo Missions to follow Gemini.

B. Objectives

The purpose of this memorandum is that of describing the basic up-data systems implemented in the three space modules and estimating the various time delays associated with the processing of an up-data message. The time delays considered are those inherent in the space vehicle--not the MSFN.

Since the number of messages sent to a vehicle varies with the type of updata being sent, an effort is made to obtain the time delays associated with the most fundamental unit of updata. That is, the time delay for a single computer word to be processed, not the time delay for the many words required; for example, in a Navigation Up-Date. Thus, comparisons can be made based on fundamental message units instead of special up-data functions. RF propagation times are neglected since they simply represent additive constants depending on the space vehicle's position.

C. Outline

In general, the scope of this memorandum is aimed at covering the following major categories:

1) Areas common to all three space modules,

2) General description of the CSM up-data system and its associated time delays,

3) General description of the LM up-data system using the CSM system as a baseline,

4) General description of the S-IVB/IU up-data system and its associated time delays,

5) Comparison of inherent time delays for all three space modules.

The descriptions contained herein may appear brief in some cases. The lack of detail is the result of holding the memorandum to a tractable size.* Note that although the data utilized in the writing of this memorandum is based on Mission AS-503, it represents that currently planned to be used for a Lunar type mission.

II. RF MODULATION

When the Unified S-Band system is used for transmitting digital data to the Command Service Module (CSM), Lunar Module (LM), and S-IVB Instrument Unit (S-IVB/IU), a 70 KHz subcarrier is frequency modulated and the subcarrier, in turn,

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*A previous memorandum[2] written by the author, covers some items in more detail.

used to phase modulate the main carrier. The status of the up dating information is telemetered to the Manned Space Flight Network (MSFN) by phase shift keying (PSK) a 1.024 MHz subcarrier which also phase modulates the main S-Band carrier. Figure 1 illustrates the spectral arrangement for all three space vehicles on the "up" and "down" links. Note that the LM and SIVB/IU operate on the same frequencies. The LM will use an S-Band up data link starting with LM 4 LM 1 and 3, as well as the SIVB/IU's in all Saturn IB's, use a UHF up data link operating at 450 MHz.

III. BASEBAND MODULATION*

The modulation technique used by the MSFN for up data transmission is the same for the CSM, LM and SIVB/IU. A stable 1 KHz tone is generated in the modulator and used as a synchronizing ("sync" or "clock") signal. A coherent 2 KHz tone is then bi-phase modulated with 1 Kbps digital data. A binary "one" is transmitted when the 2 KHz tone is in phase with the 1 KHz sync tone and when the 1 KHz sync tone is crossing zero with a positive slope. Figure 2 illustrates the modulation techniques utilized by ground station. In Figure 2-A, a binary "zero" is transmitted as the inverse of the binary "one" (180° phase difference). The 1 KHz sync tone and the modulated 2 KHz tone are algebraically summed yielding the composite waveform indicated on Figure 2-C. The individual period synchronization is obtained by extracting the 1 KHz sync tone from the composite signal onboard the space vehicle. The spectrum, shown on Figure 3, indicates the 1 KHz tone falling into one of the data signal nulls. This allows for its extraction without any significant effect on or by the data.

IV. CODING

Sub-bit encoding on a ratio of five sub-bits for one information bit is used for up data transmissions to the LM, CSM, and SIVB/IU. The first three information bits (the vehicle address bits) have different sub-bit patterns than the remaining information bits.

It follows that the space vehicle must first recognize a particular sub-bit pattern to establish an information bit being transmitted and then monitor the following

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*Reference 3 discusses the merits of PSK versus FSK for Apollo Up Data links.

two information bits to determine if the MSFN is transmitting information to the particular space module in question. Note that the sub-bit pattern is the same for all three space modules. Obviously, the vehicle address portion (information bits) is different for each space module (LM, CSM, and SIVB/IU).

The Apollo System Specification calls for no more than one correct message in 1000 to be rejected by the space vehicle and that the probability of accepting an erroneous message be less than 10^{-9}. These criteria apply to all three space modules.

V. UP DATA TO THE CSM

Four basic types of up data messages are transmitted to the CSM from the Apollo MSFN, namely:

1. Real Time Commands (RTC) to turn spacecraft equipment on and off and to change operating modes (e.g., transmitter high power to low power).
2. Up dating information for the Command Module Computer (CMC). This information is used to bring the spacecraft computer up to date in accordance with the new information developed at the Control Center as a mission continues.
3. Up dating information for the time accumulator in the Central Timing Equipment (CTE). The message contains units of time in seconds, minutes, hours, and days.
4. Test Messages (T/M) to obtain a self-check on the spacecraft digital decoder.

A. Message Format[4]

The message format used for the Apollo CSM Up data link (UDL) is similar to that used in the Gemini program. The general format and types of messages used are depicted in Figure 4. As previously mentioned, the number of bits shown represent the number of information bits transmitted and that each one of these information bits represents the transmission of 5 sub-bits at a 1 kbs rate. A particular sub-bit pattern (5 bits) is selected to represent an information logical "one" and the complement of this pattern is selected to represent the information logical "zero". Messages are similar in that each message consists of a 3 bit vehicle address (15 sub-bits), a three bit system address, and a data word. The sub-bit pattern selected for the vehicle address, however, is different than that for the remaining portion of the message.

B. Demodulation

The Block II CSM Up Data Equipment (See Figure 5) receives a modulated rf carrier operating at S-Band, verifies the data, determines the system for which it was intended and directs it to that system. The S-Band transponder heterodynes the incoming rf signal to a 10 MHz i-f through a double conversion process. The 10 MHz i-f in the S-Band transponder contains a 70 KHz sub-carrier which has been frequency modulated (± 5 KHz) with up data. The 70 KHz sub-carrier is extracted from the i-f signal (by the wide band phase demodulator) and the composite audio up data detected by a 70 KHz demodulator. This audio signal is then presented to the PSK demodulator.

C. PSK Demodulation[5]

Since the sub-bit code used for the vehicle address is different from the remaining portion of the message it acts as a "sign post" indicating the beginning of an up data message. The successful reception of an up data message depends on the correct detection of each sub-bit from the composite audio signal. Since a sub-bit binary "one" or "zero" is represented by a unique phasing arrangement between the 1 KHz and 2 KHz tones, the sampling periods must be timed precisely so that the correct interpretation of a sub-bit being a logical "one" or "zero" is accomplished. This precise timing or phase reference is provided by the 1 KHz signal transmitted from the Apollo MSFN.

Figure 6 illustrates the technique used in the CSM to separate the clock (or sync) signal from the up data composite signal and how it is used as a phase reference for sub-bit detection. In Figure 6 it is seen that the composite audio signal at the output of the demodulator is fed into two different phase detectors. The lower phase detector compares the composite waveform with a 1 KHz reference signal derived from the Voltage Controlled Oscillator (VCO). The VCO output, operating at 4 KHz is divided by a 2 in the first flip flop and divided by a 2 again in the second flip flop yielding a symmetrical 1 KHz reference signal. This reference signal locks on to the 1 KHz portion of the incoming signal and in so doing provides the necessary timing reference for sub-bit detection in the upper most phase detector circuitry. The circuitry derives a waveform as shown on Figure 7b and it is this waveform which is to be integrated before making a decision on whether a "1" or "0" is present. By comparing Figures 7b and 7c it is seen that integration takes place over four half cycles of the 2 KHz data. At the end of this period the integrated signal is either positive or negative and thus a binary "1" or "0".

D. Decoder Operation

The sub-bits arriving from the PSK demodulator (see Figure 8) are shifted into a 5 bit shift register.* Once the register is full, the pattern (5 bit) is compared with a pre-wired pattern to see if a valid information bit is present. This information bit and the two succeeding bits determine the vehicle address bits or vehicle code. Thus, the vehicle address might be designated as an access code in that it opens the door for the remaining portion of the message. Its successful verification also causes the stored sub-bit pattern to be charged in the appropriate manner for verification of succeeding information bits.

Depending on the system address bits, the remaining portion of the message will be a Real Time Command (RTC), Command Module Computer (CMC) message, Central Timing Equipment (CTE) up date, or Test Message (TM). Figure 8 illustrates the bit structure associated with the commands. After successful detection of an up-data message, the decoder sends a Message Acceptance Pulse (MAP) to an encoder where a four bit word or pattern is generated and sent to the telemetry equipment. Since the MSFN is monitoring the telemetry bit stream, it will see the MAP (code) indication.

E. Message Acceptance Pulse (MAP)[6]

As mentioned previously, the decoder sends a MAP to telemetry upon successful detection of an up-data message. The MAP does not indicate that the function being commanded was actually performed, e.g., "A relay closed" as in the case of an RTC. It simply indicates that the decoder has accepted the message. However, the MSFN can determine if the function commanded actually responded by monitoring telemetry data other than the MAP. Actually, the MAP causes a four bit word to change its coding arrangement in the down telemetry bit stream. This is to say that the telemetry equipment is sampling the coding status of the four bit word continuously; sending whatever code happens to be present (e.g., a stand-by code is sent when the decoder is in a stand-by condition).

The length of the MAP is time dependent on the data rate being used for telemetry. If telemetry is operating in the High Bit Rate Mode (51.2 Kbps), the MAP appears for 55 milliseconds. If in the Low Bit Rate Mode (1.6Kbps) the

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*NOTE: The output flip flop shown on Figure 6 is actually the first stage of the 5 bit register.

MAP appears for 250 milliseconds. In the high bit rate mode, the telemetry equipment looks at the code status every 20 milliseconds and in the low bit rate mode, every 100 milliseconds. Thus, the transmission of at least two MAP codes is assured for the 55 ms and 250 ms durations. Note: if the MSFN were to send RTC's at the decoder processing rate (see Section V-K), which is 90 ms, and if the telemetry equipment were in the low bit rate mode, the MAP codes from one message could be confused with those of another. That is, after the first message, the MAP is held for 250 ms during which time two additional messages could have been processed.

Since the basic word length in the telemetry bit stream (see Section V-J) is eight bits, four filler bits are added to the 4 bit MAP code by the PCM telemetry equipment for down-linking.[6]

F. Real Time Command (RTC) Word Process

A particular arrangement of system address bits tells the decoder that an RTC has been transmitted. There are 32 internal relays which can be "set" or "reset" in the CSM Block II decoder. They are broken down into relay banks A,B,C, and D with 8 relays per bank. A special feature exists whereby any one of the relay banks (A,B,C, or D) can be reset by a single message. That is, a specific system address* indicates a "salvo" reset condition and the remaining data bits select the particular bank to be reset.

G. Command Module Computer (CMC) Word Process[7]

The computer word (16 bits) is shifted serially from the decoder into the CMC at 1000 bits per second. These 16 bits are stored in the "in-link counter" as shown on Figure 9 The first bit into the counter is always a "1" and is called on overflow bit. It should be noted that it corresponds to bit 7 shown in Figure 4. When this bit is shifted to the end of the register, a program interrupt is generated. The following bits (8 - 22) represent the data to be processed. The first 5 bits (8 - 12) are data (called a key code K). The next 5 bits (13-17) represent the data complement ($\overline{K}$), the last 5 bits (18-22) repeat the data (K); thus, the $K\overline{K}K$ arrangement shown previously in Figure 4. The program then proceeds to perform a $K\overline{K}K$ check to see if the message is valid. First $K_3 + \overline{K}_2$ must add to zero (a logical 1 in this computer represents a minus 0); second, $K_3 + \overline{K}_1$ must add to zero. Having passed these checks,

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*An RTC system address different than that normally used for RTC's.

bit 4 of Flag word 7 is checked to see if it is a "1", thus, checking to see if the previous message failed the $K\bar{K}K$ check. If bit 4 is a zero, 3 bits of K will be stored in an accumulator. If bit 4 is a "1" the computer will ignore this message and all succeeding messages until the MSFN sends a reset message.*

The reception of five $K\bar{K}K$ data messages will fill the accumulator and the sixth message, an ENTER message, will cause the 15 bit word to be sent to Buffer Storage.

Notice that buffer storage information is being telemetered to the MSFN via PCM telemetry. The MSFN uses the telemetry of this information to verify that the contents in Buffer Storage is that which was transmitted. Upon verification of the complete up date of Buffer Storage, a FINAL ENTER Command is sent causing the buffer storage information to be transferred to a memory location where the computer can utilize it in its calculations.

The down-link list, shown on Figure 9 is read once every two seconds when the high bit rate telemetry mode is used and once every ten seconds in the low bit rate telemetry mode.

The PCM timing signal causes an interrupt signal every 20 milliseconds. This tells the computer to fill registers A and B with data for down-linking. For simplicity, assume that the Index Register is pointing to parameter 3 at the time of interrupt. Parameter 3 will have an address corresponding to a memory location with the information pertaining to parameter 3 stored therein. This information is put in register A as shown. The same procedure is followed for filling register B. Note that upon interrupt, the computer really takes parameter 3 then 4, one right after the other, filling up register A and B almost instantly. That is, every 20 ms (high bit rate mode) the contents for parameter n and n+1 are stored in registers A and B for down linking via PCM telemetry. The parity bit is assigned by the CMC before sending the data from the accumulator to buffer storage.

The Down-Link List contains other parameters beside those representing the Buffer Storage contents. For example, Flag Word 7 mentioned previously and also DSKY - Distab Information. By monitoring the Distab information the MSFN can

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*This is sometimes referred to as "Up-BLOCK" condition.

see, for example, Verbs transmitted by the ground station or punched into the DSKY by the astronaut.

H. CSM Central Timing Equipment Word Process

Upon receipt of a CTE system address, the decoder generates a series of pulses having 50 microsecond pulse widths at 200 pulses per second for the purpose of resetting the CTE time accumulator to 0 days, 0 hours, 0 minutes, and 0 seconds. CTE up dating then occurs in the following sequence: (1) Seconds (2) Minutes (3) Hours (4) Days. The maximum time input is 13 days, 23 hours, 59 minutes and 59 seconds.

I. CSM Test Message Process

Two test messages, "A" and "B", are transmitted to the CSM in order to exercise all process, transfer and program control logic within the CSM decoder.

After the three bit vehicle address and 3 bit system address have been recognized, the remaining bits of test message "A" -- 7 through 30 -- are shifted into the decoder serially at 200 bits per second. Test message "B" is handled in the same manner. The results of these tests are telemetered by sending unique validity signals (the MAP code previously mentioned in Section V-E) for these test messages.

J. CSM PCM Telemetry

The Pulse Code Modulation (PCM) telemetry equipment converts data inputs, from various sampling points throughout the spacecraft, into a serial bit stream to be transmitted to the MSFN. The bit stream bi-phase modulates a 1.024 MHz subcarrier which in turn phase modulates the main carrier operating at 2287.5 MHz. The bit rate is either 51.2 kbps in the High Bit Rate Mode or 1.6 kbps in the Low Bit Rate Mode.

Each analog and each digital input is assigned to a channel. Each channel is represented by an 8 bit word. Thus, the word rate is either 6400 words/second or 200 words/second. There are 128 Words/Prime Frame and 50 Prime Frames/Sub Frame. These Frame/Word allocations are illustrated on Figure 10 for the High Bit Rate Mode.

K. Estimate of Time Delay From Data Entry to Exit (CSM)

It is of interest to examine just how long it takes the CSM to process a given message. That is, the overall time delay from message entry to a status indication on the down telemetry link. RF propagation delay from the MSFN to the space vehicle and back will of course be an additive constant depending on the space vehicle's position (e.g., Earth orbit or lunar distance). The VCO (Figure 6) is also assumed in a "locked" condition.

Take, for example, a Real-Time Command (RTC) word:

1) Since the word length is 60 ms, it takes 60 ms to place the message in the decoder.

2) The decoder holds this information for an additional 30 ms to insure relay closure.

3) A Message Acceptance Pulse is sent to telemetry on the ninety-first millisecond.

4) If the telemetry equipment is operating in the high bit rate mode, it will see the MAP within 20 ms. (Sample rate - 50 samples per second).

5) Thus, within 110 ms the telemetry equipment will have an indication of the message acceptance.

6) An additional 80 ms must be added to this time delay if telemetry happens to be operating in the low bit rate mode (Sample rate - 10 samples per second).

For the case of Computer words, the decoder requires 110 ms to receive the word (22 bits) and an additional 16 ms to shift the 16 bits of data to the computer. Thus, the MAP is issued after 126 ms.

Figure 11 lists the corresponding time delays associated with all four types of up data messages to the Command Service Module. The delay indicated for a computer type message is not very meaningful since it is understood that the MSFN does not rely on the presence of a MAP for verification, but instead monitors the telemetry bit stream for the presence of the actual computer word transmitted to the space vehicle. The telemetry of computer words (Buffer Storage) was indicated previously in Section V-G. These words are sampled once every second in the high bit rate telemetry mode and once every 10 seconds in the low bit rate mode. Furthermore, the computer itself can cause an additional delay depending upon the routine being carried out at the time the decoder presents its data. This is to say that the computer can be performing routines which it must finish before recognizing the up data interrupt.

Assuming that the computer has been successfully interrupted by a "VERB XX" transmission from the MSFN, it is of interest to consider the time required to up date one computer word in buffer storage. Five K$\overline{K}$K messages plus an ENTER must be received. It is estimated that the computer requires 20 ms to perform the K$\overline{K}$K checks (Figure 9) and place the corresponding three bits in the accumulator and that after filling the accumulator an additional 50 ms is required to assign the parity bit and fill a buffer storage location. PCM telemetry will see this buffer storage word within 1 second in the high bit rate mode. Figure 12 combines the above mentioned time delays to arrive at an estimate of the total time delay for up dating a buffer storage word. Presently, the MSFN allows 160 ms for each K$\overline{K}$K transmission. It must be kept in mind, however, that this memorandum is aimed at space vehicle delays divorced from MSFN procedures as much as possible (See Section I-B).

Note that it has been assumed, in the above time estimate, that the 20 ms for data verification by the computer, falls in the time period being used by the decoder during the subsequent K$\overline{K}$K decoding operation with the exception of the last message -- the "ENTER".

VI. UP DATA TO THE LM

Since the up linking capabilities of the Lunar Module are similar to the Command Module, the previous discussion pertaining to the CSM is used as a baseline in discussing up data to the LM. Only those areas where it is felt that significant differences exist are discussed in any detail.

Three basic types of up data messages are transmitted to the Lunar Module (LM) from the Apollo MSFN. These are as follows:

1. Real-Time Commands (RTC) for turning LM equipment on and off. The relay capability is not planned for LM 4 and subsequent, although the decoder logic remains and probably will be used.

2. Up dating information for the LM Guidance Computer (LGC).

3. Test Message (T/M) for a self-check of the digital decoder. It can also be used to inhibit a malfunctioning decoder (redundant decoders)

A. Message Format[4]

The message format used for the LM is identical to that used for the CSM (see Figure 4) with one exception -- the Test Message length is 22 bits instead of the 30. Obviously, the information bit encoding for the vehicle address is different from the CSM.

B. Demodulation

For LM 3 an UHF (450 MHz) receiver is used for receiving up dating information. The receiver is contained in the Digital Command Assembly (DCA). After LM 3 (see Figure 13) all up dating information will be supplied via the S-Band transceiver. To allow for this, the DCA has been modified to accept a 70 KHz subcarrier modulated with up data and, of course, the UHF receiver has been removed. In its modified form, the DCA is designated the Digital Up-Link Assembly (DUA). The DUA contains the necessary circuitry for receiving 64 RTC messages although present plans call for no RTC transmissions to the DUA.

C. PSK Demodulation[8]

Figure 14 illustrates the technique used by the LM to demodulate the composite PSK audio signal to the original sub-bit "ones" and "zeros" instituted at the MSFN. The "notch" filter simply separates the 1 and 2 KHz signals. The 1 KHz filter output is used to provide clock timing throughout the decoder system. Once the 1 KHz timing signal is doubled it is used to multiply the 2 KHz data signal coming from the second filter output. The multiplier output is integrated over 4 half cycles of the 2 KHz data. At the end of these cycles, the output is sampled to see if it is positive or negative. If positive, the demodulator decides a sub-bit "one" was sent and if negative a sub-bit "zero" was sent. The essential difference between this technique and that used by the CSM is that no phase-lock loop is used for timing.

D. Decoder Operation[8]

Following the PSK demodulator's decision on whether a sub-bit "1" or "0" is present, the sub-bits are shifted into a 5 bit shift register (see Figure 15) where the coding is checked to see if it is a valid representation of an information "1" or "0". The information bits are then shifted into a 3 bit vehicle address register where first the vehicle address is verified. Upon verification, the following 3 bits are shifted into this address register as the vehicle address bits are shifted out. These 3 bits are then checked to see what system is to be commanded (RTC, LGC, or TM). From this point in time, all succeeding information bits are shifted into the main data shift register. The number of bits corresponding each type of message (RTC, LGC, or TM) are monitored in addition to the checks previously mentioned and the system reset if any of these tests fail.

The decoding system is essentially the same as that previously discussed for the CSM. However, it should be noted that in the processing of an RTC or a TM, the decoder must be given 250 milliseconds to do so. It will not respond to RTC's or Test Messages any faster than once every 250 milliseconds. For the case of LGC messages, separate timing features are incorporated to accept data at a faster rate.

An additional feature incorporated in the LM and not in the CSM is that of redundant decoders. Both decoders operate simultaneously on the input data and drive a common output. Whenever a decoder is suspected of operating improperly, it can be turned off by transmitting a unique Test Message (for details see Section VI-H).

E. Message Verification (MAP)

The LM decoder generates a 55 millisecond Message Acceptance Pulse (MAP)after verifying the correct coding of an up data message. This pulse is encoded into an 8 bit word and sent to PCM telemetry. The telemetry equipment samples it once every twenty milliseconds. The 20 millisecond sample time is representative of the High Bit Rate Telemetry mode (51.2 Kbps) and it is the only mode by which the decoder issues a MAP. Recall that the CSM decoder can generate a 250 millisecond pulse which can be sampled once every 100 milliseconds in the Low Bit Rate Telemetry Mode. This is not the case for the LM.

In the absence of the MAP, the decoder sends an 8 bit stand-by code to telemetry. When the MAP occurs this code is changed in accordance with what type message has been accepted. Note that LM sends an 8 bit code instead of the 4 bit code sent by the CSM (Section V-E).

F. Real-Time Command Word Process

As previously mentioned, this capability will exist for LM 3 and may not exist for subsequent LM's. Originally on LM 1, for example, there existed the capability of commanding 62 latching relays. The 62 latching relays were divided in groups A and B; representing relay banks A and B respectively. The system address portion selected the type relay bank and the remaining 6 bits designated the particular relay and whether it was to be "set" or "reset." Thus, 128 possible RTC messages could be sent to the LM.

For LM IV and subsequent, the Digital Up-Link Assembly (DUA) has the necessary circuitry for 64 RTC messages. That is, the original capability of commanding relay bank B will still remain. However, the actual relay bank will not be on board. This capability remains in the DUA in case it is decided to incorporate RTC's in the LM.

G. Lunar Module Computer Word Process[9]

The process of an up dating message for the LM Guidance Computer (LGC) is essentially the same as that given for the CMC in Section V-G.

H. Test Message Word Process (LM)

The test message process is essentially the same as that mentioned for the CSM; its purpose being that of exercising the decoder to check its performance. The telemetry of an 8 bit code (slot normally filled with the MAP) indicates its operation. One significant difference, however, is that the DUA contains two decoders versus one for the CSM. Normally, both decoders are operating simultaneously. The output of the decoder which is first to complete processing a message is the one utilized for the command or up dating of a given parameter. The parallel operation of these decoders allows for the transmission of unique Test Messages to turn a suspected malfunctioning decoder off. That is, given that Decoder A is malfunctioning, a unique Test Message can be sent to Decoder B which will turn off Decoder A and visa versa. Another unique Test Message can also be transmitted to turn on an already off Decoder.

I. PCM Telemetry

The telemetry bit stream associated with the Lunar Module is essentially the same as that mentioned in Section V-J. Note, however, the MAP code does not occur in the low bit rate telemetry mode as mentioned in Section VI-E.

J. Estimate of Time From Data Entry to Exit

For RTC and TM type messages, the decoder will not respond any faster than four times per second. The decoder is locked out from incoming messages by a 250 millisecond multivibrator. During this time period, the MAP code will appear on the down telemetry link (when it is operating in the High Bit Rate mode -- see Section VI-E). For LGC messages, a design modification has been incorporated (DCA and DUA) to overcome this 250 millisecond delay. It is estimated that it is possible to process LGC messages once every 136 milliseconds. This includes 5 ms for sub-bit ones preceding the message, 30 ms for the vehicle and system address bits, 80 ms for the data word (16 bits), 5 ms for data checking and 16 ms to shift the LGC word into the computer.

Except for the additional 10 ms for decoded operation, the estimate of time delay for computer words is the same as that given in Section V-K for the CSM. Figure 16 illustrates the time estimates for MAP issuance and Figure 17 shows an estimate for a single computer word (Buffer Storage Word).

VII. UP DATA TO THE IU

For the SIVB Instrument Unit (IU) Command Communication System (CCS) there are two fundamental Up Data messages. These are:

1. Mode Command

2. Data Command

The Mode Command (MC) acts as an indicator to determine what type function is to be carried out and it always precedes Data Commands. The distinguishing characteristics between Mode Command Words and Data Command Words are evident in the format or information bit arrangement.

A. Message Format[4]

The SIVB/IU Up Data message format is considerably different than the LM or CSM. First of all, the fundamental word length (in information bits) is always 35 bits. Three bits are used for the Vehicle Address (VA), 14 bits for the decoder address, 6 bits for control, and 12 bits for data true and data complement. The sub-bit encoding for the VA is different from the remaining portion of the word (or message). Figure 18 shows how the information bits and decoder address bits are interlaced.

B. Demodulation

Figure 19 shows the overall SIVB Instrumentation Unit (IU) Command Communication System (CCS). Up Data is modulated onto a 70 KHz subcarrier in the same manner as mentioned previously for the CSM and LM. The main carrier operation at 2101.8 MHz is then phase modulated by the 70 KHz subcarrier. It follows that the demodulation process from S-Band to the composite 1 KHz and 2 KHz tones is the same as the LM and CSM.

The data for the Launch Vehicle Digital Computer (LVDC) arrives by means of the Launch Vehicle Digital Adapter (LVDA). Actually, the LVDA serves as an input-output device for the many systems within the IU; accepting discrete inputs for the Stage Switch Selectors, Telemetry Computer Interface Unit, Telemetry Data Multiplexer, etc.

C. PSK Demodulation[10]

Figure 20 depicts the basic demodulation scheme utilized for sub-bit detection in the SIVB/IU. Notice that the technqiue used is different from that previously shown for the CSM and for the LM. The narrow band 1 KHz filter separates the 1 KHz sync tone from the composite input waveform, and after being inverted and reshaped, triggers a multivibrator. The multivibrator output is differentiated to provide a narrow sampling pulse at the two AND gates shown. Notice that the inverted 1 KHz signal is summed with the composite signal and the resultant (after being clipped) is presented to the AND gates also. When a "1" is present AND-2 will trigger the "1" multivibrator. In the same manner, AND-1 will trigger the "0" multivibrator. The sub-bits are then passed into a shift register where each sequential five sub-bits represents an information binary one or zero in accordance with a predetermined pattern. This pattern is prewired into a decoder plug which will respond to the sub-bit patterns for the VA or to the pattern utilized for the remaining portion of the message.

D. Decoder Operation

Figure 21 illustrates how the incoming data is decoded. The five bit shift register and compare circuitry checks the proper sub-bit coding for an information "one" or "zero." The 3 bit vehicle address is then verified. If the VA is valid, the decoder knows that the incoming message is for the SIVB/IU. The remaining 32 bits are decoded as required (sub-bit pattern being different) and shifted into the 32 bit shift register shown on Figure 21. Here the 14 bit address portion of the message is verified and a 60 millisecond pulse sent to the PCM telemetry equipment. An enable signal then allows the remaining 18 data bits to be sent to the Launch Vehicle Digital Computer (LVDC) in parallel form. When the LVDC accepts these data, it sends a Computer Reset Pulse (CRP) to the decoder. This pulse clears the 32 bit register and at the same time, the decoder sends a 60 millisecond CRP signal to PCM telemetry. If the CRP signal does not appear before the beginning of the next message, a bit counter in the decoder will reset the 32 bit shift register when it counts the second bit of the Vehicle Address portion of the next message.

E. Message Verification (AVP and CRP)[4, 10, 11]

As mentioned previously the decoder sends a 60 millisecond Address Verification Pulse (AVP) to telemetry when the decoder address bits are correct. The remaining 18 bits of information are then sent to the LVDC via the LVDA. The LVDC either accepts or rejects these data. If accepted, a Computer Reset Pulse (CRP) is sent to the decoder to clear (or reset)it. The decoder, upon receiving the CRP also sends a 60 ms pulse to telemetry. The absence of this CRP in the PCM down telemetry tells the MSFN that the computer has rejected the message. A 10 bit word in the down link telemetry, which is sampled 120 times/second, is changed in bit positions 1 and 2 to indicate AVP. The CRP changes bits 3 and 4 of this same 10 bit word. It follows that at least 6 AVP's and 6 CRP's occur during their respective 60 ms time periods. MSFC had intended that both the CRP and AVP be combined in the ground processing for verification. It is understood, however, that the MSFN uses only the presence of the CRP for verification. The standard up dating procedure is to send one message at a time and wait for verification (CRP's) before sending the next. Reference 11, however, indicates that under critical load conditions the option exists for transmitting one message right after the other neglecting the normal verification routine.

F. Launch Vehicle Computer Word Process[12]

In Section VII-D it was pointed out that the decoder supplies 18 bits of information for the LVDC. Two of these bits are interrupt bits and two are sync bits or Orbital Mode/Data bits. The two interrupt bits are ANDed together by the LVDA and the result presented to the LVDC as a decoder interrupt bit. The two sync bits are handled in a similar manner and presented to the LVDC as the OM/D bit. If the decoder message is a Mode Command, the OM/D bit will be a logical "1"; if a Data Command a logical "0".

The remaining 14 data bits of the Command Word represent information in a true-complement form (see Figures 18 and 23). The LVDC performs a true-complement test for each word as shown on Figure 22. It also performs other tests depending on the routine being executed. If any tests fail, the LVDC will ignore the information, send an error message to telemetry, not send a CRP to the decoder, and increment an error counter. Figure 23A illustrates the error message format utilized by the LVDC. Note that the LVDC also sends a status word to telemetry containing the true form of the Mode or Data Word. Figure 23B illustrates the make-up of this status word.

If the commanded routine requires data, the LVDC will issue a CRP once the program has been initialized to accept the proper number of data words. When a data word is received, the OM/D, true-complement, and sequence bits are verified and the data stored in a temporary location. The LVDC then determines if more data words are required. If so, and the above tests are passed, a CRP is issued to the decoder and the LVDC returns to its main orbital program prepared to receive the next data word. If no more data words are required, a CRP will be issued after all program tests are performed successfully. Of course, the number of data words depends on the routine being commanded. For example, consider the case when the MSFN is providing a Navigation update. Six navigation parameters and one execution time are sent to the LVDC. Figure 23C shows that only six information bits are transmitted per data word. Thus, to provide a single LVDC word (26 bits) five data word transmissions are required. It follows, that the six parameters plus execution time require the transmission of 35 data words.

Another example is the data words sent to the LVDC from the MSFN for Switch Selector (SS) commands as shown on Figure 23D. Switch Selector Commands resemble the Real-Time Commands mentioned previously for the CSM and LM in that relays are commanded into operation. In constrast to the CSM and LM, however, they are not issued by the up data decoder, but instead are issued by the LVDC/LVDA. Each stage and the IU contains a SS which decodes digital flight sequence commands from the LVDC/LVDA and operates proper stage circuits.

Upon entering the SS routine (receipt of a Mode Command) the LVDC sends a SS status word to telemetry and prepares to accept the two data word shown on Figure 23. When the LVDC verifies the second data word, it checks to see if the main program is presently servicing a SS function. If the main program is presently servicing an SS function, the LVDC will wait until it is finished before executing the commanded SS function. The waiting time is no more than 250 ms. If an SS function is waiting to be processed and another request is received, no CRP will be issued for the second mode command.

G. PCM Telemetry[13]

Figure 24 illustrates the basic format used on the PCM telemetry link from the SIVB/IU to the MSFN. There are 10 frames and 30 channels per frame with a 10 bit word in each channel. Two 40 bit words are sent from the LVDC/LVDA during each frame thus occupying 8 channels per frame. The frames are sampled 12 times per second; producing 240 LVDC/LVDA words per second on the down telemetry link.

H. Estimate of Time From Data Entry to Exit

The decoder requires no more than 177 ms from the time of data entry to the leading edge of the Address Verification Pulse. Telemetry equipment samples the condition of the AVP 120 times per second. Thus, within 185.3 ms the AVP will begin to appear on the down telemetry link. Even though data is presented to the LVDC/LVDA at 177 ms, the Computer Reset Pulse (CRP) may not be issued from the LVDC for another 100 ms. This variable delay stems from the fact that the computer may be in a particular loop at the time of data presentation from the decoder. The computer chooses to ignore input data until it has finished certain routines. The 100 ms figure is an estimate of the maximum time delay before a CRP is issued. The telemetry equipment will then pick up the CRP status within 8.3 ms from this time of issuance. For status word telemetry an additional 12 ms must be allowed for the output registers to supply the status information from the LVDC. Figure 25 summarizes these time delays.

VIII SUMMARY

All three vehicles receive the same type up data signal and demodulate it to a baseband signal in the same manner.

The technique used in extracting the sub-bits is different for each vehicle.

The CSM and LM decoders operate on the up data message in a very similar manner since the bit formats are essentially the same. The format used for messages to the IU differs considerably from the CSM and LM.

The decoders in the CSM and LM have the capability of issuing commands to equipment other than the computer whereas the IU decoder interfaces with the LVDA/LVDC only and it is up to the computer to issue command to the various sub-systems.

When the decoder interprets the up data message as being correct, it issues a Message Acceptance Pulse to telemetry in the case of the LM and CSM. The IU performs a similar function in that it issues an Address Verification Pulse to its telemetry equipment upon correct decoding operations.

The MAP is issued in the High Bit Rate telemetry mode for both the LM and the CSM. For the Low Bit Rate telemetry, the CSM issues a MAP, not the LM. For the IU, there is only one telemetry rate for the AVP (and CRP).

The MAP code bit lengths are 4 bits for the CSM, 8 bits for the LM, and 2 bits (AVP) for the IU.

The LVDC issues a CRP upon data verification (2 bits in the telemetry bit stream). The LM and CSM do not issue any CRP's.

The computer can be up dated by voice instruction to the Astronaut for the LM and CSM.

For computer messages, the decoder sends the data to the CMC and LGC, serially, at 1 Kbps. For the IU, however, the data is sent in parallel to the LVDA/LVDC.

All three computers check the data presented by the decoder for a particular data-data complement arrangement.

All three computers present the information bearing content of the up data message to the telemetry equipment for transmission to the MSFN in 40 bit word slots.

The basic word length in the PCM bit stream is 8 bits for the CSM and LM bits and 10 bits for the IU.

The IU is normally up dated one message at a time and verified at the MSFN each time through telemetry of CRP's, and requires 5 data messages to make up one computer data word. The LM and CSM require 5 data messages to make up one computer data word also, but these are normally transmitted one right after the other and it is not until the data word is transferred to the "Up-Buff" storage location that telemetry has an indication of the data itself.

Figure 26 summarizes the time delay estimates for updating a single computer word for the CSM and LM. Since, normally, each message must be verified by the MSFN in the case of the IU it is not meaningful to try to compare this time delay with the LM and CSM. It is meaningful, however, to compare the decoder delays before issuance of a MAP or an AVP (indicating decoder acceptance of a single computer type message). This comparison is shown in Figure 27.

2034-WJB-hls

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Attachments
Figures 1-27

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4. MSC Apollo Universal Command System - Command Data Format Control Book, (CDFCB), Revision May 2, 1968.

5. Lenett, S. D., Apollo Digital Up Data Link Description, NASA-TMS-1146, Manned Spacecraft Center - October 1965.

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7. MIT Instrumentation Laboratory - Guidance System Operations Plan (Section II, GNCS Data Links) for Manned CM Earth Orbital Missions - Program "Sundisk" - R547 Revision I, November 1967.

8. AVCO, Design Report for Lunar Module Digital Uplink Assembly - Report No. 80045 x U Q 39/867.

9. MIT Instrumentation Laboratory, Guidance System Operations Plan (Section II, Data Links) for Manned LM Earth Orbital Missions - Program "Sundance" R-557 Revision I, December 1967.

10. MSFC, Command Decoder (S-IU-204 thru 212/501 thru 515)- Saturn Instrument Unit Technical Manual - MSFC No. III 5-510-17, IBM No. 66-966-0019, March 1, 1967.

11. MSFC, Saturn V Launch Vehicle Instrumentation/MSFN Performance and Interface Specification, ICD 50 M13106, June 6, 1967.

12. MSFC, LVDC Equation Defining Document for the AS-503 Flight Program, Saturn Instrument Unit, MSFC NO. III-4-423-10, IBM NO. 7915041, November 21, 1966.

13. Covington, W.O., Gevarter, W.B., IBM Presentation on Apollo Launch Vehicle Digital Computer Flight Program Development, Case 310, Bellcomm Memorandum for File, January 19, 1968.

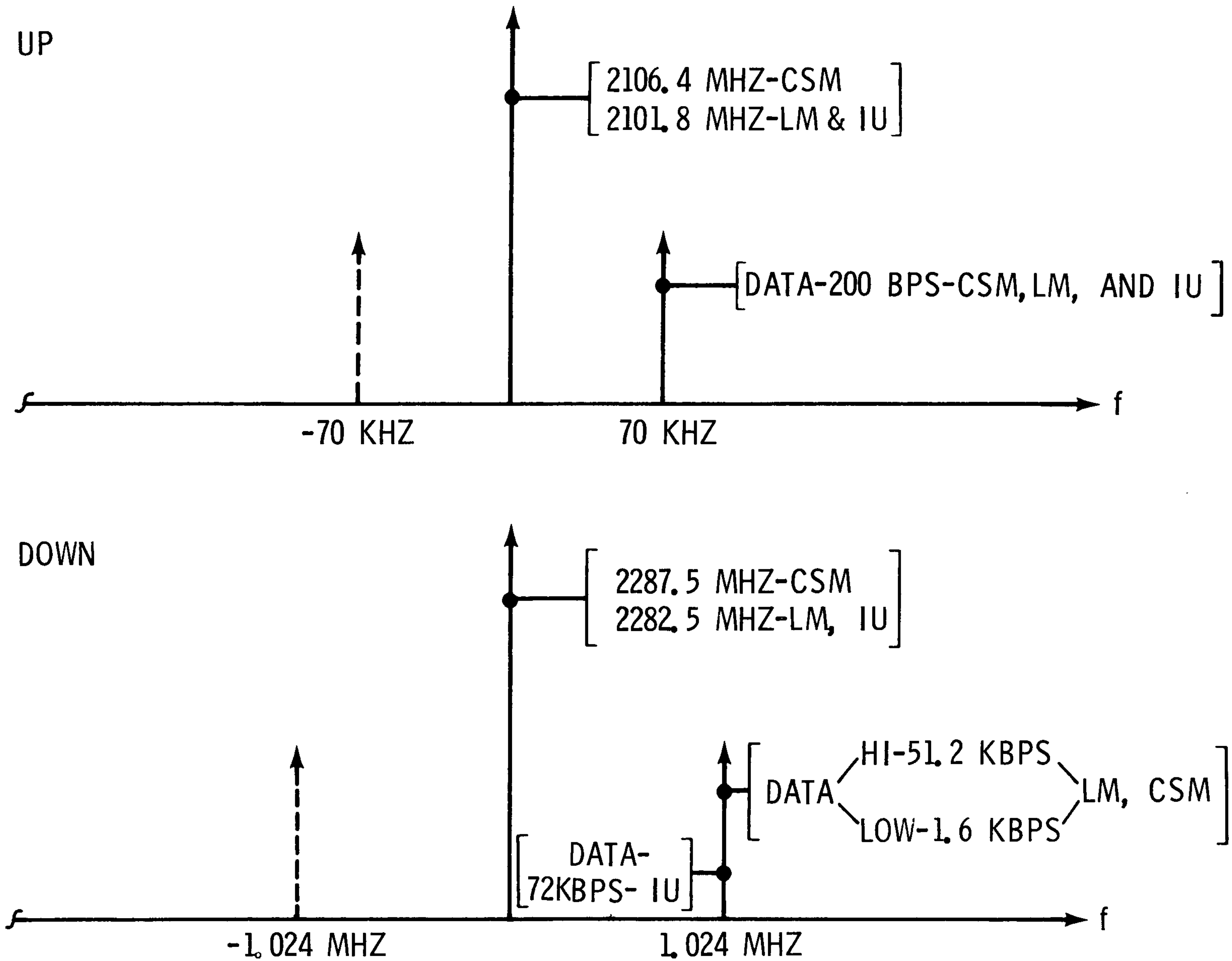


FIGURE 1 - MODULATION FOR UP-DATA AND DOWN TELEMETRY
(CSM, LM, S-IVB/IU)

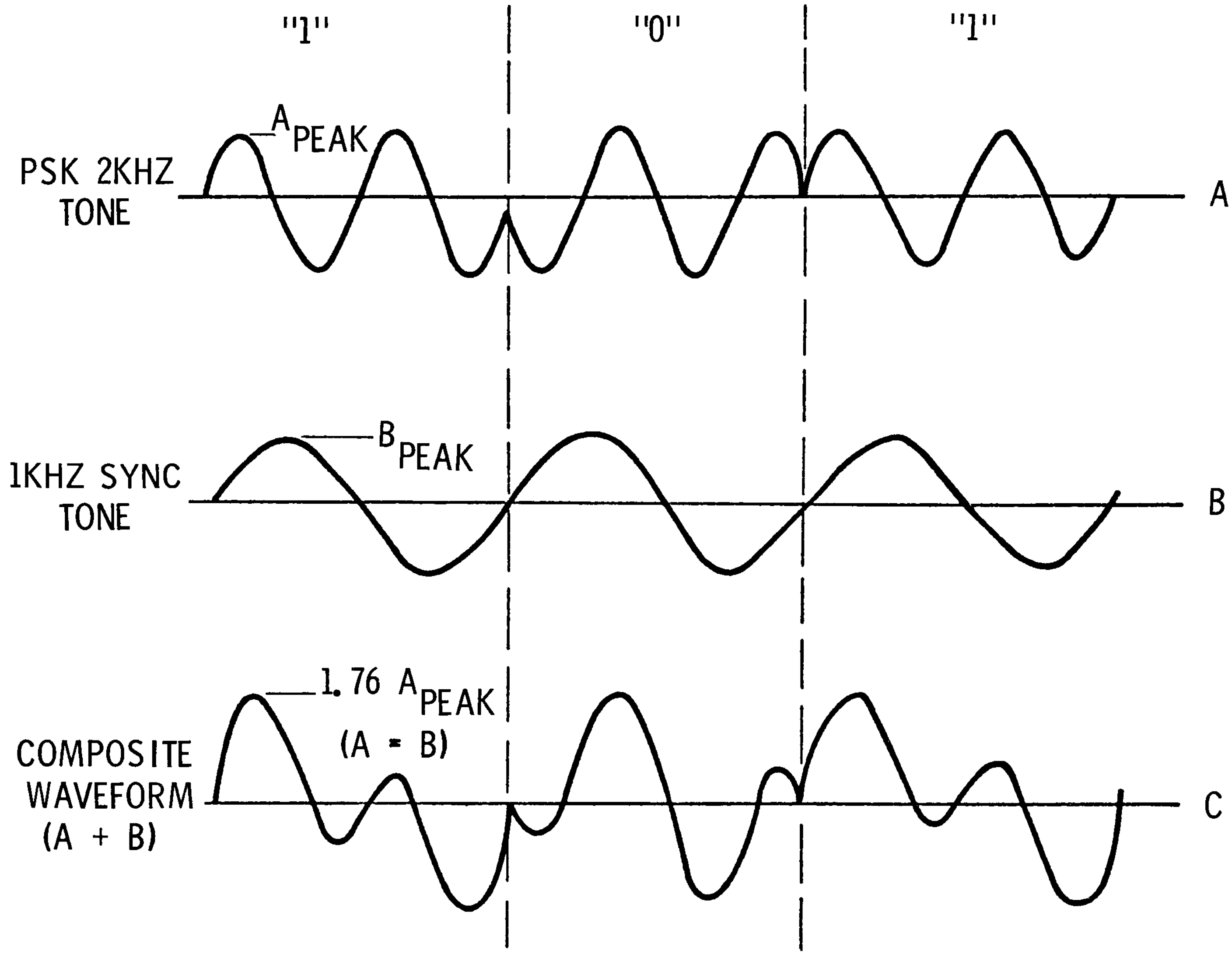


FIGURE 2 - COMPOSITE UP-DATA WAVEFORM

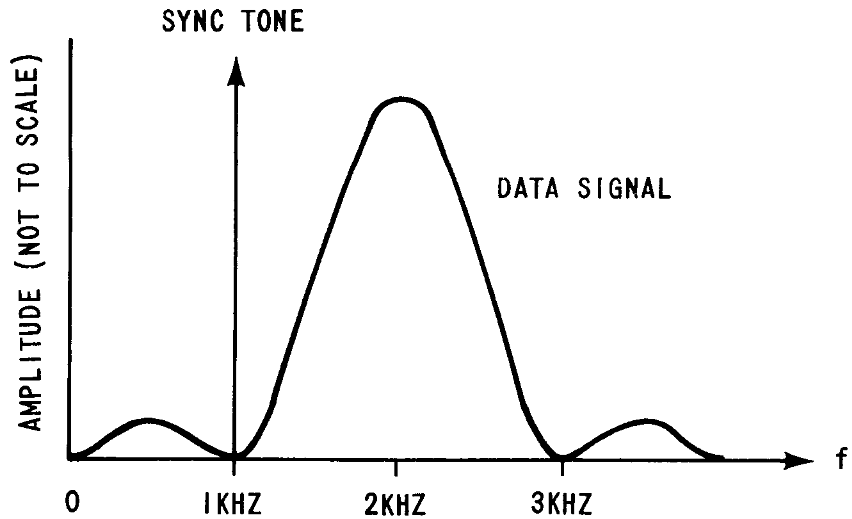


FIGURE 3 - SKETCH OF UP-DATA SPECTRUM (CSM, LM, AND SIVB/IU)

REAL TIME COMMANDS

BITS	1 2 3	4 5 6	7 8 9 10 11 12
	VEHICLE ADDRESS	SYSTEM ADDRESS	DATA

COMMAND MODULE COMPUTER

BITS	1 2 3	4 5 6	7	8 9 10 11 12	13 14 15 16 17	18 19 20 21 22
	VA	SA	*	DATA (K)	DATA COMPLEMENT($\overline{K}$)	DATA (K)

* OVERFLOW

CENTRAL TIMING EQUIPMENT

BITS	1 2 3	4 5 6	7 8 9 10 11 12	13 14 15 16 17 18	19-24	25-30
	VA	SA	SECONDS	MINUTES	HOURS 6 BITS	DAYS 6 BITS

TEST MESSAGE

BITS	1 2 3	4 5 6	7 8 9 10 - - - - - - - - - - - - - 30
	VA	SA	TEST MESSAGE (24 BITS)

FIGURE 4 - APOLLO UP-DATA INFORMATION FORMATS (CSM)

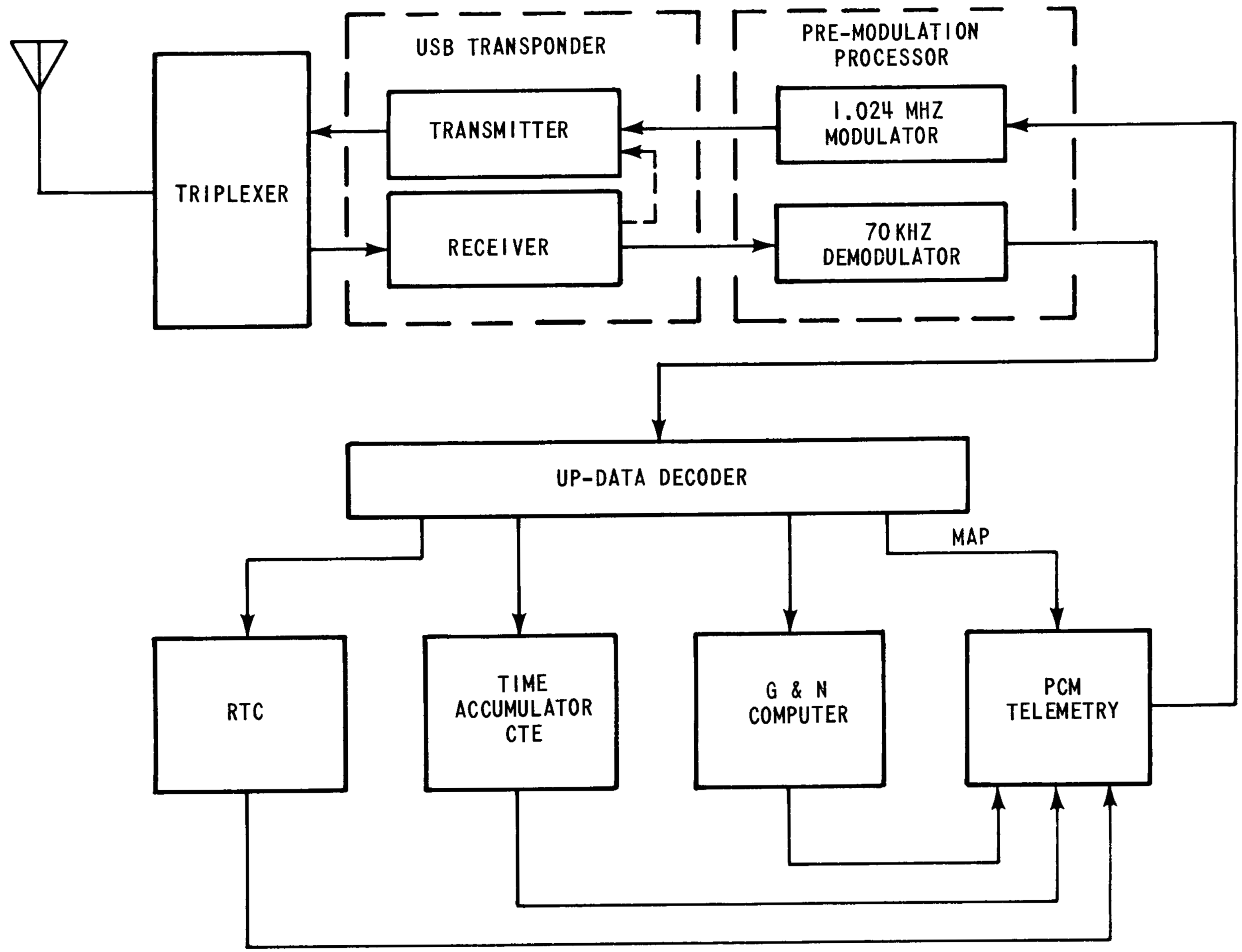


FIGURE 5 - BASIC CSM UP-DATA DETECTION AND DISTRIBUTION

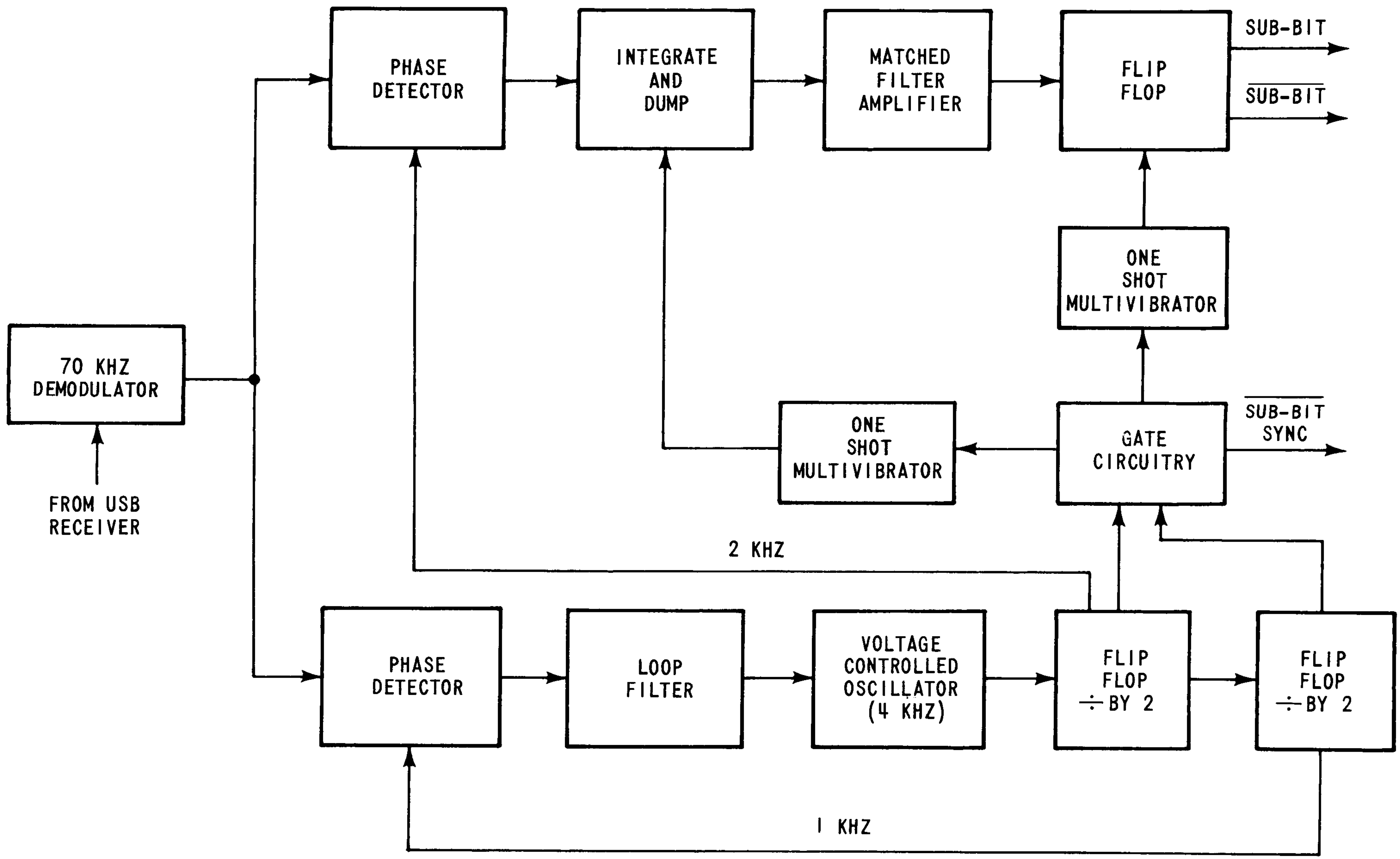


FIGURE 6 - BASIC CSM PSK DEMODULATION

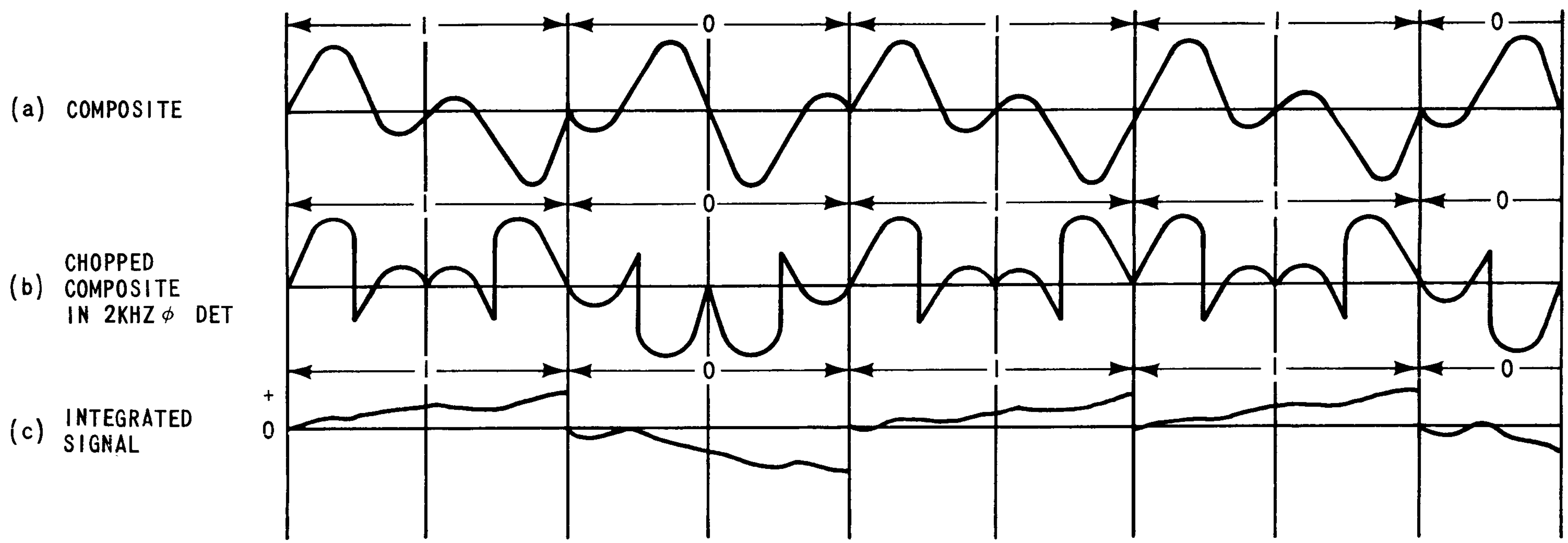
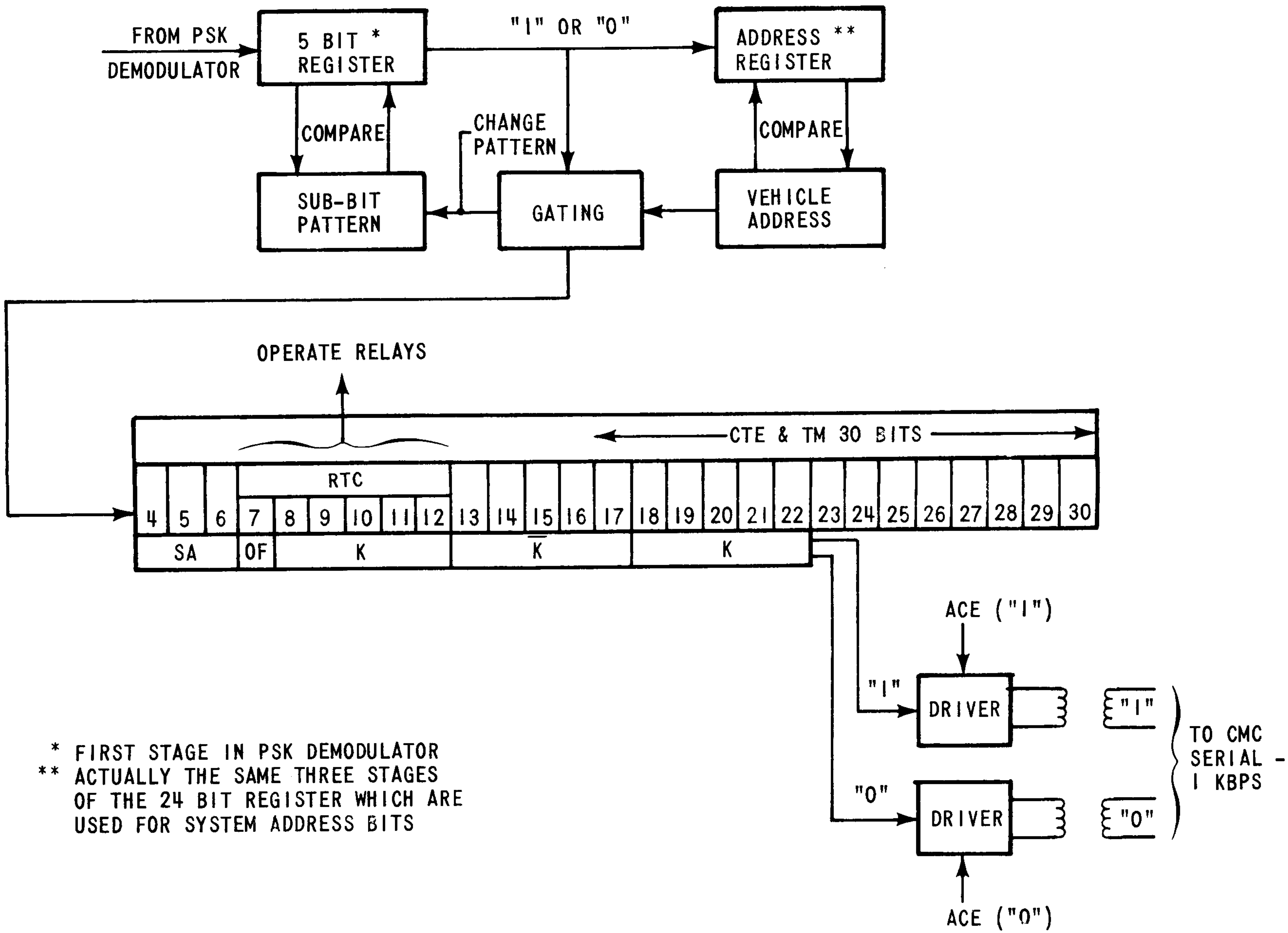
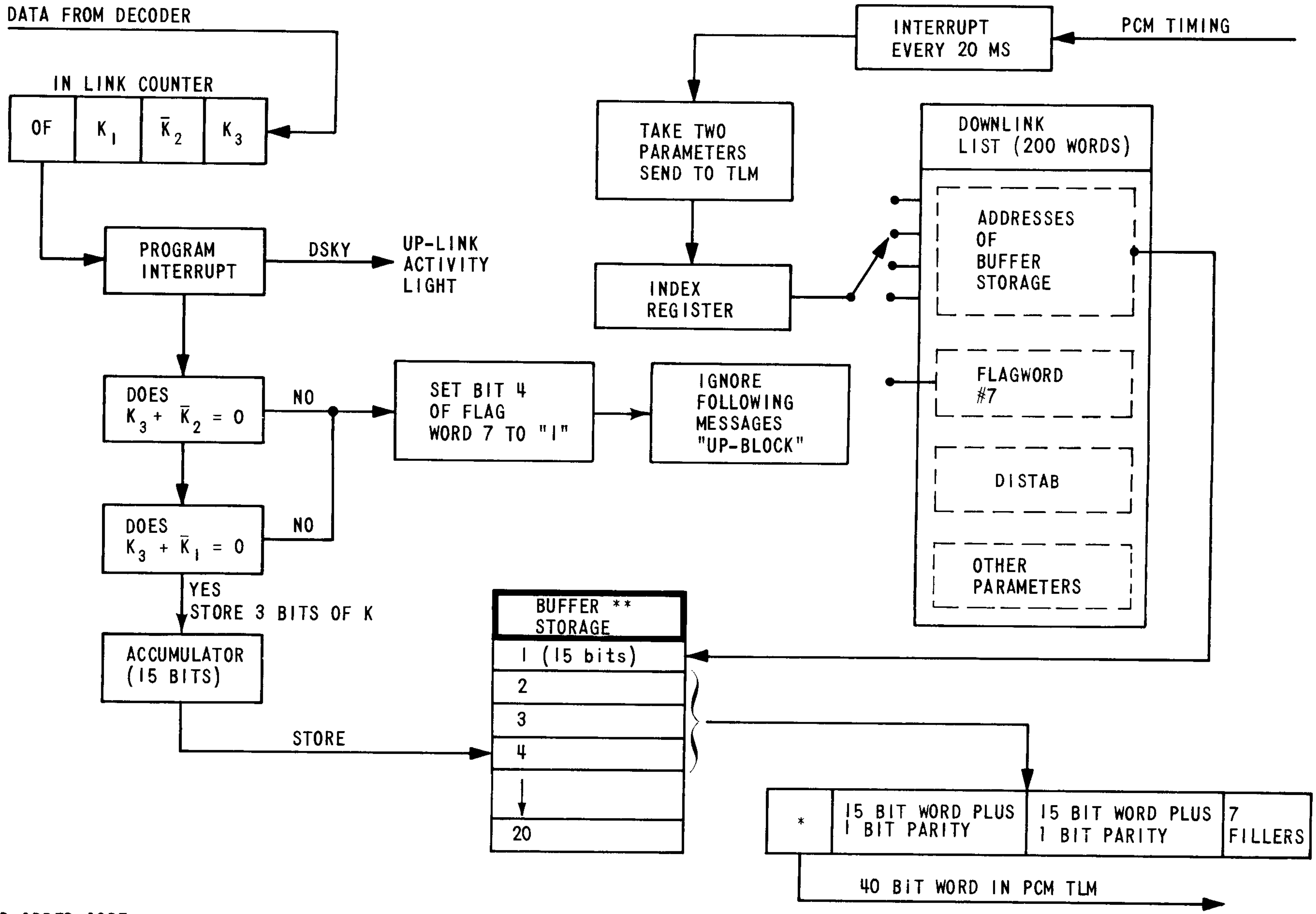


FIGURE 7 - SOME BASIC WAVEFORMS FOR PSK DETECTION



* FIRST STAGE IN PSK DEMODULATOR
** ACTUALLY THE SAME THREE STAGES OF THE 24 BIT REGISTER WHICH ARE USED FOR SYSTEM ADDRESS BITS

FIGURE 8 - BASIC DECODER OPERATION (CSM)



* WORD ORDER CODE
** CONTENTS TRANSFERRED TO WORKABLE MEMORY UPON FINAL COMMAND TO ENTER FROM MSFN

FIGURE 9 - BASIC COMPUTER OPERATION ON UP-DATA MESSAGE (CSM)

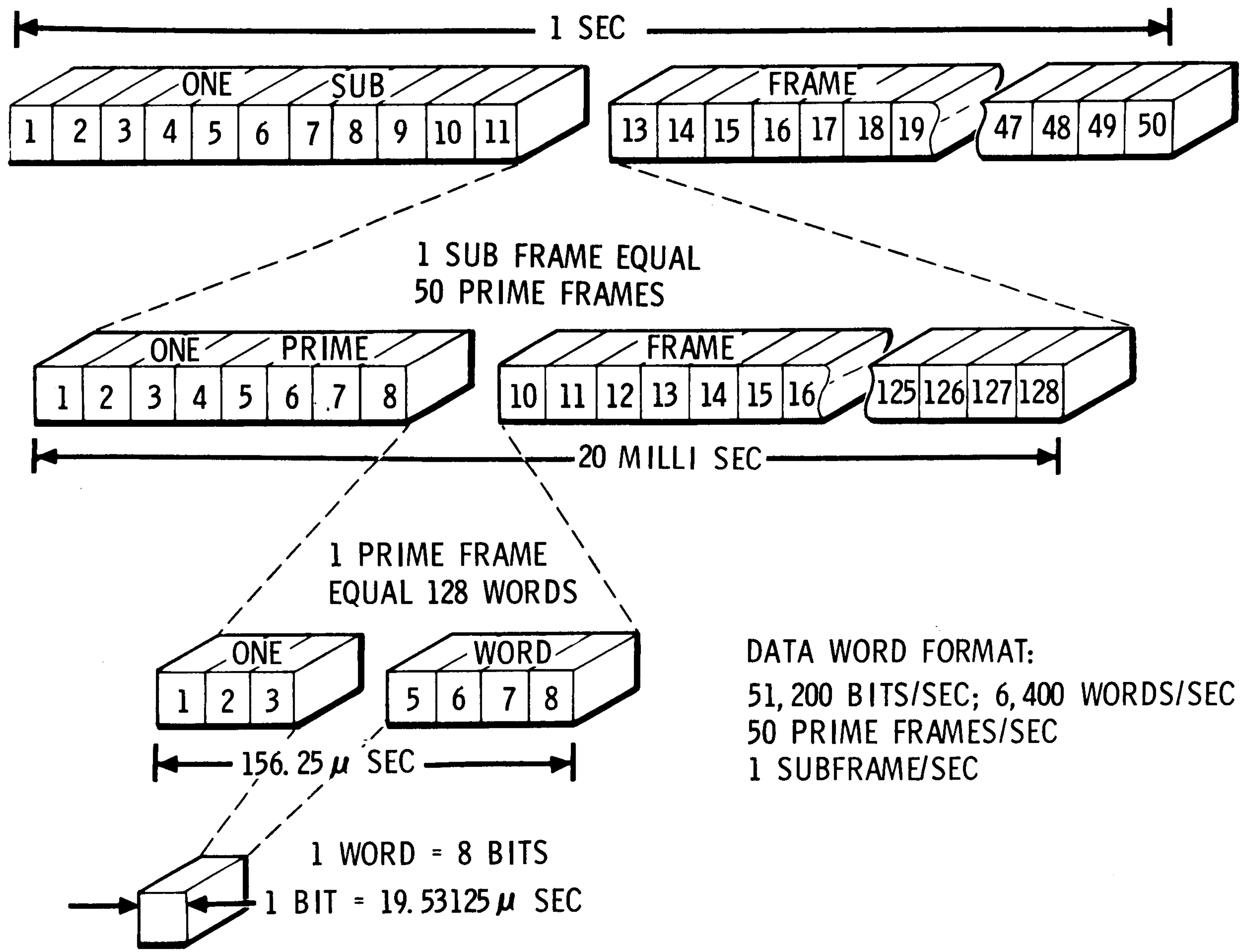
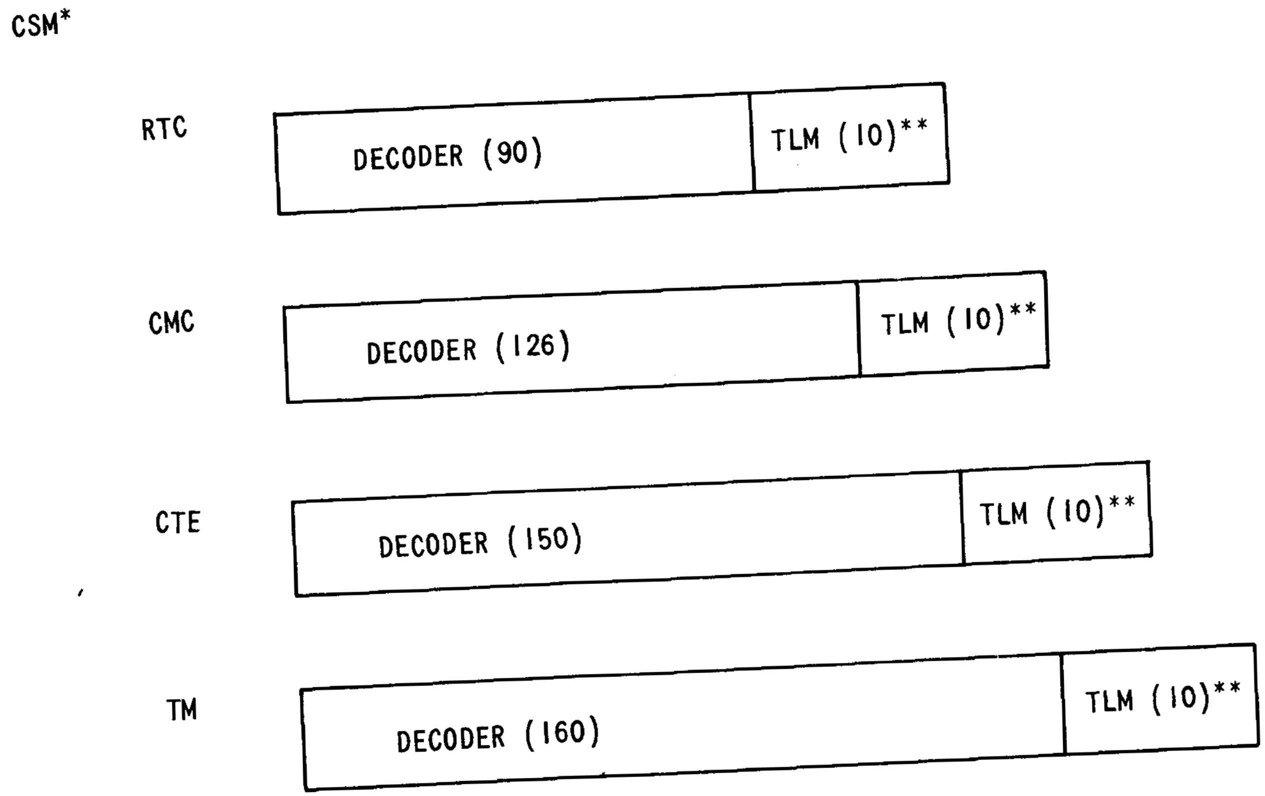


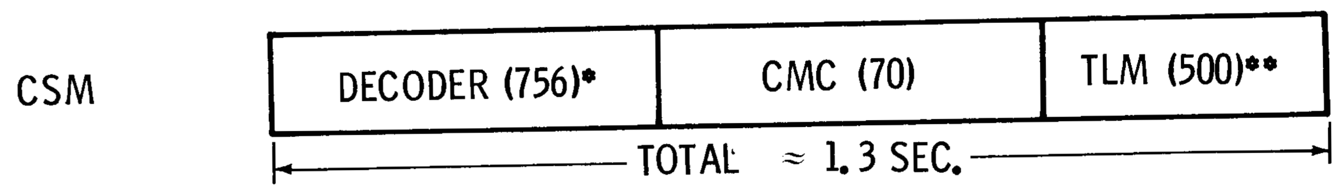
FIGURE 10 - PCM FORMAT-CSM



*ADD 80 MS
FOR LOW BIT RATE
TELEMETRY

**ASSUMING AN AVERAGE VALUE - MAXIMUM = 20 MILLISECONDS

FIGURE 11 - ESTIMATE OF TIME DELAY (MILLISECONDS) FOR MAP TO APPEAR ON DOWN LINK (CSM) (SINGLE MESSAGE)



*SIX MESSAGES (5 DATA WORDS PLUS ENTER)
**ASSUMING AN AVERAGE VALUE - MAXIMUM = 1 SECOND

FIGURE 12 - ESTIMATE OF TIME DELAY (MILLISECONDS) FOR SINGLE COMPUTER WORD STATUS TO APPEAR ON DOWN LINK

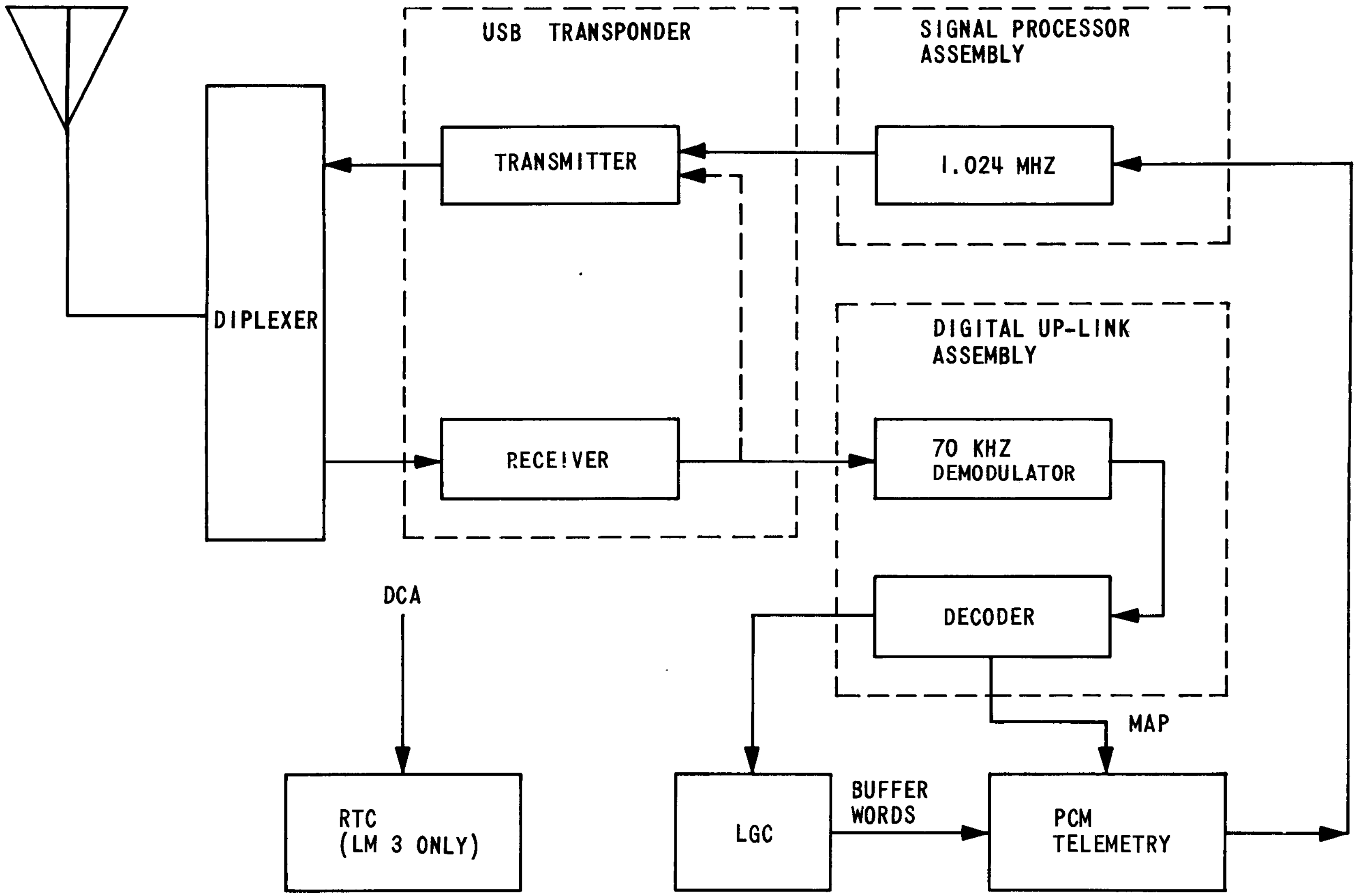


FIGURE 13 - UP-DATA DETECTION AND DISTRIBUTION-LM

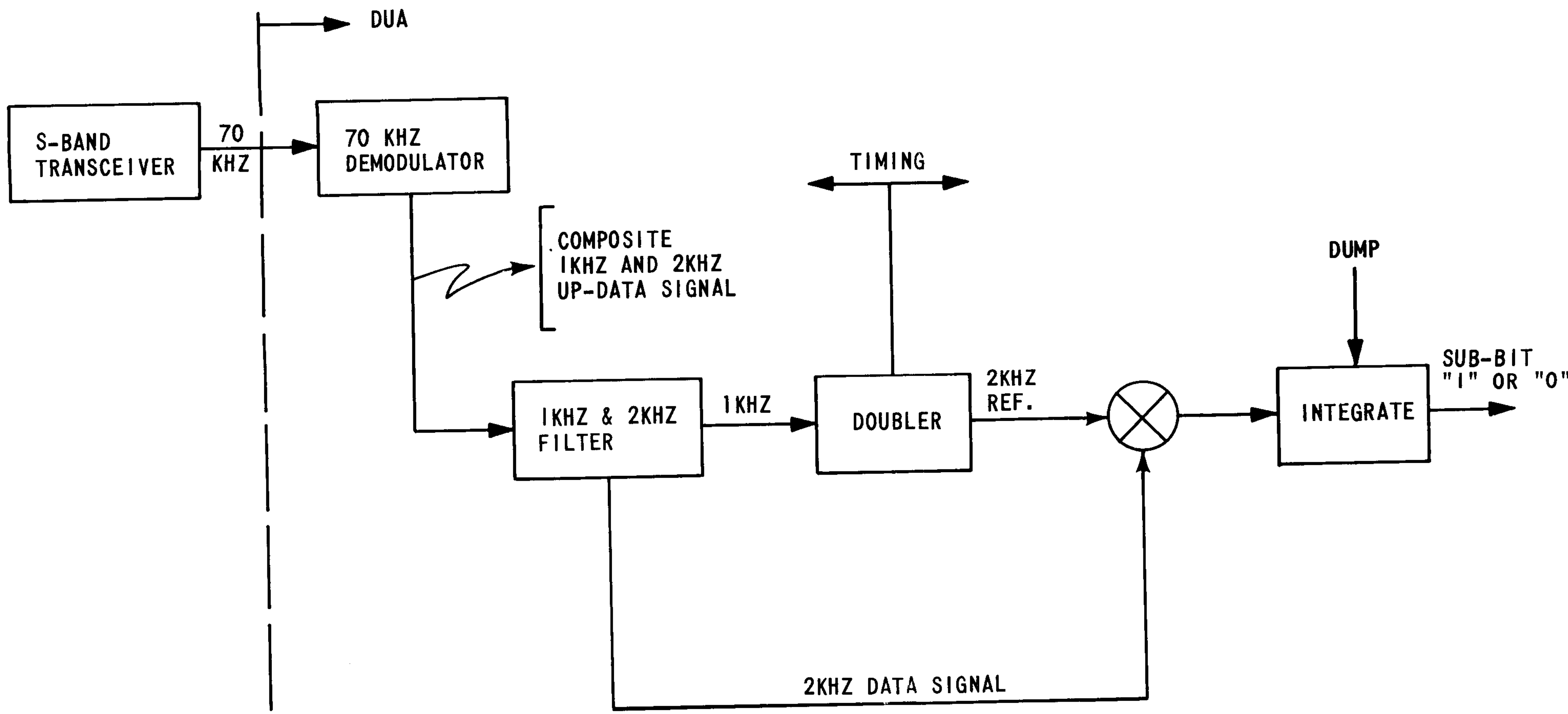
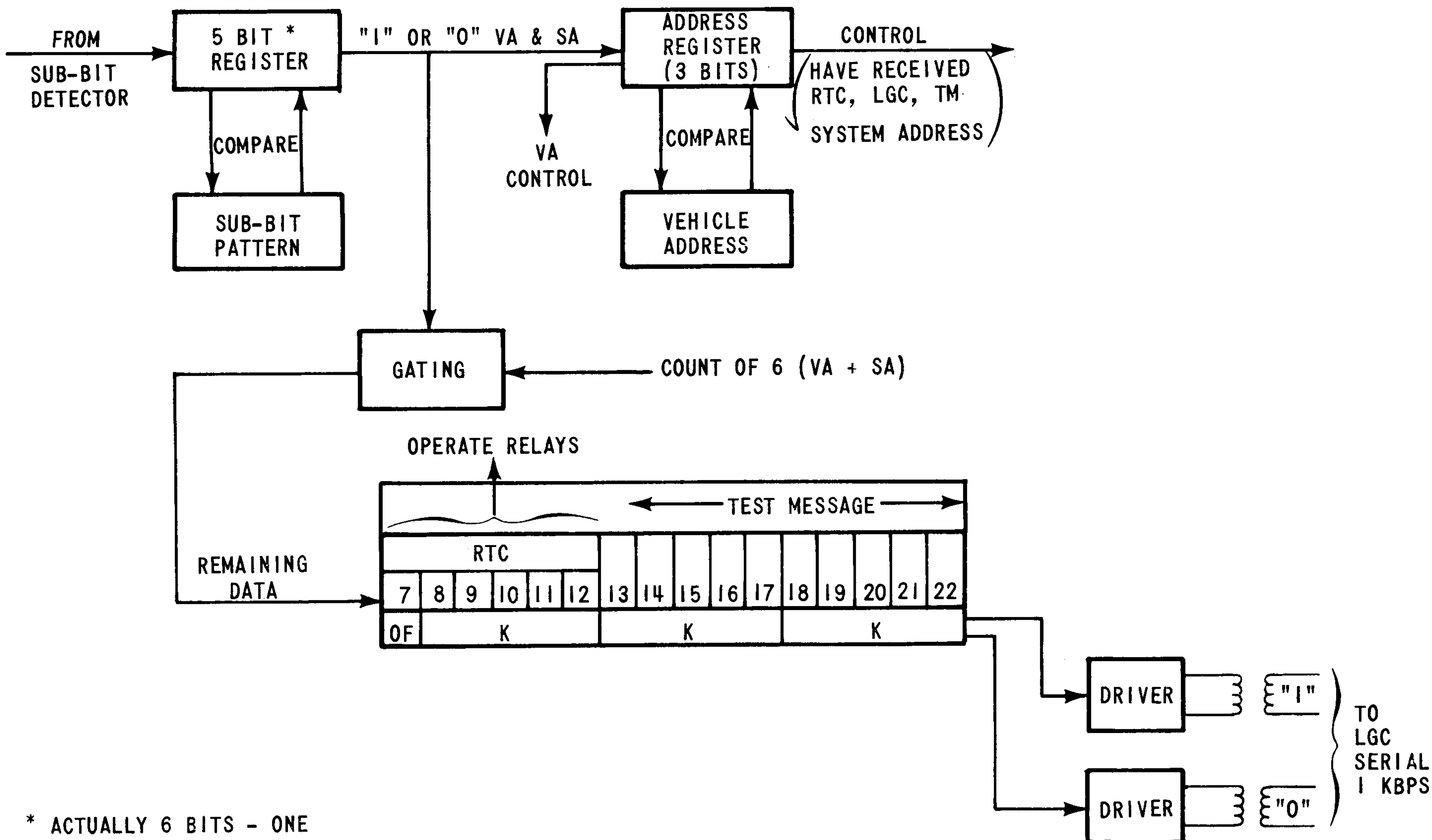
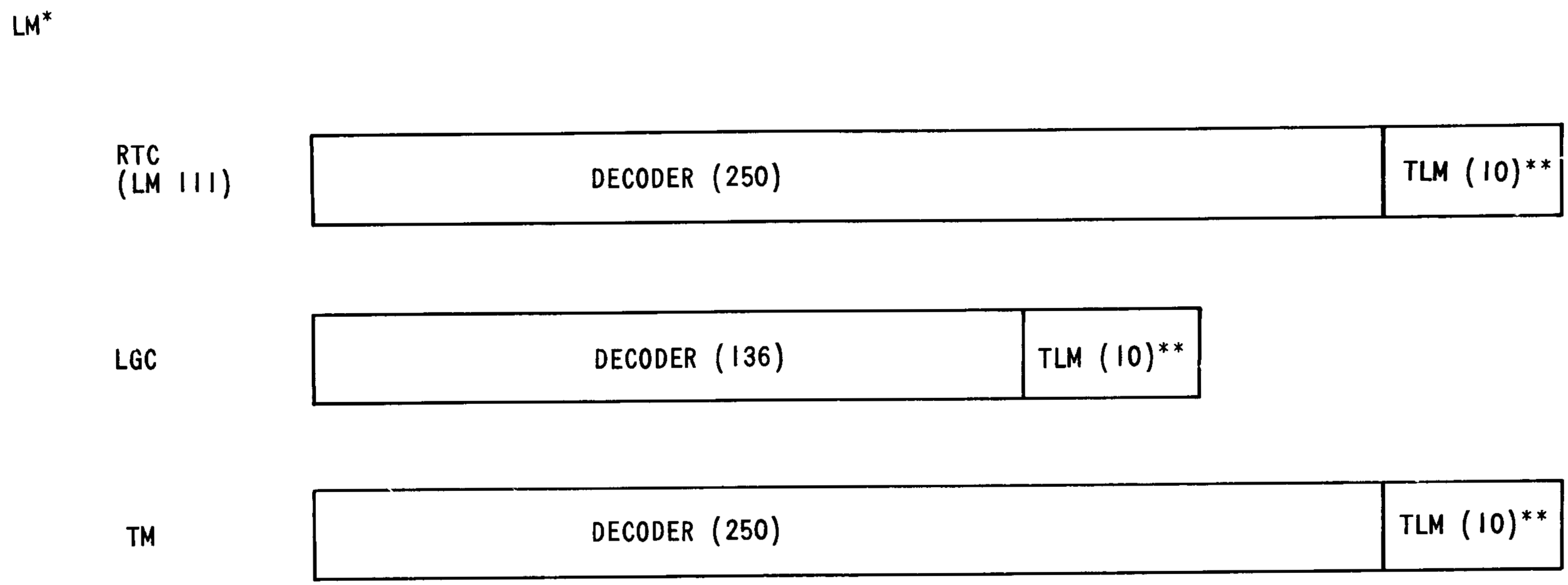


FIGURE 14 - BASIC SCHEME FOR LM PSK DEMODULATION



* ACTUALLY 6 BITS - ONE BIT BEING USED FOR CHECKING PURPOSES

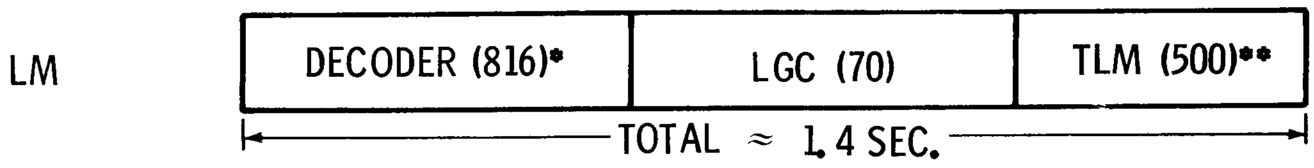
FIGURE 15 - BASIC LM DECODER OPERATION



*NO MAP INDICATION
IN LOW BIT RATE
TLM

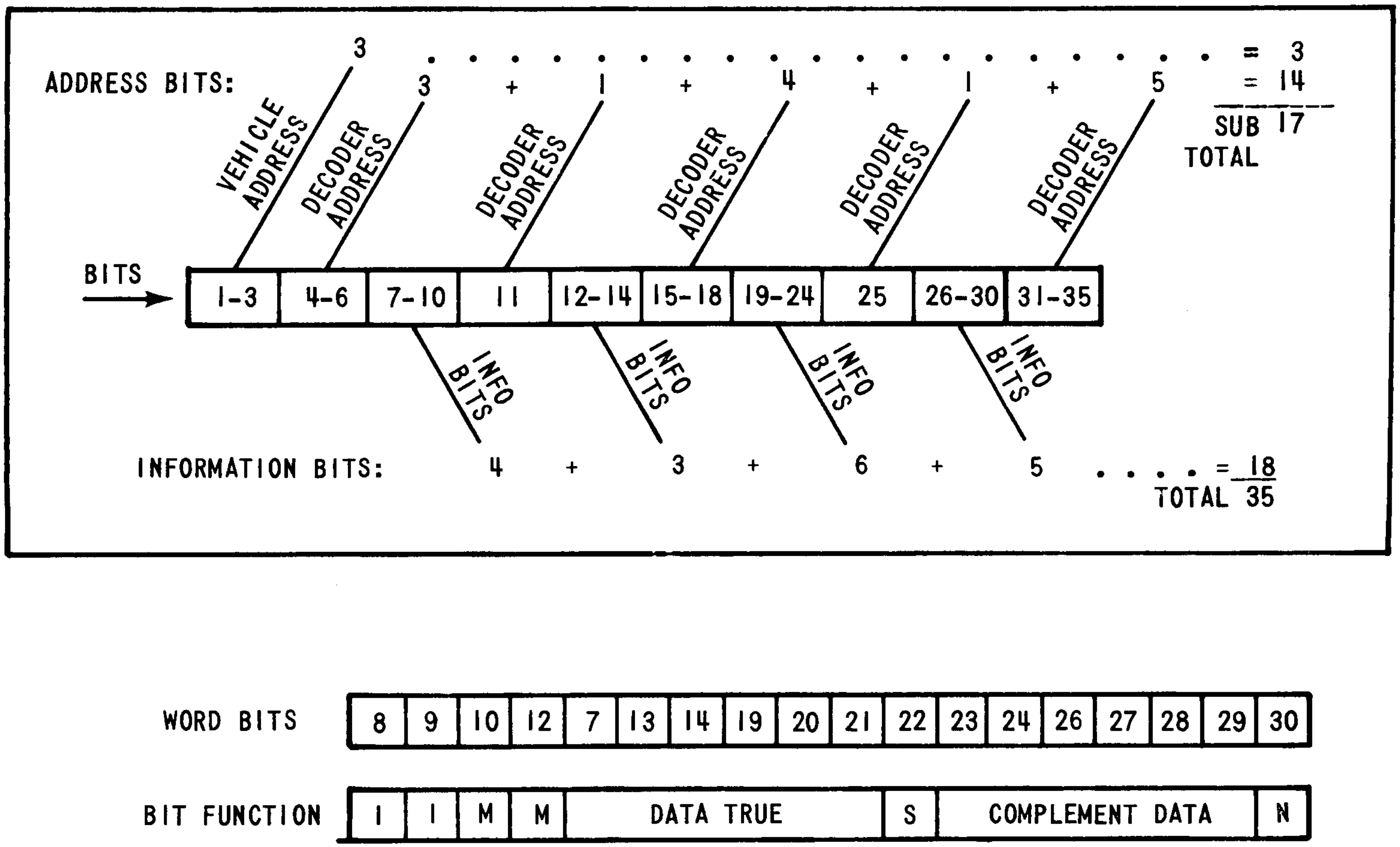
**ASSUMING AN AVERAGE VALUE - MAXIMUM = 20 MILLISECONDS

FIGURE 16 - ESTIMATE OF TIME DELAY (MILLISECONDS) FOR MAP TO APPEAR ON DOWN LINK (LM) (SINGLE WORD)



* 6 MESSAGES (5 DATA WORDS PLUS ENTER)
**ASSUMING AN AVERAGE VALUE - MAXIMUM = 1 SECOND

FIGURE 17 - ESTIMATE OF TIME DELAY (MILLISECONDS) FOR SINGLE COMPUTER WORD STATUS TO APPEAR ON DOWN LINK



I = INTERRUPT
M = MODE/DATA..MODE = 1 DATA = 0
S = SEQUENCE BIT
N = COMPLEMENT OF SEQUENCE BIT

FIGURE 18 - SIVB/IU TRANSMISSION WORD FORMAT

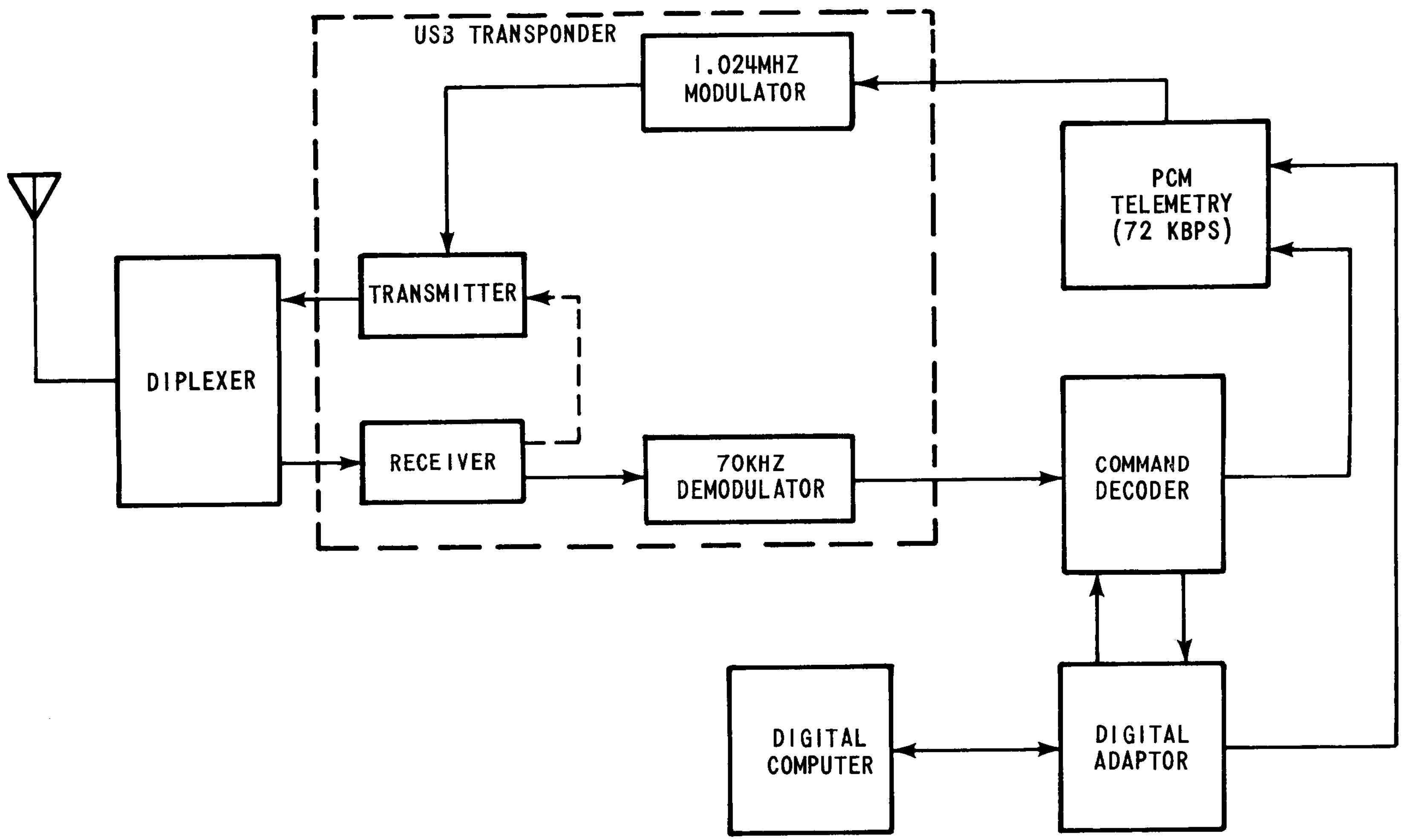


FIGURE 19 - S-IVB/IU UP-DATA DISTRIBUTION (SATURN V)

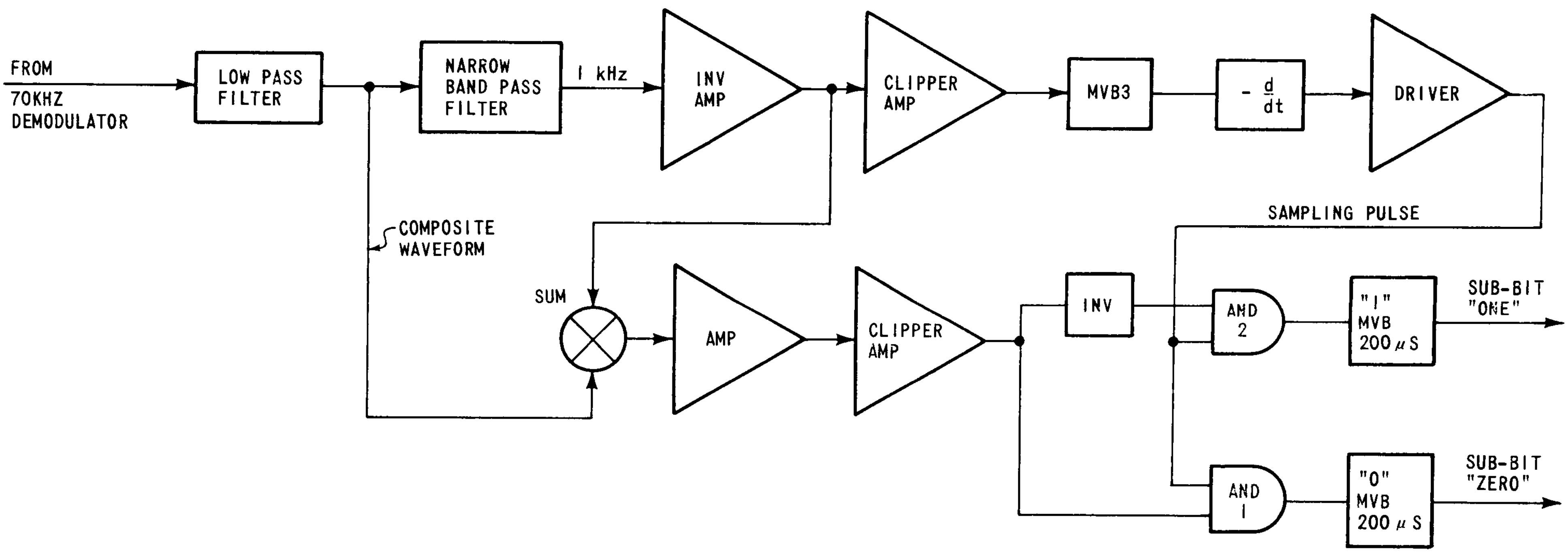


FIGURE 20 - BASIC PSK DEMODULATION (SIVB/IU)

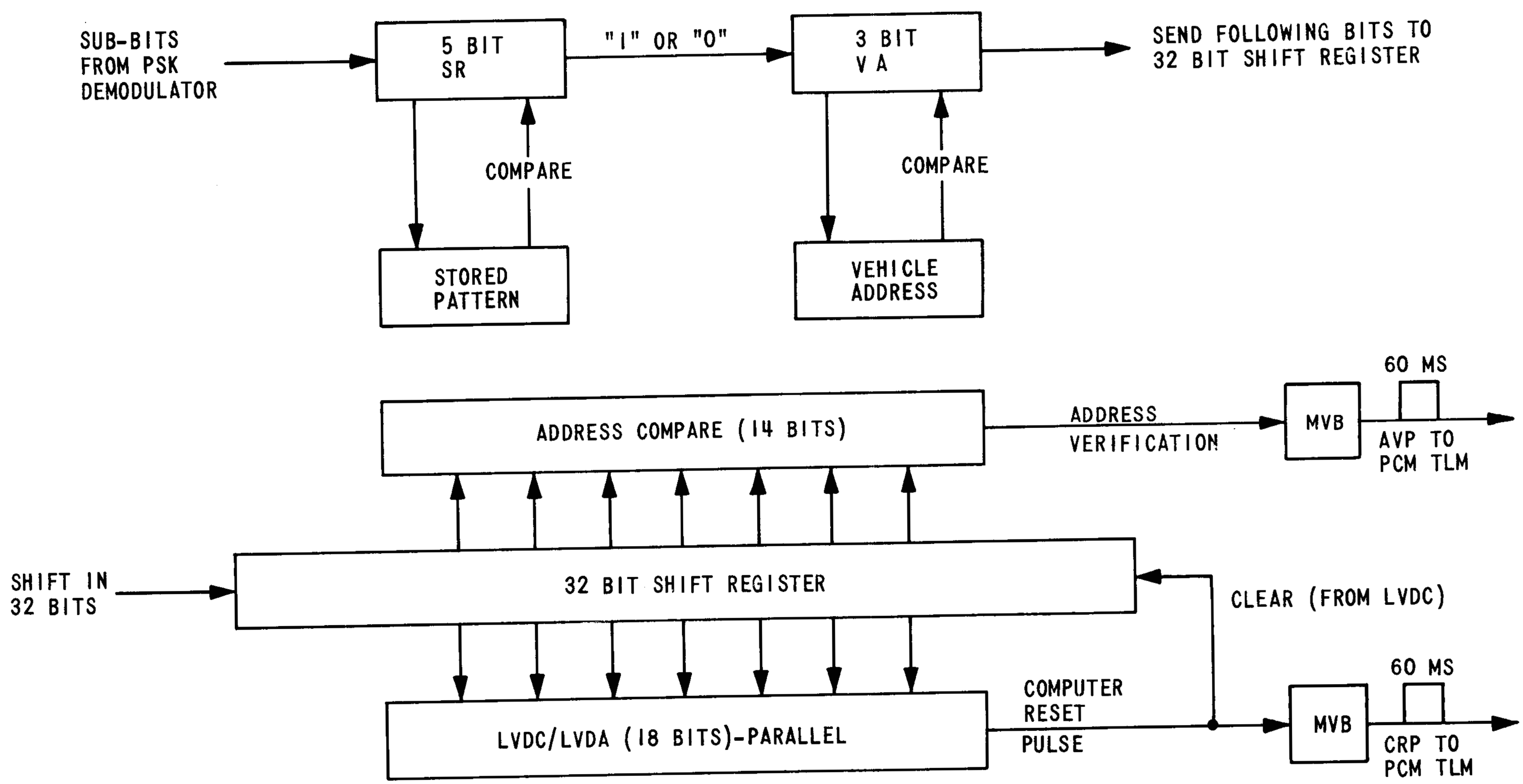


FIGURE 21 - BASIC SIVB/IU DECODER OPERATION

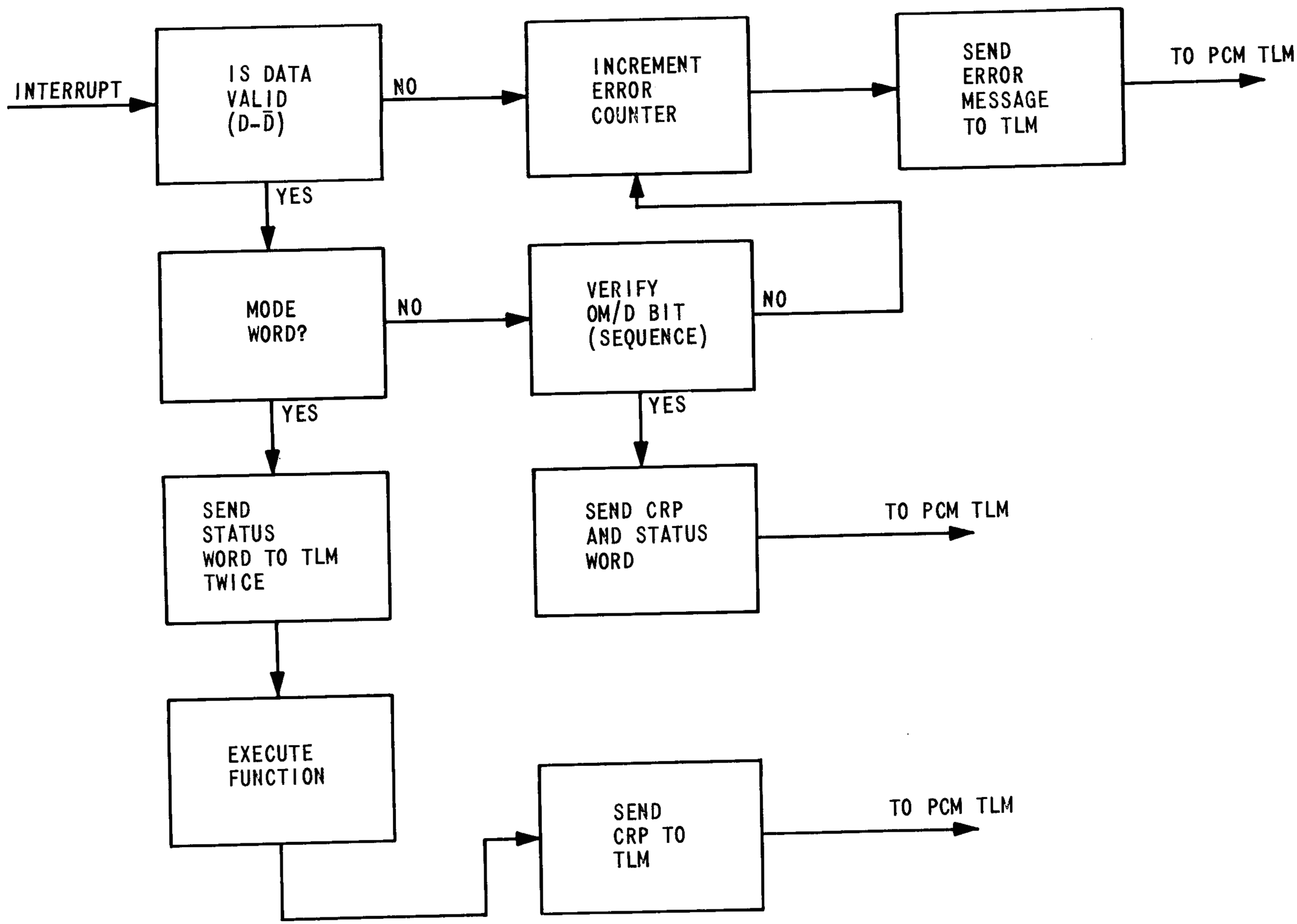


FIGURE 22 - BASIC LVDC OPERATION ON UP-DATA MESSAGE

TAG 8 BITS	1 VALIDITY 1 ADDRESS 3 MODE	LVDA BUFFER REGISTER		
		26 - 18	17 - 15	14 - 1
ONE UNIQUE CODE INDICATING AN ERROR MESSAGE IS CONTAINED IN THE DATA (NOT DEFINED)		UNIQUE CODE FOR EACH DIFFERENT ERROR	ERROR COUNTER	DATA FOR EVALUATION OF FAILURE (WHEN POSSIBLE)

A ERROR MESSAGE

TAG - 8 BITS	1 VALIDITY 3 MODE 1 ADDRESS	BUFFER REGISTER	
		26 - 20	19 1
ONE UNIQUE CODE FOR ALL STATUS CODES		TRUE FORM OF MODE/DATA COMMAND	

B STATUS MESSAGE

14	13	12	11	10	9	8	7 . . . 1
DATA ←					→ DATA	SEQ. BIT	COMPLEMENT OF 14-8

C NAVIGATION DATA WORD

14	13	12	11	10	9	8	7 . . . 1
IU STAGE	S-IVB STAGE	X	ADDR 8	ADDR 7	ADDR 6	SEQ. BIT	COMPLEMENT OF 14-8
ADDR 5	ADDR 4	ADDR 3	ADDR 2	ADDR 1	X		COMPLEMENT OF 14-8

D SWITCH SELECTOR DATA WORDS

FIGURE 23 - TYPICAL MESSAGES TO AND FROM SIVB/IU

-- 10 FRAMES
-- 30 CHANNELS PER FRAME
-- 10-BIT DATA PER CHANNEL
- LVDC/LVDA CHANNEL ASSIGNMENT
-- TWO GROUPS OF FOUR CHANNELS (8, 9, 10, 11 23, 24, 25, 26), GIVING TWO LVDC/LVDA WORDS PER FRAME
-- EACH FRAME IS SAMPLED 12 TIMES PER SECOND, PROVIDING A TOTAL OF 240 LVDC/LVDA WORDS PER SECOND

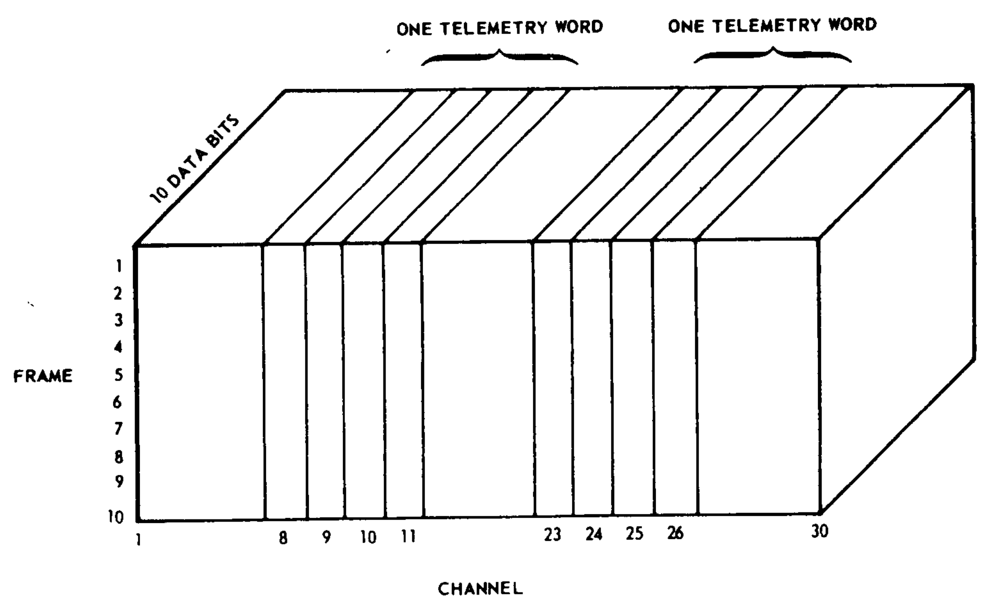
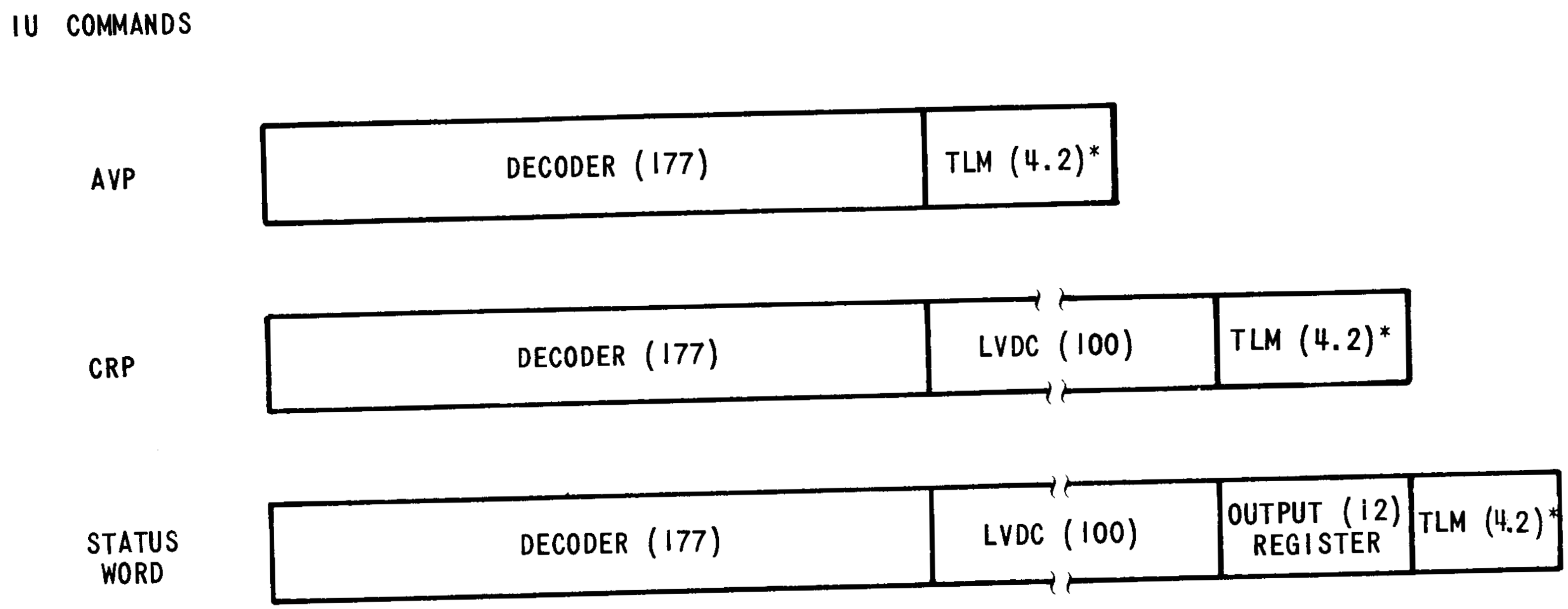
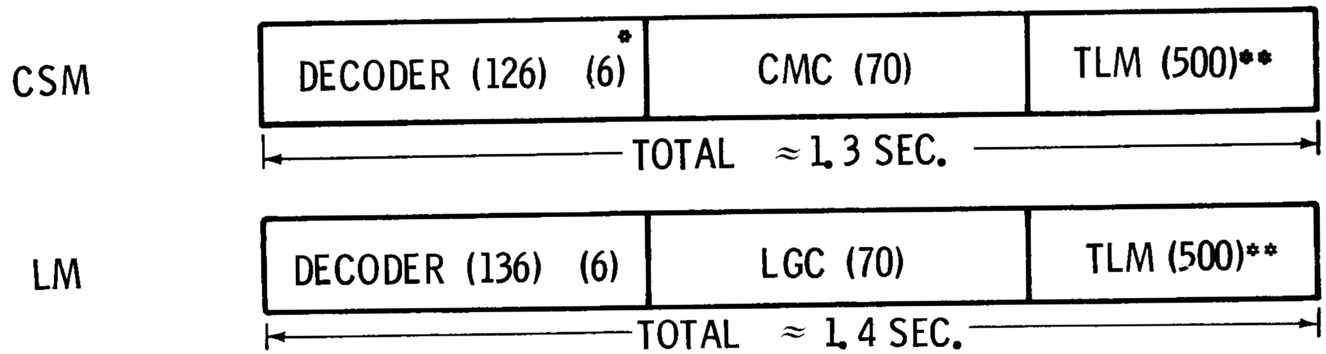


FIGURE 24 - PCM FORMAT - S-IVB/IU



*ASSUMING AN AVERAGE VALUE - MAXIMUM = 8.3 MILLISECONDS

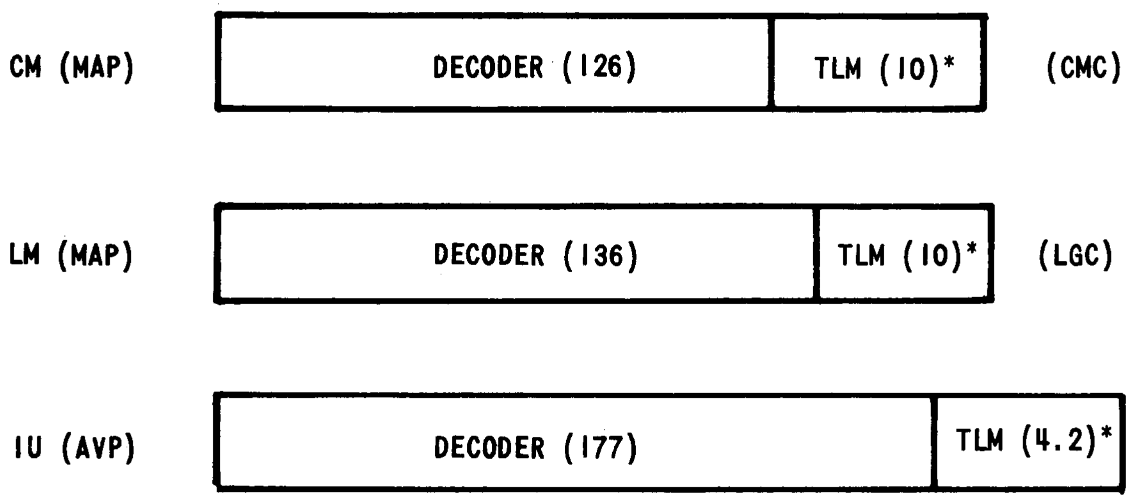
FIGURE 25 - TIME DELAY (MILLISECONDS) FOR AVP, CRP, AND STATUS TO APPEAR ON DOWN LINK (SIVB/IU) (SINGLE MESSAGE)



*SIX MESSAGES (5 DATA WORDS PLUS ENTER)

**ASSUMING AN AVERAGE VALUE - MAXIMUM = 1 SECOND

FIGURE 26 - ESTIMATE OF TIME DELAY (MILLISECONDS) FOR SINGLE COMPUTER WORD STATUS TO APPEAR ON DOWN LINK



*ASSUMING AN AVERAGE VALUE - MAXIMUM = 20 MILLISECONDS FOR CSM AND LM
= 8.3 MILLISECONDS FOR IU

FIGURE 27 - ESTIMATE OF TIME DELAY (MILLISECONDS) FOR MAP (AVP) TO APPEAR ON THE DOWN TELEMETRY LINK WHEN A COMPUTER TYPE MESSAGE IS SENT