LoJack III

Theory of Operation

And

Tuning Procedure

Motorola AIEG

Revision: A

May 16, 2000

FORWARD

This document describes the theory of operation and the transmitter tuning procedure for the third generation LoJack Vehicle Locating Unit (VLU) transmitter. Please refer to Motorola Schematic 79D43701L01 for circuit and part references.

The LoJack III VLU (LJU3) is a VHF radio transceiver controlled by a remote network of computer activated transmitters. It is meant to be the tracked device in a vehicle location and recovery system. The VLU and associated antenna assembly are mounted in a secret location within the vehicle in a standby state until activated via a radio signal broadcast. Active state transmissions consist of periodic transmissions of coded data that can be tracked by a compatible tracking receiver.

OVERVIEW

The LJU employs a phase continuous Fast Frequency Shift keyed sub-carrier at 1200 bps data rate. The sub-carrier data modulation method complies to the following specifications:

Sub-carrier modulation: Phase continuous FSK
Bit rate: 1200 bits per second
Modulation rate: 1200 baud
Binary “0”: One and one half cycles of 1800 Hz sine wave
Binary “1”: One cycle of 1200 Hz sine wave
The transmitter modulation is adjusted to between 3.9 and 4.2 kHz deviation in the factory.

The transmitter uses a digital to analog circuit from the microprocessor through a low pass filter to generate the sub-carrier signals. Filter characteristics are provided with the submitted documentation. An emission designator of 13K2F2D is being requested for the device. The necessary bandwidth was calculated according to the formula B = 2M + 2DK given for frequency modulated digital signals. This calculation was based on the system’s rated maximum modulating frequency of 1800 Hz and frequency deviation of 4 kHz.

The Uplink modulation consists of a two frequency FSK
Bit rate:
Binary “0”: 17.92 mSec low frequency
Binary “1”: 17.92 mSec high frequency
The transmitter modulation is adjusted to between 250 and 350 Hz low to high. The modulation BW of the Uplink message is much smaller than the BW required for normal MSK data.

The LJU transceiver is shipped with out an antenna to LoJack. The unit is installed, hidden, in a vehicle with an antenna attached. The typical LoJack antenna is 50 Ohms, passive, and omni-directional. The installation of the unit in the vehicle tends to reduce the effectiveness of the omni-directional radiation pattern.

TRANSMITTER

The LJU3 transmitter is a 2.0 Watt RF output, VHF FM device operating at 173.075 MHz. The transmitter is comprised of the following subsections: power supply, microprocessor controlled bias/modulation, baseband filter, crystal oscillator/modulator/tripler, 2nd frequency tripler, preamplifier, driver amplifier, power amplifier, transmit/receive switch, and lowpass harmonic filter.

Power Supply

The LJU3 is designed to be power from a vehicle’s 12 V power system. In the event that the vehicle power goes out of regulation, the LJU3 module contains an internal non-rechargable 6 V lithium manganese battery cell. The unit will operate the transmitter from the primary power supply under normal operating conditions. Before powering the transmitter the microprocessor measures the primary power supply voltage. If the supply is out of range, the transmitter is powered from the back up battery.

The 12 V primary supply to the transmitter is regulated down to 8.2V to power the transmitter. When the back up battery is used the cell voltage (6 volts), combined with the loss in the switching and protection circuitry, limits the voltage.

A precision voltage reference is also provided to the transmitter to provide for increased oscillator frequency stability and to provide for controlled biasing of the preamplifier stage. This reference voltage is switched on by the microprocessor.

Microprocessor

The microprocessor is a Motorola MC68HCL11E9 microcontroller. It uses an external 8 MHz crystal and an internal 2 MHz bus. The microcontroller performs the following functions related to the transmitter: power switching, PA bias control, reference voltage switching, generation of the modulation signal, and carrier frequency tuning.

As detailed in the Power Supply section the micro determines the voltage at the primary power supply to determine if the transmitter should be operated from primary or back up power. The micro also uses a 6-bit discrete digital to analog circuit to provide a DC bias to the MOSFET power amplifier device and controls a voltage reference circuit that is used in the transmitter section. Finally the micro also uses a discrete 8-bit digital to analog circuit to tune the receiver and to tune and modulate the transmitter.

Baseband Filter

The baseband filter is a passive two-pole low-pass filter. The filter smoothes the output of the 8-bit D/A to reduce the high frequency components in the sinusoidal MSK signal used to modulate the carrier frequency.

Crystal Oscillator/Modulator/Tripler

The transmitter crystal oscillator tripples the 19.23055MHz crystal frequency to 57.69165 MHz. The frequency is pulled using a varactor diode in series with the oscillator crystal. A buffer circuit isolates the crystal oscillator from the next tripler stage and a cap-coupled three-stage band-pass filter provides harmonic attenuation.

2nd Tripler

The 2nd Tripler stage tripples the 57.69165 MHz frequency to the173.075 MHz carrier frequency and provides power gain before the transmitter signal is fed to the preamplifier stage. The 2nd tripler also provides additional harmonic filtering using a three-stage cap-coupled band-pass filter.

Preamplifier

The output of the 2nd tripler is fed into the preamplifier stage. This stage uses the voltage provided by the voltage reference to bias a bipolar transistor into Class A. The stage amplifies the signal provided by the 2nd tripler and provides the higher amplitude signal to the driver stage of the transmitter. The preamplifier stage uses a fixed value 'T' matching circuit to match the output of the 2nd tripler to the input of the transistor and a 'shunt L series C' combination to match to the input impedance of the driver device.

Driver

The driver stage consists of a Class C biased bipolar device. The device uses feedback to insure stability and amplifies the signal delivered by the preamplifier stage for delivery to the power amplifier (PA) stage. The driver is matched to the PA using capacitive tapped coupling.

Power Amplifier

The power amplifier (PA) is a MOSFET device. It is biased from the microprocessor through a 6 bit digital to analog converter. The digital to analog circuit has bypass capacitance in the form of C3 and C75 to minimize any transference of RF between the micro and the PA and vice versa. The PA is matched to the transmitter switch via the first section of the low pass harmonic filtering.

Harmonic Filter

The harmonic filter in the transmitter consists of two sections. The first section consists of two 'series L, shunt C' circuits (L25, C109, L24, C107) that provides both low pass filtering and matching from the PA to the transmitter switch. After the transmitter switching diode a second section of filtering consists of a 'T' circuit (C114, L23, C117). This circuit (coupled to the antenna via C113) provides filtering for the transmitter and receiver and insures that the antenna is matched to the transmitter and receiver circuits.

Transmit/Receive Switch

The transmit/receive switch allows the use of a single antenna for both transmit and receive functions. PIN diodes D13 and D10 are unbiased in the receive mode. In this mode both diodes are of high impedance which isolates the transmitter from the antenna. When the transmitter is powered, both diodes are biased "on" via L18 and R123. This causes both diodes to look like low impedance circuits, D13 then connects the transmitter to the antenna.

TRANSMITTER TUNING

The LoJack III will be electronically tuned in a manufacturing test bay. The tuning procedure is as follows:

Center Frequency Tuning:

Establish two way serial communications to the LJIII unit. Command the unit to turn on the transmitter with no PA bias and no modulation. Measure the carrier frequency. Move the modulation digital to analog value until the frequency is as close to 173.075 MHz as step size allows. The frequency must be within 5 ppm of 173.075. Store the level in EEPROM. If center frequency can not be obtained that is within test limits fail unit.

MSK Modulation Tuning:

Establish two way serial communications to the LJIII unit. Command the unit to turn on the transmitter with no PA bias and no modulation. Measure the center frequency. Move the modulation digital to analog value until the center frequency is as close to 173.075 MHz + 5200 Hz as step size allows. Calculate the difference between the center frequency measurement D2A value and the value used to move the carrier to 173.075 MHz + 5200 Hz. Load this value into EEPROM. Using test software engage MSK modulation and measure the deviation. Insure that the deviation falls between 3800 and 4200 Hz. (Since there is a low pass filter in the D2A section, the MSK modulation will be lower than the frequency shift that was measured using a steady carrier signal. This is why 5200 Hz is measured during this test using as a carrier offset, but the same value of D2A results in an average of 4000 HZ MSK modulation.)

Uplink Modulation Tuning:

Establish two way serial communications to the LJIII unit. Command the unit to turn on the transmitter with no PA bias and no modulation. Measure the center frequency. Move the modulation digital to analog value until the center frequency is as close to 173.075 MHz + 1950 Hz as step size allows. Move the modulation digital to analog value until the center frequency is as close to 173.075 MHz - 1950 Hz as step size allows. Using the two frequencies measured in this section and the center frequency measurement calculate the D2A values for 300 Hz modulation inside of these two measured frequencies.

Also calculate two more sets of frequencies that will create a pair of inner modulation frequencies. The inner pairs should be equally spaced between the outer. (Approximately ± 600 Hz around the center frequency.)

This will result in four discrete uplink message frequency pairs. Two about 600 Hz away from the center frequency of 173.075 MHz and the other two that are further out. The outer frequencies are defined by the outer most frequency in the modulating pair. This frequency is defined to be at 1950 Hz away from the center or less. This insures that the uplink pairs all remain well within the allowable occupied bandwidth and emissions masks.

PA Bias:

Establish two way serial communications to the LJIII unit. Command the unit to turn on the transmitter with no PA bias and no reference voltage. This will bias the transmitter with no RF present. Measure the current into the unit. Increase the PA bias digital to analog value until the current level increases by 25 to 55 mA. The bias level that is the lowest in the range should be stored in EEPROM. If bias level between 25 to 55 mA is not obtained fail unit.

Turn on transmitter including PA bias and reference. Measure the power out of the transmitter. If power out is above 2.4 Watts or below spec adjust PA bias down or up respectively until power out is in spec. If power is not in spec within two digital to analog step sizes fail unit.