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FUZE VAF-M17 MICROCONTROLLER SOFTWARE

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Abstract: *This paper provides detailed description of the microcontroller software workflow for the fuze vAF-M17 alongside with detailed hardware and software architecture. Fuze vAF-M17 together with arming initiator vFI-M17 is intended for use with the aerial bombs MK-82, MK-84, BLU-109 and has the same functional characteristics as fuze FMU-139. The heart and brain of the fuze vAF-M17 that manages its whole operation, is the 8-bit microcontroller. Hardware and software are designed in a way so that the main emphasis is on the handling safety to prevent any unwanted effects. For that purpose, the design of the hardware took into account the differential pressure-measuring unit which is installed inside the arming initiator and which gives the information about the velocity of the aviation bomb. The electronics has the knowledge that the first safety condition is fulfilled and that the aviation bomb has reached a clear distance from the aircraft and the pilot to perform the needed functionality of the fuze (activating the explosive filling inside the bomb through detonation). Another important sensor for proper functioning is the accelerometer, which has a possibility of impact detection that can be preset by an operator with a desired "g" value.*

Keywords: *fuze, microcontroller, software, millitary, vlatacom.*

1. INTRODUCTION

Fuze vAF-M17 together with initiator vFI-M17 is intended for use with the bombs MK-82, MK-84, BLU-109, and has the same functional characteristics as fuze FMU-139. Bomb fuze vAF-M17 is designed to initiate an explosion at fuze device. It is powered from the Lithium battery 10.8V. Its arming time and its function delay time are selcted before flight by means of two rotary swtiches with 16 positions. The electric fuze remains safe until it is energized from its own lithium battery. Because of the safety interlocks, electrical charging can occur only after the bomb is released from the aircraft. At this time, the fuze receives electric power required for selection of the desired arming and delay times.

Fuze functions after the bomb is released from the aircraft in ACTIVE mode, and if special environmental sensor, located in the initiator detects air stream, which means that the bomb is released from the aircraft and is moving away from the aircraft reaching a safe distance. If the air stream doesn't exist arming will not happend and explosion will not occur.

When arming conditions are fulfilled the fuze becomes armed, and is free to operate on impact and the bomb explosive charge can be detonated.

Detonation delay time starts when shock sensor detects that the bomb hit the target.

Figure 1. Fuze vAF-M17

2. ELECTRONIC BLOCK OF THE FUZE

Electronics circuit of the fuze provides:

a) Checking if all necessary conditions for arming are satisfied.
b) Electrical pulse for activation of the Arming capsule (EID)
c) Detection of the bomb impact on target.
d) Electrical pulse for activation of the Detonator capsule (ED) after detonation delay time is finished.
e) Test basic characteristics of the fuze and its functionality

Block diagram of the electronic block of the fuze is shown in Figure 3.

The heart of the fuze vAF-M17 electronic block is the microcontroller (PIC18F45J50), 8 bit with 10 bit AD converter, 32k program memory, 3776 bytes SRAM memory, 22 IO ports, SPI, I2C, USB, USART etc.

There are two rotary switches located on vAFRSW PCB which are accesible from front side of the fuze, Figure 2. Arming rotary switch serves for arming time setting. Delay rotary switch serves as detonation delay time setting. Each rotary switch has 16 positions. One with 12 arming times and the other with 13 detonation delay times. When one or both rotary switches are in the position 'x' arming process and detonation delay processes are blocked, fuze is passive and can't activate the bomb explosives. The microcontroller reads rotary switches positions immediately after battery is connected to the microcontroller.

There are two modes of operation:

1. Functional mode of operation
2. Operation Test mode

Power supply of the electronic block is three lithium batteries (3x3.6V) with a shelf life of 15 years. Battery (BAT+) is connected to the initiator via CONF 4-pin connector. When launch sensor is active, when the bomb is released from the aircraft in ACTIVE mode, this battery voltage comes as MP1 signal via CONF connector to electronic circuits. MP1 (VC) voltage comes to EID FIRING CIRCUIT (AFC), ED FIRING CIRCUIT (DFC) and VOLTAGE REGULATOR VR3. Voltage VC charges firing capacitors CA and AFC and CD in DFC circuits which serves for activation EID and ED capsules.

Capacitance of these capacitors is (440 μF) each. Charging starts when the microcontroller enables this process immediatelly when the bomb is released in ACTIVE. Capacitors are charged for approximately one second. Charged energy in these capacitors are much greater than needed for proper activation of the capsule and can be given by:

$$E = \frac{1}{2} * \left(C * V^2 \right) \approx 22 \text{ mJoul}$$

Energy stored in capacitor (CA) discharges through the EID capsule, when all conditions for that are satisfied.

Energy stored in capacitor (CD) discharges through the ED capsule, when all conditions for that are satisfied.

Power supply from battery via MP1 switch connects to a voltage regulator VR3 which provides power supply VDD=3V DC for microcontroller, accelerator sensor, and other parts.

When the fuze is connected with a computer, in the Operation Test mode, energy capacitors are not charged. In this case only microcontroller, accelerometer sensor and circuits for capsules continuity testing works. Power supply, 5VC, from the computer, comes via TEST connector and diodes D3 to input of the voltage regulator VR3. By this way always same power supply is obtained, VDD=3V.

The continuity (bridge wire) of the arming and detonator capsules can be checked in the Operationl TEST mode of operation using two electronic circuits EID Capsule TEST and ED Capsule TEST. This test is done by passing a current about 2.1mA (much less than MNFC, 100mA), and monitor the capsule continuity. If coninuity exists, then the microcontroller generates a TRUE signal which means that the connection between EBAF and bridge wire is ok and that bridge wire inside the capsules is ok.

DATA, MP2I, from environmental sensor, ENVS, located in the initator, comes from collector of transistor Q1 and via sprial cable, CONF connector and MP1/MP2 ESD protection circuit to input of the microcontroller, input MP2. If this data is TRUE (HIGH level) microcontroller concludes that the bomb moves away from the aircraft and arming process can be continued.

The fuze utilizes a semiconductor accelerometer, g sensing device (ADXL377), for the detection of the bomb impact on the target.

The (ADXL377) device is a small, thin and low power complete 3-axis accelerometer with conditioned analog signal voltage outputs. The (ADXL377) measures acceleration resulting from motion, shock, or vibration with a full-scale range of ±200 g.

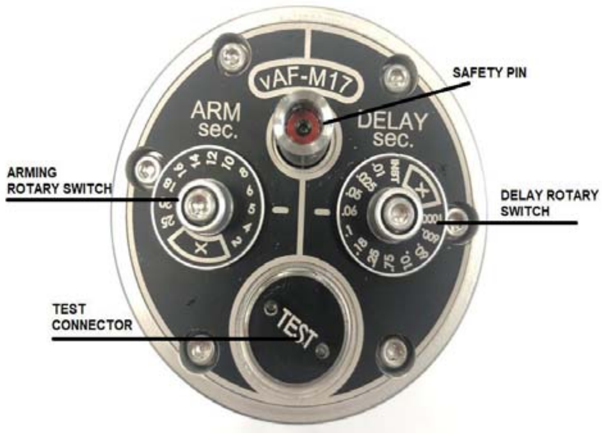

Figure 2. Arming and detonation delay time setting rotary switches

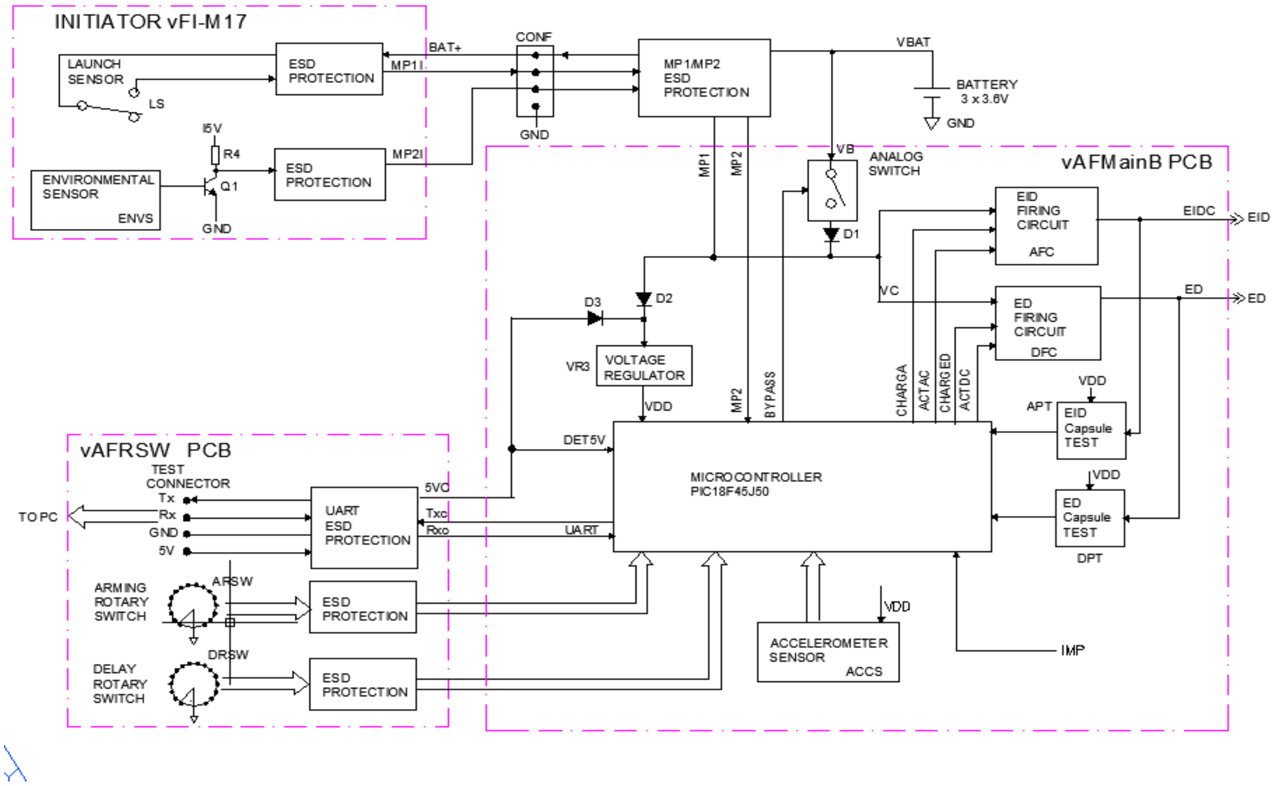

Figure 3. Electronic block diagram of the fuze

3. MICROCONTROLLER PIC18F45J50

The heart and brain of the fuze vAF-M17 that manages its whole operation, is the microcontroller, Figure 4. The microcontroller used in the fuze design vAF-M17 is PIC18F45J50 with 44-Pin, Low-Power, High-Performance USB microcontrollers.

Main features:

– Power supply is 2.15V to 3.6V.

– External or Tunable Internal Oscillator (31 kHz to 8 MHz, or up to 48 MHz with PLL)

– Two 8/bit Timers and Three 16 bit Timers

– Allows independent I/O mapping of many peripherals

– 10-Bit, up to 13-Channel Analog-to-Digital (A/D)Converter module:

– High/Low-Voltage Detect module

– Two Enhanced USART modules:

– Supports RS-485, RS-232 and LIN/J2602

– Auto-Wake-up on Start bit

– Four Programmable External Interrupts

– Two Master Synchronous Serial Port (MSSP) modules Supporting Three-Wire SPI (all four modes) and I2C™ Master and Slave modes

– Single-Supply In-Circuit Serial Programming™ (ICSP™) via two pins

– In-Circuit Debug (ICD) w/Three Breakpoints via 2 Pins

– Operating Voltage Range of 2.0V to 3.6V

– On-Chip 2.5V Regulator

– Flash Program Memory of 10,000 Erase/Write Cycles Minimum and 20-Year Data Retention

– Sleep mode: CPU off, Peripherals off, SRAM on,

– Fast Wake-up, Currents Down to 105 nA, Typical

– Auto-Baud Detect

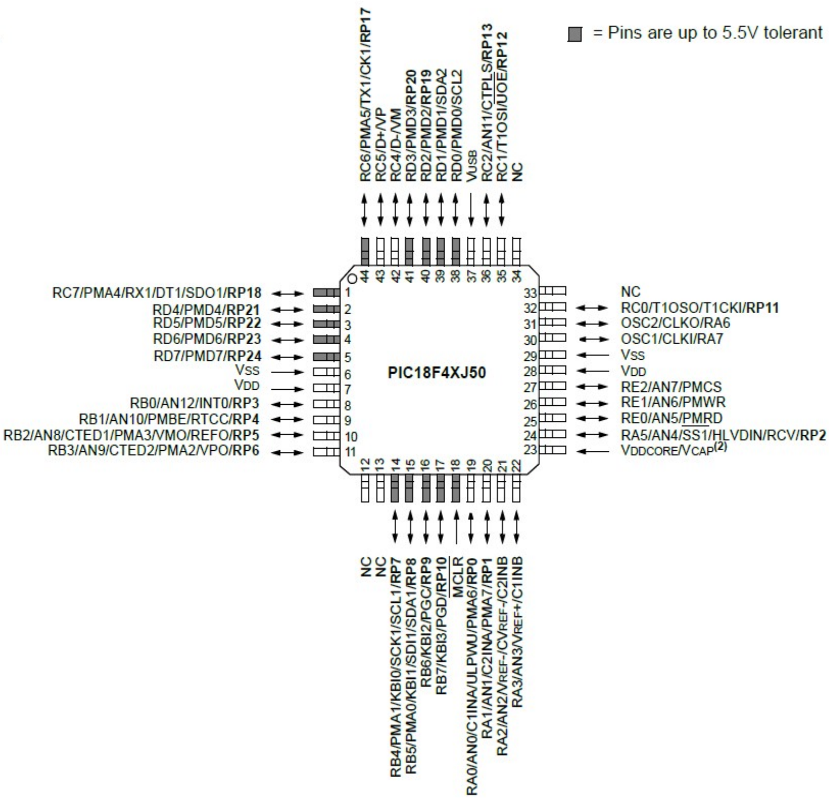

Figure 4. Microcontroller PIC18F45J50 pin out

4. MICROCONTROLLER SOFTWARE

Basic microcontroller state diagram is shown on Figure 5.

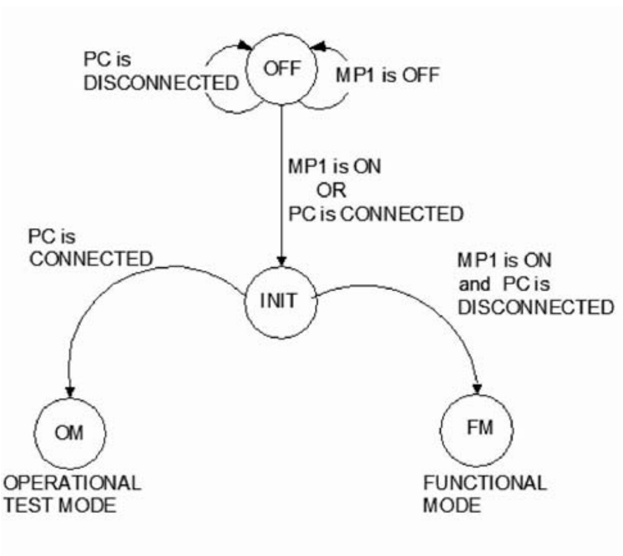

Figure 5. Basic microcontroller state diagram

When MP1 switch, located in the initiator, is open, (the initiator is in safe position inside the bomb) and when a computer is not connected with the electronic block, microcontroller does not work because there is no power supply. If MP1 switch is ON or if a computer is connected the microcontroller goes in the INIT state, initialization state.

If a computer is disconnected and MP1 switch is ON, the microcontroller performs regular operation routine and this is the fuze Functional mode of operation.

If a computer is connected, the microcontroller goes to Operation TEST mode of operation. This will happen if before that signal MP1 is False (Switch MP1 in the initiator is open).

4.1. Functional mode of the fuze operation

Microcontroller performs Functional mode of operation when a computer is not connected with the electronics and when the MP1 switch is closed. Microcontroller state diagram in functional mode of operation is shown on Figure 6.

First step is reading position of the rotary switches and creating command for start charging process of the capacitors for activation EID and ED capsules.

After that the microcontroller goes in Arming process and starts the timer (TIMER0). After that the mictrocontroller waits 0.9 of Arming time, defined by position of the rotary switch. When this time has expired, microcontroller goes to state MP2 CHECKING. Microcontroller remains in this state until it detects the MP2 signal that it is TRUE. If the microcontroller detects MP2 signal that it is TRUE after the arming time has expired the microcontroller goes in the state of NO ARMING and remains there forever.

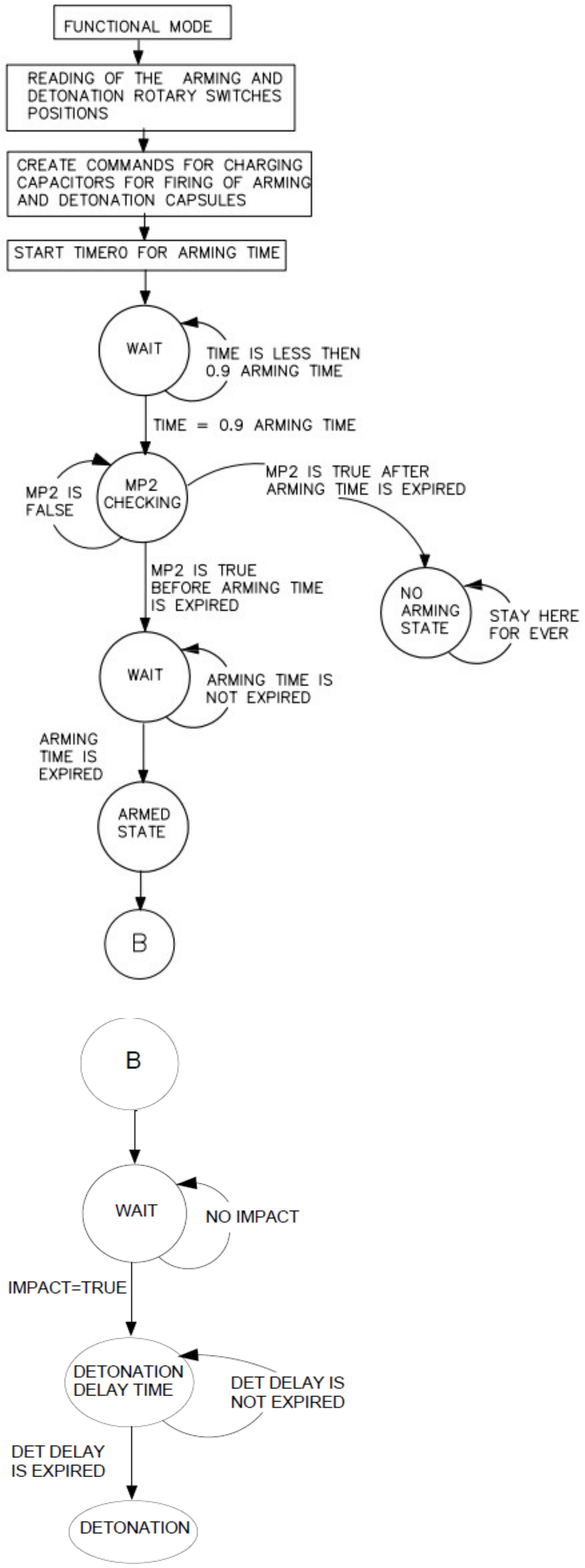

Figure 6. Microcontroller operational mode state diagram

If the microcontroller detects MP2 signal that it is TRUE before the arming time has expired, it goes in the WAIT state. When arming time has expired the microcontroller goes in the ARMED state. Fuze is armed and EID capsule should be activated.

After completion of the ARMED state, detonation process begins. First step of the detonation process is to check if the impact occured. The microcontroller remains in this state until it detects the impact signal greater than preset value of the 'g' threshold. When the microcontroller detects that impact is greater than preset 'g' threshold, it start the timer (TIMER0) for detonation delay time. When detonation delay time expires ED capsule should be activated and should lead to explosion.

4.1.1. Software flow diagram for funcitonal mode of operation

Software flow diagram for functional mode of fuze operation is shown on Figure 7.

As soon as microcontroller gets power supply it starts initialization. Most important task is to disable the firing circuits for EID and ED capsule. After initialization phase, the microcontroller reads positions of arming and detonator rotary switches and arming time begins (2 seconds is minimal arming time).

Microcontroller monitors signal MP2, which is high (TRUE) when the pressure of the air stream is greater than 0.4 Psi, coming from the comparator inside the initiator. A true data means: 3 consecutive readings of HIGH level of the signal MP2 from the comparator output. Interval between reading is 100 µsec.

Microcontroller begins to monitor signal MP2 after 0.9 of arming time. If this signal is TRUE before the arming time has expired arming process can be continued. When preset arming time is finished, flag <arming> is TRUE, microcontroller generates command ACTAC, sends it to the EID firing circuit. EID capsule should be activated.

If MP2 signal becomes TURE after the arming time has expired, arming process will stop, no arming state and microcontroller remains in this state forever.

If signal MP2 is FALSE arming process can not be finished and microcontroller remains in this state forever, further functions of the fuze are blocked. Thus the fuze cant and will not activate the bomb filling.

Following, the microcontroller starts to monitor data from accelerometer sensor. When data from any axis (X, Y or Z) are greater than preset 'g' threshold, and if the fuze is armed, then the microcontroller starts detonation process, that is the detonation delay time.

If rotary switch for detonation delay is set at position INST, the microcontroller immediately after detecting that data from the accelerometer sensor have exeeded the preset threshold and after checking that the fuze is armed, it activates the ED firing circuit and ED capsule. When detonation delay time is finished the microcontroller activates the ED capsule, via ED firing circuit, which further activates the KL-34 and TD capsule as well as the booster of the fuze.

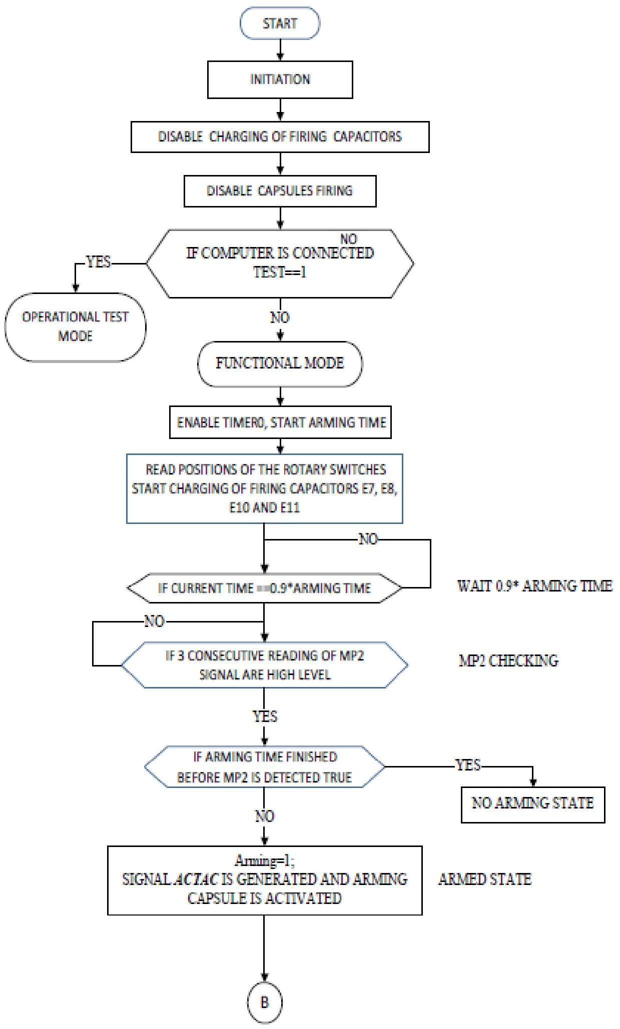

Figure 7. Workflow of the microcontroller Functional mode of operation

4.2. Operational TEST mode

Microcontroller performs Operational TEST mode of operation when a computer is connected with electronics.

During this TEST mode of operation the following parameters can be checked:

Arming rotary switch functionality
a) Delay rotary switch funcitonality
b) SAT time
c) Continuity of the EID capsule
d) Continuity of the ED capsule
e) Battery voltage
g) Voltage at accelerator sensor outputs for X, Y and Z
h) Written value for 'g' threshold
i) Firmware version written in the microcontroller
j) Write new value for 'g' threshold

In order to perform operational test it is necessary to connect the fuze with a computer using the interface and appropriate cable. Connecting the fuze and a computer can be performed using serial interface USB UART. The interface module is a separate part which is using a module CP2102 USB UART IC. In order to use this interface on a computer driver CP210x-Windows-Driver (Silicon Labs Company) must be installed.

Microcontroller state diagram in TEST mode of operation is shown on Figure 8.

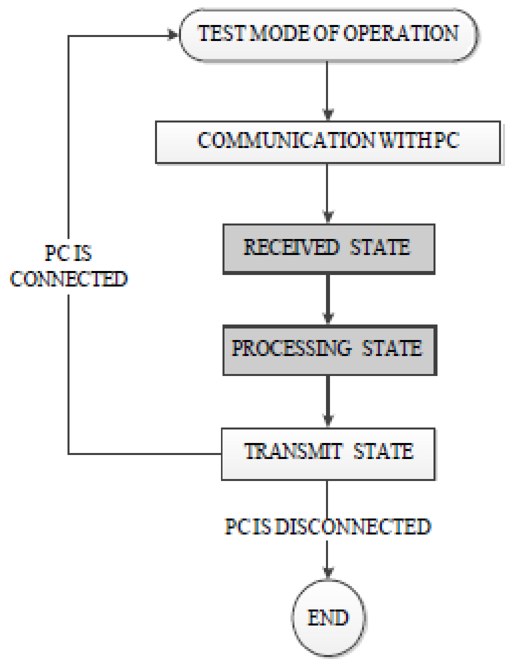

Figure 8. State diagram in TEST mode of operation

TEST mode of operation is possible only if the computer with appropriate software (vAF-M17 fuze test) is connected with the EBAF.

The computer is set as master and the fuze (or EBAF) is slave. The communication performs using 1200 bps. The computer sends request “[R]” to EBAF.

EBAF, upon receiving the request “[R]”, goes in PROCESSING STATE (subroutine proc_received) and sends following data to the PC: [B*****[C*[E*[A*[D*[G***[S*****[Y****[X****[Z****[V**]

Microcontroller goes in this routine when a computer is connected with the EBAF. As soon as the microcontroller gets power supply it starts initialization. Most important task is to disable charging of the energetic capacitors and primer drivers.

5. CONCLUSION

Safety and arming are primary roles performed by a fuze to preclude initiation of the munitions before the desired position or time. Safety and arming device prevent fuze arming until an acceptable set of conditions has been achieved and subsequently allows arming and functioning.

In order to preclude unintended fuze arming, the fuze safety system shall not initiate the arming sequence but only as a consequence of an intentional launch. Also the fuze design shall prohibit premature fuze arming or functioning if any or all electrical safety or energy control features fail in any given state or credible mode. These modes include both random and induced failures which occur prior to, during or after application of electrical power to the fuze. All of these procedures and sequences are controlled and supervised by the brain, which is the microcontroller inside the fuze itself.

Thus taking into account all the safety and arming requirements, Vlatacom Institute developed the entire microcontroller software workflow for the purposes of project P126.

References

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