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Choice and analysis of a block of electronics for the antitank guided missile

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This paper describes the design of a block of electronics for the second generation antitank guided missile. The detailed analysis of the block of electronics functions is done during the missile launching sequence, flight to the target and missile action against the target. The solutions of the electronic circuits for the missile function control are explained, along with their operation and main characteristics. The signals, running through communication link launcher-missile in both directions are shown, together with the signals which, via missile interfaces, the block of missile electronics sends to or gets from the missile subsystems.

Key words: **anttank missile, guided missile, imicro-cable guiding, electronic circuit, interface, thrust vector.**

Notation and symbols

ARM11	–arming position of the SAM1
ARM22	–arming position of the SAM2
ATGM	–anti-tank guided missile
BC	–ballistic cap
BE	–block of electronics
BE1	–BE for SRM ignition
BE2	–TVC actuator BE
BE3	–gyroscope BE-
BE4	–DC/DC convertor BE
BE5	–MC interface BE
BE6	–THCW BE
BE7	–flare BE
BRM	–booster rocket motor
BRMI	–booster rocket motor ignition
CC	–contact cap
CF	–contact foil
CFS	–signal after the contact foil break
CLU	–command and launch unit
COM	–bipolar command signal
D	–“45°” signal from gyroscope
D32	–signal after 32 D-signals obtained
EI	–electrical initiator
EI11	–electrical initiator of the fuse for the first safety position of the SAM1
EI12	–electrical initiator of the fuse for the second safety position of the SAM1
EI21	–electrical initiator of the fuse for the second safety position of the SAM2
EI22	–electrical initiator of the fuse for the second safety position of the SAM2
EDD11	–double action electrical detonator in the SAM1
EDD22	–double action electrical detonator in the SAM2
EMI	–electromagnetic interferences
ERA	–explosive reactive armor
F	–flare
G	–gyroscope
GND	–signal ground
GS	–gyroscope bipolar signal
ICG	–impulse command generator
$I_{FL_{m,n}}$	–electromagnet forced current
$I_{L_{m,n}}$	–electromagnet steady current
IP1, IP2	–ionization probes within WH1
IP1+IP2	–signal from IP1 and (or) IP2
IR	–infra-red
LB	–lithium batteries
LED	–light emitted diode
L_{mnb}	–beginning of the TVC system actuator electromagnet coil
L_{mne}	–end of the TVC system actuator electromagnet coil
LT	–launching tube
MB	–missile electronical assembly mother board
MC	–micro-cable
MEA	–missile electronical assembly
MCRC	–micro-cable returning conductor
PCB	–printed circuit board
PTL	–pyrotechnic lock of the missile
PTLI	–pyrotechnic lock ignition
PTLRC	–pyrotechnic lock switch returning conductor
SAM1	–safe and arming mechanism of WH1
SAM2	–safe and arming mechanism of WH2
SRM	–sustainer rocket motor
SRMI	–sustainer rocket motor ignition
START	–start of the missile
$\overline{\text{START}}$	–inverted start signal
TB	–thermal battery
TBGI	–thermal battery and gyroscope ignition
THCW	–tandem hollow charge warhead
THCW BE	–THCW block of electronics
TVC	–thrust vector control
TVSINC	–signal for the flare synchronization and power supply

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TVT –signal for the flare synchronization during the missile flight
U_{K1}, U_{K2} –unipolar command signals
V –vertical signal from the gyroscope
WH –warhead
WH1 –auxiliary warhead
WH2 –main warhead
J_1 –CLU connector
J_2 –“umbilical” connector
J_3 –micro-cable connector
J_4 –lithium battery housing connection
J_5 –pyrotechnic lock connection
J_6 –BRMI connection (Q_1)
J_7 –connection at the end of MC (Q_1)
J_8 –flare connection (Q_1)
J_9, J_{10} –connectors of the TVC left and right actuators (Q_2)
J_{11} –SRMI connection (Q_3)
J_{12},J_{13} –THCW electronic assembly micro-connectors (Q_4)
J_{14} –MC CF connection

Introduction

THE missile block of electronics is an electronic assembly consisting of printed circuit boards with micro computers, digital and analogue electronic circuits, aimed at controlling the missile subsystems during its flight from the launching post up to the target.

Usually, the missile BE controls and tests the launching sequence, the missile guidance and control, as well as the process of safety, arming and synchronizing of the tandem hollow charge warhead on the target. The complexity of BE depends on the missile type and generation in the sense of the solutions and technologies applied within a particular missile. The second generation ATGM’s BE is much simpler than those belonging to the command guided air-to-surface missiles or the third generation ATGMs having homing heads. Considering the command guided missiles, the guidance “intelligence” is located at the launching post within CLU, so the missile BE is a simple one and has the task of controlling the missile during the flight. On the other hand, in the homing missiles, the BE is more complex because its task is to support both the control and guidance from the moment when the target is located to the moment when it is destroyed.

The missile BE design means implementation of modern microprocessors, integrated electronics circuits and multi-layer printed circuit boards for the sake of reliable functioning of electronic circuits intended for the rocket motors ignition, the THCW initiation and complete missile operation with the final goal to make the gunner, vehicle or launching craft as safe as possible. Because of that, for the rocket motors ignition control, or for the THCW arming and initiation, electronic circuits are used in combination with pyrotechnic delay lines, inertional switches, micro-switches, etc. Those elements, on the basis of the physical parameters obtained during the missile flight (acceleration, number of rotations, distance from the firing post, the wings opening) enable carrying out particular activities during the launching sequence and missile flight. The up-to-date electronics achievements give reliable, pure electronical solutions, such as the line for the THCW action delay at the target. The delay reproduction time within the range of a few hundreds of microseconds and within a wide temperature range of operation, could be obtained in no other manner.

Missile BE design and functions

The ATGW’s front section, comprising BE, is shown in Fig 1, [1].

In the front section there are:

- TB, for the missile electric energy supply;
- G, for the missile angular position and angular rate around the axial axis measurements;
- BE, for the missile functions control;
- WH1 with SAM1, for ERA activation;
- CC assembly, for the THCW initiation.

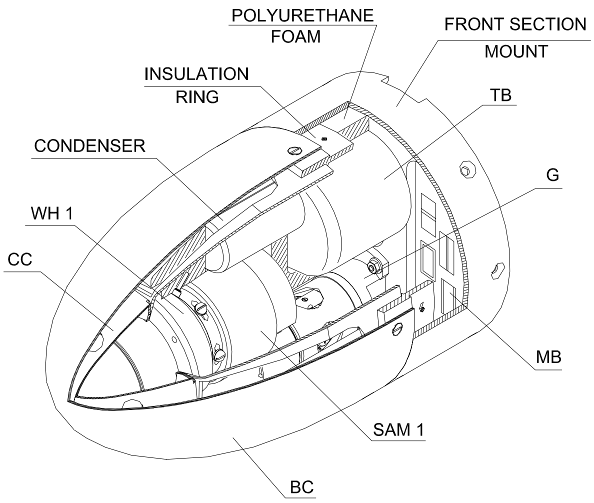

Figure 1. ATGW’s front section

Missile BE consists of the following blocks for:

1. Generating, forming and sending of the G signals, via MC, towards the CLU;
2. DC/DC conversion of the TB voltage to the needed operating voltages;
3. MC interface to the missile BE, for two-way communication realization between the missile and the CLU;
4. SAM1 and SAM2 control, for securing, arming and synchronizing of the THCW action;
5. IR F working control at the working frequency in synchronization with the CLU coordinator.

The missile BE, Fig.2, comprises the blocks of electronics from 1 to 5 in the form of three PCBs with MB and coated by the polymer compound to form an adequate shape corresponding the inner profile of the missile front section, as shown in Fig.1. On PCB1 and PCB2 there is BE2, for the SRM right nozzle and left nozzle. On PCB3 there are BE1, BE4 and BE5, while BE3 is placed on the PCB within the gyroscope.

BE6, Fig.3, is inside a separate housing and is located in the WH2 compartment, around SAM2.

BE7, Fig.4, is made of two circular PCBs coated by the polymer compound and situated on the BRM bottom within the missile wing compartment. On one of those PCBs there are 77 pieces of IR LEDs, and on the other, there is a BE for the flare control.

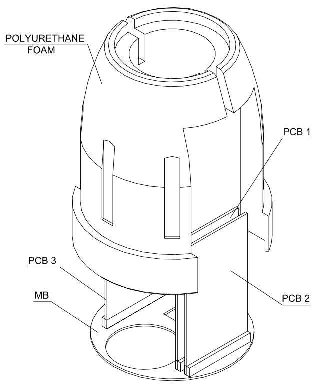

Figure 2. Missile BE

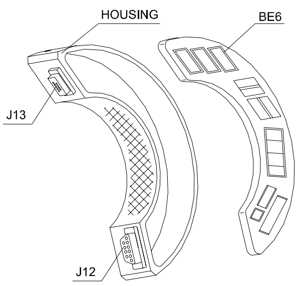

Figure 3. THCW BE

Missile BE design

The missile BE electrical scheme and interface are shown in Fig.5, [2].

BE2, Fig.6, is made of timers 1 and 2, current regulators CR1 and CR2, control logical circuits and power units. Timer 1, which is activated by the command signal front edge, determines the time of electromagnets forced saturation directly from TB during the spoiler movement when they come into the nozzles. Timer 2, which is activated by the command signal aft edge, determines the time of electromagnets' forced saturation directly from the TB during the spoilers movement when they are coming out of the nozzles. CR1 determines the electrical current of keeping the spoilers outside the nozzles, while CR2 determines the electrical current of keeping the spoilers inside the nozzles. The control logical circuits control the switch operation of power units. The power unit consists of transistor switches for the actuators (electromagnets) supply control and it is controlled by the $\overline{START}$, U_{K1} and U_{K2} signals via control logical circuits.

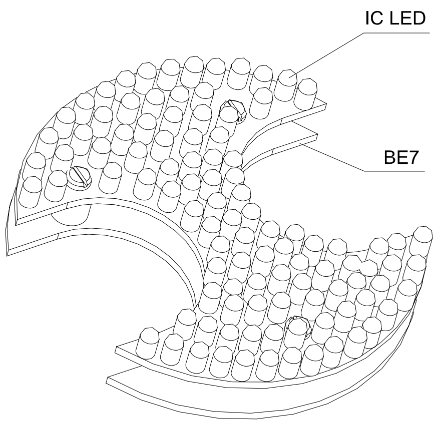

Figure 4. Flare BE

BE2 for the left and right SRM nozzles are the same on PCB1 and PCB2, [3,4]. The BE2, Fig.6, main design characteristics are:

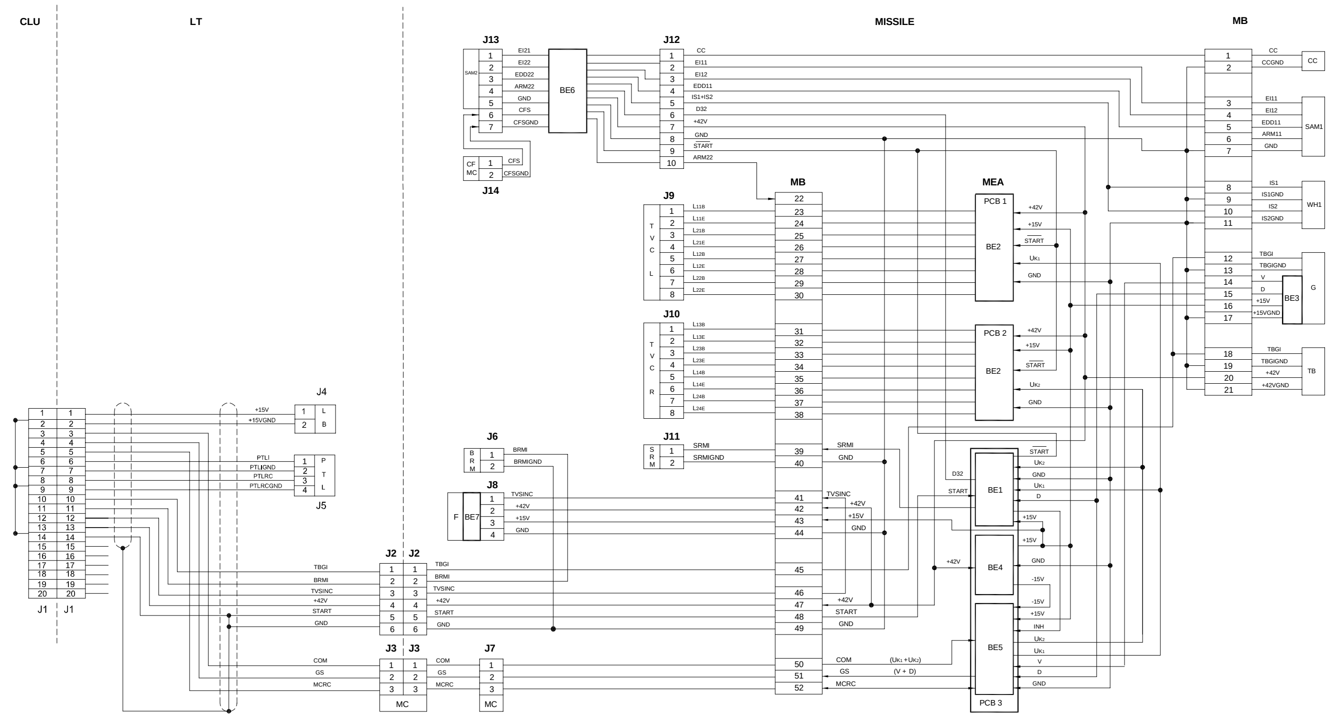

Figure 5. Missile BE electrical scheme and interface

1. The optimum regime of electromagnet power supply. The full voltage from TB, via Q3, Q4, Q11 and Q12 is transmitted only during the spoiler movement for the front and aft edges of command signal duration. That process is determined by timers 1 and 2, respectively, Fig.6. During the command signal stationary period, the supply voltage is reduced to the value defined by the steady current necessary to keep the electromagnets anchors, utilizing current regulators CR1, CR2 and shunt resistors R53, R54, R76 and R77, Fig.6. In that way, the electric energy consumption from TB is reduced, but very good dynamic characteristics of the TVC system are obtained while forcing the spoiler movement, [5].
2. Optimum dynamic characteristics of the TVC system, expressed by the 7 ms of minimum command duration. Those characteristics are realized by the electromagnetic mode of power supply and by the minimization of the self-induced counter electromotive force influence. The electromagnetic voltage of supply is opposed to that force when Q_9, Q_{10}, Q_{15} and Q_{16} are disconnected, Fig.6, [5].
3. The minimum number of current regulators CR1 and CR2 is common for every pair of electromagnets utilizing shunt resistors R_{53}, R_{54}, R_{76} and R_{77}, Fig.6, which determine the feedback referent current, [5].

The time diagrams of the BE2 operation, for a single command, are shown in Fig.7. The signal $\overline{START}$, with the help of timer 2 and switches Q_3 and Q_{11} for forced supply of electromagnets directly from TB, holds the TVC system spoilers in their extreme positions out of the nozzles, until the SRM ignites and the first command appears, Fig. 6.

When U_{K1}, from zero value, goes to the logical level 1 (the front edge of command signal), then electromagnets L_{11} and L_{21} have to release the spoiler anchors and electromagnets L_{12} and L_{22} has to hold them.

The control logics have to:

1. Activate timer 1, during time τ, which should close switches Q_4 and Q_{12} in order to supply electromagnets with forced currents $I_{FL12} = I_{FL22} = 8A$, from the TB, Figures 6 and 7.
2. Disconnect, at the same time, switches Q_9 and Q_{15} in order to minimize the self-induced counter electromotive force influence of the electromagnets L_{11} and L_{21}, but to switch on the switches Q_{10} and Q_{16} and CR1, which, via feedback R_{54} and R_{77} generates the steady current for the spoilers anchors holding within the nozzles, I_{L12}, and I_{L22}, Fig.7.
3. When the time τ passes away, CR1 dictates the work of switches Q_4 and Q_{12} by width modulated impulses Q'_4 and Q'_{12}, while the steady currents $I_{L12} = I_{L22} = 0,6A$

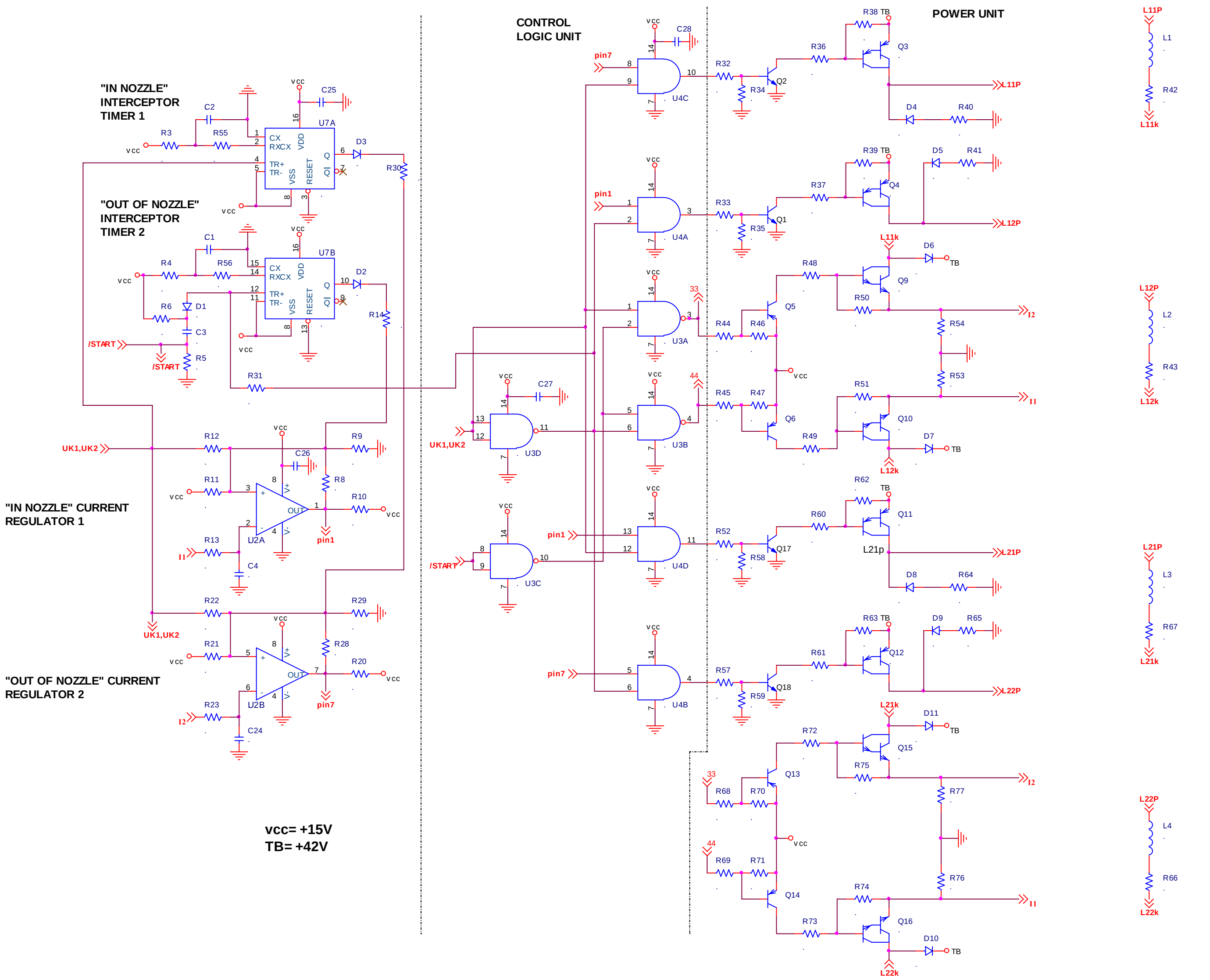

Figure 6. BE2 electrical scheme at PCB1 and PCB2

are running through electromagnets, Fig.7. When voltage U_{K1}, from logical level 1 falls down to 0 (the aft edge of command signal), electromagnets L_{12} and L_{22} have to release the spoiler anchors and electromagnets L_{11} and L_{21} should hold them. The control logics have to:

4. Activate timer 2, during time τ, which should close switches Q_3 and Q_{11} and the forced currents $I_{FL11} = I_{FL22} = 8A$ are running through electromagnets, Figures 6 and 7.
5. Disconnect, at the same time, switches Q_{10} and Q_{16} and to connect switches Q_9, Q_{15} and CR2, which via feedbacks R_{53} and R_{76} establish the steady currents I_{L11} and I_{L21} in order to hold the spoiler anchors out of the nozzles, Figures 6 and 7.

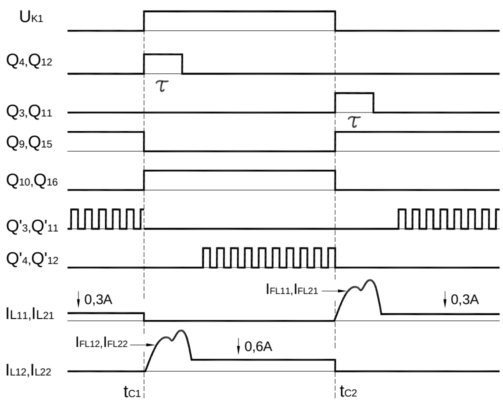

Figure 7. Time diagrams of BE2

6. When the time τ passes away, CR2 dictates the work of switches Q_3 and Q_{11} by width modulated impulses Q'_3 and Q'_{11} while the steady currents $I_{L11} = I_{L21} = 0.3A$ are running through electromagnets, Fig.7.

BE1, BE4 and **BE5** are located at PCB3, Fig.8.

BE1 is made of timers 1, 2 and 3, counters D8 and D32, ignition circuit for SRM, logical circuits LC1 and LC2 and logical block LC3, Fig.8, [5]. The BE1 has the following functions:

7. Igniting the SRM at a distance of about 3 m from the LT muzzle, when the gunner is safe.
8. Permiting the SRM ignition only during the time period of 400 ms from the moment of J_2 disconnection. After that, the SRM ignition is not allowed in order to suspend uncontrolled missile flight for the case of the gyroscope improper work.
9. Blockading the TVC system for, at least, 20 ms after the SRM ignition signal generation till the moment when the SRM membranes burst out and the command signal is zero. In that way, the uncontrolled execution of a part of the command is avoided during the critical phase of the missile entering the "guidance tunnel", [6].

BE1 generates a signal for SRM ignition when the following conditions are satisfied:

- 230 ms have to pass after J_2 disconnecting and the beginning of the START signal, the time which is determined by timer 1, Fig.9, and
- the counter D8 has to count eight D impulses from gyroscope, after which D8 signal falls down to zero.

The counter D32 is used for control of the THCW SAMs, [6].

Logical circuit LC1 controls those conditions satisfaction and generates a 20 ms duration signal for the activation of the SRM ignition circuit, Fig.9. The current I_{ig} in ignition circuit activates EI in the SRM igniter, Fig.9.

The timer 3 controls the SRM ignition circuit by the Twin signal, Fig.9. The SRM will not be ignited if the LC1

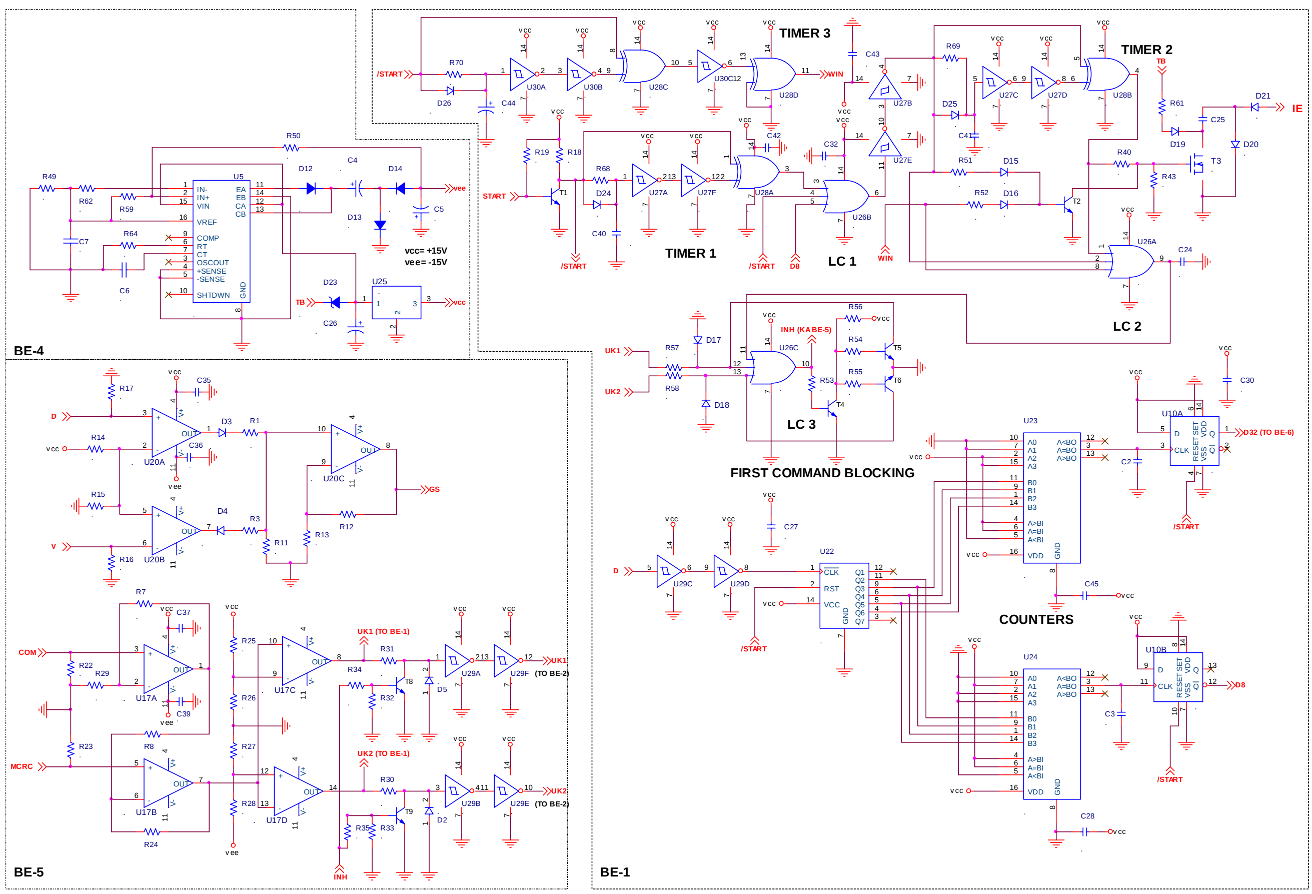

Figure 8. Electrical schemes of BE1, BE4 and BE5 on PCB3

signal drops to zero after 400 ms when J_2 is disconnected, when Twin is at the logical 1.

The TVC system blockage is controlled by timer 2 (via logical circuit LC2) and logical block LC3 (via INH signal), Fig.8. The timer 2, via LC2 and LC3, block the TVC system during 20ms, because the INH signal cancels the command signal at the TVC system actuators ports in BE5, Fig8. The LC3 permanently unblocks the TVC system after, at least, 20ms from the SRM ignition, when the command signals are absent.

BE4 comprises DC/DC convertors which transform TB voltage to the working voltages of -15V and +15V necessary for the missile BE operation, Fig.8

BE5 is an interface at MC with the missile BE in order to enable two-way communication between the missile and CLU, Fig.8, [5]. To the BE5 port, the gyroscope V and D signals, generated during the missile rotation, are brought from BE3, Fig.10. Exploiting the unipolar signals V and D, operational amplifiers U_{20}A, U_{20}B and U_{20}C within BE5 generate the bipolar signal GS which is, through MC, sent to the CLU and gives an information about the missile angular position for the COM signal formation, Fig.10.

The bipolar signal COM from CLU, via MC, enters at the opposite side of the interface, [7]. Operational amplifiers U_{17}A and U_{17}B detect the COM signal polarity and U_{17}C and U_{17}D have the roles of impulse comparator and separator and at their outputs, the voltages U_{K1} and U_{K2} are generated, Figures 8 and 10.

The INH signal from BE1 connects U_{K1} or U_{K2} to the zero if the TVC system deblockage occurs during the command signal presence.

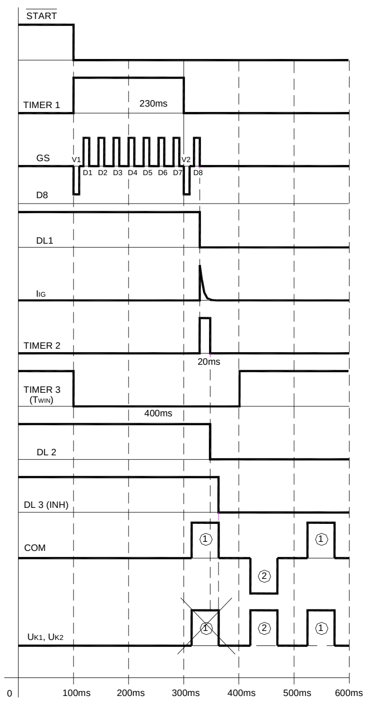

Figure 9. Time diagrams of BE1

In the CLU, at MC side, there is an interface with function similar to BE5, [8].

The MCRC has a function of the BE5 interface virtual mass, and its voltage, in relation to the missile mass, varies ±0,5V, due to asymmetry between signals GS and COM, Fig.10. The comparators U_{17}C and U_{17}D determine the comparison threshold higher than the interference level, so the good reconstruction of the U_{k1}, U_{k2}, V and D signals is provided at both ends of the MC within corresponding interfaces.

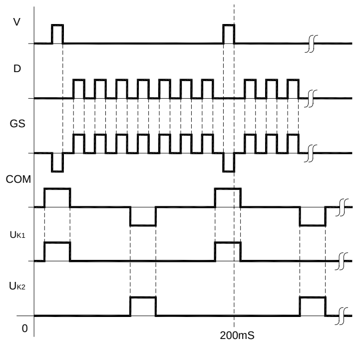

Figure 10. Time diagrams of BE5

BE3 is located at PCB inside the G. BE3 supplies the optical receivers and emitters, also forms the V and D signals, Fig.11. At the exit port of BE3, the V and D signals are generated at the moment when a disc in G, rotating together with the missile, bisects the rays of optical receivers and emitters, [1]. From BE3, the V and D signals are brought into BE5, Fig.8.

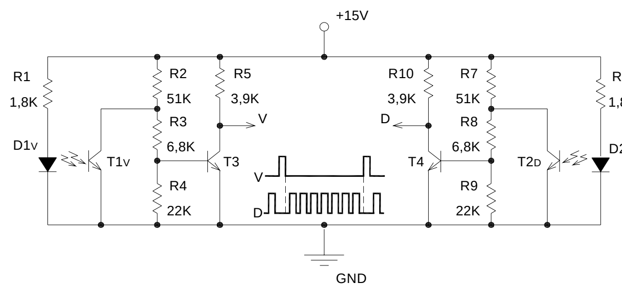

Figure 11. BE3 Electrical scheme and signals

BE6 is located at PCB inside the housing near SAM2 and controls SAM1 and SAM2 in order to ensure, arm and synchronize the action of THCW, Fig.12.

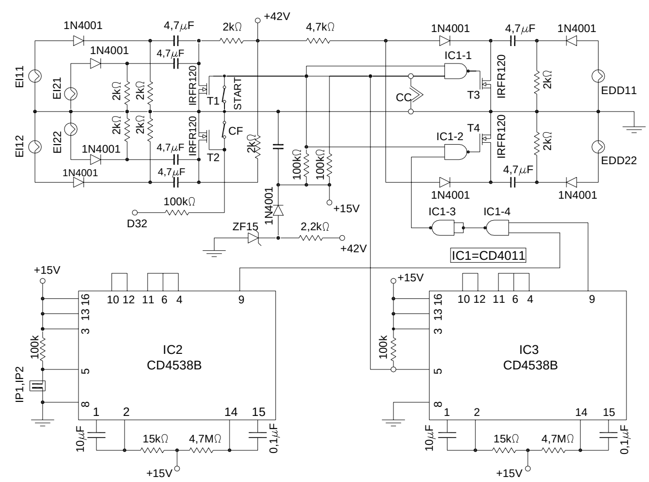

Figure 12. Electrical scheme of BE6

SAM1 and SAM2 have two degrees of safety before arming, [2], [6]. When in safe position, EDD11 and EDD22 are short circuited, positioned out from the axes of WH_1 and WH_2 and can not activate them. Their path to the armed position, EDD11 and EDD22, being located at the rotors in SAM1 and SAM2, have to pass in two steps, which correspond to elimination of two steps of the SAM safety.

The first degree of safety is eliminated when J_2 is disconnected and signal START is generated and the missile reaches the initial acceleration of 100m/s^2 within the LT.

The START signal, Fig.13, activates the FET transistor T1, Fig.12, and enables ignition of EI11 and EI21, which, on the other hand, enables the rotors in SAM1 and SAM2 to pass the way to the second degree of safety. For the second degree of safety elimination it is necessary for the CFS signal to be generated when MC tears the CF at the distance of about 25m from the LT muzzle. Furthermore, the D32 signal must be generated after the missile makes four rotations and 32 D impulses appear, Fig.13. The signals CFS and D32, at the logical unit, activate the FET transistor T2 and enable ignition of EI12 and EI22 thus making the rotors free to bring EDD11 and EDD22 to the WH1 and WH2 axes. In that way, the arming of SAM1 and SAM2 is completed, [6].

In the armed position, the initiating circuits EDD11 and EDD22 are completed in both of the SAMs. When the missile hits the target, the CC makes a short circuit, Fig.13, the FET transistor T3 is closed and activates EDD11 in WH1. Simultaneously, IC3 line is activated to achieve 200µs of delay of WH2 self-destruction, Fig12. The ionization effect of the WH1 detonation brings IP1 and IP2 to the short circuit and the signal IP1+IP2 activates the IC2 line for the WH2 activation delay of 150µs. Signal IC2, being at the logical zero, Fig.13, closes the FET transistor T4 which activates EDD22 in WH2. The IC3 signal, being at the logical zero, Fig.13, activates EDD22 in WH2 for the self-destruction of WH2 in the case its action fails.

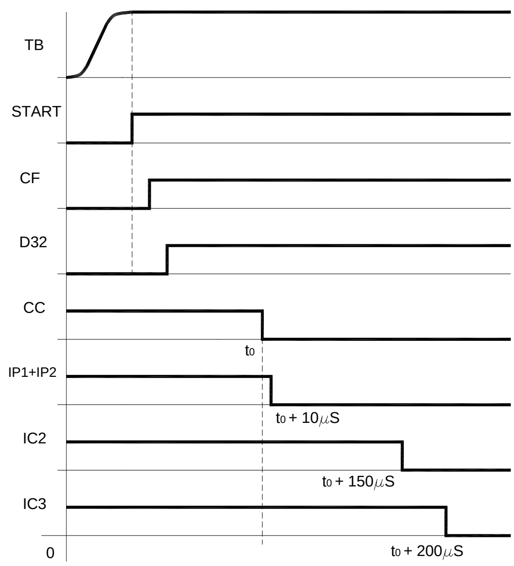

Figure 13. Time diagrams for BE6

BE7 controls supply and operation of the IR flare, which works in impulsive mode (ON-OFF), at operation frequency and in synchronization with the CLU coordinator. Thus, the flare time and frequency discrimination is achieved in reference to the background, as well as the anti-jamming protection of the CLU coordinator. The protection from another flare is higher than 99%, [8], [9], [10].

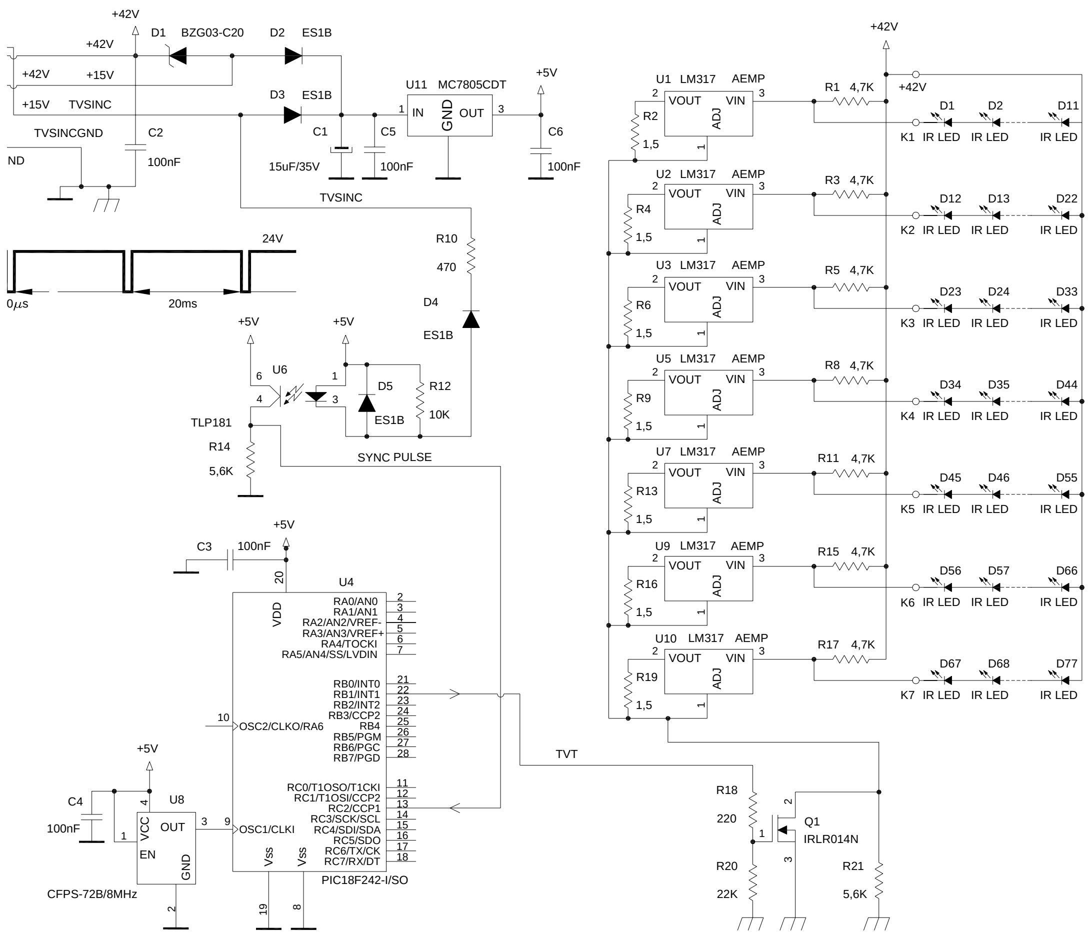

Figure 14. Electrical scheme of BE7

The synchronization between the CLU coordinator and T is established during the missile prelaunch preparation phase, by the TVSINC signal, which the CLU sends to the missile via J2, Fig.5. At the CLU input port, the TVSINC signals are the CCIR separated signals for the TV halfpictures synchronization. At the BE7 input port, those impulses have characteristics as shown in Fig.14 and they are processed in the CLU. The TVSINC secure voltage of +5V for the BE7 to be supplied prior to TB activation and enables microcontroller to identify the coordinator working frequency.

The microcontroller program considers that the coordinator working frequency is identified if eight TVSINC signal periods in series, are constant. In that case, the microcontroller generates the TVT impulses which control the ON/OFF mode of the flare IC diodes lighting and maintain their synchronized operation with coordinator, at least 60s after the TVSINC signal is shot off, during the missile flight, [9].

The IR diodes are supplied from TB in seven parallel lines, by means of seven current regulators and the FET switches which are controlled by the TVT signals, Fig.14. The T radiation is a narrow band at the central frequency of 880nm, it is not monochromatic and coherent, therefore it is not dangerous for the gunner's eyes. The T radiation angle is ± 10° and represents a compromise between the maximum spatial density of radiation and reliable visibility for the expected yaw angles of the missile in flight. The T radiation intensity is sufficient for the T image to have a maximum illumination at the coordinator's CCD cameras picture, during missile's flight to the target. In that manner, the amplitude discrimination of T, in reference to the background, is also achieved, [9].

Check-out and registration of the missile BE key functions is made before it is assembled within the missile. In that test verification of the BE1, BE2, BE4 and BE5 are included. BE3 is to be checked during the gyroscope acceptance tests, while BE6 and BE7 are to be checked during the acceptance tests of THCW and flare.

Conclusion

The missile block of electronics is an electronic assembly which controls the missile subsystems during its flight from the launching post to the target. From the functional point of view, the missile BE consists of blocks of electronics from BE1 to BE7: BE1 for the SRM ignition, BE2 for the TVC system control, BE3 for the gyroscope signal generation, BE4 for DC/DC conversion of the TB voltage to the BE working voltages, BE5 for interface MC with BE, BE6 for the control of SAM1 and SAM2 of the THCW and BE7 for the IR flare control. BE1, BE2, BE4 and BE5 are located on three PCBs with MB, all of them coated by the polymer compound and forming a compacts assembly of profiled shape in order to be packed in the missile front section. BE3 is located at the gyroscope PCB and BE6 at the housing around SAM2 in the missile main warhead section. BE7 consists of two circular boards of IR flare, coated by the polymer compound, located in the missile wing section on the BRM aft bottom. The missile BE is checked before it is assembled within the missile, so BE1, BE2, BE4 and BE5 also pass the control.

BE3 is controlled during the gyroscope acceptance tests, but BE6 and BE7 are controlled during the THCW and flare acceptances tests.

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Izbor i analiza jednog rešenja bloka elektronike protivoklopne vođene rakete

Prikazano je jedno rešenje bloka elektronike protivoklopne vođene rakete 2. generacije. Izvršena je detaljna analiza svih funkcija bloka elektronike u toku sekvence lansiranja, leta do cilja i dejstva rakete na cilju. Prikazana su rešenja elektronskih kola za kontrolu svih funkcija rakete. Opisan je njihov rad i date osnovne karakteristike. Prikazani su signali koji se kroz komunikacioni kanal lanser-raketa šalju u oba smera, kao i signali koje,kroz interfejs rakete, blok elektronike šalje ka, ili prema, od podsistema rakete.

Ključne reči: **protivoklopna raketa, vođena raketa, vođenje pomoću mikrokabla, elektronsko kolo, interfejs, vektor potiska.**

Выбор и анализ одного из решений блока электроники противобронированной управляемой ракеты

В настоящей работе показано одно из решений блока электроники противобронированной управляемой ракеты 2-ой генерации. Здесь сделан подробный анализ всех функций блока электроники в течении последовательности запуска, полёта ракеты до цели и действия ракеты на цель. Тоже показаны решения электронных цепей для контроля всех функций ракеты, описана их работа и даны основные характеристики. А приведены и сигналы отсылающиеся через канал связи пусковой установки - ракеты в двух направлениях, а в том числе и сигналы которые блок электроники через интерфейс ракеты отсылает к подсистеме ракеты или принимает от неё.

Ключевые слова: противобронированная ракета, управляемая ракета, управление при помощи микрокабеля, электронная цепь, интерфейс, вектор тяги.

Choix et analyse d’une solution du bloc électronique chez le missile antichar guidé

La solution d’un bloc électronique du missile antichar guidé de la deuxième génération est présentée dans ce papier. Une analyse détaillée de toutes les fonctions électroniques a été effectuée pendant la séquence du lancement, au cours du vol jusqu’à l’objectif et durant l’action du missile sur l’objectif. On a exposé les solutions des circuits électroniques pour le contrôle de toutes les fonctions du missile. On a décrit leur fonctionnement et donné les caractéristiques principales. On a présenté aussi les signaux qui sont envoyés par le canal de communication lanceur-missile dans les deux sens, ainsi que les signaux que, au moyen de l’interface du missile, le bloc électronique émet ou reçoit du sous-système du missile.

Mots clés: **missile antichar, missile guidé, guidage par microcâble, circuit électronique, interface, vecteur de la force ascensionnelle**