Annex B of report TNO –DV 2008 A064

Report on the influence of magnet(-tools) on the type 72B anti-personnel mine

By Frank de Wolf, TNO Defence, Security and Safety

Introduction

In relation to International Test and Evaluation Programme (ITEP) work on magnetic clutter reduction efficiency by means of a strong magnet the issue was raised that the Type72b anti personnel mine could be set off even when the battery is completely depleted. This report concerns the analysis of the electronics circuitry of a Type72b anti personnel mine. The analysis aims at understanding the electronics and tries to give a prediction model for the magnetic induction characteristic needed to set off the detonator.

First, a short general description of the mine is given to confirm the unmodified Type72b anti personnel mine by means of a series of photos. The operation of the electronics is explained after that. To that end a circuit schematic is extracted from the printed circuit board (PCB) and its operation and characteristics are analysed. Special attention has been paid to the possible detonation caused by induced electromotive force (EMF). An estimation of the required magnetic induction with a worse case approach is added to show that it is highly unlikely that a magnet will cause a detonation.

Type 72B construction

A series of photos is added to give a view of the mine. No comment is added since the photos are self-explaining. At the end some remarks are made.

Figure 1 Left: exterior Type72b top view, right: exterior Type72b bottom view

Figure 2 Type72b opened, bottom casing interior

Figure 3 Type72b opened, bottom casing exterior

Figure 4 Type72b top casing with safety pin pulled

Figure 5 Type72b top casing, PCB (trace side shown) removed

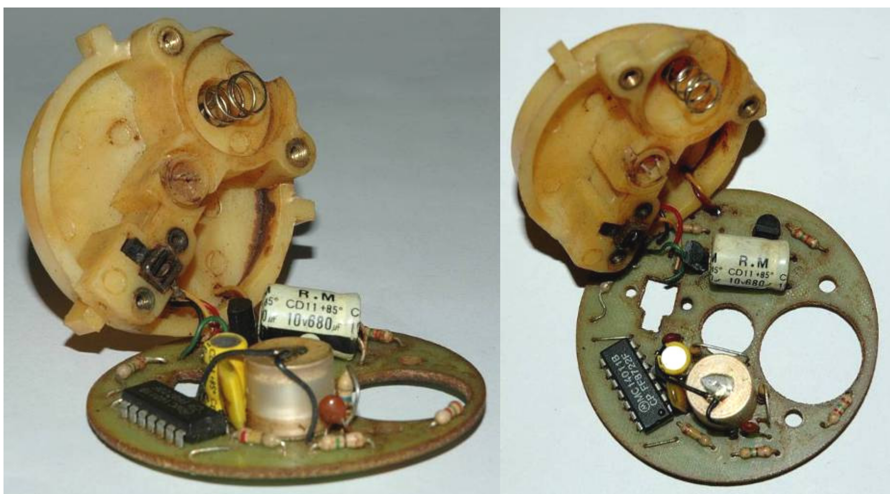

Figure 6 Type72b PCB component side, plastic cap removed. The tilt switch is the component with the two black wires soldered on the top. The electrolytic capacitor (10V680µF) is C1; the DET CAP.

Figure 7 Type72b printed circuit board trace side

Although no comment is added a few remarks are in place:

- The behaviour of the electronics circuitry will depend on the resistance of the detonator, the speed of C1 discharge is also determined by this value. This speed determines the power that is needed for detonation.
- No mechanical detonation device is found nor an electrical connection to the PCB for such a device.
- Around the detonator there is a trace with two solder points that are not connected to anything, what is the use of this, is this a kind of 'grounding' for the detonator?
- It is not one hundred percent sure whether the electronics of this specimen will still function properly, it is still worth a try.
- Based on the trace there is no reason to believe that a significant magnetic induction will/can occur based on an extreme low frequency magnetic field. A direct charging of the capacitor is therefore also unlikely (maybe not impossible).

Schematics analysis

The schematics are retrieved from the printed circuit board manually. The switching capabilities have been left out. The armed status will be depicted. The circuitry is not too complicated and the schematic is found in Figure 8. The whole principle is based on a sensor that detects tilting/displacement of the mine and which is basically a switch. When the amount of tilt is too much or the movement to abrupt (large acceleration) then the switch (U5) will close and cause a detonation. The switch, when not armed, shorts the upper lead of the detonator (the one connected to C1) to ground and at the same time keeps the ground disconnected from the battery.

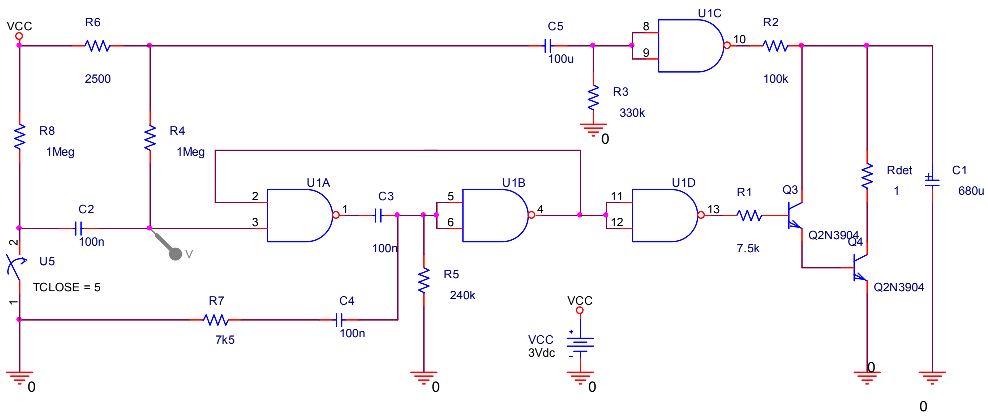

Figure 8 Circuitry schematics for Type71B anti personnel mine

From start-up, evoked by the removal of the safety pin, the mine gets into a (relatively) stable but armed condition. A short time after the circuit is activated (determined by the time constant $\tau_{C5.R3} = 33$ seconds) the detonation capacitor C1 will be charged. Q3 and therefore Q4 will be closed and the output of gate U1D will be low. The input of the same gate therefore has to be high (this gate is switched as an inverter). Further towards the input, if the input of U1D is high then the output of U1B, used as an inverter, is high and its input is low. A high input of U1D means a high input for U1A on 2 and combined with the high input on 3 this produces a low output on U1A. C3 blocks DC signals and when the gate output of U1A changes a filtered signal will be passed on into the chain of gates towards the bipolar switching transistors. So far the stable, resting, status is described.

When switch U5 closes a short negative pulse will appear on U1A input 3 (bringing it towards ground), combined with the high input 2 the output of U1A will become high. Again a short pulse will pass C3 and make the input of the U1B inverter low. The feedback from the inverter output towards the input 2 of U1A makes the circuit freeze into a new stable condition in which the output of U1B is kept low (as long as switch U5 does not close again). The stable condition with the input of U1D in a low condition produces a high output on the same gate. The high output switches Q3 and Q4 in de open condition thus enabling the capacitor C1 to discharge, through Rdet, to ground. When this happens fast enough sufficient power is produced to ignite Rdet (the detonator).

The stable condition could be maintained long when the battery (lithium cell) is capable of keeping C1 charged long enough and when current consumption is low (high internal impedance of the battery). Once the capacitor is charged it only needs only very little current to remain charged. The only current it looses is probably due to the leakage in its own internal resistance.

Note: C2, C3, C4 values are guesses (no clear marking). U1 is a M14001B logic NAND-gate. Q1 and Q2 are respectively a SS9011 NPN AM converter and a C2500 NPN medium power amplifier. The detonator characteristics are not known and therefore an internal resistance of 1 Ohm is chosen (this is a representative value).

Simulations

Some simulations have been carried out in MSim8 PSpice. Due to simulation limitations the simulation had to be carried out with a different supply voltage. The logical components are default supplied with a 5Volt supply voltage internally in the model.

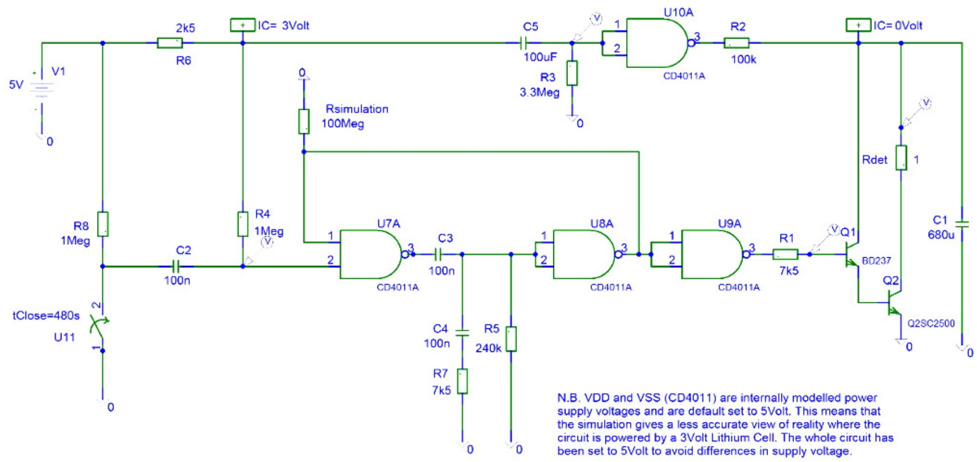

Figure 9 Schematics used for simulation

The circuit in Figure 9 is used in the simulations. The IC (Initial conditions) labels are used for the simulation itself to set a certain voltage level at the start of the simulation making the start-up more realistic. The IC also help to solve convergence problems in the simulation. The pointers with V in them are probes and they designate the spots that are directly probed for their voltage and these probe voltages are shown after the simulation. The simulation results are shown in Figure 10, Figure 11 and Figure 12. These figures give the simulation results for respectively the start up behaviour and the trigger behaviour. The trigger moment is set at t = 240 seconds.

The assumption that the circuit could remain active very long could not be simulated because of the implemented model constraints for the 4011 logic devices. A series resistance for the power supply could otherwise have been implemented. However, it is more than likely that the circuitry will remain active for a long period since none of the components uses any serious power and current consumption is extremely low (less then 0.25µAdc for the 4011 device). The battery doesn't provide the current for the detonation but C1 does, so when Q1 and Q2 are opened then C1 is discharged. Only the power needed for the opening of Q1 comes from the battery.

The start up is delayed by the combination of R3 and C5. V(R3:1) shows a falling voltage that crosses the input threshold for the NAND gate at approximately 3.5 Volt , this happens at t = 120 seconds. This condition is apparently a kind of meta state and lies in between the logic 0 and logic 1 thresholds. The input is nevertheless inverted at the output and the C1 capacitor starts to charge. The second start up simulation plot shows the transition to the defined logic state. A concrete step is recognised at 150 seconds towards a new level (5Volt).

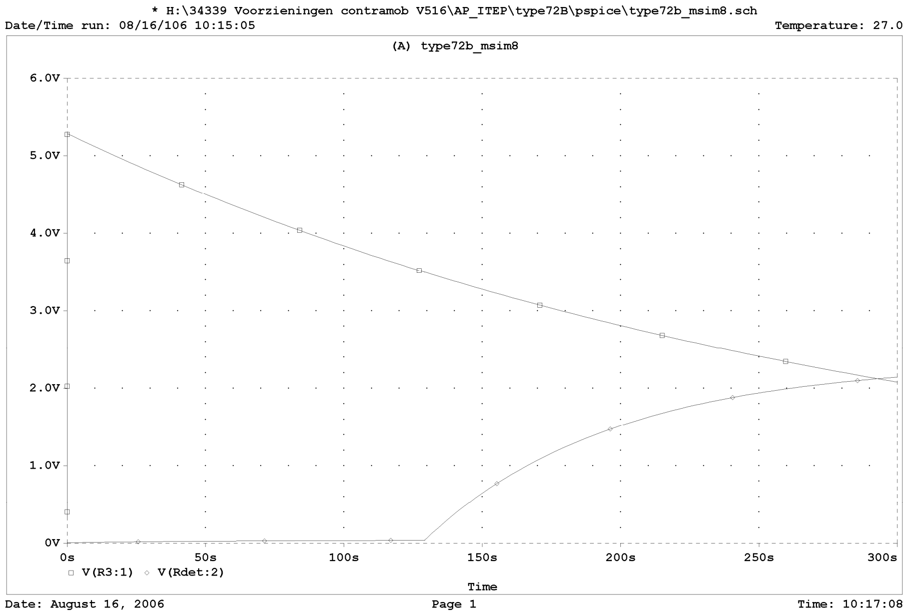

Figure 10 Initialisation; Start-up with R3C5 time constant

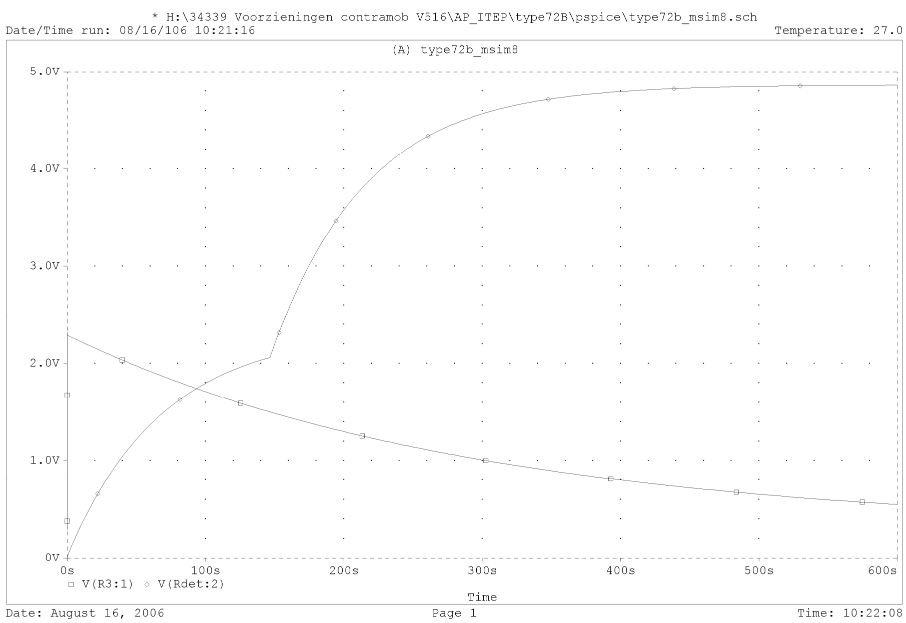

Figure 11 Initialisation; Start up with R3C5 time constant, after approximately 150 seconds C1 gets charged at a different voltage.

It may be clear that the mine is only safe during the first 120 seconds after start up (based on simulation results, which therefore has to be verified). It is estimated from the simulation results that the mine can be considered to be in its (stable) operation condition after approximately 4-5 minutes. However, it is possible that the mine can go off before that in the phase between 2 and 4 minutes after removing the safety pin.

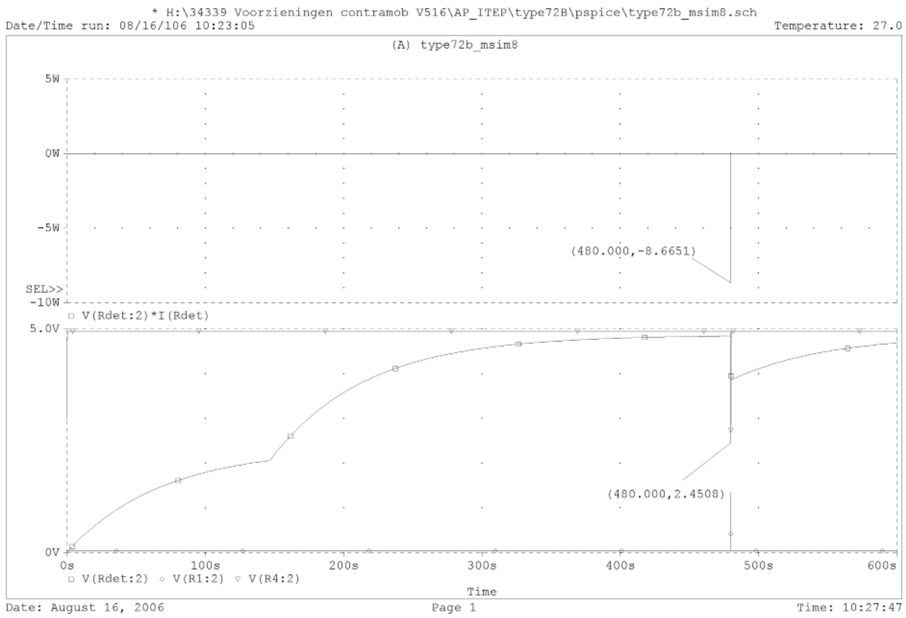

Figure 12 Triggering behaviour; Top trace shows power development over Rdet, mind that the power supply voltage level is almost twice as high as in reality (due to simulation restraints). The lower plot shows the trigger events at different locations in the circuitry.

The detonation is triggered when the switch is closed. The switching moment is set at t = 480 seconds. V(Rdet:2) clearly shows a drop in voltage, which means that C1 is shorted (through Rdet) to ground by Q2. The power peak developed for this simulation (Vcc = 5Volt!) is approximately 8 Watts. The duration of the pulse is determined by C3 and R5 (τ_{R5C3} = 2.4 msec).

The circuit impedance around C1 will become very high once the battery has run out. There is no loop and therefore it is impossible for C1 to become charged due to inductive phenomena. A worse case scenario might be considered in which a coarse reduction of the circuitry is assumed. This scenario is discussed in the next paragraph.

Field estimation (needed for detonating)

The amount of energy needed by the detonator follows from the value of the capacitor. The time constant made up by the detonator impedance and the capacitor determine the power that could result from this situation (the capacitor is shorted through the detonator to ground).
The energy stored in the capacitor follows from $E_{CAP}= ½ .C.V^2$; where C is the capacitance (680µF) and V the voltage over the capacitor (3 Volt). That makes E_{CAP} = 3.06 mJ. When this energy is released in a time span of one τ ($\tau = R_{det}.C_{det}$ = 1Ω . 680 µF = 680 µs) then $P_{det,\tau} = E. \tau^{-1}$ = 4.5 Watt.

If the circuitry is reduced to a single coil with a diameter of 6 cm then a worse case approach is possibly to estimate the magnetic field strength and its change that is necessary to provide sufficient power/energy to set off the detonator. Note: this scenario is assuming what could happen when a coil with the 6cm diameter is found on the PCB. If any loops are found on the PCB then they most certainly will be smaller than this worse case one and therefore less capable of picking up any fields.

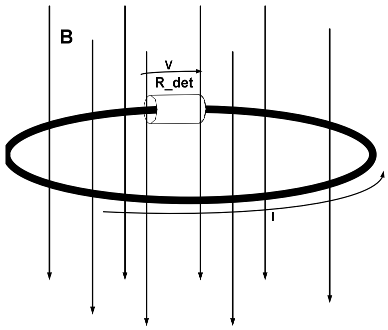

Figure 13 Coil in field

The assumed situation is represented in Figure 13. The homogenous field is perpendicular to the coil and Rdet is placed somewhere in the coil. For this particular situation it can be derived that $B(t) = B_o.\sin\omega t$ and $\varphi_B(t) = N.S.B_o.\sin\omega t$ with $S = 2\pi r^2$. The electromotive force (EMF) is $V_E(t) = d\varphi_B(t)/dt = -N.S.\omega.\cos\omega t$.

The power, developed over $R_{detonator}$, is $P_{det,Beff} = V_E^2/R_{detonator} = P_{det,\tau} = 4.5$ Watt.

Substituting N=1 and r = 0.03m we find,

$B_o = \omega^{-1}. (P_{det,\tau}.R_{detonator}.\sqrt{2})^{½} .(-2.\pi.(0.03)^2)^{-1} = -71.f^{-1}$ where f is the frequency.

The table below gives the B_o for a number of frequencies. Even for a frequency of 10kHz the required field is still 7.1mT, which is considerably large (160x the magnetic induction of the earth magnetic field).

Table 1 B_o for given frequencies

Frequency [Hertz]	B_o [Tesla]
1	71
10	7.1
100	0.71
1000	0.071
10000	0.0071

When a magnet is moved manually the frequency components that may be expected are smaller then 10Hz, so this means that the magnetic induction involved must be larger than 7.1Tesla. This is not very likely. Taken into account the fact that this is a worse case scenario and a stated before, the loop that is assumed is considerably large so the field needed will be consequently much larger that the ones calculated here.

The conclusion may therefore be that there is no reasonable way to set off the detonator in this circuitry by means of a manually moved magnet.

General conclusion

Setting off a Type72b anti-personnel mine of which the battery is completely depleted by means of a manually moved magnet is not possible, not by charging the detonation capacitor nor by direct induced power.

A warning is in place although: When the battery is not completely depleted but is still maintaining sufficient power to keep the logic devices running and to prevent the detonation capacitor from discharging then a severe risk is present that the tilt-switch is set off. This situation can occur during a long period after deploying the mine. The components run on extreme low power and the capacitor will discharge only very little. Although the battery soon will no longer be able to provide large current, because of a high internal resistance of the battery, it will still be able to keep the circuitry operational. How long this situation will persist can not be said without elaborate measurements and analysis. One could however bear in mind that LCD clock modules seem to run for years on the same battery (often the same kind of Lithium cells).