A Guide to Using EPIC / MEPIC Igniters in Pyrotechnic Applications

By Rodolphe Cauro

INTRODUCTION

The markets for pyrotechnic applications such as detonators and initiators require ever-higher levels of performance, reliability, and safety. These days, the bridge wire (BW) is the leading technology in a wide range of industries, including mining (rock fragmentation), automotive (airbags and seatbelt pre-tensioners), demolition (tunneling and building), military (missile destruction), and special effects (fireworks and movies). Although BW technology provides good performance, it requires specific detonator / initiator designs in which the header and the wire always have to be adapted to one another. In order to offer design and process alternatives, Vishay has developed surface-mount (SMD) solutions whose performance is not dependent on the header: the EPIC and MEPIC series. Furthermore, these SMD solutions enable manufacturers to build a productive assembly process based on standard state of the art equipment (pick and place from reel packaging, reflow soldering, and post cleaning).

PYROTECHNIC APPLICATION REQUIREMENTS

The generic concept is to apply an energetic (pyrotechnic) material in close contact with the heating zone of the EPIC / MEPIC, called the active area. Upon different electrical solicitations (from capacitive discharge or direct current pulse), the energy provided to the EPIC / MEPIC will be either fully thermally transferred to this primer pyrotechnic material or sufficiently dissipated through the substrate, leading to two major functioning modes:

- All fire: ignition will occur because of the high temperature rise of the primer pyrotechnic material
- No fire: ignition will not occur because of the insufficient temperature rise of the primer pyrotechnic material

We can also consider electrostatic discharge (ESD) as a no fire mode, because the goal is that ignition will not occur while applying ESD stress to the EPIC / MEPIC.

In some cases, the end of production electrical test is also a no fire requirement to fulfill.

ILLUSTRATION

EXAMPLES OF TYPICAL REQUIREMENTS	MINING	AUTOMOTIVE	MILITARY
Pyrotechnic material (ignition temperature)	PETN (190° C)	ZPP (400 °C)	KDNBF (210 °C)
All fire	6.8 µF / 5.6 V	1.75 A / 0.5 ms	30 µF / 4.5 V
No fire	6.8 µF / 3.3 V	0.6 A / 10 s	1 A / 5 s
ESD	-	25 kV (10 pulses)	-

A Guide to Using EPIC / MEPIC Igniters in Pyrotechnic Applications

EPIC AND MEPIC MANUFACTURING AND TECHNOLOGIES

The EPIC and MEPIC are manufactured according to two different technologies.

EPIC - 0603 Case Size

Materials: alumina substrate, tantalum nitride resistive layer, terminations with gold or tin finish over nickel

The manufacturing process is based on semiconductor equipment (thin film deposition), with end of production controls based on automatic optical inspection (AOI).

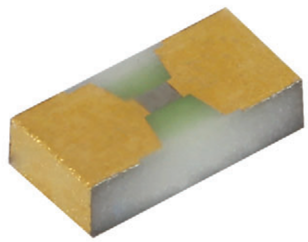


Fig. 1 - EPIC Construction

MEPIC - 0805 Case Size

Materials: epoxy-based substrate, NiCr resistive layer on adhesive, terminations with a tin finish over copper

The manufacturing process is based on both printed circuit and semiconductor equipment (foil technology), with end of production controls based on AOI

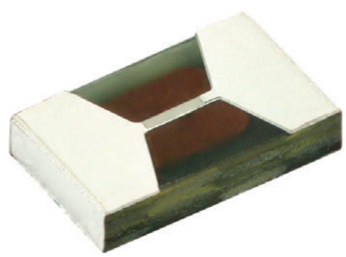


Fig. 2 - MEPIC Construction

For both EPIC and MEPIC product lines, the end of line manufacturing tests are based on AOI, which consists of using a high resolution CCD camera to perform a detailed inspection of the top side (including active area) of the devices.

This AOI testing is specifically measuring the width of the active area of each device and will reject those out of the specified range. The measuring accuracy is in the range of ± 1 μm. In addition to dimensional measurements of the active area, the AOI will also check its integrity (no damage, no missing resistive material, and no pollution).

Furthermore, the AOI will also check for different visual defects or cosmetic effects from the top-side terminations in accordance to Vishay's internal specifications.

In addition to the AOI testing, the resistance value of each device is measured and those that are out of tolerance are rejected. The reference for this electrical measurement is taken on the back-side terminations.

In addition to the monitored manufacturing process for both the EPIC and MEPIC series, this 100 % end of life testing is one of the key benefits to providing reproducibility and reliability in an application.

For the purpose of qualification, Vishay also performs some "Bruceton" type test based on the capacitive discharge method (without pyrotechnic material) in order to verify the duration of active area breakage (DAAB). This DAAB is taken as an internal indicator without being part of a requirement (depending on the pyrotechnic paste property).

A Guide to Using EPIC / MEPIC Igniters in Pyrotechnic Applications

For both EPIC and MEPIC technologies, the active area will be designed according to customer requirements and Vishay's know-how in order to provide the appropriate active area volume. In addition to the resistance value requirement, Vishay will also consider the different levels of energy or current for the application and the type of pyrotechnic material (through its auto-ignition temperature) to calculate the appropriate dimensions (thickness "T" - length "L" - width "W") to build the active area. The active area shape is very often rectangular, but for high energy application other shapes might be considered. The basic concept is to enable high energy monitoring capabilities for both all fire and no fire modes.

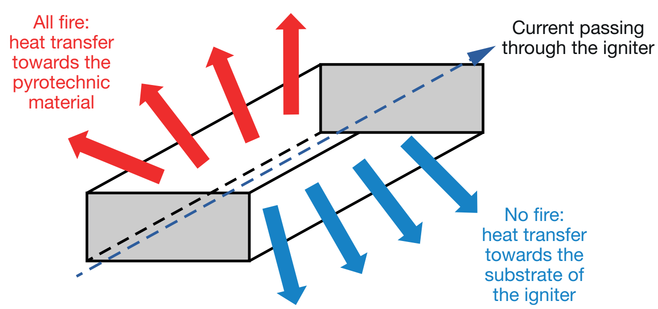


Fig. 3 - Basic Concept of Igniters

The electrical energy provided to the EPIC or MEPIC is: E_{ELEC} (J) = R (Ω) x I (A) x I (A) x t (s)

The resistance value is: R (Ω) = [ρ / T] x [L / W]

ρ is the volume resistivity of the resistive material

T, L, W are the dimensions of the active area

The current intensity I (A) and pulse duration t (s) are dependent on the firing method (direct current or capacitive discharge) and set up.

The electrical energy is transformed into thermal energy (1): E_{THERM} (J) = m (kg) x Cp x ΔT (°C)

m is the mass of the active material

ΔT is the temperature rise of the active area

Cp is the thermal capacity of the resistive material

Note

(1) For peculiar applications, when the sublimation of the active material is required (plasma ignition), the "Gibbs-Helmholtz" sublimation enthalpy $\int_{T_{sub}}^{T} \frac{\Delta H_{sub}}{RT^2} \times dT$ term has to be taken into account

To shorten the iteration sequence needed to define the right active area design, and thus minimize the time and cost for qualification, the customer is asked to provide Vishay with the maximum amount of information regarding the application requirements. For this purpose Vishay has built a common design guide for both EPIC and MEPIC (linked to the datasheets) devices, and after analyzing all the data Vishay will state whether the EPIC or MEPIC will best fit the application.

Generally speaking, the EPIC will more likely fit very low energy applications with very fast ignition, whereas the MEPIC will more likely fit applications where energy levels are larger and where the component itself must be able to withstand higher ESD. In any case, Vishay will propose the solution that best fits the customer-specific requirements.

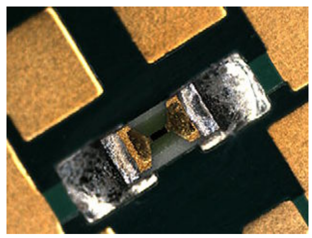
On the application side, the mining industry uses both EPIC and MEPIC resistors, whereas specific focus is given to the EPIC series in military applications and the MEPIC series in automotive applications.

A Guide to Using EPIC / MEPIC Igniters in Pyrotechnic Applications

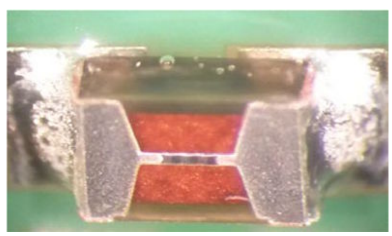
REFLOW SOLDERING ASSEMBLY

Being SMD components, the EPIC and MEPIC enable the use of the standard reflow processes for assembly. In addition to providing a good electrical contact, the assembly must take extreme care in insuring that the active areas of EPIC and MEPIC resistors remain clean from flux residues from solder paste to provide intimate contact with the pyrotechnic material. In combination with the use of standard land patterns (according to P datasheet - P0603 or P0805), the EPIC and MEPIC series have specific constructions that will strongly minimize the presence of flux at the active area. Nevertheless, post cleaning must be performed in good conditions in order to not generate any pollution that could be redeposited on the active area.

- The EPIC 0603 with gold terminations includes a "solder stop" function, which keeps the solder away from the active area. The solder will not spread beyond the area of the top-side part of the wraparound termination, and therefore the flux will remain far from the active area to eliminate any risk of pollution



- The MEPIC 0805 has a substrate thickness of 0.6 mm, which will not allow the flux to migrate to the active area. Flux could spread via the epoxy-based substrate (cut edges) and not from the wraparound termination sides. In combination with appropriate land pattern, the 0.6 mm thick substrate ensures that the flux will stay at the level of the cut edges and that it will not be able to migrate to the MEPIC top side. Flux is then kept away from active area to eliminate any risk of pollution



For full assembly precaution recommendations, please consult the datasheets.

Note that the EPIC and MEPIC are compliant with standard SMD component reflow profiles.

PYROTECHNIC MATERIALS

The pyrotechnic materials are chosen by the customer.

In this document we will only speak about the primary pyrotechnic material (primer), which is in direct contact with the active area of EPIC / MEPIC resistors and initiates the explosion. The heat provided by EPIC / MEPIC devices when submitted to an electrical solicitation will provide a sufficient temperature rise to make the primer explode. Following this first-stage explosion, a secondary-stage explosion will be initiated by the heat generated from the first, and will create the final explosion (inducing shock wave for detonators or gas generation for airbags).

The customer process for the primer pyrotechnic material can be in a lacquer form (applied by dispensing or by dipping) for the so-called "wet process" or in a powder form to be compressed on the active area for the so-called "dry process".

The major characteristic of a primer pyrotechnic material is its auto-ignition temperature. The most commonly used family of primers are listed below.

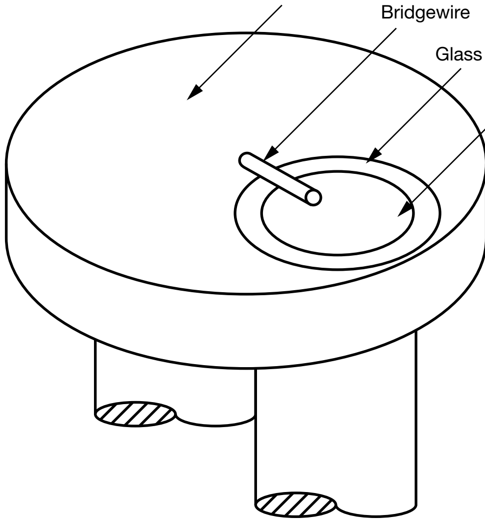
ILLUSTRATION		
PRIMER CODE	PRIMER NAME	IGNITION TEMPERATURE
PETN	Pentaerythritol tetranitrate	≈ 190 °C
KDNBF	Potassium dinitrobenzofuroxane	≈ 210 °C
BKNO3	Boron potassium nitrate	≈ 210 °C
ZPP	Zirconium potassium perchlorate	≈ 400 °C

A Guide to Using EPIC / MEPIC Igniters in Pyrotechnic Applications

Despite the chemical nature of the primer, it is important to consider the particles' size to enable intimate contact with the active area. For very sensitive applications with small active areas, it is strongly recommended to consider nanometer particle sizes instead of micrometer. In addition, for the purpose of performance reproducibility, the primer must be prepared in a manner to obtain a very homogeneous mixture without air bubbles inside.

THE ASSEMBLY PROCESS ALTERNATIVES

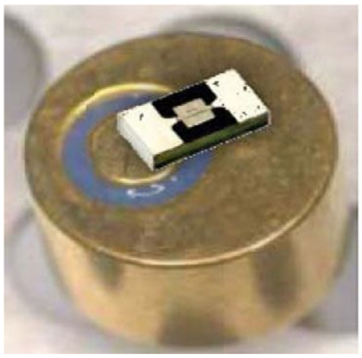
The principal assembly concept in BW technology is to electrically solder a NiCr wire onto a header with a highly lapped surface to provide an intimate contact. This construction is mostly applied for high performance applications (in airbags), whereas standard fuse heads will use standard PCBs. The resistance value is given by the length of the wire, and depending on this length and the wire diameter, the header design or PCB might need some adjustment (the provided example is an automotive header).

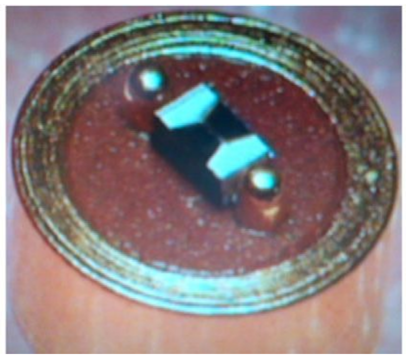


Being SMD products, EPIC and MEPIC resistors are most often reflow soldered on flat PCBs. As the resistance value is fully dependent on the active area dimensions being part of the global package size (0603 for the EPIC and 0805 for the MEPIC), the PCB will not need any design adjustment and the standard land patterns will be used, whatever the intended ignition performance.

A Guide to Using EPIC / MEPIC Igniters in Pyrotechnic Applications

In addition to conventional uses for EPIC and MEPIC devices, we can also consider various mounting possibilities for user who have specific requirements and are ready to develop complete solutions.





DETONATORS AND INITIATORS

After assembling the EPIC and MEPIC using a reflow soldering process and applying the different stages of pyrotechnic materials (depending on the application), the next step will be to enable the electrical connection between the detonator and the firing equipment. For that purpose, it is necessary to solder copper-insulated wires (cables) onto the PCB pads, which will have different lengths depending on the intended usage. On the other side of the cable, an appropriate connector will be soldered. For process productivity reasons, cables will never be attached to the detonator prior to the pyrotechnic material application, even for simple devices like electric-matches or fuse heads, because the handling of cables during the process is very inappropriate.

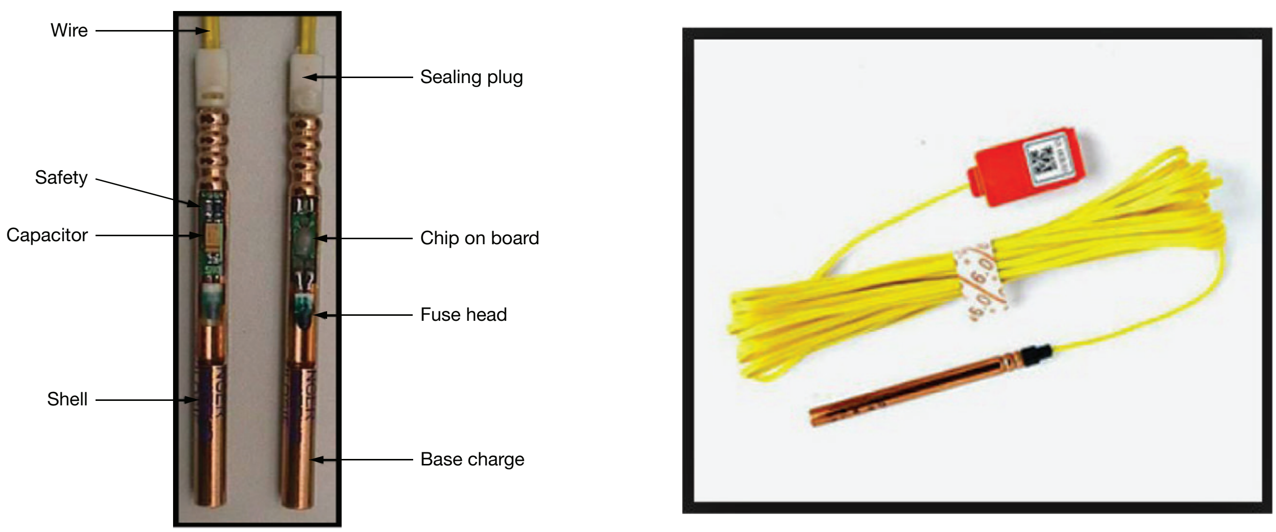


Fig. 4 - Detonator Construction

A Guide to Using EPIC / MEPIC Igniters in Pyrotechnic Applications

THE FIRING METHODS

The two usual firing methods used for providing electrical energy to ignite electro-explosive devices (EED) like electronic detonators and initiators are the capacitive discharge and the direct current.

The capacitive discharge is usually employed where a rapid rate of energy input is required. This is accomplished by making the discharge time τ (with τ = R x C, R being the sum of EPIC / MEPIC resistances and serial resistance values for adjustment purposes, and C being the capacitance value charged at the appropriate voltage V) short in comparison to the cooling time of the active area of the EPIC / MEPIC (the same principle as for the bridge wire). τ is typically in the range of a microsecond. It is also important to consider that both the energy ($E = ½ C \times V^2$) and the discharge time τ must be compatible with the pyrotechnic chemistry in order not to generate a blow up of the active area without leaving enough time for the heat to ignite the pyrotechnic primer (this would cause a misfire).

Direct current pulses are generally not employed in the low microsecond region because of the difficulty in shaping and regulating a high amperage square wave pulse.

NECESSARY SKILLS FOR THE DEVELOPMENT OF PYROTECHNIC DETONATORS BASED ON EPIC / MEPIC PRODUCTS

Although Vishay has advanced expertise in the design and manufacturing of EPIC and MEPIC resistors for pyrotechnic applications, it is not sufficient for advising in detail on the design and manufacture of complete pyrotechnic solutions. It is necessary for the user / designer to have specific skills in the chemistry of explosives, electronic skills to find the best firing method and sequence for high performance, and industrialization for manufacturing in a reliable and reproducible manner.

Based on a customer's overall requirements, Vishay will be able to propose an EPIC / MEPIC product as a base for the project's start, but all the set up will require a lot of testing and maybe some compromises on the initial requirements. It is very important to test all customer configurations to always validate that the thermal exchange towards the pyrotechnic material (all fire mode) or towards the substrate (no fire mode) is under control. Once an EPIC / MEPIC is qualified, it is also important to consider that the qualification is valid for the given application and that for further projects a completely new qualification must take place.

The features provided in this document are for information and guidelines only and the devices must not be taken as "turn-key" solutions.

ADVANTAGES OF USING EPIC AND MEPIC TECHNOLOGIES COMPARED TO BW

Using EPIC and MEPIC resistors offers several advantages compared to BW, mainly in the deployment of standard SMD methods for both the design and manufacturing of detonators and initiators.

The PCB, or so-called header, will be designed with a common SMD footprint (0603 or 0805 case size) and the assembly process will be based on pick and place from tape and reel packaging, followed by a standard reflow soldering process. By using such standard processes, the achievement of high throughput is possible. Moreover, SMD technology allows designers to avoid using the costly polished headers that are mandatory for BW technology.

To meet specific performance requirements, Vishay is able to customize the active area of the EPIC and MEPIC without affecting their case size, and hence without affecting the initial footprint on the PCB or header, which will provide a common base for various applications. From a design and development point of view, it is also important to consider that despite the interface with the pyrotechnic material, the use of EPIC and MEPIC devices will avoid any reliability issues from electric soldering during assembly and will also enable a downsizing level where only the reflow soldering can be applied. Smaller case sizes could be considered (please consult Vishay).

Regarding performances, the low active mass of the EPIC allows it to use very low firing energies (typically < 100 μJ).

Finally, the highly monitored manufacturing process for both EPIC and MEPIC resistors, combined with the strong AOI, will provide high reproducibility and reliability, which remains a key issue in insuring safety in field applications.

A Guide to Using EPIC / MEPIC Igniters in Pyrotechnic Applications

FEATURES

For the purposes of a specific study with EPIC / MEPIC resistors in combination with pyrotechnic primer mixtures (KDNBF and ZPP), the EPIC / MEPIC devices were soldered onto a small PCB specifically designed to simulate the start of the manufacturing of an electronic detonator. They were then coated with the different primer mixtures (several wet pyrotechnic and drying sequences) and ready to be exposed to a capacitive discharge energy pulse.

To avoid busting of the EPIC / MEPIC active area before all the capacitive discharge energy is transmitted, and to safely enable the heat transfer to the primer mixture, the testing procedure had to define the best combination of firing circuit parameters (capacitance value and additional serial resistance).

By using this procedure, it is possible to complete the energy transfer from the capacitor to the firing circuit. As a result, the firing data cannot be expressed purely in the form of absolute energy stored at the firing capacitor, but must be expressed in the form of specific impulse of energy density in the firing circuit, which is shown in the form of Joule per resistance (J/Ω). Consequently, the necessary energy for the initiator function is given as the product of specific impulse and the EPIC / MEPIC resistance value.

The global test summary is given in the below table, which has to be taken as an example of the possible performances from an “electronic detonator”. These features were generated from tests “in the air,” which means without a confined environment (not encapsulated like in real detonators).

Note that for the understanding of some performance features, it is important to consider that the active area volume is a key parameter. The Joule per resistance (J/Ω) has to be completed with some design considerations, which are part of Vishay’s know-how.

FEATURES					
PART NUMBER	**EPIC0603L2R0S**	**EPIC0603M9R5K**	**MEPIC 8805**	**MEPIC 8805**	**MEPIC 8022**
Technology	Thin film (Ta_2N)	Thin film (Ta_2N)	Foil (NiCr)	Foil (NiCr)	Foil (NiCr)
Design type	Low energy (small active area)	Medium energy	Standard	Standard	Massive active area
Resistance (Ω)	2 ± 0.6	9.5 ± 1.5	2 ± 0.25	2 ± 0.25	8 ± 0.8
Primer type	KDNBF	KDNBF	KDNBF	ZPP	ZPP
AFC (mJ/Ω) (1)	0.0227	0.0132	0.240	0.806	0.569
NFC (mJ/Ω) (2)	0.0225	0.0101	0.147	0.437	0.294
Function time (ms) (3)	0.45	0.213	0.36	2.01	2.00
Circuit capacitance (µF)	1.9	0.64	1.9	15.97	1.9
Circuit resistance (Ω)	80	22.6	20.1	15.14	70.7

Notes

(1) AFC (mJ/Ω): all-fire impulse with 99.9 % reliability and 95 % single-sided confidence of firing

(2) NFC (mJ/Ω): no-fire impulse with 0.01 % reliability and 95 % single-sided confidence of firing

(3) Function time (ms): tested at the conditions of 99.9 % all-fire point firing energy with AF average of 10 trials.
The Function time is the time between the firing impulse and ignition response of the test sample, detected by a phototransistor

A Guide to Using EPIC / MEPIC Igniters in Pyrotechnic Applications

ANNEX 1

Detailed Statistical Features for MEPIC 8805 With KDNBF

RESULTS OF RELIABILITY / SAFETY DATA			
FIRING CIRCUIT PARAMETERS			
R: 20.1 Ω	C: 1.9 µF	RC: 38 µs	
CDF PARAMETERS			
µ:	0.19 mJ/Ω	σ:	0.055 mJ/Ω
AF (R = 99.9 %):	0.224 mJ/Ω	NF (R = 0.01 %):	0.158 mJ/Ω
NFC / AFC ESTIMATES (C = 95 %)			
AFC (mJ/Ω)		NFC (mJ/Ω)	
99 %:	0.227	1 %:	0.155
99.9 %:	0.240	0.1 %:	0.147
99.99 %:	0.252	0.01 %:	0.140
99.999 %:	0.262	0.001 %:	0.134
99.9999 %:	0.272	0.0001 %:	0.129

FUNCTION TIME RESULTS FOR 8805 KDNBF				
FIRING CIRCUIT PARAMETERS				
R: 20.1 Ω	C: 1.9 µF	RC: 38 µs		
TIME (ms)				
	Average	Min.	Max.	Std.
1 x AF (U_0 = 69 V)	0.36	0.22	0.45	0.078
2 x AF (U_0 = 97 V)	0.35	0.21	0.46	0.095
3 x AF (U_0 = 120 V)	0.32	0.14	0.43	0.116
5 x AF (U_0 = 155 V)	0.24	0.056	0.47	0.150

Detailed Statistical Features for EPIC0603M9R5K With KDNBF

RESULTS OF RELIABILITY / SAFETY DATA			
FIRING CIRCUIT PARAMETERS			
R: 22.6 Ω	C: 0.64 µF	RC: 14.5 µs	
CDF PARAMETERS			
µ:	11.67 µJ/Ω	σ:	0.032 µJ/Ω
AF (R = 99.9 %):	12.89 µJ/Ω	NF (R = 0.01 %):	10.35 µJ/Ω
NFC / AFC ESTIMATES (C = 95 %), SINGLE SIDED			
AFC (µJ/Ω)		NFC (µJ/Ω)	
99 %:	12.84	1 %:	10.62
99.9 %:	13.22	0.1 %:	10.31
99.99 %:	13.54	0.01 %:	10.06
99.999 %:	13.83	0.001 %:	9.85
99.9999 %:	14.10	0.0001 %:	9.67

FUNCTION TIME RESULTS FOR 2072 KDNBF				
FIRING CIRCUIT PARAMETERS				
R: 22.6 Ω	C: 0.64 µF	RC: 14.5 µs		
TIME (µs)				
	Average	Min.	Max.	Std.
1 x AF (U_0 = 30 V)	213	188	256	24.6
2 x AF (U_0 = 43 V)	133	108	180	23.3
3 x AF (U_0 = 52 V)	123	102	148	14.0
5 x AF (U_0 = 67 V)	101	77	145	19.6