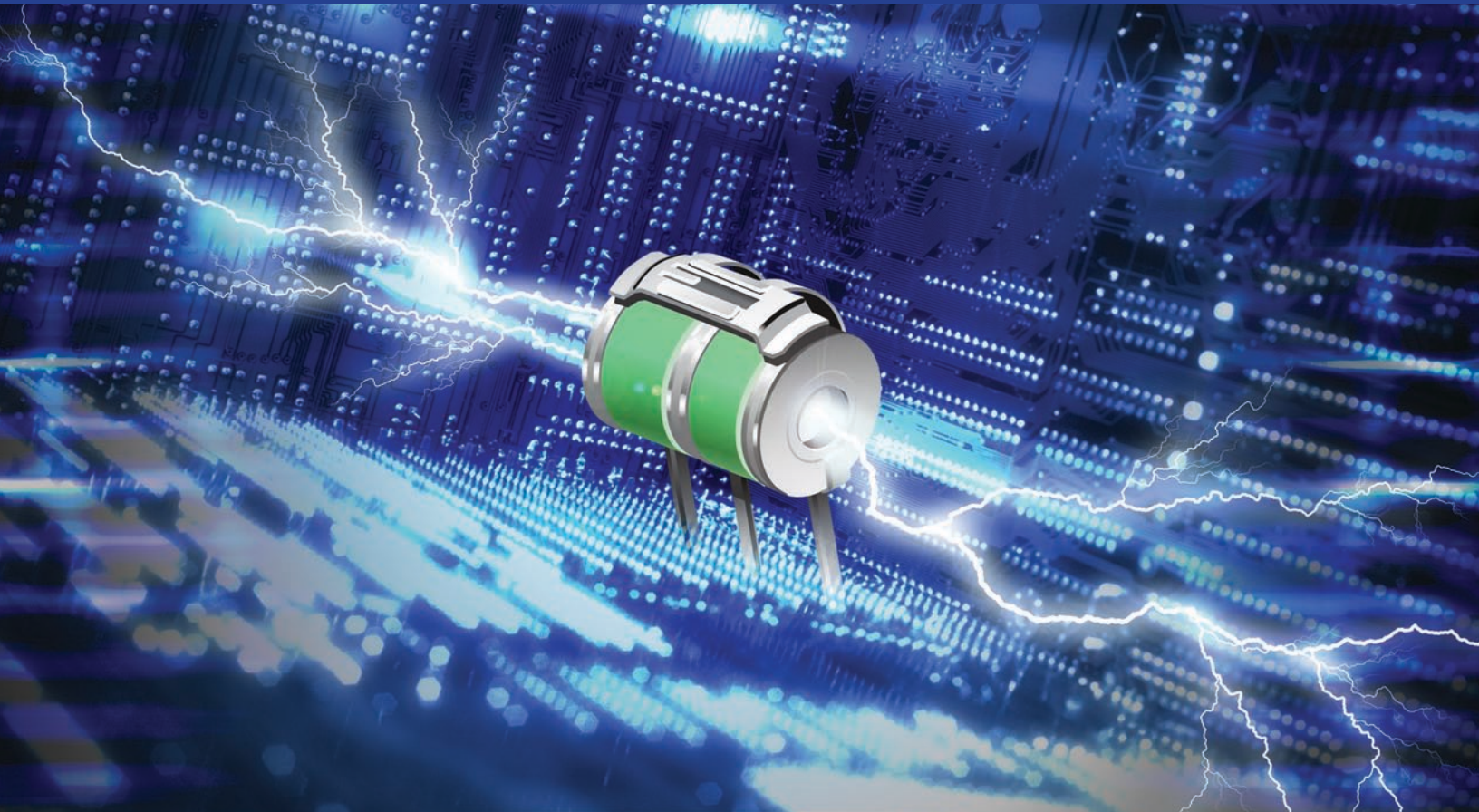


# First Principles of a Gas Discharge Tube (GDT) Primary Protector



*Rev. 2*



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The earliest reference to experiments involving lightning was Benjamin Franklin's kite experiments in 1752. However, it was in 1859 that Yale University described the use of the first spark gap protection solution. The document uses Franklin's experiment to harness the energy of a lightning storm. The kite was tied to an insulated post where the metallic string going to the kite was connected to a brass ball on the post. A second brass ball was grounded with a 2-inch gap between it and the isolated ball. If the energy on the kite string became too intense, an arc would occur between the two brass balls to conduct the energy to ground.

It was Humphrey Davy who investigated the basic spark gap and the nature of the arc between the conductors. He discovered that with enough potential difference between the two conductors, the air or the gas between the electrodes would ionize to provide a conductive medium for the current that would produce the arc. The traditional brass ball spark gaps evolved into carbon blocks that still use the local atmosphere to control the point of the arc. Spark gap technology has evolved where the atmosphere or gas between the two electrodes was confined in a container so that the external atmosphere did not affect its arcing performance. The gas discharge tube (GDT) as it has become known has evolved to provide reliable and effective protection solutions during lightning storms and other electrical disturbances. GDTs have been replacing carbon blocks in central office and remote access equipment installations due to their robustness and better electrical performance in the traditional POTS (Plain Old Telephone Service) type applications. With the recent explosion of broadband (digital) applications over copper, the GDT is becoming the market leader, even over solid state (semiconductor solutions) due to their ultra-low capacitance along with low insertion and return loss performances.

Gas discharge tubes are extensively used for the protection of telecommunications plant and equipment against overvoltages caused by lightning, power switching and fault conditions. This document covers:

- Bourns part numbering for discrete components and 5-pin modules and the general operation of a GDT.
- Investigating how the key electrical parameters and their relationships relate to each other with ramp and surge waveforms.
- Defining the expected ramp impulse and surge impulse of a GDT.
- The life cycle of a GDT under surge and how its parameters change over its life.



# Bourns® Discrete Components & 5-Pin Primary Protection Solutions

The Bourns® discrete components GDT family are available in both 2-electrode and 3-electrode options. The 3-electrode, common chamber GDTs protect both the TIP and RING (outside conductors) to ground (middle conductor). The series is available with a variety of lead configurations. The 3-electrode options are also available with a mechanical switch grade fail-short mechanism. The Bourns® 3-electrode common chamber GDT has the benefit of ionizing the second chamber simultaneously to aid both the TIP and RING lines to switch into a virtual short circuit (arc region) at the same time. This is especially important with transformer coupled interfaces where a large differential voltage across the line-side (primary) of the transformer will transfer a higher secondary voltage. Using two discrete GDTs to provide the same function will cause a scenario where one GDT will operate before the other, thus one side of the transformer will be at ground potential while the other side is at or below the GDT's impulse sparkover voltage. The Bourns® GDT series are:

## 3-electrode discrete through-hole options



The 2026-xx-XX series is a through-hole solution available with DC breakdown (DCBD) voltages from 75 V to 600 V and is rated for a single surge of 40 kA 8/20  $\mu$ s and >10 operations of 20 kA 8/20  $\mu$ s. The 2026-xx-XX series is also available with the mechanical switch grade fail-short mechanism in a variety of lead configurations and is available in RoHS compliant versions. The 2026 series is about 11.5 mm (length) x 8 mm (diameter) without the fail-short mechanism, or with a diameter of less than 10 mm with the fail-short mechanism.

The 2026-xx-XX-MSP series has precision-matched metal oxide varistors (MOVs) in parallel, which are connected across each of the GDT chambers to ground. Adding the MOVs reduces the impulse breakdown voltage under fast rising voltage transients. The series is rated as well for a single surge of 40 kA 8/20  $\mu$ s and 20 kA 8/20  $\mu$ s with more than 10 operations. The Bourns® MSP® series also has the mechanical fail-short mechanism included and has a length of about 14 mm and a height of less than 10 mm.



The 2036-xx-XX series is the miniature through-hole option and is rated for a single surge of 20 kA 8/20  $\mu$ s and greater than 10 operations of 10 kA 8/20  $\mu$ s. The 2036-xx-XX series has dimensions of approximately 7.5 mm (length) x 5 mm (diameter) and is available with DCBD voltages from 75 V to 600 V. The series is also available with the mechanical switch grade fail-short mechanism that adds approximately one mm to the diameter.

## 3-conductor discrete surface mount options



The 2036-xx-SM series is the miniature option with DCBD voltages from 75 V to 600 V. The series is rated as the standard 2036 series and has dimensions of approximately 7.5 mm (length) x 5.2 mm (diameter). The 2036-xx-SM has approximately twice the DC sparkover voltage rating between the TIP to RING conductors compared to its TIP/RING to ground conductors.

The 2038-xx-SM miniature series builds on the 2036-xx-SM but provides a symmetrical DC sparkover voltage rating between any two of the three conductors. The 2038-xx series will be available with DCBD voltages from 150 V to 1100 V and is rated for a single 10 kA 8/20  $\mu$ s surge and a minimum of 10 operations of 5 kA 8/20  $\mu$ s. The dimensions are identical to the 2036 series of 7.5 mm (length) x 5.2 mm (diameter).

## 2-electrode discrete through-hole options

The 2027-xx-XX series is a through-hole package solution with options of formed and straight leads. The series is rated for a single surge of 20 kA 8/20  $\mu$ s and >10 operations of 10 kA 8/20  $\mu$ s. The mechanical dimensions are 6 mm (length) and 8 mm (diameter). The DCBD voltages are available from 90 V to 600 V.



The 2037-xx-XX series is a through-hole package solution that is rated for 10 kA 8/20  $\mu$ s with dimensions of 5 mm (length) x 5 mm (diameter). The DCBD voltage range is from 90 V to 600 V.

The 2035-xx series is a through-hole package solution that is rated as the 2037 series, but with a slightly shorter body length of about 4 mm.

## 2-electrode discrete surface mount options



The 2027-xx-SM series is a surface mount solution of the standard 2027-xx-XX series with the same ratings. The length is approximately 6.4 mm and the diameter 8 mm.

The 2035-xx-SM series is a surface mount solution of the 2035 series with identical ratings. The length is approximately 4.4 mm and the diameter is 5 mm. The 2035-xx-SM has been designed for robustness and longevity, with a voltage option from 90 V to 600 V.

The 2039-xx-SM series has DCBD voltage options from 470 V to 1100 V. This series extends the DCBD range of the miniature GDT series and is rated for 5 kA 8/20  $\mu$ s. The dimensions are approximately 4.4 mm length and 5 mm diameter.

The 2055-xx-SM series provides a DCBD voltage range of 230 V to 420 V and is rated for 2.5 kA 8/20  $\mu$ s. The dimensions are 4.2 mm length and 6.2 mm diameter. The 2055-xx-SM has been designed for customer premise equipment (CPE) where high surge current ratings are not as important as price.

## Plug-in 5-pin primary protection selection

The worldwide telecommunications industry has come to rely on Bourns® surge protection devices to protect sensitive communications equipment from electrical surges. Bourns offers a full range of surge protector modules for central office, outside plant and customer premise. The customer premise modules have been designed to fit into the NID (Network Interface Device, which Bourns also provides), mounted on the side of the property. The 5-pin module is used in central office and remote access locations, where two basic series of our 5-pin protectors can be considered:



The 2410 series modules - The patented Bourns® MSPs® (Multi-Stage Protectors) are based on the discrete 2026-xx-XX-MSP series of 3-element GDTs and provide superior thermal protection with the patented Bourns® “switch grade fail-short” mechanism. The 2410 series of 5-pin modules have been designed to improve transmission performance and reach in broadband circuits based on balance and a lower capacitance of less than 15 pF (the capacitance is due to the MSPs® hybrid design).

The 2420 series modules - The Bourns® 2420 series is based on the discrete 2026-xx-XX series, common chamber 3-element GDTs and the switch grade fail-short device. It is UL listed according to the UL Seal-Test program and recognized to be used without an air-back-up Gap (BUG) device. The BUG-less feature results in longer trouble-free service life by eliminating the most common cause of premature failure of the protector assembly. The 2420 also has ultra-low capacitance of less than 5 pF to make them suitable for the emerging high-speed broadband applications.

The 2410 and 2420 series are UL listed and analyzed according to Telcordia GR 974 and SR 5165 requirements. Both products meet CAT 5 requirements. The 2410 and 2420 series feature gold plated solid brass pins, optional test access points and optional sealed unit construction. Tin plated pins are available on request.

**Note:** All Bourns® telecom GDTs and protector units are UL listed according to the UL Seal Test program and Bourns® 2410-MSP and 2420 BUG-less series of 5-pin primary protectors are analyzed by Telcordia according to the requirements of GR-974-CORE and SR 5165, reference Telcordia Analysis Report DA 1547.

## General Operation of a GDT

When a voltage disturbance reaches the GDT sparkover value, the GDT will switch into a virtual short, known as the arc mode. In the arc mode, the GDT practically shorts the line, diverting the surge current through the GDT to ground and removes the voltage surge from the plant and equipment. At normal operating voltages below the GDT rated DC sparkover voltage (measured at a rate of rise between 100 to 2000 V/s), the GDT remains in a high impedance off-state condition. All of our GDTs are rated at a minimum insulation resistance of  $10^9 \Omega$  at 200 V, 100 V bias or 50 V bias for the different breakdown values. With an increase in voltage across its conductors, the GDT will enter into its glow voltage region. The glow region is where the gas in the tube starts to ionize due to the charge developed across it. During the glow region the increase of current flow will create an avalanche effect in gas ionization that will

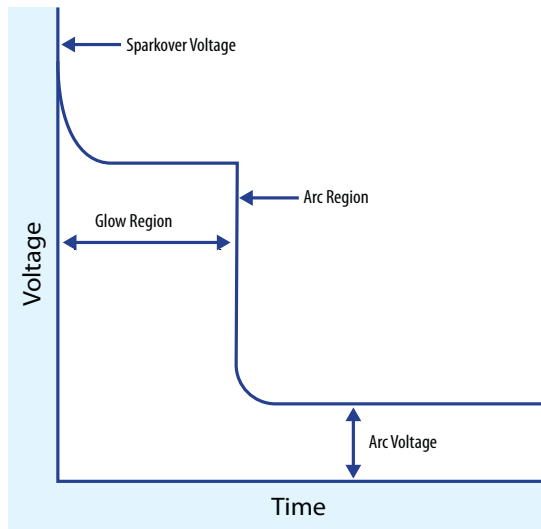


Figure 1 – Ramp impulse voltage vs DCBD voltage options

transition the GDT into a virtually short circuit mode and current (dependent on the impedance of the voltage source) will pass between the two conductors. The voltage developed across the GDT with a short circuit condition is called the “Arc Voltage”  $V_{ARC}$ . The transition time between the glow and arc region is dependent on the available current of the impulse, the distance and shape of the electrodes, the gas composition, gas pressure and the proprietary emission coatings. Bourns active emission coatings allow the tubes to transition into the arc mode at currents much lower than 500 mA.

The arc voltage is the voltage rating that is specified as  $<10 \text{ V @ } 1 \text{ A}$  for Bourns® GDTs. The GDT will switch back or reset into a high impedance state once there is not enough energy to keep the device in the arc condition. This is sometimes also called the “Extinguishing Voltage, Holdover Voltage or Impulse Reset Voltage”. Figure 1 shows the basic switching characteristic of a GDT.

Due to the typical arc voltage of less than 10 V, a GDT is ideal for protecting against high-energy impulses and AC power cross conditions. Under AC, the power dissipated ( $V_{ARC} \times I_{GEN}$ ) in the device needs to be carefully monitored. The switch grade fail-short mechanism is available for the 2026/2036 series and protects against thermal overload under AC conditions. At elevated GDT temperatures, a spring-loaded clip will operate like a switch to short the TIP/RING conductors to ground. The 2026-xx-xx-F series is recommended where high AC or long duration AC conditions exist or to meet Telcordia GR-974-CORE requirements. The switch grade fail-short mechanism cannot be used to meet Telcordia GR-1089-CORE requirements as there are first level AC tests where the equipment must work correctly after the test. It is also not a good practice to hold a GDT in its glow region as this will significantly reduce the life expectancy of the device. In this condition, significant heat can be developed on the electrodes that can damage the special emission coatings and cause premature failure of the tube. Using a variable AC source such as a curve tracer or equivalent to vary the voltage and power across at its DCBD voltage should be avoided. It is highly unlikely that a condition could exist in the field which would maintain a GDT in the glow mode. Bourns uses an active proprietary coating that provides a very low glow to arc transition current, helping to reduce or eliminate these issues.

**Note:** The sparkover voltage shown in Figure 1 can be generated by either a ramp voltage defined as V/s or V/ $\mu$ s or a peak surge voltage defined as  $T_{RISE}/T_{FALL}$  in microseconds. The sparkover voltage from a ramp voltage waveform is referenced as the “ramp impulse voltage” where the sparkover voltage caused by a surge waveform is a “surge impulse voltage”.

## GDT Electrical Parameters and Their Relationships

This section investigates the relationship between the electrical specifications and how they relate to the dynamic performance such as disturbances from lightning and AC. Understanding the primary protector dynamic performance defines the expected performance under surge waveforms and aids the selection of the secondary protection when assembled in modules or in close proximity of each other.

*As an example, for the Bourns® GDT families we use the 2026 Series DCBD voltage and ramp impulse breakdown voltage in the following discussion.*

### 4.1 2026 Series DCBD Voltage and Ramp Impulse Breakdown Voltage

All the series of Bourns® GDTs have a wide variety of voltage options where the family's DC breakover voltage (voltage ramp rate of 100 V/s) were plotted against the ramp impulse voltage (voltage ramp rates of 100 V/ $\mu$ s and 1000 V/ $\mu$ s) specified in the data sheet. Figure 2 shows the relationship between these two parameters. It can be seen that the Bourns® GDT impulse rating is directly related to the DC series breakdown voltage. The ratio of the DCBD voltage to ramp impulse voltage performance for each individual voltage family is approximately 1.4:1 for 100 V/ $\mu$ s and 1.6:1 for 1000 V/ $\mu$ s. To calculate the typical impulse performance with a DC series breakdown voltage ( $V_{DCBD}$ ) rating, the formula below can be used:

$$V_{IMPULSE @ 100 V/\mu s} = (1.4 \times V_{DCBD}) + 140$$

$$V_{IMPULSE @ 1000 V/\mu s} = (1.6 \times V_{DCBD}) + 300$$

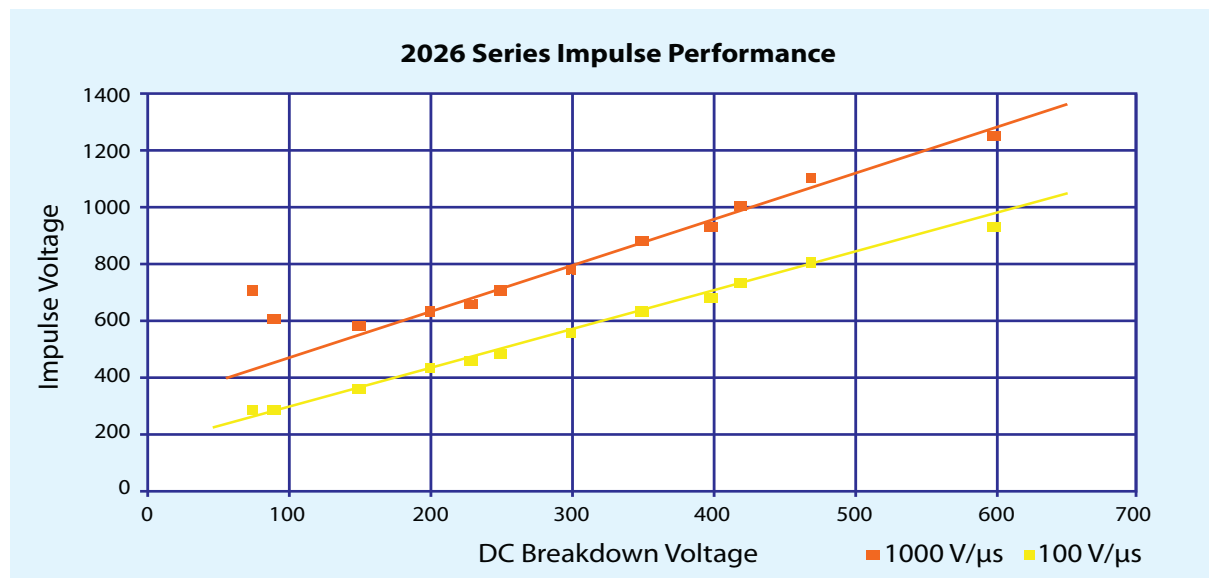


Figure 2 – Ramp impulse voltage vs DCBD voltage options

Figure 2 shows that for instance the 2026-07 has a 75  $V_{DCBD}$  rating that does not follow the same curve as the rest of the voltage family in the series and the deviation gets worse as the ramp impulse voltage increases. This is due to the low voltage options having different gas and pressure properties to achieve the low voltage breakdown which is at the limitation of the gas discharge technology. Figure 2 also shows that the 75 V and 90 V tubes have a higher ramp impulse performance than the 150 V option. For limiting the maximum voltage across a twisted pair of cables under fast rising transients, the 150 V option may be a better design proposal.



**Note:** The impulse voltage is specified in the data sheet, which should be used to determine the maximum voltage protection value or “let-through voltage”. The DCBD voltage value can easily be measured with the Bourns® 4010 handheld tester, where the relationship between a single device measurement and its dynamic performance is discussed in sections 4.3 to 4.5. The low end DCBD value is the voltage that should be used to determine the minimum required withstand voltage to avoid interference of the GDT with the normal system operating voltage.

## 4.2 2026 Series DCBD Voltage and Surge Impulse Voltage

The 2026 series was measured for DCBD voltage and then exposed to a surge with a 1 kV, 100 A 10/1000  $\mu$ s. The surge impulse voltage was measured where figure 3 shows that there is a correlation between the different voltage ranges in the 2026 series and the surge impulse voltage. The relationship also looks to be directly proportional to the measured DCBD voltage rating of the device, which is covered in section 4.3. The ratio of DCBD voltage to surge impulse voltage for each voltage family is approximately 1.12:1 for the 10/1000 type surge as shown by the slope of the approximation line in figure 3.

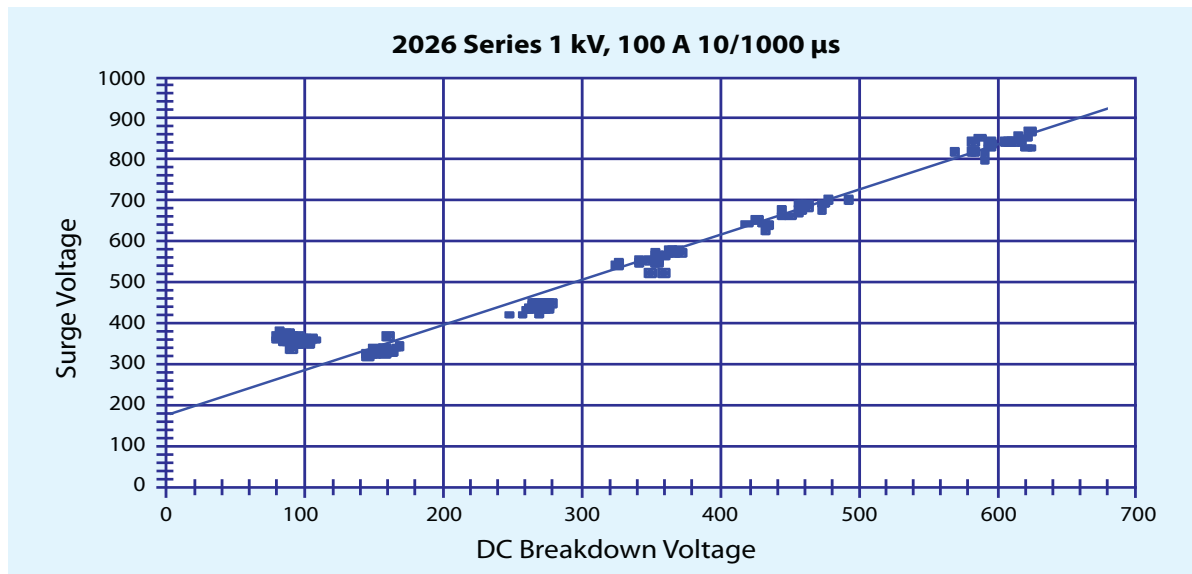


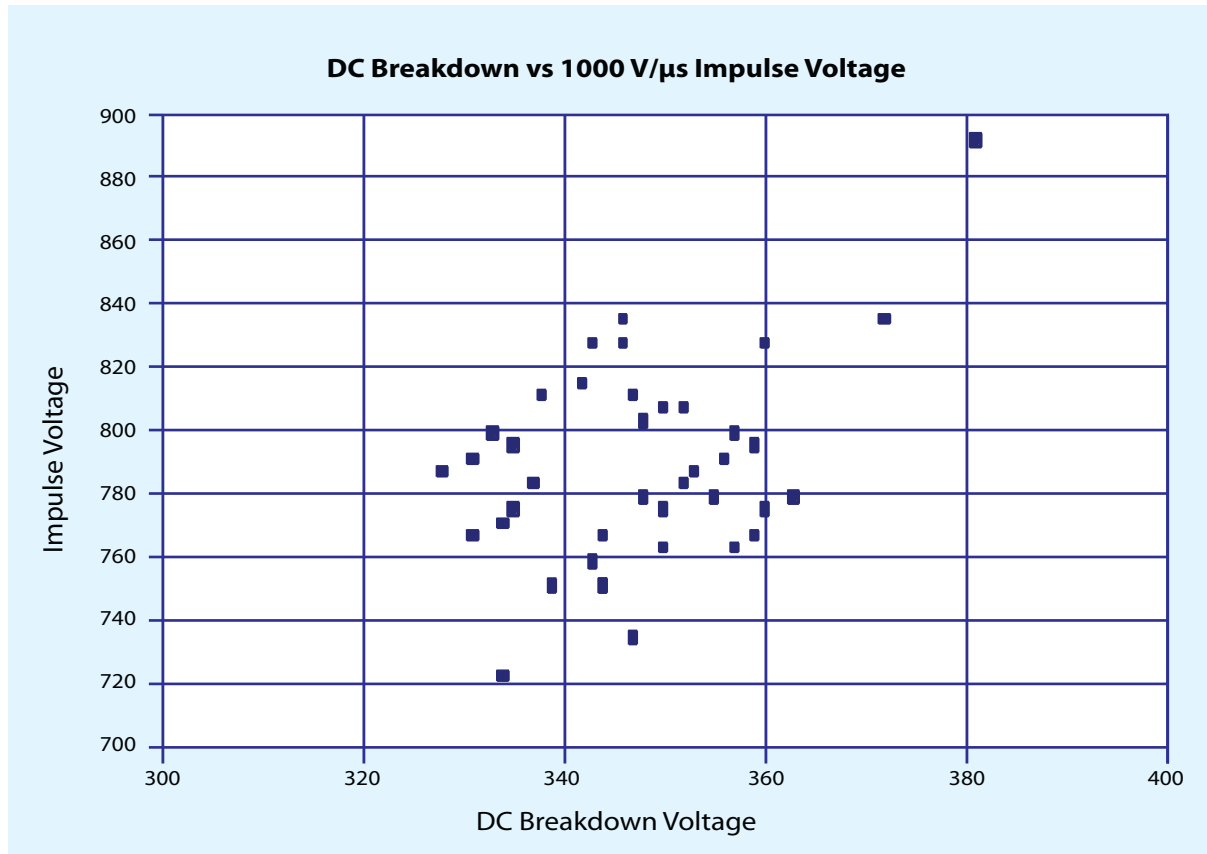
Figure 3 – 2026 series surge impulse voltage during 1 kV, 100 A 10/1000  $\mu$ s

**Note:** The 2026-07 (75 V) and 2026-09 (90 V) options show noticeable performance differences compared to the rest of the voltage options in the family. Figure 3 shows that the 150 V 2026-15 would provide a better protection solution under common surge impulse waveforms while providing a higher maximum working voltage before the GDT operates. The 75 V and 90 V series are ideal for very slow rising impulses.

Comparing figures 2 and 3 shows that using a 1000 V/ $\mu$ s rating of a GDT to define a 10/1000  $\mu$ s surge rating is not providing an accurate representation. This difference is approximately 57 % of additional safety margin. The 100 V/ $\mu$ s impulse sparkover rating is much closer to the expected surge values and still provides 17 % of additional tolerance under 10/1000  $\mu$ s. Using the 100 V/ $\mu$ s appears to be a better method for dynamic comparison between the two test methods. This is especially important when designing to Telcordia GR-1089-CORE, issue 4 which uses some of the GDT dynamic performances to help define the secondary protection requirements. The assumption can be made that using the 1000 V/ $\mu$ s impulse rating will also cover faster surge impulse transients. However, the fast rising transients such as the 1.2/50  $\mu$ s voltage wave shape (8/20  $\mu$ s current) only yielded a 7 % increase in surge voltage with the same peak open circuit voltage. This area is covered in more detail in section 5; dynamic performance with telecom surges.

### 4.3 2026-35 DCBD Voltage and 1000 V/ $\mu$ s Impulse Voltage

A GDT life tester was used to measure the actual DCBD voltage and ramp impulse sparkover voltage at 1000 V/ $\mu$ s for each GDT. The 2026-35 (350 V) series was tested to see if there is individual device correlation (higher DCBD voltage results in higher impulse voltage) between the dynamic parameters. Section 4.1 showed that there was correlation between these two parameters when looking at the voltage selection options in the GDT family. Figure 4 shows that there was a distinct grouping of the measurements, but there was no direct correlation between the DCBD measurement and impulse voltage measurement.



## 4.5 2026-35 1000 V/μs Impulse Voltage and 10/1000 μs Surge Impulse Voltage

The data collected in sections 4.3 and 4.4 was used to see if there was any direct correlation between the 1000 V/μs ramp impulse voltage measurement and 10/1000 μs surge impulse voltage measurements. There was a distinctive grouping of the measurements, but again there was no direct correlation between these two measured electrical parameters. Surging the devices 100 times for each surge current (10 A to 500 A) increased the standard deviation (scatter area), but no direct correlation was found between the two electrical parameters. This increased scatter effect started the investigation of the life expectancy of the GDT, as the DCBD voltage was changing under each surge and was very noticeable with the 300 A and 500 A tests. This is covered in more detail in section 6, life cycle of a GDT.

## 4.6 Section Summary and Recommendations

There was correlation found between each voltage in the 2026-xx-XX series, but not between each individual GDT's measured DCBD value and its measured impulse or surge impulse voltage value. Therefore, finding the surge impulse voltage can be calculated by using the series DC voltage selection options in the data sheet.

The surge impulse voltage and ramp impulse voltage is only defined by the voltage and its rate of rise across it<sup>†</sup>. The DCBD voltage selection in a GDT series can be used to provide a good indication of the expected surge impulse voltage during a 10/1000 μs surge as shown in figure 3.

Defining the typical impulse voltage and surge impulse voltage from the DCBD voltage option can be approximated by:

$$V_{\text{IMPULSE @ 100 V/}\mu\text{s}} = (1.4 \times V_{\text{DCBD}}) + 180$$

$$V_{\text{IMPULSE @ 1000 V/}\mu\text{s}} = (1.6 \times V_{\text{DCBD}}) + 300$$

$$V_{\text{SURGE (10/1000 }\mu\text{s)}} = (1.2 \times V_{\text{DCBD}}) + 170$$

**Note:** These formulas can be used for DCBD voltages of 150 V or more.

With fast (greater than 100 V/μs) impulse and telecom surges, the 150 V<sub>DCBD</sub> option can provide better protection than the 75 V and 90 V options in the GDT series. The benefit of the low voltage options is with slow rising voltages of 2000 V/ms or less such as AC mains voltages for example.

<sup>†</sup> The minimum telecom surge current tested was 10 A which is significantly above the glow to arc current specification of 500 mA. There may be GDT dynamic performance considerations if the short circuit current is close to the arc transition current which was not explored in this document.

## Dynamic Performance with Telecom Surges

The GDT impulse sparkover specifications are characterized by an impulse voltage waveshape such as  $100 \text{ V}/\mu\text{s}$  or  $1000 \text{ V}/\mu\text{s}$ . This ramp voltage is not an accurate representation of the real world scenario. Electrical disturbances entering into the building by twisted pair cable from a lightning strike are based on rise and decay times since the lightning strike is charge (Q) related being dissipated in an impedance of the line. Section 4 showed there was a relationship between the DCBD voltage and both the ramp impulse voltage and surge impulse voltage. This highlighted a typical value from a one lot batch. Different test units were selected from different batches of GDTs and surged on two separate  $100 \text{ A } 10/1000 \mu\text{s}$  generators. Figure 5 shows the results plotted on the same curve shown in figure 3 and the  $100 \text{ V}/\mu\text{s}$  curve shown in figure 2. Figure 5 shows that there are similar performances between the  $100 \text{ V}/\mu\text{s}$  impulse breakdown voltage and the  $100 \text{ A } 10/1000 \mu\text{s}$  surge impulse voltage performance.

The formula on page 8 is a good approximation if the  $100 \text{ V}/\mu\text{s}$  ramp impulse voltage is not specified in the data sheet for the GDT.

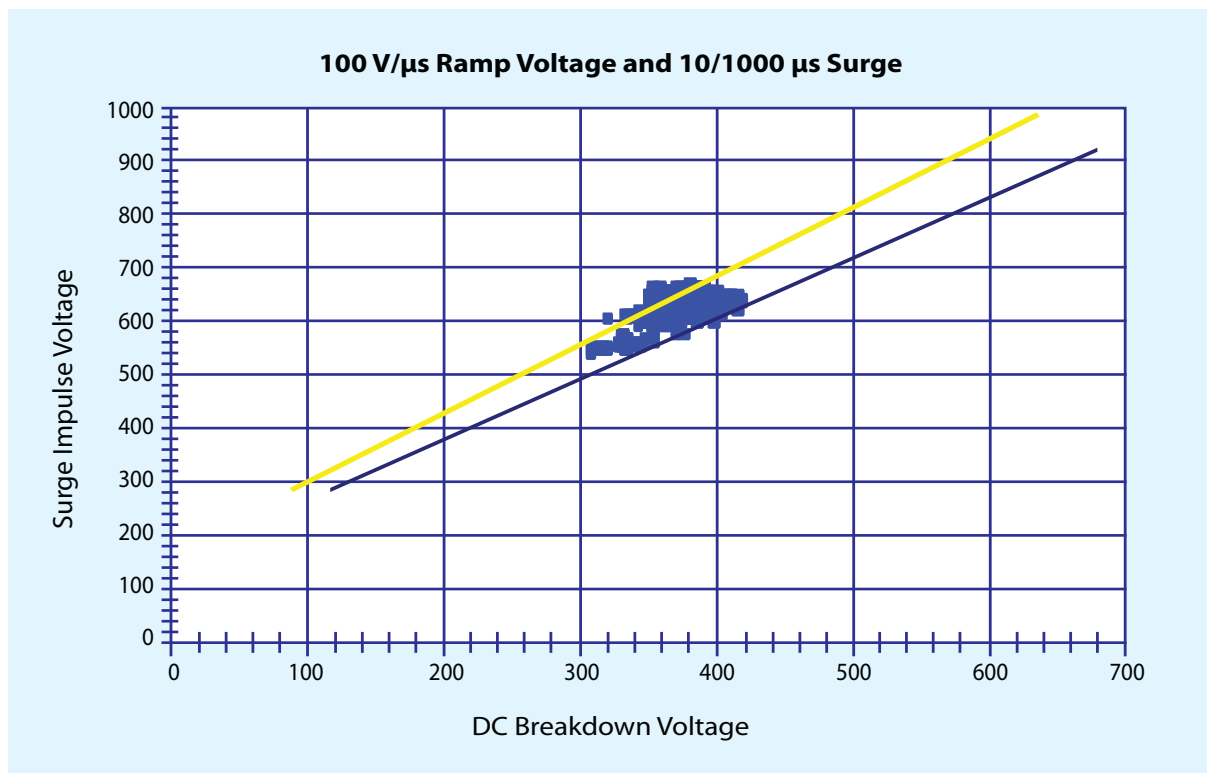


Figure 5 – Variation of 2026-35 with  $100 \text{ A } 10/1000 \mu\text{s}$  surge

Field studies have shown that the strike energy is similar to a  $10/250 \mu\text{s}$  waveform for a positive stroke. The primary protection telecom standards such as Telcordia GR-974-CORE also specify end of life mode tests using a series of surge generators of  $10/1000 \mu\text{s}$ ,  $10/250 \mu\text{s}$  and  $8/20 \mu\text{s}$  type waveshapes. The dynamic performance of the GDT with these telecom surge waveshapes are less known. As secondary protection is often required to protect voltage sensitive equipment from the primary protector let-through, it is important to know how the GDT performs under these types of impulses. Standards such as Telcordia GR-1089-CORE for secondary protection are still based on worst case, carbon block type primary protection technology to cover legacy equipment. GR-1089-CORE, issue 4 release allows the secondary protection to be more dependent on the primary protector technology used in the field.



## 5.1 Switching Performance

The 2026-35 was surged with a 1 kV, 100 A 10/1000  $\mu$ s. The current and voltage waveforms are shown in figure 6. From the curve, it can be seen that the glow region is very short (cannot actually be seen) under this condition. The two switching times to consider during the operation of the GDT are the peak voltage breakdown and the transition into the arc region.

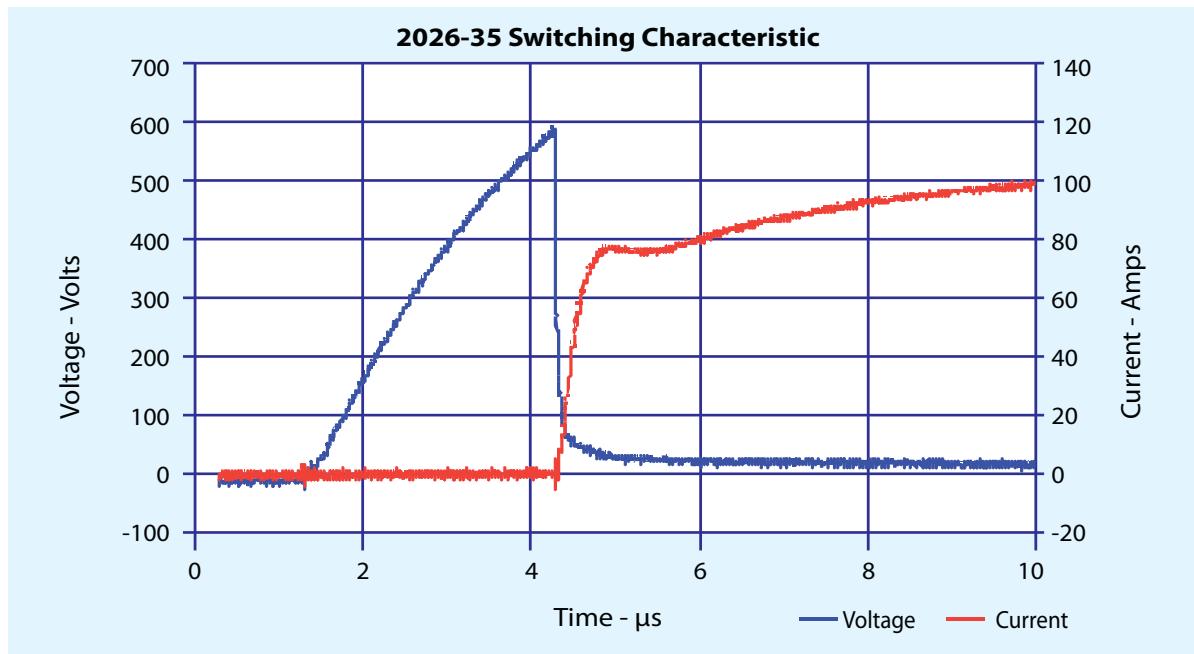


Figure 6 – 2026-35 GDT switching characteristic with 1 kV, 100 A 10/1000  $\mu$ s surge

### 5.1.1 Peak Voltage Switching Time

This is the time measured from the start of the impulse applied to the GDT to when the GDT switches into a virtual short circuit. Figure 7 shows the 2026-35 switching characteristic with a peak surge impulse voltage of 588 V. The voltage curve rising edge is the rise time (10  $\mu$ s to 1000 V) of the surge generator before the GDT switches into a virtual short and started further investigation covered in section 5.2.1 to 5.2.3. This indicates that the surge impulse voltage is directly related to the generator open circuit voltage and is only voltage rise dependent. Therefore, if a GDT conducts at a lower peak voltage, it will provide a faster switching time. Figure 7 shows the dynamic impact of a GDT operating at a 450 V surge impulse sparkover compared to 550 V. The 450 V option will have a typical switch time of 3.4  $\mu$ s where the 550 V will be 4.1  $\mu$ s (reduction of 0.7  $\mu$ s with 100 V less let-through). As the rising edge (dV/dt) increases, the switching time also reduces, since the impulse sparkover performance is normalized between the two. This benefit needs to be considered when compared against the reduced life span of a faster acting GDT. For a GDT used as a primary protector, the longevity and current withstand capability over the minor savings of faster switching performances may be more important. A GDT primary protector providing a tighter protection window to reduce the secondary requirement should be a serious consideration. However, without a significant reduction in the impulse voltage specifications, like the solid-state TISP® thyristor, for example, the actual impact is minimal to the secondary protection in the equipment. GR-1089-CORE, issue 4 specifies three forms of primary protector that can be considered. The solid state (low voltage) needs to develop 400 V across it to ensure operation, a GDT (medium voltage) is 600 V and a carbon block (high voltage) is 1000 V. This provides clear differentiation between the different primary protection technologies.

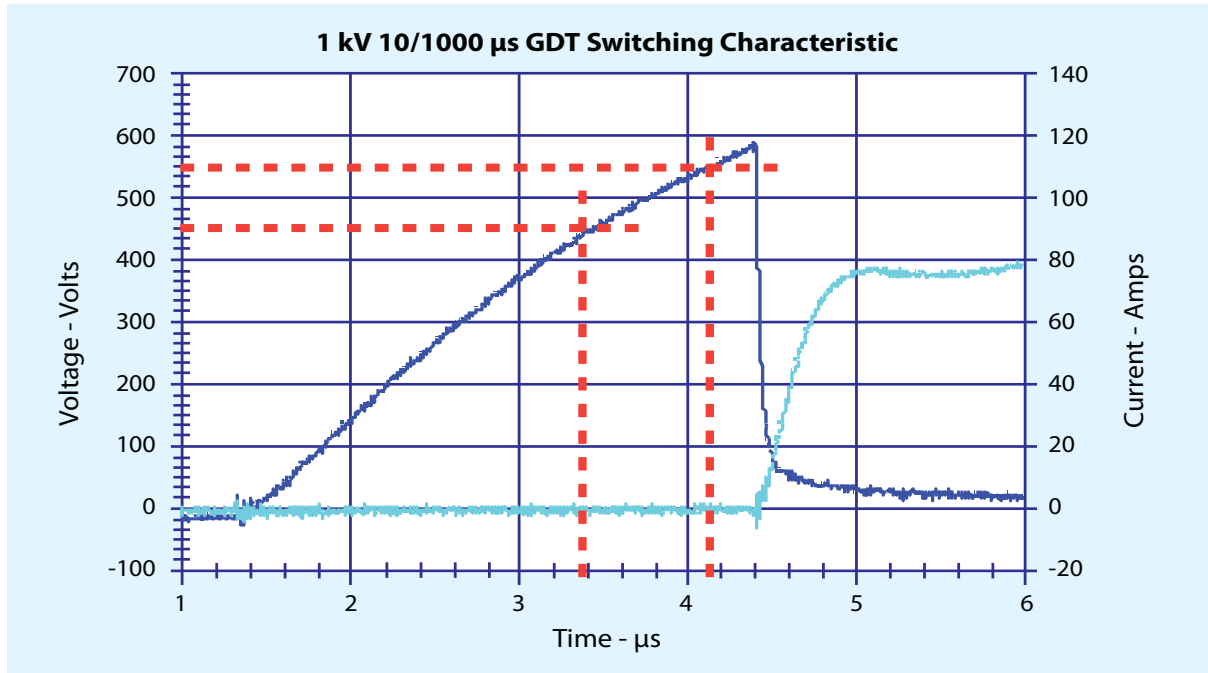


Figure 7 – Reducing the impulse sparkover value of the GDT

### 5.1.2 Arc Region Transition Time

The representation of the arc region transition time is shown in figure 1 and is the time between the impulse sparkover voltage to the arc voltage. Figure 7 shows the 2026-35 GDT has a very fast transition time to 70 V where this transition time for the 2026-35 was in the region of 100 ns. The 2026-35 was surged with different impulses to see if there was any difference in the arc transition time.

	2/10 μs 2500 V, 500 A			8/20 μs 2500 V, 1000 A			10/1000 μs 2500 V, 1000 A		
	Surge Voltage (V)	Time (ns)	Surge Current (I)	Surge Voltage (V)	Time (ns)	Surge Current (I)	Surge Voltage (V)	Time (ns)	Surge Current (I)
Min.	500	77.67	116	492	82.2	260	512	64	43.2
Max.	628	127.2	564	668	104.8	1210	616	76	110
Avg.	588	97	N/A	623	92	N/A	564	68	N/A

Table 1 – Transition time during a surge

The variation of transition time to surge current seen in figure 8 indicates the previous surge impacted the transition time rather than the peak current or voltage. The impurities released from the tube's internal material can increase transition. The emission coatings used in the GDTs will attract (getter) the impurities released which will make the next surge transition time revert to the initial values. This process will repeat itself over the lifetime of the GDT. A summary of the results are shown in table 1.

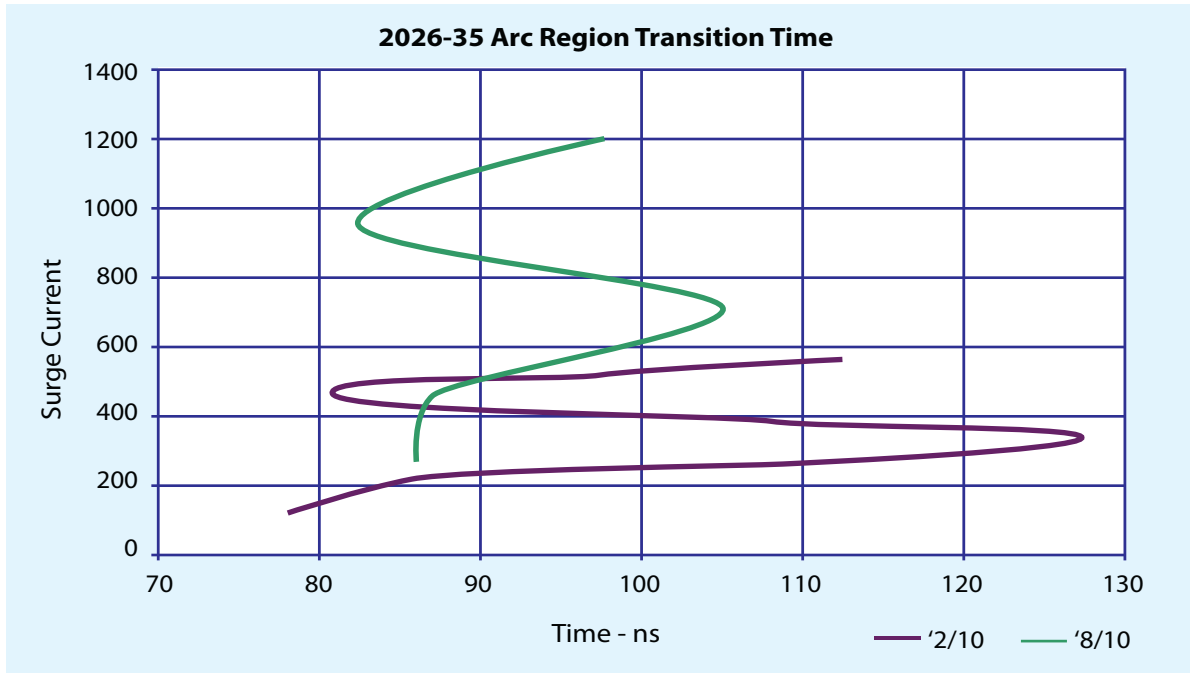


Figure 8 – Arc region transition time

## 5.2

### Surge Performance

Section 4.2, figure 3 compares the different DCBD voltage selection options of the 2026 series under 10/1000  $\mu$ s surge and indicates that there is correlation between the voltage family and the surge impulse voltage. This section will investigate further how GDTs behave under different telecom surges.

#### 5.2.1 2026 Series Switching Time and Surge Impulse Voltage with 10/1000 $\mu$ s

The voltage options in the 2026 series were surged with 1 kV, 100 A 10/1000  $\mu$ s waveform. The surge impulse voltage and switching time was measured and plotted against the generator open circuit voltage waveform. The results are shown in figure 9 where the performance of the different voltage options can be seen. Figure 9 shows five groupings, while six voltage options were tested. The 90 V series had a slightly higher impulse voltage compared to the 150 V series, and therefore, when plotted on the curve looked like one distribution. Figure 9 also showed the surge impulse voltage or switching time tolerance varied with voltage option and tracked the open circuit surge voltage characteristic. The lower breakdown voltage series had a better standard deviation in switching times than the higher voltage options and the higher voltage options had a better surge impulse voltage standard deviation for the same open circuit waveform.

A summary of the results from this test is shown in table 2.

	2026-09		2026-15		2026-25		2026-35		2026-47		2026-60	
	Impulse (V)	Time ( $\mu$ s)	Impulse (V)	Time ( $\mu$ s)	Impulse (V)	Time ( $\mu$ s)	Impulse (V)	Time ( $\mu$ s)	Impulse (V)	Time ( $\mu$ s)	Impulse (V)	Time ( $\mu$ s)
Avg.	352	1.48	330	1.43	435	1.93	551	2.73	668	3.65	832	6.08
Std.	7.14	0.04	10.58	0.03	9.63	0.06	21.92	0.10	21.77	0.25	17.22	0.76
Ratio	2.02		1.06		1.06		1.09		1.06		1.10	

Table 2 – 10/1000  $\mu$ s surge impulse voltage statistics

The ratio factor was calculated using the formula highlighted in section 3.6, where the

$$\text{ratio} = (V_{\text{SURGE}} - 170) / V_{\text{DCBD}}.$$

All the voltage options, except 90 V series had similar ratios. This showed that all the GDT voltage series performed in the same manner and that their dynamic performance will be similar in ratio to their DCBD value. The 350 V 2026-35 series is a popular option and will be used to further investigate the GDT during surge conditions.

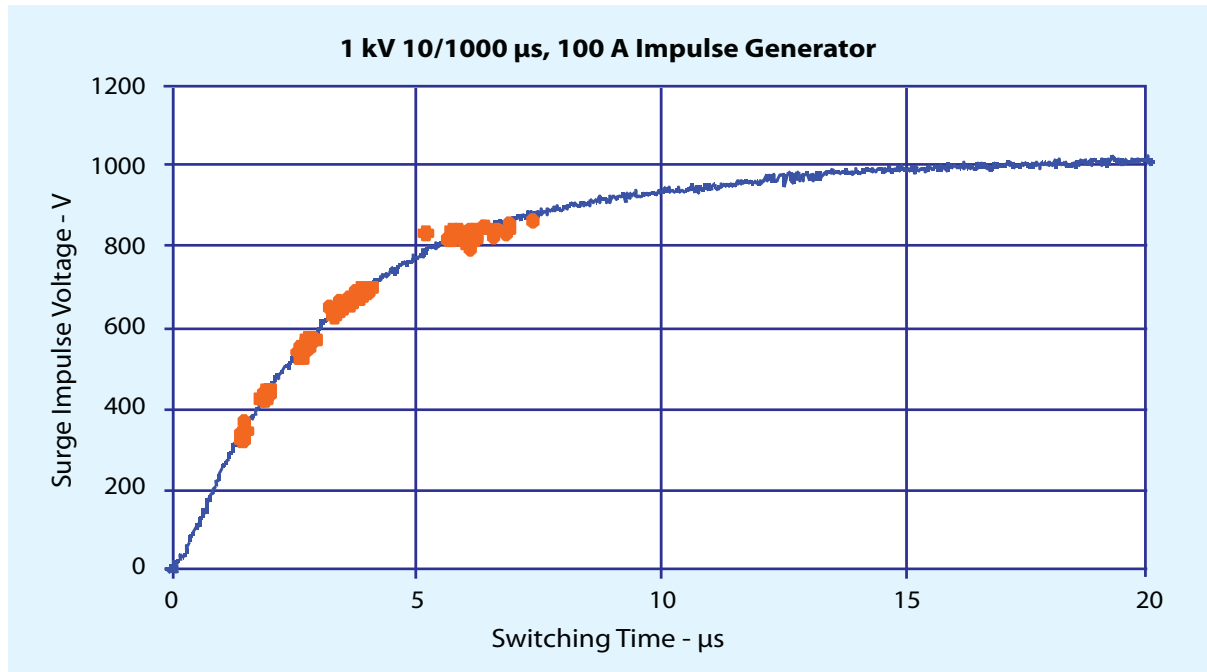


Figure 9 – 2026-xx series switching time with 10/1000 μs surge

### 5.2.2 2026-35 Switching Time and Surge Impulse Voltage with 10/1000 μs

The 2026-35 was surged with different generator open circuit voltages. The peak voltage from the impulse generator was varied between 400 V to 1000 V where the peak surge impulse voltage and the open circuit delay time was measured. The generator voltage was set to 400 V to ensure the GDT would still operate. At 400 V, the surge impulse voltage of the GDT was very consistent between each device. The wide variation between each device occurred in the switching time. As the impulse generator voltage increased, the switching time became more consistent, but the surge impulse voltage variation increased. Figure 10 shows this variation between time and voltage. The generator open circuit voltage (blue curve) is also plotted on figure 10 to provide a point of reference. Table 3 summarizes the test results.



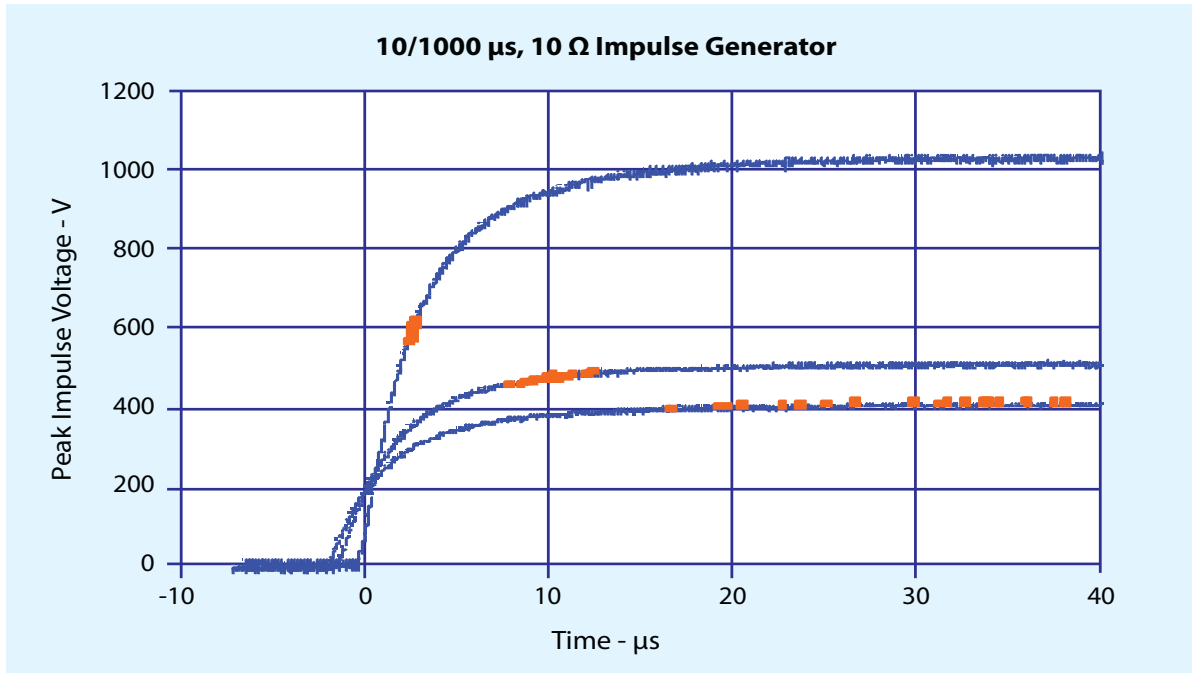


Figure 10 – 2026-35 switching time with 10/1000  $\mu$ s surge

2026-35 with 10/1000 $\mu$ s Impulse						
Generator Voltage	412 V		520 V		1048 V	
	Impulse (V)	Time ( $\mu$ s)	Impulse (V)	Time ( $\mu$ s)	Impulse (V)	Time ( $\mu$ s)
Avg.	408	28.75	473	10.38	596	2.73
Std.	5.34	6.80	8.79	1.22	14.94	.10

Table 3 – 2026-35 with different 10/1000  $\mu$ s generator voltages

**Note:** Bourns® 2026-xx series will operate with a 10/1000  $\mu$ s voltage which is 20 % above its DCBD voltage specification. The typical surge impulse voltage can be found using the formula on page 8.

### 5.2.3 2026-35 Switching Time and Surge Impulse Voltage with 2/10 $\mu$ s

The 2026-35 was surged using a 2/10  $\mu$ s impulse where the results are shown in figure 11. The 2026-35 did not switch into a virtual short circuit with a voltage of 400 V. The voltage was increased to 500 V to ensure all the units operated. Figure 11 shows that the GDT was just operating at a peak generator voltage of 500 V, which indicates this voltage is close to the minimum requirement for reliable GDT operation. Table 4 shows the summary of the test.

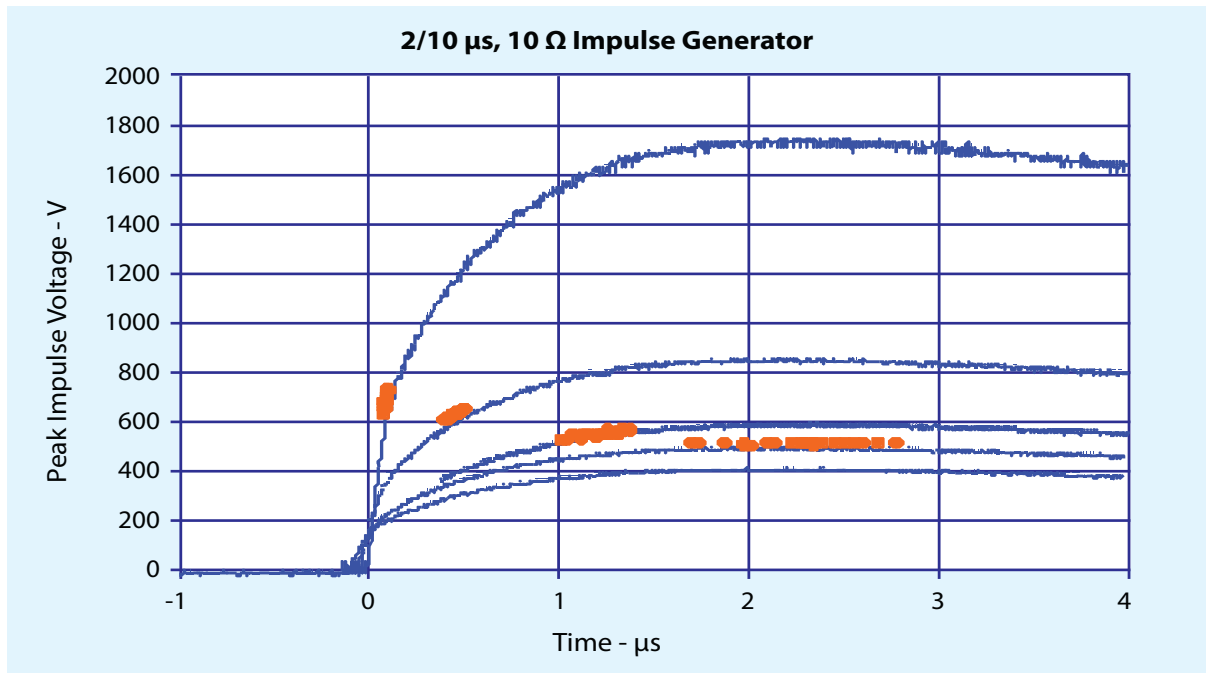


Figure 11 – 2026-35 switching time with 2/10  $\mu$ s surge

**Note:** Bourns® 2026-xx series will operate best with a 2/10  $\mu$ s generator if the voltage is 50 % above its DCBD voltage specification.

2026-35 with 2/10 $\mu$ s Impulse								
Generator Voltage	512 V		600 V		864 V		1760 V	
	Impulse (V)	Time ( $\mu$ s)	Impulse (V)	Time ( $\mu$ s)	Impulse (V)	Time ( $\mu$ s)	Impulse (V)	Time ( $\mu$ s)
Avg.	512	2.27	548	1.21	634	0.46	688	0.09
Std.	2.56	0.30	12.17	0.10	13.52	0.03	24.51	0.01

Table 4 - 2026-35 with different 2/10  $\mu$ s generator voltages

When comparing the results of table 4 with table 3, the surge impulse voltage increased due to the faster rising voltage of the 2/10  $\mu$ s waveform while the switching times reduced. The surge impulse voltage however only increased by 7 % between the two waveshapes. The same phenomenon was seen with the 10/1000  $\mu$ s test where the variation between surge voltage and switching time changed depending on the generator voltage. Section 4.2 highlighted that the ratio between the voltage options in the 2026 series remained constant. Therefore, the original formula needs to be modified to take into consideration the increased surge impulse rating. From table 4, the average surge impulse voltage was 688 V which changes the formula highlighted on page 8 to approximate:

$$V_{\text{SURGE}} = (1.2 \times V_{\text{DCBD}}) + 280$$

### 5.2.4 2026-35 Switching Time and Surge Impulse Voltage with 8/20 $\mu$ s

The 2026-35 was surged with the 8/20  $\mu$ s (1.2/50  $\mu$ s voltage waveform) where the results are shown in table 5. With an open circuit generator voltage of 400 V, only 70 % of the units tested switched into the arc region. This indicated that the 350 V GDT series would need a minimum of 450 V to ensure it switched into a virtual short circuit. This was comparable with the 2/10  $\mu$ s results where the GDT was assured to operate with a voltage of 500 V.

2026-35 with 8/20 $\mu$ s Impulse								
Generator Voltage	500 V		610 V		1210 V		1740 V	
	Impulse (V)	Time ( $\mu$ s)	Impulse (V)	Time ( $\mu$ s)	Impulse (V)	Time ( $\mu$ s)	Impulse (V)	Time ( $\mu$ s)
Avg.	406	8.91	490	2.03	638	0.37	668	0.25
Std.	2.42	2.92	3.78	0.38	32.09	0.03	24.83	0.03

Table 5 - 2026-35 with different 8/20  $\mu$ s generator voltages

Table 5 shows the same phenomenon of impulse and switching time variation of surge impulse voltage as shown with the 2/10  $\mu$ s and 10/1000  $\mu$ s waveforms in tables 3 and 4. The results also highlight very similar performances of the surge impulse voltage and switching times between the 2/10  $\mu$ s waveform. It was expected that the faster voltage rising edge of the 8/20  $\mu$ s impulse would further increase the surge voltage of the GDT, but this was not the case.

### 5.3 Surge Voltage Under Extreme Conditions

Section 5.2 showed the surge impulse voltage increased as the generator voltage increased. Extrapolating the data points in figure 11 or 12 indicates that there will be a maximum surge impulse voltage. This would define the worst case surge impulse voltage and therefore the maximum peak voltage seen by the equipment. An 8/20  $\mu$ s generator with a maximum voltage of 6 kV was used to investigate this further. The generator series resistance was measured as 2.48  $\Omega$  and the current was monitored during the testing using a Pearson Electronics current transformer.

Figure 12 shows that the surge impulse voltage developed across the GDT started to decline after 800 A with an open circuit voltage of 1984 V (800 A x 2.48  $\Omega$  = 1984 V). The 2/10  $\mu$ s, 10  $\Omega$  generator was also used as a quick comparison. The peak surge impulse voltage occurred with an open generator voltage of 1700 V with a similar shaped curve.

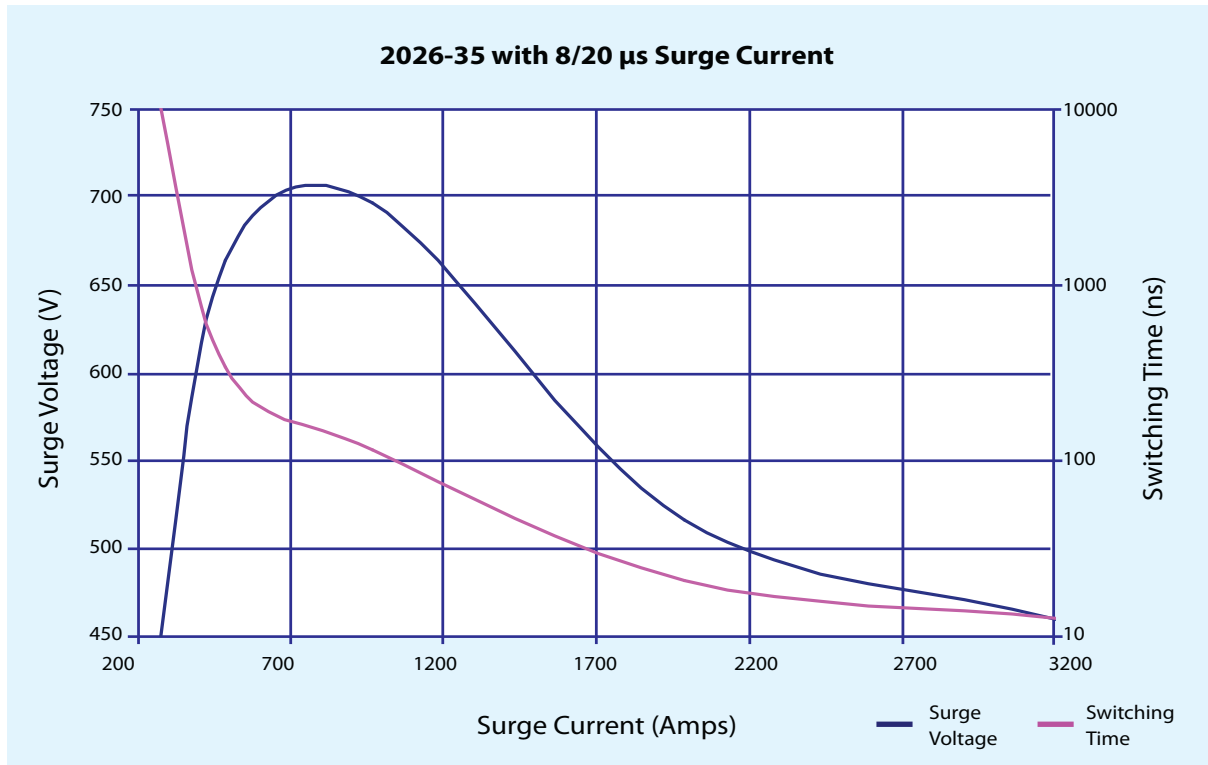


Figure 12 – Surge voltage versus generator short circuit current

This shows that the worst stress surge voltage applied to the secondary protection or equipment is when the GDT is subjected to a 2 kV 2/10  $\mu$ s or 8/20  $\mu$ s surge. Increasing the generator voltage past this point will reduce the surge impulse voltage. The increased current will only be testing the ground return current path. If the GDT data sheet is specified with a surge impulse voltage rating with a 2 kV, 2  $\Omega$  8/20  $\mu$ s surge, this will help to ensure voltage coordination for the secondary protection on line cards, for example. This test can also be useful for equipment being used in high lightning, remote access applications. GR-1089-CORE, issue 4, section 4.7 covers lightning protection tests for equipment to be located in high exposure customer premises or OSP facilities and uses a 10/250  $\mu$ s generator up to 4 kV, 500 A capability. Further investigation needs to be done with this waveform to see if 4 kV actually provides maximum stress on the equipment.



## 5.4 Arc Voltage

The arc voltage ( $V_{ARC}$ ) is developed across the GDT during its “virtual short circuit” condition. This parameter defines the power dissipation of the GDT during its protection mode. A low arc voltage is desirable to keep power dissipation at a minimum, which in turn increases the life expectancy of the tube due to a lower operating temperature. The miniature surface mount series GDTs are, in addition to other applications, being considered for secondary protection in broadband solutions, but require other considerations. For these types of applications, the overcurrent protectors need to be carefully selected to ensure that the GDT is bypassed correctly. If this is not performed correctly, the GDT could be damaged before the overcurrent protector operates under the AC power cross tests.

The arc voltage will also define how the primary and secondary protection solutions perform together. The principle is to have an overcurrent protector between the primary and secondary overvoltage protectors. The belief is that once the GDT operates, the virtual short of the GDT will redirect the energy away from the secondary protection and the secondary will reset. It is common for a secondary protector such as a TISP® thyristor to be used. If the overcurrent protector solution is a fuse, it has been established that the fuse will need to clear before the GDT can operate if there is not enough impedance between the two voltage protectors. Resistance to achieve voltage coordination to allow the protection solution to reset is usually between 5  $\Omega$  to 50  $\Omega$ , but is dependent on the secondary protector withstand current capability. The current through the TISP® thyristor has to fall below its holding current,  $I_H$  (150 mA min. at an ambient temperature of 25 °C) for it to reset back into a high impedance state. The TISP® thyristor on-state voltage,  $V_T$  is approximately 3 V (dependent on surge current and impulse shape), so with a 50  $\Omega$  series resistance, the arc voltage must be lower than 10.5 V ( $0.15 \times 50 + 3$ ). Lower resistance values compound the problem. Having a higher arc voltage GDT will increase the stress for the secondary protection where a ceramic positive temperature coefficient (CPTC) thermistor, such as the Bourns® CMF-SD50 series, would help in this instance.

### 5.4.1 Arc Voltage Under AC Conditions

The arc voltage is specified with a 600  $V_{RMS}$ , 1 A generator. To reconfirm the data sheet specifications, the 2026-35 arc voltage was measured with 600  $V_{RMS}$  with 0.92 A and 3.4 A. The  $V_{ARC}$  did not change between the two load current values where the typical arc voltage was just 8.1 V.

### 5.4.2 Arc Voltage Under Surge

The 2026-xx series was surged with a 1 kV, 100 A 10/1000  $\mu$ s and the arc voltage measured. The results highlighted a voltage variation from 11.78 V to 12.20 V between the different voltage options in the series. This variation is too small to be further investigated in this report and therefore concludes that there is no major variation between different voltage options in the GDT series. This also showed that the arc voltage changed over the duration of the impulse. The arc voltage of the 2026-35 was re-measured at 1000  $\mu$ s where the typical  $V_{ARC}$  was just 11 V as shown in figure 13. As the delay time stayed constant during the original voltage measurements, comparisons could still be made between the different voltages in the series.

Reducing the peak 100 A 10/1000  $\mu$ s surge current by 50 % did not show any significant change in the arc voltage as shown in figure 13. This shows that the arc voltage is not current dependent under surge.

The 2026-35 was surged with a 2/10  $\mu$ s impulse to see if the waveshape changed the arc voltage characteristic. The arc voltage did not significantly vary between the 10/1000  $\mu$ s and 2/10  $\mu$ s impulse.

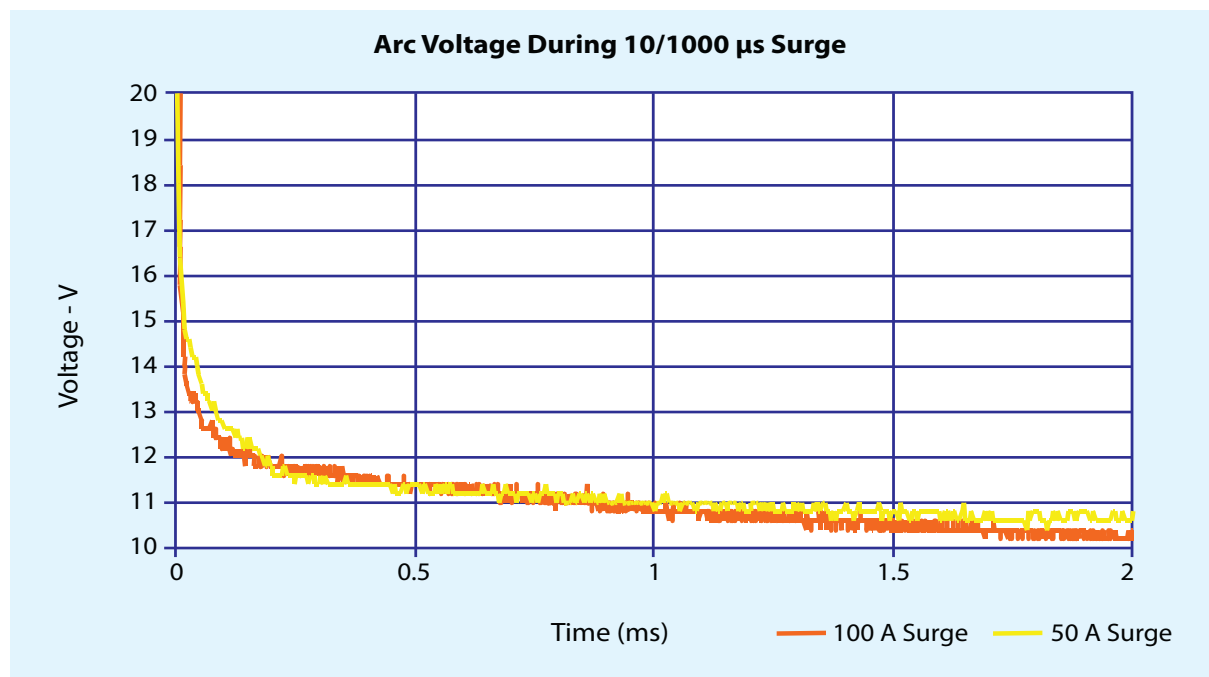


Figure 13 – Arc voltage variation during a 10/1000  $\mu$ s surge

**Note:** It is recommended to define the time delay after the start of the surge impulse to allow accurate comparisons of the arc voltage. For this application note, the  $V_{ARC}$  measurements were taken at the decay value time of the surge waveform being used. Telecom surges specify the fall time at 50 % of the peak value where the measurement for a 10/1000  $\mu$ s surge was measured at 1000  $\mu$ s and 10  $\mu$ s for a 2/10  $\mu$ s.

## 5.5 Section Summary and Recommendations

The most suitable waveform for testing voltage coordination between the primary and secondary protector is either 2/10  $\mu\text{s}$  or 8/20  $\mu\text{s}$  as this developed the highest surge impulse voltage. Telcordia GR-1089-CORE, issue 4 specifies 1000 V/ $\mu\text{s}$  rating if the primary does not conform to GR-974-CORE (specifies 600 V for a medium voltage protector). Using the 1000 V/ $\mu\text{s}$  specification for the surge impulse voltage adds significant head room which makes the solution more robust, but at the expense of the secondary protection being “over-engineered” for the task. The more realistic specifications to use are the 100 V/ $\mu\text{s}$  specifications.

- Using the  $V_{\text{DCBD}} + 50\%$  to set the peak surge generator voltage will provide maximum stress to the secondary protection with the GDT removed from the circuit. This also simplifies additional testing to find the GDT threshold.
- A 2 kV 8/20  $\mu\text{s}$  generator voltage with a 2  $\Omega$  generator impedance produced the highest surge impulse voltage of the 2026-35. Section 5.2 showed that there was no significant difference in the surge impulse voltage between the 8/20  $\mu\text{s}$  and 2/10  $\mu\text{s}$  waveforms when using the same generator open circuit voltage, so either waveform can be used to evaluate the protection circuit.
- The impulse sparkover rating with a 100 V/ $\mu\text{s}$  is a good indication of the expected maximum surge impulse voltage when considering the 10/1000 surge. The increase of surge impulse voltage during a 8/20  $\mu\text{s}$  or 2/10  $\mu\text{s}$  impulse generator is minimal (7 %) which allows the 100 V/ $\mu\text{s}$  rating to be a good approximation when designing to other telecom surge waveshapes.
- To calculate the coordination voltage with a known series DC sparkover voltage option, use  $V_{\text{SURGE}} = (1.3 \times V_{\text{DCBD}}) + 280$ . This is for GDTs where the  $V_{\text{DCBD}}$  is greater than 150 V. GDT voltage selection options less than 150 V will provide higher surge impulse voltages and will need another formula to calculate the expected surge impulse voltage.
- The maximum stress applied to the secondary protection during a surge is just before the GDT switches into a virtual short. This can be estimated as:
 
$$\begin{aligned} 10/1000 \mu\text{s surge is } V_{\text{DCBD}} + 15\%. \\ 2/10 \mu\text{s surge is } V_{\text{DCBD}} + 50\%. \end{aligned}$$
 Surging above these breakdown points of the GDT will reduce the energy seen by the secondary protection.
- Surging ports above 2 kV with telecom surges does not necessarily stress the secondary equipment or test voltage coordination between the primary and secondary protector. The surge impulse voltage can actually reduce with an increase in surge generator voltage. The increased current with the higher generator voltage will test the durability of the GDT and the ground return path of the GDT.
- Using the 1000 V/ $\mu\text{s}$  rating of the GDT is not an accurate method for identifying peak surge impulse voltage. The peak voltage seen was  $V_{\text{DCBD}} + 113\%$  where the 1000 V/ $\mu\text{s}$  rating for the 2026-35 is  $V_{\text{DCBD}} + 150\%$ . Using the 1000 V/ $\mu\text{s}$  rating of the GDT just increases the safety tolerance, but can make the secondary protection circuitry more expensive than necessary.
- Switching time is dependent on the rise time to impulse sparkover voltage rating of the GDT. A fast rising edge waveform will provide a consistent switching time where a slow rising edge will provide a consistent surge impulse voltage.
- The arc region transition time to 70 V is less than 100 ns and is not significantly affected by the surge waveform or impulse current. The arc voltage is also not affected by the impulse current or waveshape. However, careful measurement is required.

## Life Cycle of a GDT

The GDT does wear out due to particulates being dislodged from the electrodes during the arcing of the tube. The impact of the arc across the tube is dependent on the energy strike, so the life of the GDT tube will be dependent on the impulse applied to it. The life of the tube is expressed in a surge waveform and the number of surges. The principle of solid state protectors such as the TISP<sup>®</sup> thyristor family having a wear out mechanism is documented, but compared to the life span of a GDT, it can be considered not to have a wear out mechanism. Thyristor measurements are also based on testing done using the “Step Stress” method (increasing a generator voltage waveform sequentially while testing the electrical characteristics between each surge for variation). The step stress test also needs the device under test to fail with a single surge.

The GDT proved difficult to run a step stress test as the DCBD voltage varied between each test and a tolerance would need to be put in place to define a pass/fail criteria. The 40 kA 8/20  $\mu$ s generator could not guarantee that the unit would fail on the first test which is key in step stress testing. Semiconductor protectors support lower impulse currents and have a tight window between an electrically good test to a short circuit failure. These two parameters make the step stress principle work well in the electrical characterization process for these types of devices, but not for the current family of Bourns<sup>®</sup> GDTs. The life cycle experiments were therefore done using a “Repetitive Stress” test method (repetitively surging the GDT with a fixed voltage/current impulse) where the DCBD was measured after each test.

**Note:** The 2035-20 (single element, 200 V) series was used in figure 14 due to it being half the impulse rating of the 2026-xx series to accelerate the end of life point of the GDT.

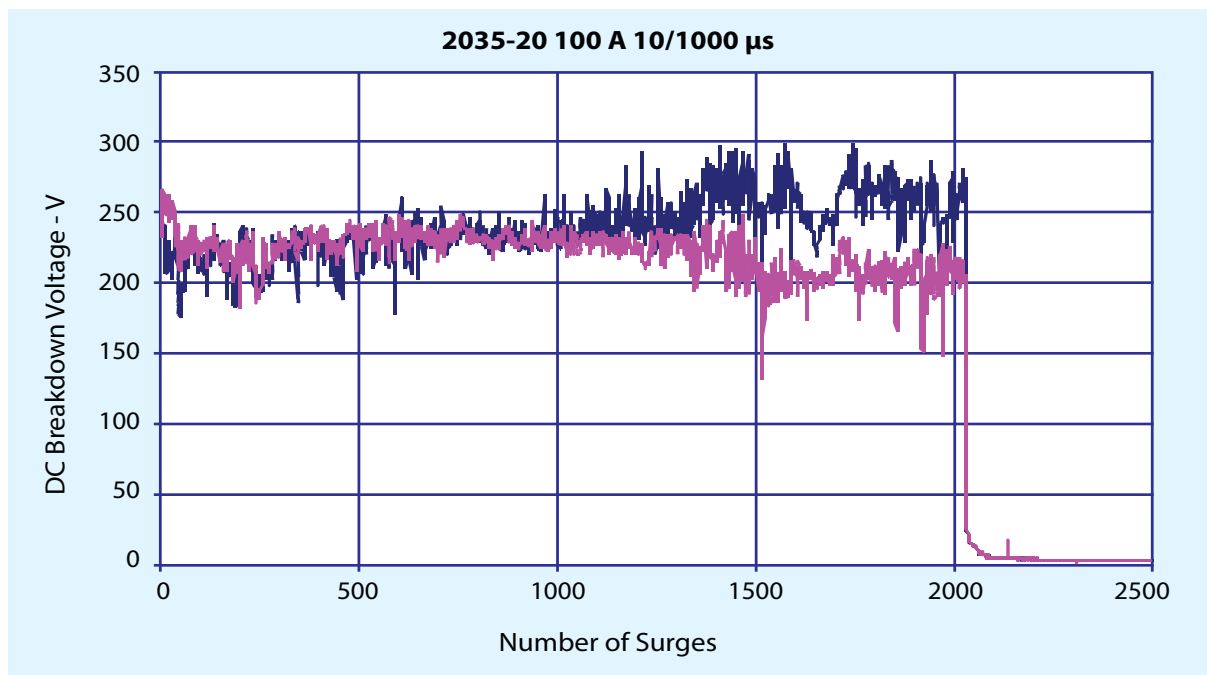


Figure 14 – 2035-20 DCBD voltage variation during repetitive surges

The separation of the two DCBD voltage measurements (positive and negative polarity measurement) shown in figure 14 is due to the particulates being attracted to a single conductor. The surge ionizing effect charges the tube and therefore attracts the particulates to one end of the tube. This has the effect of changing the electrical properties such as the DCBD.

**Note:** Alternating polarity (+/-) surging on each impulse test increases the longevity of the tube due to the particulates being dislodged from each of the electrodes, rather than just one. The data captured in figures 14 and 15 was tested with a repeated single polarity (+) surge to ensure a worst case scenario.

The end of life shorting of the GDT is caused by the rapid breakdown of the emission coating and the electrode material (metal) that further increases contaminates within the tube. The loose materials in the tube attach themselves to the side of the ceramic body between the two electrodes. This has the effect of causing a “virtual short” between the two electrodes.

## 6.1 Longevity and End of Life

Telcordia GR-974-CORE tests the primary protector to ensure adequate life of the tube in the field. The 2026-35 was subjected to 1000 impulse tests under a 500 A 10/1000  $\mu$ s surge where the average DCBD voltage stayed within its 20 % tolerance. GR-974-CORE specifies 100 repetitions at 300 A 10/1000  $\mu$ s, so this test setup can be considered well beyond normal requirements. The plan was to see what happened at the actual end of life of the GDT. Figure 15 shows the results of the 2026-35 average DCBD voltage and peak surge impulse voltage with 500 A 10/1000  $\mu$ s over 1000 impulses. The blue boundary lines in figure 15 highlight the minimum and maximum DCBD voltage limits specified as the tolerance in the data sheet. It can be seen that the average DCBD voltage did not exceed this specification window in the data sheet during 1000 surges.

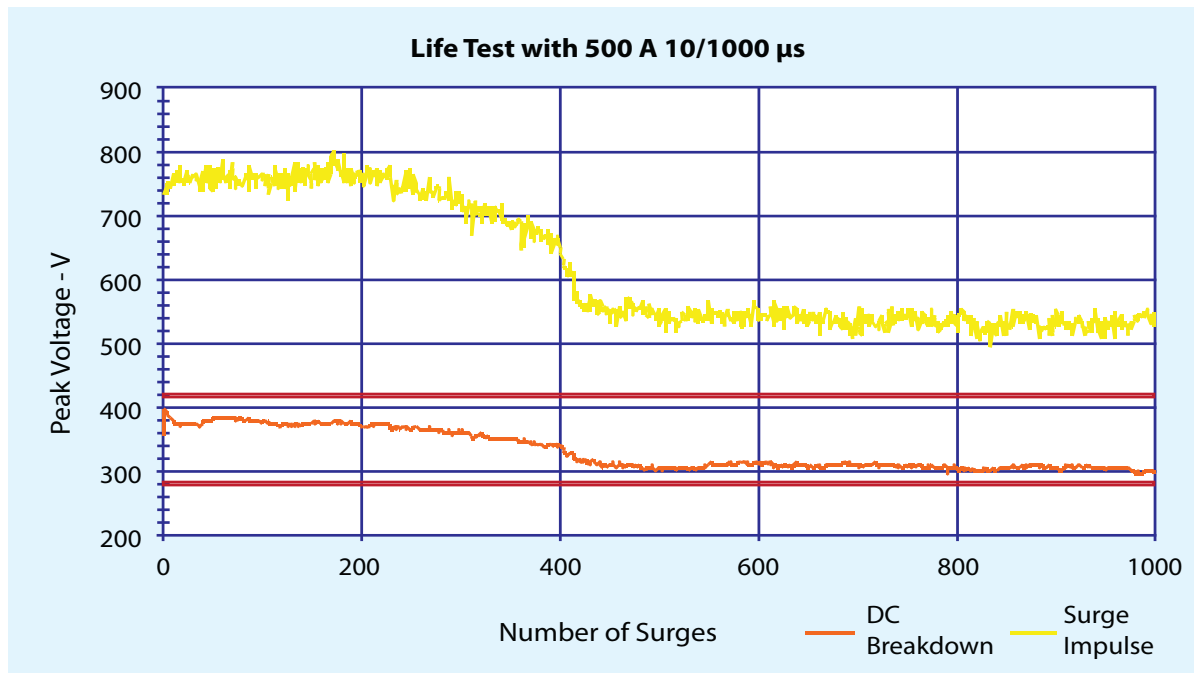


Figure 15 – 2026-35 life test during 1000 surges of 500 A 10/1000  $\mu$ s

**Note:** A good quality GDT reduces replacement in the field which ultimately saves cost. This is especially important when units are deployed in remote locations and lightning rich areas.

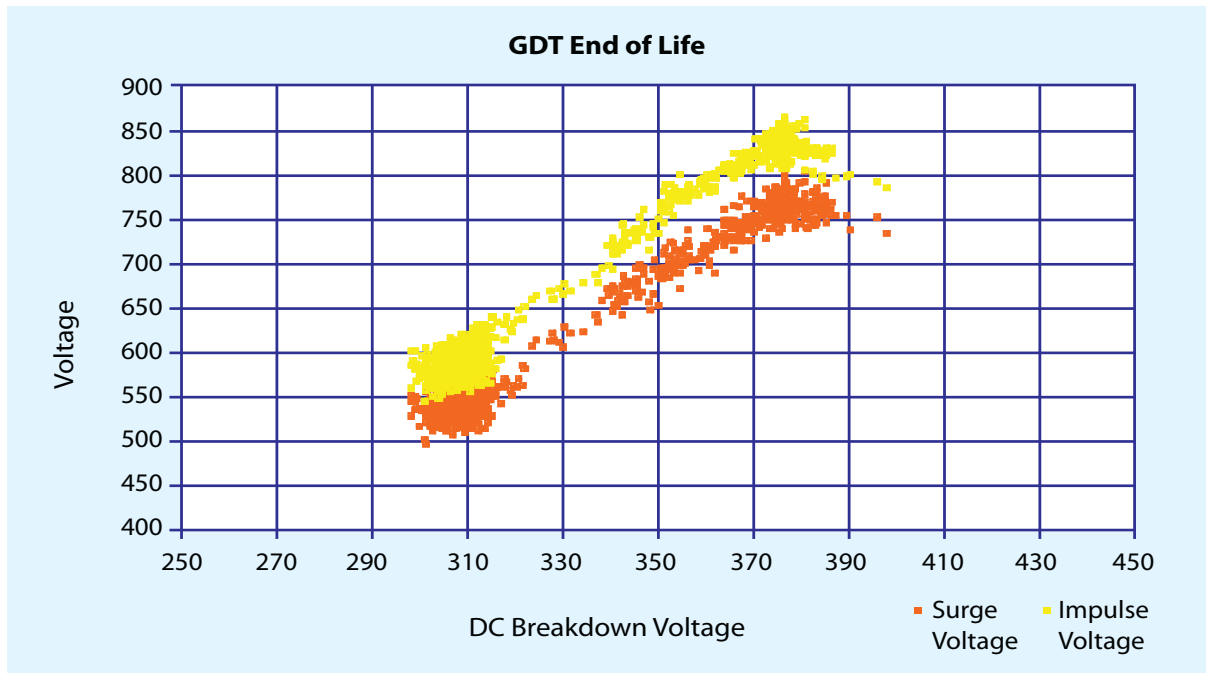


Figure 16 – 2026-35 surge impulse vs DCBD voltage with 500 A 10/1000  $\mu$ s

The surge impulse voltage from 500 A, 10/1000  $\mu$ s (figure 16, orange dots) and the 1000 V/ $\mu$ s impulse voltage (figure 16, yellow dots) was plotted against the DCBD voltage measurements over 1000 surges. A direct relationship can be seen between the DCBD voltage and the surge impulse voltage under repetitive surging. This ensures the equipment is still protected as the GDT comes to the end of its life. Figure 14 shows that the DCBD voltage would have suddenly gone to a few volts highlighting that the GDT had completely failed safe into a virtual short circuit.

## 6.2 The Dark Effect

GDTs have the reputation that the first surge on the tube will result in a higher breakdown than the next successive surges. As the GDT is normally housed in a plastic module and deployed in a dark cabinet, the term was called the dark effect. The initial strike ionizes the gas to make it settle into a consistent breakdown voltage specification. First generation GDTs used to see the first breakdown voltage in the region of 50 % to 70 % above the average sparkover rating. Equipment secondary protection would not distinguish between the first and subsequent strikes, so this set the precedence on the voltage let-through of the GDT. Today's GDT still exhibits the dark effect, but Bourns has significantly reduced the impact by changing the geometry and emission coating composition of the gas tube. Figure 17 shows the dark effect with the 2026-35 series GDT with a 10 A 10/1000  $\mu$ s. The average impulse let-through was 800 V, where the first surge impulse was only 11 % higher. Subsequent surges saw the impulse voltage drop down 9 % (5 surges) from the average voltage.

Surge tests done with higher impulse current levels did not see this phenomenon, which indicates the dark effect is dependent on the surge current. Higher surge currents also points to a higher rate of voltage rise due to the fixed generator resistance, but further investigation is required.



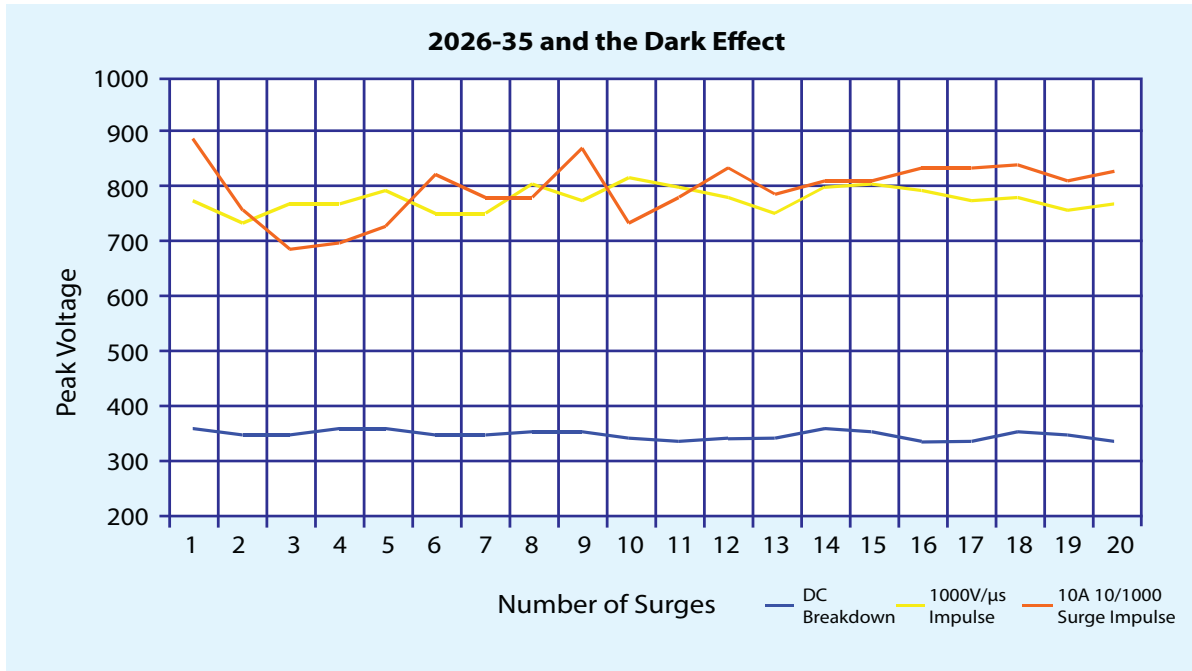


Figure 17 – 2026-35 dark effect

**Note:** The Bourns® primary protectors such as the 2410 and 2420 have the dark effect included in the tolerance of the GDT. The 5-pin 2410 and 2420 are tested to Telcordia GR-974-CORE to ensure that the maximum peak voltage of the GDT is below 600 V under a 1000 V/μs rate of rise.

## 6.3

### The Spark Effect

The 2026-35 was surged with 500 A 10/1000 μs to look at the dark effect at elevated impulse currents. At 500 A, the dark effect did not show in the test data results as the impulse voltage continued to increase slightly under each subsequent surge test. There was a high increase in the DCBD voltage between the first and second surges as shown in figure 18. This became known as the “spark effect”.

**Note:** The “Spark Effect” is a term created by the author and is not currently defined in any standards.

The spark effect is due to the arc being of a high enough energy density to cause contaminants (impurities) to be released from the internal materials into the GDT gas atmosphere under a single surge. These contaminants in the gas cause the increase of the DCBD voltage. Figure 18 shows an increase of 12 % between the first two surges. Subsequent surges will trigger the “getter” effect of the special emission coating that will attract the impurities (contaminants) and reduce the breakdown voltage to their original level. Contaminants suspended in the gas will change the gas composition and decrease or increase the breakdown voltage according to the Paschen curve of the particular gas mixture.

Figure 18 shows the DCBD voltage changing from 356 V to 398 V on the first surge (DCBD is measured before the surge is applied). The 2026-xx series has a DCBD tolerance of ±20 % to give a range of 280 V to 420 V. The current failure tolerance point for Telcordia is 600 V (265 V for all surges up to 300 A 10/1000 μs) where the 2026-35 is still well within specification.

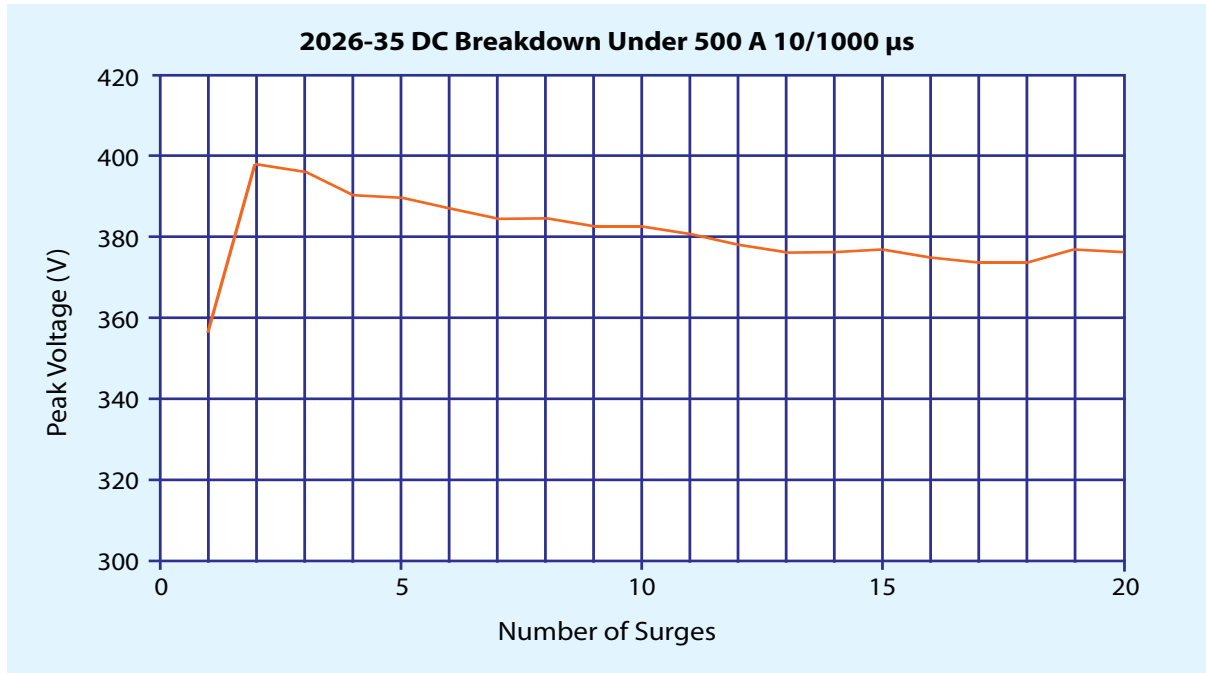


Figure 18 – Spark effect during repetitive 500 A 10/1000  $\mu$ s surges

**Note:** The tolerance of the Bourns® GDT device includes the spark effect.

The second area of interest shown in figure 18 is that the DCBD reduces as the number of surges increase. The emission coating on the inside of the GDT electrodes is activated due to the heat generated during each strike. This has the effect of attracting the contaminants to the emission coating on the electrodes. As the impurities reduce in the GDT gas atmosphere, the DCBD voltage also reduces. The DCBD voltage and impulse surge voltage will stabilize. Figure 15 showed the DCBD voltage of the 2026-35 GDT settling at 310 V after 447 strikes.

**Note:** The use of inferior electrode material will release more contaminants into the gas to cause premature failure. Bourns® GDT products are designed for extended longevity.

## 6.4 GDT Resistance Below Its Breakdown Voltage

The resistance of a GDT and its capacitance (RC filter) indicates the insertion and return losses of the component in high frequency applications. Bourns has independent test reports for insertion and return loss of the 2410 and 2420 series of 5-pin modules up to 100 MHz. These reports are available on request. Figure 19 shows the average resistance of the 2026-35 series GDT during 1000 surges of 500 A 10/1000  $\mu$ s. The resistance did not vary significantly during the test.

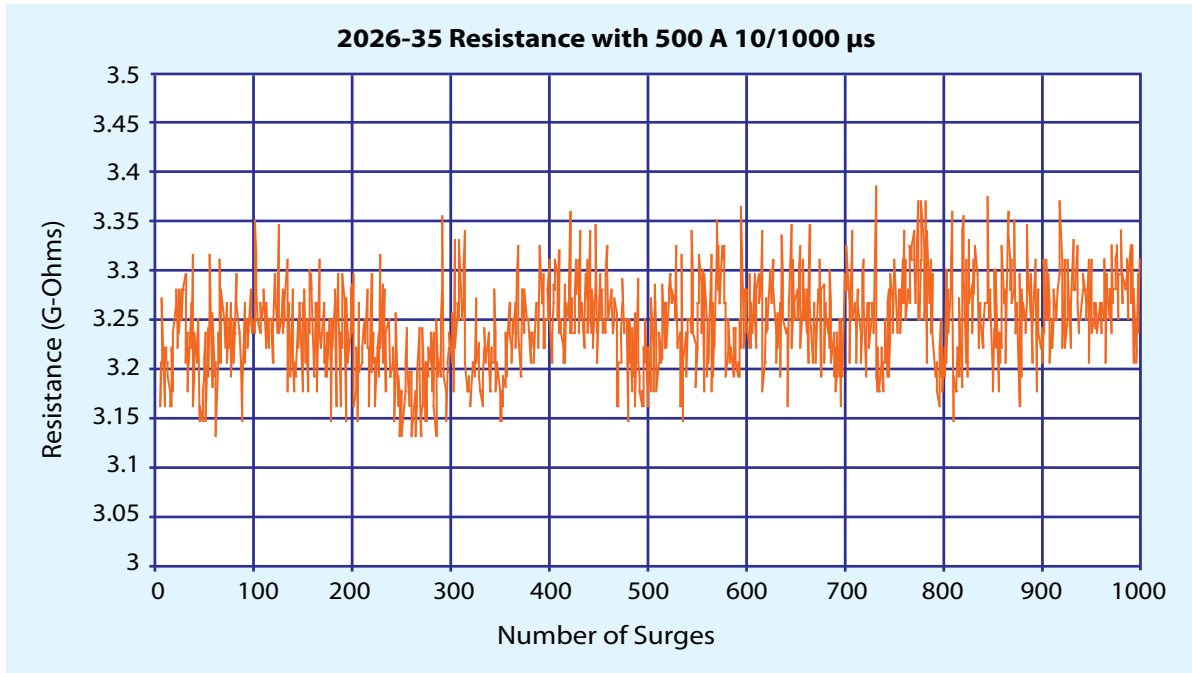


Figure 19 – Average resistance variation with 500 A 10/1000  $\mu$ s surges

**Note:** Test measurement of such high impedances can be influenced by the equipment testing tolerance and therefore any variation may not be a true representation of the GDT's actual insulation resistance.

## 6.5

### Section Summary and Recommendation

The Bourns® series of GDTs have been designed with longevity and reliability in mind where the 2026 series can withstand a lot more repetitive surges than required by the current standards.

The old issue of the “dark effect” where the first strike would yield the highest surge impulse voltage has been minimized in today's product. Depending on the first impulse surge, a new effect called the “spark effect” was seen. The increase in the surge impulse voltage is due to contaminants from the first strike increasing the DCBD, which takes subsequent surges to rectify.

These voltage increases are within the DCBD tolerance of the Bourns® GDT to ensure quality, reliability and dependability.

The Bourns® GDT will fail into a virtual short circuit where a reduction of the DCBD voltage is first observed before the final rapid decline to a virtual short. There are occasions where a GDT can recover to a level of if its DCBD, but a few subsequent surges will make it a permanent short.

## Summary

A GDT is often considered a slow operating overvoltage protector, but these devices are intended to handle impulse currents many times higher than faster technologies such as solid state (semiconductor) devices. The GDT has to develop enough voltage across the conductors to create an arc across it. The gas between the contacts controls the electrical parameters and makes them repeatable under a wide variety of environments. GDT technology has also evolved to provide “faster” switching devices that reduce the impulse sparkover rating, but often at the expense of other key parameters such as tube life and high glow to arc transition current or a high arc voltage. A GDT can also be designed with lower quality materials such as the electrode material or electrode coating material for cost reduction, at the expense of the GDT life in the field. Establishing the tradeoffs of the dynamic parameters, longevity and price is key to designing in the correct product for the application. It might not be necessary to design in a GDT that will last 20 years in a product that is expected to have only 5 years of service life.

A second area often questioned is that the electrical measurements of a GDT are never consistent. Some of the experiments done in this document showed that this is indeed the case. The variation is due to contaminants introduced into the gas from the normal operation of the GDT. Contaminants change the electrical characteristics of the device where the emission coatings in the tube are designed to attract the contaminants released into the gas. This results in the variations seen in the measurements during repeated tests on the same device. Knowing these variations exist and having the manufacturer specify the tolerance to take these variations into account allow the GDT to be designed correctly for a specific application.

**Note:** It is important to consider specifications for end of life tolerances, not just new tube tolerances. This varies between GDT manufacturers.

Lightning strikes have been characterized as being a minimum of 30 kA up to 250 kA with a very short duration, but the energy seen by a primary protector at the end of a twisted pair is more like a 500 A 10/250  $\mu$ s surge. There are also GPRs (ground potential rises), that can have surges entering the ground plane and equipment being damaged through the backplane. There is a belief that a faster rising voltage will provide a higher impulse voltage. This is correct, but Bourns® GDT surge and ramp impulse voltage will actually decline as the rate of rise of the surge voltages continue to increase as seen in figure 12. The ramp or surge impulse voltage can now be calculated to find the expected peak voltage with a known DCBD voltage option. This is simplified where the surge impulse voltage rating is just impacted by the shape of the surge voltage waveform. It was observed that the 2026-xx series only requires a surge voltage of about 15 % above the DC sparkover rating for a 10/1000  $\mu$ s. This only increased to 50 % under a 2/10  $\mu$ s type impulse to ensure the GDT operates. This allows the maximum stress (GDT not operating) for the secondary protection to be specified by just knowing the DCBD value of the GDT primary protector.

A common belief is to use the 1000 V/ $\mu$ s rating which is often 150 % above the DC sparkover rating and not an accurate representation. Using the 1000 V/ $\mu$ s will provide a worst case scenario or provide maximum tolerance, but at the expense of increased secondary protection requirements. A formula is now available that will provide a more accurate method for defining coordination voltages to cover the wide voltage options available in the GDT families.

Primary protectors have to meet Telcordia GR-974-CORE and GR-1361-CORE for the US and ITU-T K.12 for most other countries. Secondary protection needs to meet GR-1089-CORE or TIA-968-A for the US and ITU-T K.20 and ITU-T K.21 for other countries. The design of primary and secondary protectors in telecom systems has previously been totally exclusive of each other. Secondary protection standards such as Telcordia GR-1089-CORE, issue 4 are the first step where the benefits of a GDT primary protector can now be taken into consideration during the secondary protection design.

# Appendix

## Key Differences Between a GDT and TISP® Thyristor

Bourns also manufactures the semiconductor TISP® thyristor series that provides an overvoltage crowbar protection solution similar to the GDT. A common question asked is “what are the differences between a GDT and the solid state semiconductor TISP® thyristor”?

- **$V_{DCBD}$  vs repetitive peak off-state voltage,  $V_{DRM}$**

Both define the maximum working voltage across the protector before conduction occurs where the protector will have high impedance so that it will not interfere with the normal operation of the system. The DCBD voltage is specified as a typical voltage where the tolerance has to be used to define the minimum rating to not interfere with system's operating voltage. The TISP® thyristor  $V_{DRM}$  is specified as an absolute maximum in the data sheets. The DCBD is measured by using a slow ramp voltage such as a 100 V/s to 2000 V/s. The  $V_{DRM}$  for the TISP® thyristor is measured at a specific current value and is specified in the data sheet as a maximum of 5  $\mu$ A at the  $V_{DRM}$  value.

For example, a 2026-35,  $\pm 350$  V DC sparkover with 20 % tolerance will have a minimum  $V_{DCBD}$  of  $\pm 280$  V. A TISP4350J3BJ has a minimum  $V_{DRM}$  of 275 V.

- **Impulse sparkover voltage vs dynamic breakover voltage,  $V_{(BO)}$**

Both define the maximum dynamic protection voltage window of the protectors. The protection voltage is the maximum voltage the system will see. The GDT impulse voltage and the  $V_{(BO)}$  impulse breakover voltage of a TISP® thyristor are specified at a ramp voltage of 100 V/ $\mu$ s or 1000 V/ $\mu$ s.

For example, the 2026-35 has an impulse sparkover specification of 875 V at 1000 v/ $\mu$ s typical (about 200 % above the upper DC sparkover voltage rating) where the TISP4350J3BJ is specified with a maximum of 364 V (32 % above the  $V_{DRM}$  voltage rating). This shows the benefit of the TISP® thyristor with its tight maximum working voltage to protection voltage ( $V_{DRM}/V_{(BO)}$ ) window.

- **Impulse discharge current vs non-repetitive peak impulse current**

These two parameters highlight the surge withstand rating of the protector where both are specified using industry standard surge waveforms. The GDT will specify a short circuit current level and the minimum quantity of operations it can withstand. The TISP® thyristor does not have a wear-out mechanism like the GDT, so its impulse current ratings are specified as an absolute maximum.

For example, the 2026-35 can support a single surge of 40 kA 8/20  $\mu$ s or 400 surges of 1000 A 10/1000  $\mu$ s. The TISP4350J3BJ is the largest current handling device in the DO-214AA (SMB) type package and is rated for 800 A 8/20  $\mu$ s and 200 A 10/1000  $\mu$ s.

- **Capacitance**

Capacitance of a GDT is significantly lower than a TISP® thyristor. The capacitance of a GDT is also not affected by any bias or signal voltages across it and does not change with temperature. A TISP® thyristor or any semiconductor overvoltage protector will have a capacitance value dependent on the surge rating (which is dependent on silicon size) and will change according to the bias voltage across it. Thyristor capacitance will also vary with the protection voltage of the same surge rating series where low  $V_{DRM}$  voltage options will have a higher capacitance value.

For example, the 2026-35 is specified with a capacitance of less than 2 pF. The 350 V TISP4350J3BJ specifies a maximum of 105 pF with 2 V bias. Increasing the bias to 100 V will decrease the capacitance to 40 pF. A 70 V TISP4070J3BJ with the same surge rating as the TISP4350J3BJ has a maximum capacitance of 235 pF at 2 V bias.

**Telcordia Technologies Generic Requirements**, GR-1089-CORE, Issue 4, June 2006,  
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Characteristics of gas discharge tubes for the protection of telecommunications installations.

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Resistibility of telecommunication equipment installed in a telecommunications center to  
overvoltages and overcurrents.

**ITU-T K.21**, July 2003,  
Resistibility of telecommunication equipment installed in customer premises to overvoltages  
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**TIA-968-A-4**, November 2006,  
Technical requirements for connection of terminal equipment to the telephone network.



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