The ZTX415 Avalanche Mode Transistor

An Introduction to Characteristics, Performance and Applications

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Introduction

Avalanche mode devices can provide extremely high switching speeds and are capable of producing current outputs far in excess of that obtained from conventional circuits.

These attributes lend themselves to many applications, including; laser diode drivers for ranging, measurement, and collision avoidance systems, Pockel cell drivers for laser Q switches, SAW device exciters, streak cameras and fast high voltage/ high current pulse generators.

The Zetex Semiconductors ZTX415 is an avalanche transistor that ideally suits this mode of operation and application. The device is available in the proven silicone E-Line package that assures excellent thermal properties to complement the high performance avalanche characteristics. It is also available in the SOT-23 surface mount package (as FMMT415) to enable very low inductance designs.

This Application Note outlines the principle of avalanche mode operation, gives details on important parameter and operating conditions, and suggests a few application circuit examples. (Please refer to Appendix A for a list of reference material).

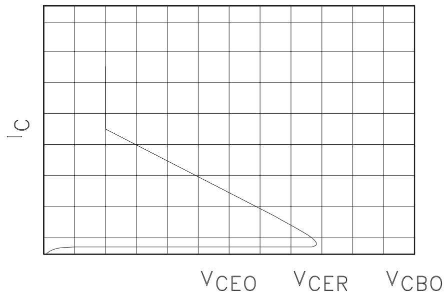

Figure 1
Transistor Characteristics in the Avalanche Region.

What Is An Avalanche Transistor?

Avalanche transistors are characterised by a negative resistance region in their V-I breakdown curve (usually called secondary breakdown) as illustrated in Figure 1. This region permits controlled switching of very high currents in nanoseconds when appropriate external circuitry is employed. The output pulse generated is limited by the primary breakdown B_{VCBO}, the transistor's 'On-state' voltage and the mean dissipation that can be tolerated.

Characteristics

This section reviews the important parameters of an avalanche mode transistor with particular reference to the ZTX415.

The current passed in the secondary breakdown condition, defined as IUSB , is dependent on the supply to the device and it's 'On-state' characteristics. The ZTX415 is capable of producing very high avalanche current as indicated by Figure 2. This shows the maximum peak current as a function of pulse width for a sinusoidal-like pulse. The area under curve 1 has been verified by extensive

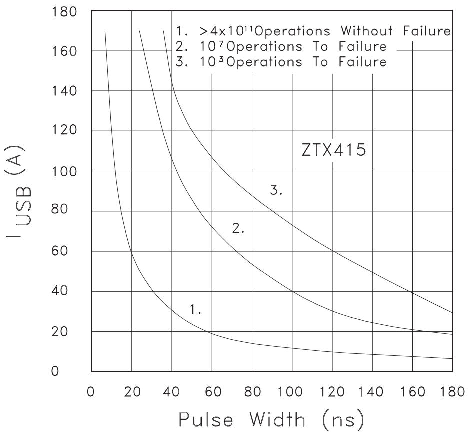

Figure 2
Maximum Avalanche Current v Pulse Width.

reliability work. For example, devices on a life test have produced current pulses of 60A peak and 10ns pulse width for over 4 x 1011 times without failure.

The diagram also shows a recorded 107 operations to failure (curve 2), and a 103 operations to failure, (curve 3, observed sudden failure points). The test circuit used to derive the measurements for these curves is shown in Figure 3, and is basically a single capacitor arrangement.

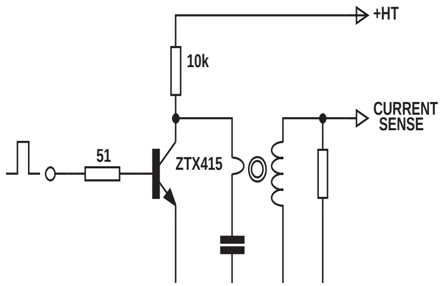

Figure 3
Single Capacitor Test Circuit for I_{usb} Measurements.

The avalanche current is again illustrated in Figure 4 for a typical device, showing its temperature dependency for the specification conditions.

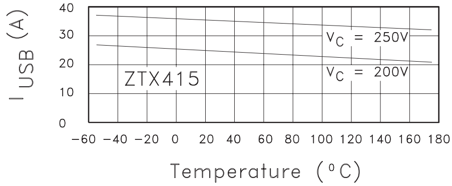

Figure 4
I_{USB} v Temperature.

When using avalanche devices, attention to the base bias and therefore the possible gain variation can be important. Figure 5 shows the gain variation versus collector current over the operating temperature range for the ZTX415.

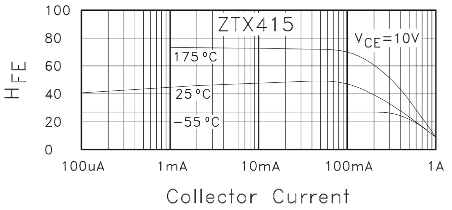

Figure 5
h_{FE} v Collector Current.

The circuit techniques employed, and ultimately the usable operating range, depend somewhat on the static voltage characteristic of the avalanche device, e.g. to obtain a high voltage pulse the transistor must have a high BVCES. The ZTX415 has been designed using high voltage technology to produce a device possessing a minimum BVCES of 260V over the specified temperature range (the 25°C minimum actually being 280V). This makes possible the generation of high current pulses with the minimum of circuitry.

Furthermore, the ZTX415 process is very closely controlled to yield a product with a relatively narrow band of BVCES (Viz: 1.2:1 compared with 2:1 for conventional high voltage product) - an important attribute when designing high voltage stacks employing many devices in series, to produce kilovolt range output pulses. This feature also releases the customer from expensive selections and matching operations, otherwise required to guarantee performance and reliability.

Another important parameter is the minimum voltage required for avalanche operation, below which the device has the switching characteristic of a device in non-avalanche mode. This ‘starting’ voltage is dependent on the external circuitry employed with the device, but for a simple single capacitor arrangement is seen to vary as shown in Figure 6.

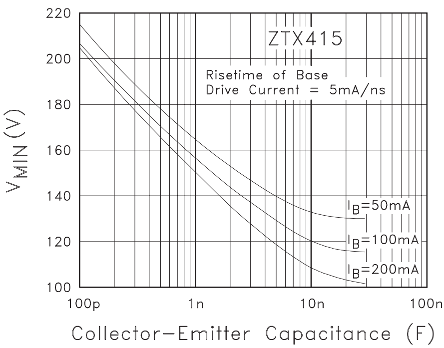

Figure 6
Minimum Starting Voltage as a Function of Capacitance.

This shows the minimum voltage required for avalanche operation as a function of capacitance, for different drive currents. The rate of change of drive current is also relevant, as Figure 7 illustrates.

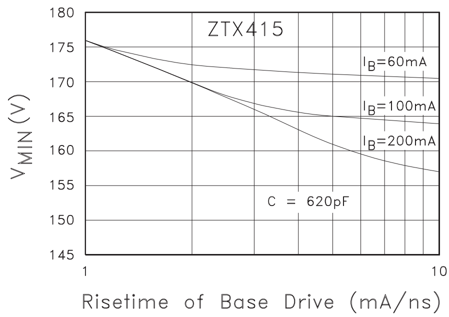

Figure 7
Minimum Starting Voltage as a Function of Drive Current.

This demonstrates that a lower starting voltage may be achieved by using a faster changing drive current.

Temperature plays a less significant role, with a typical coefficient of 0.11V/°C over the whole operating range, but as low as 0.05V/°C over a more usual range as shown in Figure 8.

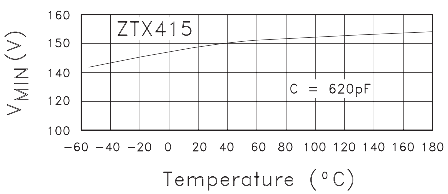

Figure 8
Minimum Starting Voltage as a Function of Temperature.

Any device is eventually limited by the maximum permitted power dissipation allowed for a particular package. However, due to the superior thermal performance of silicone packaging, Zetex devices out-perform any other TO92 style packages available. Referring to Figure 9 will show that the ZTX415 is usable without heatsinking up to an ambient temperature of 175°C. This enables higher currents (or voltages), and higher pulse repetition frequencies to be realised than with alternative types.

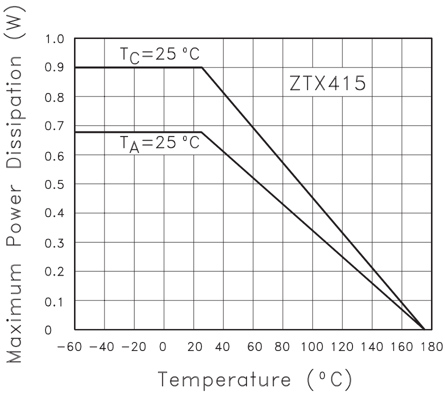

Figure 9
Dissipation De-rating Curves.

Reliability

Extensive reliability research has been performed on all of the DC and Avalanche characteristics of the ZTX415, confirming both the power rating and the inherent quality produced by proven device design techniques. Environmental, life test, and high temperature reverse bias (HTRB) trials are carried out routinely to guarantee continuing quality.

Applications

Avalanche mode characteristics can be realised in a wide variety of circuits from simple single capacitor arrangements through shaped pulse circuits, fast monostables and high current/high voltage pulse generators. The following gives some typical application examples.

The delay line pulse generator, shown in alternative configurations in Figures 10a and 10b, is so called because it depends on a charged delay line - the coaxial cable. The circuit produces a rectangular pulse, dependent on the length and characteristics of the cable.

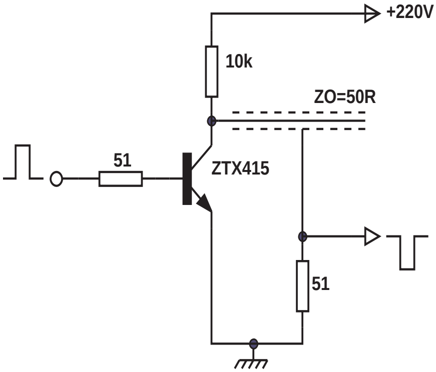

Figure 10a
Delay Line Pulse Generator.

Similar to the delay line generator but using a single capacitor arrangement, is the circuit shown in Figure 11(a). Using a ZTX415, this circuit is capable of producing sinusoidal-like pulses of tens of amperes, as reproduced in Figure 11(b). This form of circuit is ideal for driving laser LEDs.

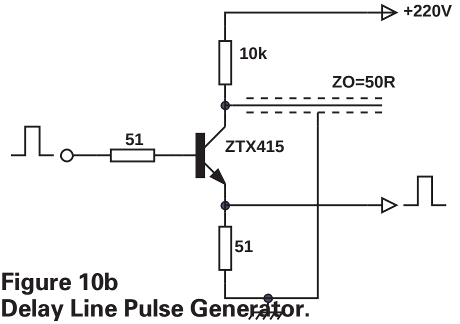

Figure 10b
Delay Line Pulse Generator.

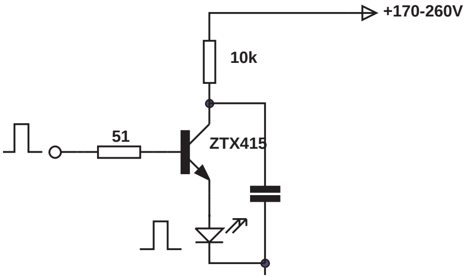

Figure 11a
High Current Pulse Generator for Laser LEDs.

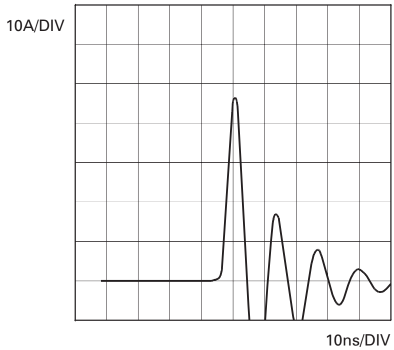

Figure 11b
Current Pulse Generated by Circuit shown In Figure 11a, showing 46A Peak 8ns Wide Sinusoid.

Pulse forming networks may be added to the basic configuration (as shown in Figure 12(a)) for specific pulse shape requirements.

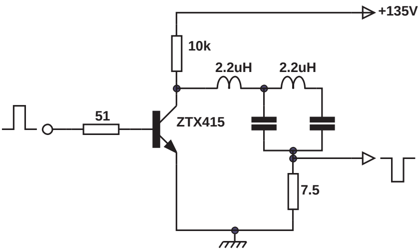

Figure 12a
High Current Pulse Generator with Pulse Forming Network.

In this way, rectangular pulses are easily produced, the form of which is dependent on the number of LC sections. Figure 12(b) shows a -6.7A peak, 90ns pulse generated by the two section generator of Figure 12(a).

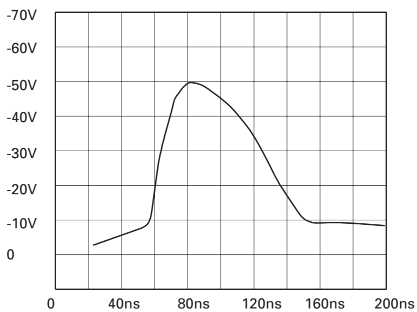

Figure 12b
Current Pulse Generated by Circuit in Figure 12a, showing -6.7A Peak, 80ns Pulse Width.

It is also possible to use the ZTX415 avalanche device in series to allow a higher supply, and therefore generate very high voltage pulses.

Large stacks of avalanche devices are possible as shown in Figure 13, which also shows an additional capacitor included on the lower devices. This is sometimes necessary, depending on

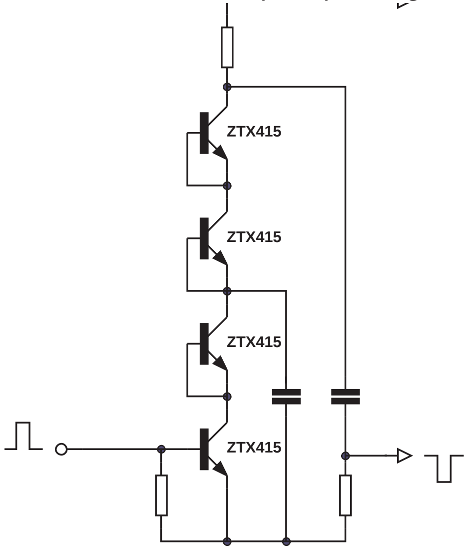

Figure 13
High Voltage Stack (or Series) Operation of ZTX415.

application, to ensure avalanche. This particular topology can, by optimising the voltage shared across each transistor, generate voltage steps of many kilovolts. Similar configurations with pulse forming networks are possible as shown in Figure 14.

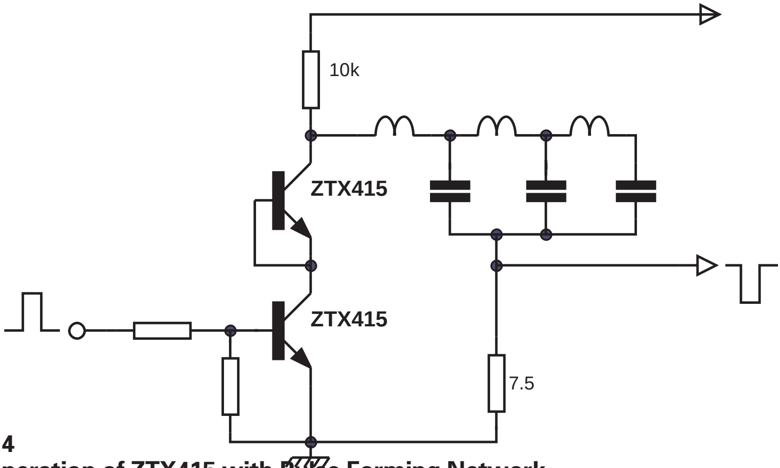

Figure 14
Series operation of ZTX415 with Pulse Forming Network.

When even higher currents are required, it is possible to devise circuitry using parallel ZTX415s as shown in Figure 15. Adjustable biasing makes possible the simultaneous avalanche of the transistor array, allowing current pulses of over one hundred amperes to be produced.

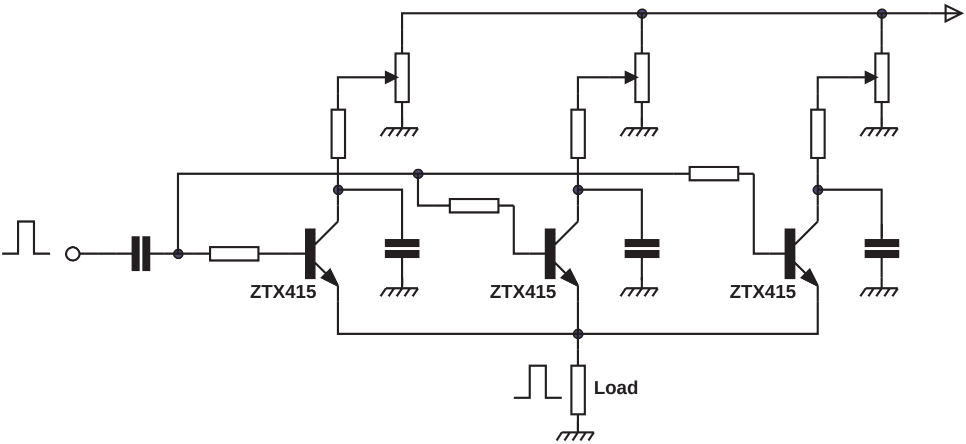

Figure 15
High Current Parallel operation of ZTX415.

Appendix A

Papers Detailing Applications Of Avalanche Transistors

1): Background:

Application Of Avalanche Transistors To Circuits With A Long Mean Time To Failure
Werner B.Herden.
IEEE Transactions on Instrumentation and Measurement, Vol.25, No.2 June 1976.

Properties of Avalanche Injection and its Application to Fast Pulse Generation and Switching
Yoshihiko Mizushima and Yoshiharu Okamoto.
IEEE Transactions On Electron Devices, Vol. ED-14, No. 3, March 1967.

Static and Dynamic Behaviour of Transistors in the Avalanche Region
Paolo Spirito.
Istituto Elettrotecnico, Universita di Napoli, Piazzale Tecchio, 80125 Napoli, Italy
IEEE Journal Of Solid-State Circuits, April 1971.

An Analysis of the Dynamic Behaviour of Switching Circuits Using Avalanche Transistors
P. Spirito and G.F. Vitale.
IEEE Journal Of Solid-State Circuits, August 1972.

2): Parallel Operation:

A Fast Risetime Avalanche Transistor Pulse generator for Driving Injection Lasers
James P.Hansen, William Schmidt. US Naval Research Lab, Washington DC.
IEEE Proceedings Feb 1967

Appendix A (Continued)

3): High Voltage Pulse Generation:

Subnanosecond High-Voltage Pulse Generator
David Brown and Don Martin.
Los Alamos National Laboratory, MS J957, Los Alamos, New Mexico 87545
Rev. Sci. Instrum. 58 (8), August 1987.

Fast High Voltage Pulsers For Nuclear Instruments
Yoneichi Honsono, Satoshi Takeuchi, Ken-ichi Hasegawa, and Masaharu Nakazawa.
Journal Of The Facility Of Engineering, The University Of Tokyo, Vol. XL, No.1 1996.

Avalanche Transistor Pulser For Fast-Gated Operation of Microchannel Plate Image-Intensifiers
Arvid Lundy, James S.Lunsford, and A. Don Martin.
Los Alamos Scientific Laboratory, University Of California, Los Alamos, NM 87545
IEEE Transactions On Nuclear Science, Vol. NS-25, No.1, Feb 1978.

Design of Reliable High Voltage Avalanche Transistor Pulsers
E.Stephen Fulkerson. Lawrence Livermore National Laboratory, Livermore, CA 94551
Rex Booth. Kaiser Engineering Livermore Inc. Livermore, CA 94551