White Paper

B-TRAN – Bi-Directional Bi-Polar Junction TRANsistor

Semiconductor power switches are critical components in power conversion for a wide variety of high efficiency and clean energy applications including motor drives, electric vehicles, renewable energy generation, and energy storage. Improving the efficiency and performance of semiconductor power switch components can have wide benefits, improving the economics and accelerating deployment of these applications.

Ideal Power Inc. has recently received five US patents, and has other patents pending, for the topology and method of operation of a new kind of semiconductor power switch, which we call a Bidirectional Bipolar Junction Transistor (B-TRAN). Worldwide patents are pending. Based on third party simulations, the B-TRAN is predicted to significantly improve performance over conventional power switches such as SCRs, IGBTs and MOSFETs, as implemented in silicon or wide-band-gap materials such as silicon carbide.

This white paper provides technical background on the B-TRAN device structure and operation, as well as predictions of B-TRAN performance compared with conventional power switches. A summary of B-TRAN applications and addressable markets are provided as well.

This paper assumes that the reader has some knowledge of power semiconductors, but the lay audience may benefit as well.

POWER SEMICONDUCTOR TOPOLOGIES (the basic layout of a power semiconductor device)

The B-TRAN may be viewed as the logical end point of the evolution of power semiconductor topologies, as shown in Figure 1 This progression, from left to right, may be described as – Figure 1 – Power Semiconductor Topologies

Figure 1 "open" – Pure silicon. This is a non-conductive device, so is useful only for insulating.

Figure 1 – "resistor" – Doped silicon. This is silicon which has an impurity that causes the silicon to become partially conductive, hence the term "semiconductor". It may be used as an electrical resistor, which is a device which conducts electric current with significant resistance, as opposed to a material such as copper which conducts with very little resistance. Some impurities produce this partial conduction by providing an extra electron per atom of impurity, and others do so by removing an electron per atom of impurity. The former is
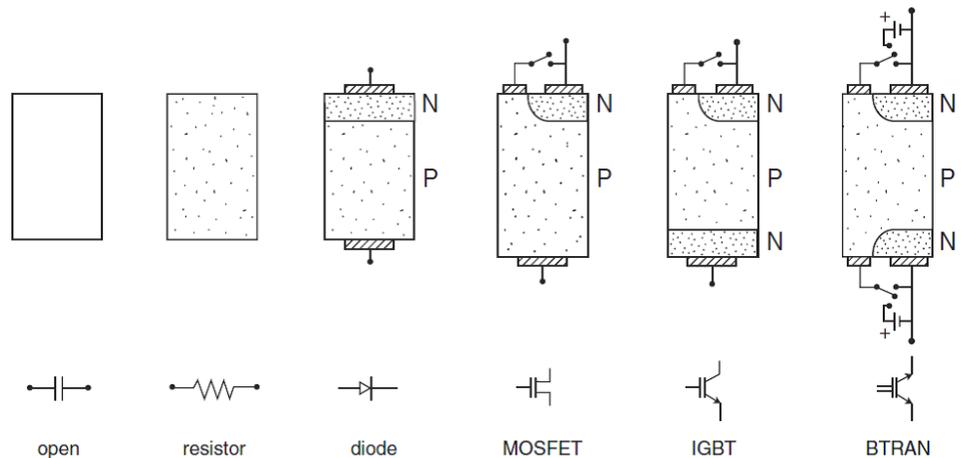

Figure 1 Power Semiconductor Topologies

referred to as "N" type and the latter as "P" type silicon. High concentrations of N are referred to as N+, while low concentrations are N-. The same is true for the P impurity. This structure of Figure 1 "resistor" has been lightly doped with a P impurity, so it is P-.

Figure 1 – "diode" This structure takes the P- resistor of Figure 1 "resistor" and adds a heavily doped layer of N material on one surface, making a P-/N+ diode. Due to differing properties of the impurities of the P- and N+ regions, the interface (or "junction") between the two regions takes on special characteristics. The junction prevents current flow in one direction (reverse bias), but allows current flow in the other direction (forward bias). In this case, current flow is blocked from the N+ to P- regions (top to bottom), but is allowed in the other direction (bottom to top), except that a voltage drop of about 0.7 V is required to generate current flow in that direction. When this occurs, the diode is said to be "forward biased", and current flow may occur at a much lower total voltage drop as compared with the resistor of Figure 1 "resistor". This happens because the forward biased junction produces many additional P and N "charge carriers", which greatly exceed in number the original amount of P charge carriers in the P- region. This voltage blocking in one direction and current conduction with low resistance in the other direction is the fundamental building block of all bi-polar power semiconductors. "Bi-polar" refers to the two polarities of charge carriers – P and N.

Figure 1 – "MOSFET" Metal Oxide Semiconductor Field Effect Transistor. This structure essentially combines the resistor with the diode, and incorporates a switch that selects between resistor and diode modes of operation. When the switch is open, it can be seen that the MOSFET is a diode, thereby blocking voltage in one direction (top to bottom), and conducting as a diode in the other direction. When the switch is closed, the diode is bypassed, allowing the MOSFET to conduct from top to bottom, but as a resistor. It can also conduct bottom to top as a resistor. As a resistor, it can turn on and off very quickly, limited only by the speed of the switch. And, as a resistor, the voltage drop is given by the doping level and thickness of the P- section, with heavier doping and less thickness giving a lower voltage drop. However, as with the diode, the maximum voltage the MOSFET can block with the switch open, while acting like a reverse biased diode, is limited by the doping level and device thickness. Increasing the doping to lower the resistance results in a reduced ability to block voltage, so the resistance, and therefore efficiency, of the MOFSET is related to its ability to block voltage. Higher voltage capable MOSFETs have higher resistance. The switch in an actual MOSFET is built into the surface of the device, and is voltage controlled. MOSFETs may be constructed in either polarity of N+/P- and P+/N-.

Figure 1 – IGBT (Insulated Gate Bi-Polar Transistor). In this structure, an additional doping layer is added to the bottom of the device, in this case another N+ layer, which significantly alters the behavior of the device. Now, when the switch is closed, instead of conduction occurring through a purely resistive P- region, conduction is now through the forward biased P-/N+ diode, and, as explained above, this results in a large reduction in the resistivity of the device, allowing it to conduct much higher current levels with lower voltage drop. This is referred to as "conductivity modulation", but is essentially just the device conducting as a forward biased diode. The diode junction does, however, impose a minimum voltage drop of about 0.7 volts (for silicon devices). There is an additional voltage drop associated with the switch, which, as with the MOSFET, is built into the surface of the device. But since the resistance of MOSFETs rises rapidly with increased voltage ratings, this conductivity modulation enables high voltage capable IGBTs to conduct much higher current at lower voltage drop as compared with MOSFETs of comparable voltage rating.

There is a price to be paid for this higher conductivity in the on-state because turn-off is much slower than with a MOSFET. That is because, when the IGBT is on, the P- region is filled with extra charge carriers supplied by the forward biased P-/N+ junction, and when the switch is opened to turn the device off, those charge carriers have nowhere to go, and the device remains partially conducting via the upper N+ layer. Conduction stops (device turns off) only when those extra charge carriers combine with each other and disappear. In a pure, high quality P- region, this can take a very long time, and such a high quality device has a low voltage drop, but it takes very long to turn off. Imperfections are intentionally introduced during the manufacturing process to accelerate the destruction of charge carriers (referred to as "recombination"), but such imperfections also increase the voltage drop while in the on-state. Thus, with IGBTs, there is an inherent conflict between low on-state voltage drop and turn-off time, with longer turn-off times causing higher switching losses. IGBT development therefore concentrates on minimizing this trade-off between conduction losses and switching losses.

 A note – most, if not all, IGBTs are made with the doping polarities opposite of that shown (PNP rather than NPN), but the operating principles are the same.

Figure 1 – "B-TRAN" (Bi-directional Bi-polar Junction Transistor) - This device has the same three-layer PNP or NPN structure of the IGBT, but has a control switch on each side. This double-sided switch arrangement enables a kind of hybrid operation, where the device may behave as a MOSFET while turning off and as a diode, IGBT, or bi-polar transistor while on. It also has identical behavior in each direction, enabling it to block voltage or conduct current in each direction with equal performance.

As an NPN IGBT (or diode), it is turned on by closing the switch on the higher voltage (collector) side while leaving the switch on the lower voltage (emitter) side open (Figure 2 – "Diode On") This may be seen to be identical to conventional (one-sided) IGBT on-state operation,

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but instead of turning off by simply opening the top switch, with the commensurate slow turn-off, the B-TRAN is turned off by first closing the bottom switch, which removes the forward bias on the lower P-/N+ diode, and restricts its ability to inject charge carriers into the P-region (Figure 2 – "Pre-Turn-Off"). Also, charge carriers are actively removed from the P- region as a result of current flow via the bottom switch. The result is a rapid and large reduction in the conductivity of the P- region just prior to final turn-off, which is produced by finally opening the top switch (Figure 2 – "Off"). In this off configuration, the device may be seen to be configured as a MOSFET rather than an IGBT, which results in fast turn-off and near-zero tail current (Figure 5).

In the following, "Collector" and "Emitter" refer to the N+ regions on each side of the device, which are identical in structure to each other, but which function differently depending on the direction of current flow or voltage blocking on the device. The emitter "emits" charge carriers into the P- central (or "drift") region, while the collector "collects" those same charge carriers, allowing for current flow.

The B-TRAN, by virtue of its external base connection, can have an on-state voltage drop (Vce – for "voltage from collector to emitter") that is much less than an IGBT or diode. As per Figure 2 "Transistor-on", this is accomplished by raising the collector-side base voltage above the collector voltage during the on-state, which requires a small, low voltage power supply between the collector and the base it is connected to (the "c-base"). In silicon B-TRANs, Vce may be less than 0.2 V, as compared with 1.4 volts or higher for IGBTs.

Unlike the IGBT, the B-TRAN has a uniform emitter/collector structure which gives high emitter efficiency, and the use of the c-base to drive the P- (base) region gives the B-TRAN a high gain (ratio of through current to c-base drive current). Other patent pending structural details also contribute to high gain at high current density. A high gain is required to minimize the base drive power. At Vce of 0.2 V, current gains of over 10 are predicted by simulations for 1200 V B-TRANs at current densities over 70 A/cm^2, and gains of over 20 are predicted for 650 V B-TRANs at current densities over 100 A/cm^2.

Since the B-TRAN has a high gain, a patent pending circuit is needed on each base connection to allow the device to achieve full blocking voltage before the controls become active and short the e-base to the emitter.
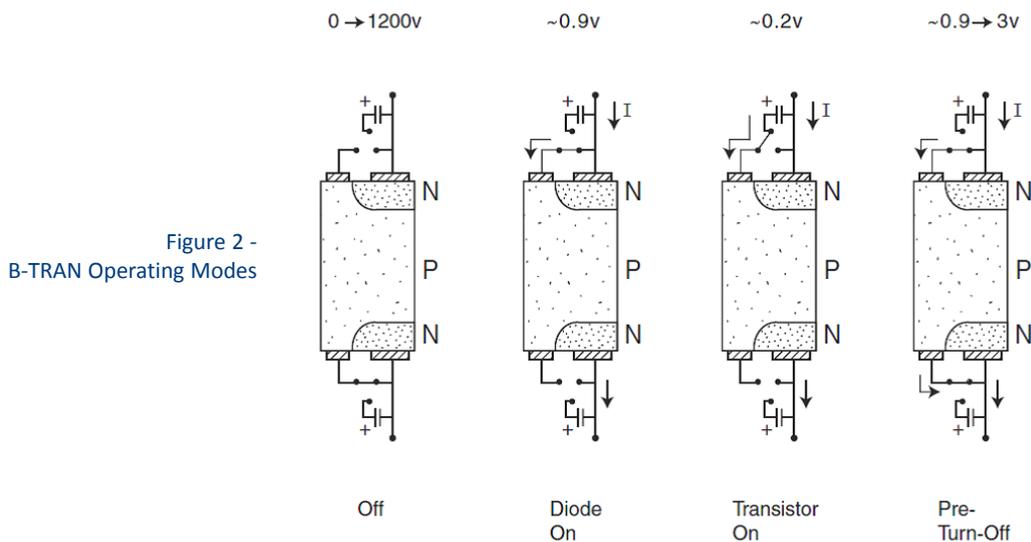

Figure 2 - B-TRAN Operating Modes

| 0 → 1200v | ~0.9v | ~0.2v | ~0.9 → 3v |
| Off | Diode On | Transistor On | Pre-Turn-Off |

B-TRAN PERFORMANCE – FROM SIMULATIONS

Table 1 and the figures below show performance simulation results, run in Silvaco Atlas, for 650 V and 1200 V B-TRANs at 25 °C. The 1200 V device has a gain of 14 at 67 A/cm^2 and Vce of 0.2 V, and the 650 V device has a gain of 24 at 100 A/cm^2 and Vce of 0.2V.

Figure 3 shows the voltage across the 1200 V B-TRAN (Vce) as well as emitter current (Iemitter) and collector-base current (Icb) during three modes of operation – diode-on, transistor-on, and pre-turn-off. From 0 to 2 uS, the device is in diode-on mode (e-base is open), which is shown in more detail in Figure 4. Total turn-on energy is only 0.34 mJ, and is calculated as the total power dissipated by the device from 0 to 2 uS. After 2 uS, Icb has fallen sufficiently for the controls to disconnect c-base from the collector, and attach it to a 7 A, 0.6 V power supply, which then lowers Vce from about 1 V to 0.2 V. Thus, an input power of 4.2 watts produces a power savings of 100 X 0.8V, or 80 W. Gain is 14.

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At 7 uS, the device enters pre-turn-off mode, where the c-base is disconnected from the power supply and reconnected to the collector, and e-base is shorted to the emitter. This produces a rapid reduction in charge carriers from the P- (base, or "drift") region. At 8 uS, c-base is opened, producing the turn-off waveform of Figure 5. Voltage rise time is about 110 nS, followed by a current fall time of less than 20 nS, which is very similar to a MOSFET turn-off current, resulting in a total turn-off energy of only 2.6 mJ.

By comparison, Figure 6 shows a typical turn-off waveform for an IGBT, showing the tail current that causes the IGBT to have much higher turn-off losses as compared with the B-TRAN.

BTRAN voltage rating	Current density – A/cm^2	Current gain at current density, Vce=0.2 V	Power gain	Turn-off loss per 100 A, mJ
1200 V	67	14	16,000	2.6@800V
650 V	100	23	19,000	0.9@300V

Table 1 – B-TRAN performance predictions – 25 °C
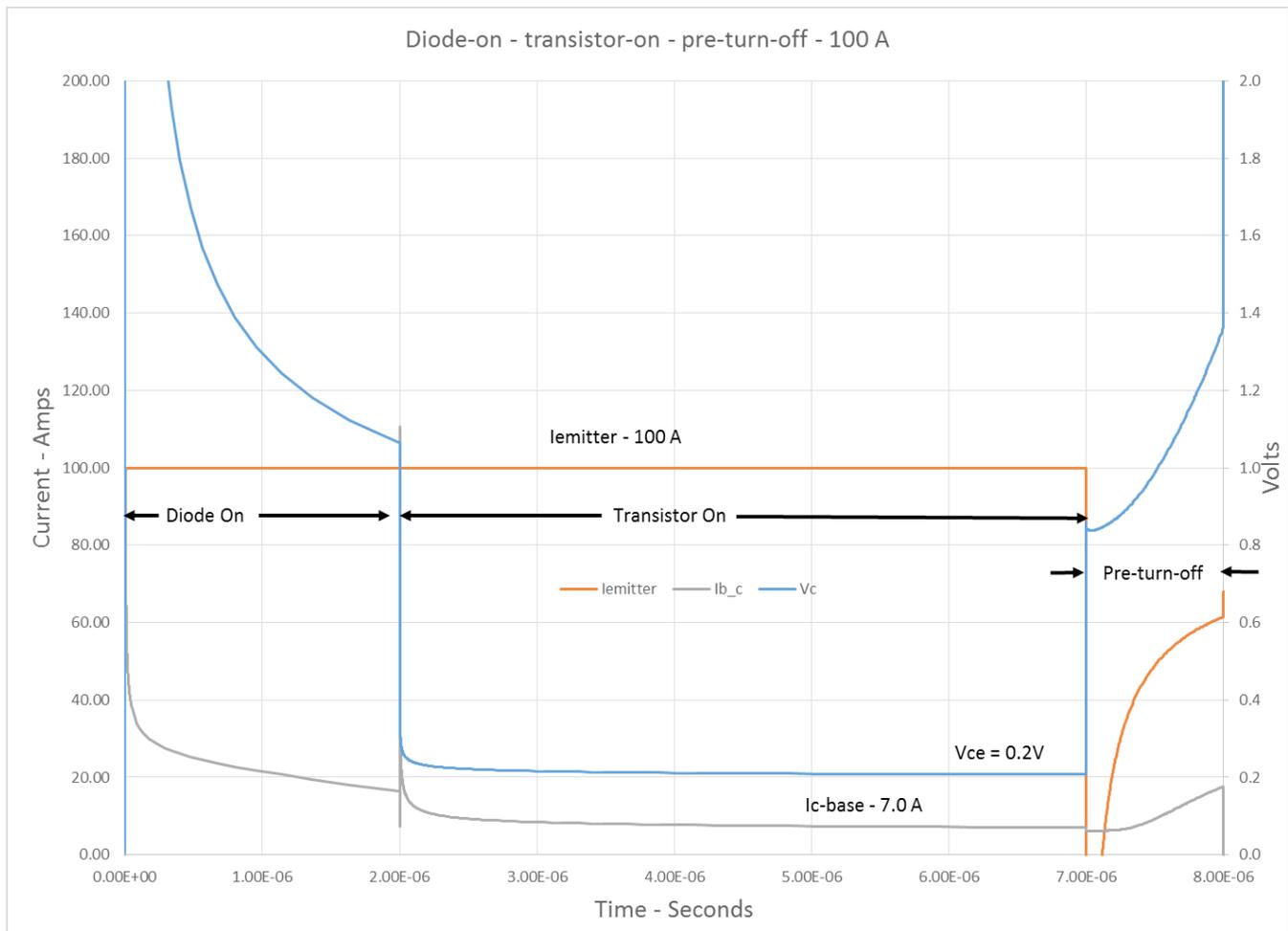

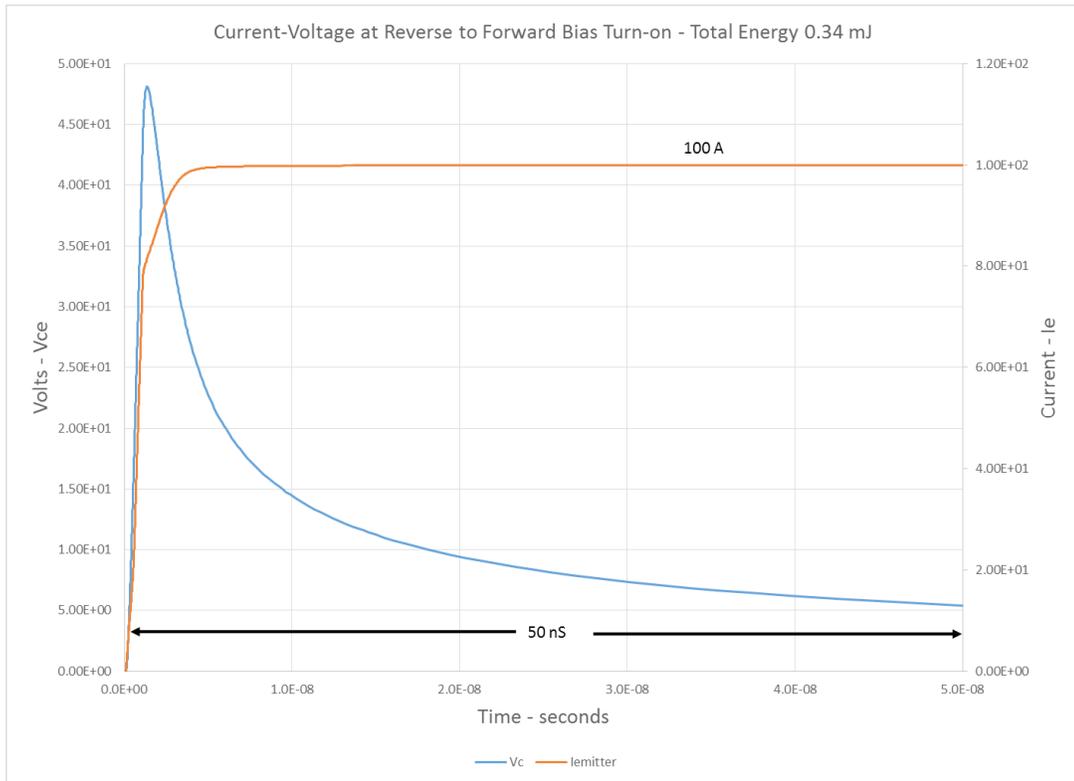Figure 3 - B-TRAN Performance - Diode-on, Transistor-on, Pre-turn-off

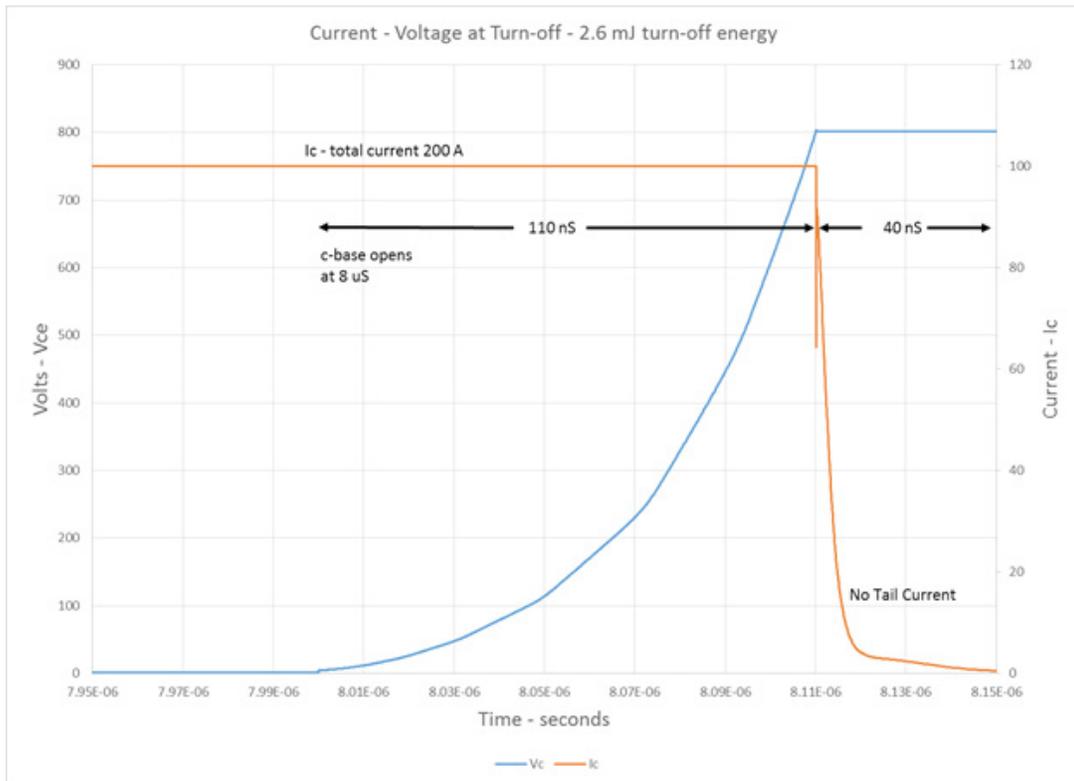Figure 4 – B-TRAN reverse-to-forward-bias turn-on – diode turn on

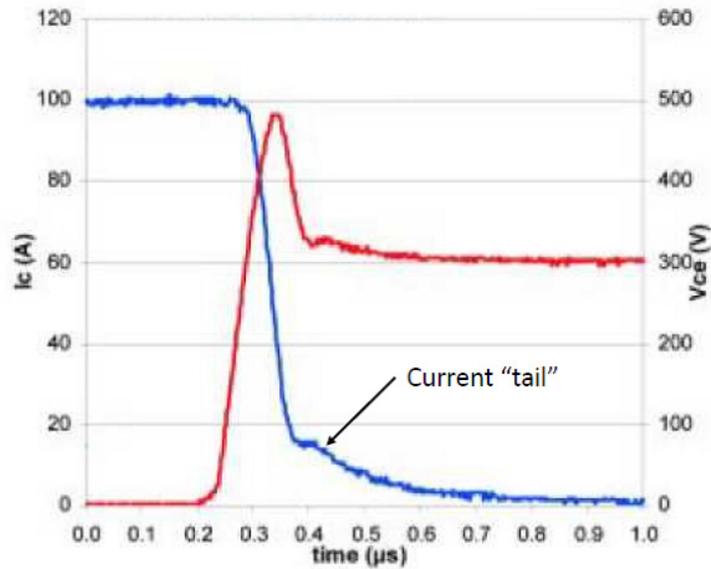Figure 5 – B-TRAN turn-off after 1 uS of pre-turn-off

Figure 6 – Typical IGBT turn-off showing current "tail"

Comparison with AC switch configurations of 1200 V IGBT/diode, 1200 V MOSFET, 1200 V SiC MOSFET

The B-TRAN will largely be used as an AC switch in topologies that take full advantage of an AC switch, such as Ideal Power's PPSA (Figure 9) or the EV drive topology shown below (Figure 7 – Ideal Power patent pending). In such topologies, reverse recovery does not occur, and converter performance can be predicted from forward voltage drop and switching losses. Thus it is instructive to compare with other device types using these parameters. To form an AC switch with IGBTs, 2 IGBTs and 2 diodes are used. To form an AC switch with a MOSFET, two MOSFETs are used back-to-back (anti-series).

Although these switches will likely be operating at higher temperatures, comparisons were done at 25 C as that was the only temperature common to all data sheets. Performance of all switches degrades with higher temperature, but the B-TRAN will degrade less since it has such low losses, and therefore will operate at lower temperatures as compared with other devices.
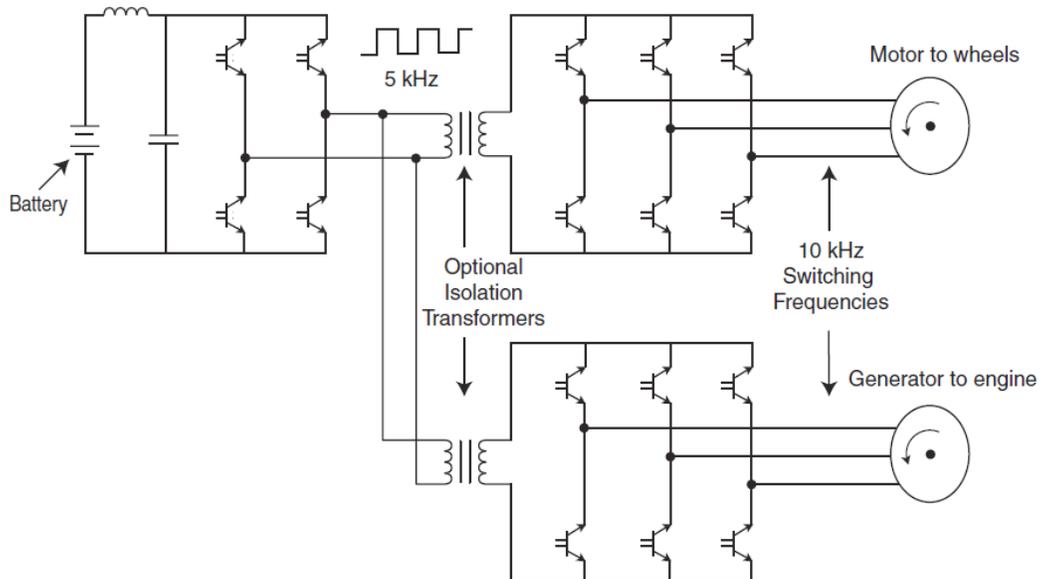

Figure 7 – B-TRAN Based EV Drive Topology

The following data is taken from published data sheets on each device. These may be found on Digikey.com, an on-line electronics distributor. Two sets of comparisons are made – 1) between the B-TRAN and IGBT/diode combinations, and 2) between the B-TRAN and MOSFETs, both silicon and silicon carbide (SiC) MOSFETs. IGBT/Diode switches cannot have a voltage drop less than about 1.4 V, whereas B-TRANs and MOSFETs may have voltage drops much less than 1 V, so the comparison with IGBT/Diode cannot be done with equal power loss as can the comparison with MOSFETs.

IGBT/Diode – 4 devices (2 IGBTs, 2 diodes) per AC switch

From the data sheets -

Device	Breakdown V	Die area	Turn-off mJ	Vce	Price per 1000
APT75GN120B2	1200 V	~ 1 cm^2	7.6 mJ@75A, 800 V	1.7 V @ 75 A	$10
80epf12	1200 V	~ 1 cm^2	N/A	1.3 V @ 80 A	$5

AC Switch Configuration – 1200 V	AC switch forward voltage drop - volts	Turn-off energy per 100 A into 800 V, inductive - mJ	Estimated inverter losses for 100 A, 800 V, 10 kHz	Cost per cm^2 die area	Die Area per AC switch – cm^2	Cost per AC switch
2 IGBTs/diodes	3	10	800 W	$7.50	5.4	$40
Silicon BTRAN	0.2	2.6	102 W *	$20	1.5	$30

* includes 10 W total base drive power

Table 2 – 1200 V IGBT/Diode vs B-TRAN for 80 kW, 10 kHz AC Link inverter – 25 C

In **Table 2** the estimated inverter losses were calculated from the 100 A current, the AC switch forward voltage drop, and turn-off (switching) losses at 10 kHz switching frequency. B-TRAN cost per unit area of die is estimated as twice the IGBT/diode average cost per unit area of die since the B-TRAN is a double sided device, yet the estimated B-TRAN cost is less than the IGBT/diode cost. B-TRAN annual production volumes, for purposes of the cost estimation, are assumed equal to the cited IGBT production volumes.

Estimated B-TRAN total loss is about 1/8th of the IGBT/Diode loss, due both to the much lower B-TRAN conduction loss, and much lower B-TRAN switching loss.

MOSFET Comparisons

From the data sheets -

Device part #	Device type	Breakdown V	On resistance	Switching - mJ	Price
IXFL32N120P*	Silicon MOSFET	1200 V	340 m-ohm	2.0 mJ@100A, 800 V	$35
C2M0025120D*	SiC MOSFET	1200 V	25 m-ohm	1.4 mJ@50 A, 800 V	$65

*two sets of devices per AC switch

AC switch configuration – 1200 V	Total switching loss at 10 kHz - W	Required AC switch resistance for 92 W total inverter loss – m-ohm	Number of devices per AC switch	Cost per AC switch
Silicon MOSFET	40	3.1	438	$15,330
SiC MOSFET	28	3.2	30	$1,950
Silicon BTRAN	42	2.0 *	1	$30

Table 3 – 1200 V Switch cost summary for 80 kW, 10 kHz inverter – 25 C   * includes 10 W total base drive power

In **Table 3** the number of Silicon MOSFET and SiC MOSFETs required to achieve the same inverter losses as the B-TRAN were calculated from the device switching losses and on resistance. The silicon MOSFET AC switch requires 438 devices, and so is prohibitively expensive for this application. The SiC MOSFET AC switch requires far fewer, but the total AC switch cost for SiC MOFSET is still 65X higher as compared with the estimated cost of the 1.5 cm^2 B-TRAN. A DC inverter configuration may be used with the MOSFETs, which would require only 8X as many SiC MOSFETs, but that would still be about 16X more expensive, and the total dissipation would be several times higher due to the high voltage drop across the SiC Schottky diodes paired with the SiC MOSFETs, and about 8X higher when running power

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from AC to DC. Only the AC switch configuration can match the B-TRAN losses in an AC topology.

B-TRAN annual production volumes, for purposes of the cost estimation, are assumed equal to the cited Silicon MOSFET production volumes

The B-TRAN, as a switch topology, may be implemented in other materials besides silicon, such as silicon carbide. A future version of this white paper will include simulation results and performance predictions for SiC B-TRANs, which will likely have much higher current densities and lower conduction losses as compared with SiC MOSFETs.

COMPARISON WITH GaN MOSFET - EPC2025 AND EPC2027

GaN MOSFETs are available in small packages up to 450 V (see data sheets for EPC2025 and EPC2027 on Digikey.com). These two devices each have a die size of 1.95 by 1.95 mm (0.038 cm^2), with the 300 V device having a 150 m-ohm resistance and the 450 V device having a 400 m-ohm resistance at 25 C, indicating that on-resistance with these devices increases by more than the square of the voltage. In an AC configuration, the 450 V GaN device has 800 m-ohm resistance, so to match the 650 V B-TRAN voltage drop of 0.2 V at 150 A on a 1.5 cm^2 die, 1200 of the 450 V GaN devices are needed. At $5 each, that's $6,000 worth of GaN to match the B-TRAN on resistance, but still not matching in voltage capability (450 V GaN vs 650 V B-TRAN).

COMPARISON WITH AC AND DC SWITCH CONFIGURATIONS FOR EV DRIVE

650 V is a common voltage for IGBT/diode modules used in EV drives. These are typically large modules that conduct high current, and are DC (block voltage in only one direction). Such a module from Bosch is summarized below (MH6560C), and compared with an equivalent capacity 650 V B-TRAN. From simulations, the 650 V B-TRAN has a high gain of 23 at 150 A on a 1.5 cm^2 die (100 A/cm^2), and for this comparison, 4 such die are assumed (6 cm^2 die area) to support 600 A.

Two topologies are possible for this application – the AC link of Figure 7, as discussed above, which eliminates reverse recovery related losses, or the conventional DC link. The AC link requires AC switches, such as the B-TRAN, or anti-series pairs of IGBT/diode modules. The following analysis discusses both versions.

Part number – Bosch MH6560C   ("under development")

Device	Breakdown V	Die area per switch	Turn-off mJ	Vce
Bosch MH6560C	650 V	~ 12.5 cm^2	16.8 mJ@600A, 300 V	1.4 V @ 75 A

Switch configuration – 600 A, 300 V, 180 kW EV Drive	Die area – cm^2	Turn-off energy per 600 A into 300 V, inductive - mJ	Turn-on and reverse recovery energy, 600 A, 300 V, mJ	Peak reverse recovery current – 6.6 kA/uS	Total switching losses at 10 kHz - W	Conduction loss, 600 A - W	Total loss, 600 A
Bosch Module – AC Switch	25	16.8	< 1	0	336	3,360	3696
650 V Silicon BTRAN – AC Link	6	5.3	< 1	0	106	270*	376
Bosch Module – DC Switch	12.5	16.8	10.2	285	676	1680	2356
650 V Silicon BTRAN – DC Link	6	5.3	22.9	456	564	270*	834

* includes 15 W base drive power each active phase leg

Table 4 – EV Drive switch loss comparisons – 180 kW, 10 kHz Drive, AC or DC bus to motor lines – 25 C

Again, the B-TRAN, as simulated, is predicted to have significantly better performance as compared with its competition, with about 10% of the total losses of the IGBT/diode module in the AC link converter. As a native AC switch, the B-TRAN is seen to perform much better in the AC link topology, with less than 1/2 the loss of the DC link topology, but even in the DC link topology the B-TRAN has about 1/3 the loss of the IGBT/diode module.

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The B-TRAN in the AC switch topology has another, previously unstated advantage – no significant voltage overshoot from reverse recovery transients. This will allow the AC link B-TRAN converter to operate with at least 50% higher DC bus voltage, thereby increasing the power rating of the converter by 50%, which decreases the relative costs of the B-TRANs.

COMPARISON WITH CONVENTIONAL BIPOLAR JUNCTION TRANSISTOR - MJW18020

The B-TRAN differs substantially from conventional Bipolar Junction Transistors (BJTs). The B-TRAN and BJT have in common a three-layer structure (NPN or PNP), and the ability to conduct current with voltage drops much less than 0.7 volts. However, they both are constructed and operated differently. The BJT has been used for over 50 years, preceding both MOSFETs and IGBTs. While the B-TRAN (like the IGBT) has thin surface layers for emitter and collector and a wide, central base layer, the BJT has a wide collector, thin emitter and thin base in between, with only a single base connection. Thus, the BJT has no collector-side base connection as does the B-TRAN and IGBT. This results in comparatively poor performance in gain vs current density, switching performance and the inability to be used as a diode. It is asymmetric so it cannot be used as an AC switch. As can be seen on the data sheet of a typical high voltage BJT (MJW18020 with 450 Vceo), the current density at a gain of 10 is only about 10 A/cm^2 (1/10th of the 650 V B-TRAN), and switching times are very long – several microseconds storage time and hundreds of nanoseconds in rise and fall times.

APPLICATIONS OF THE B-TRAN

Just a few of the many possible applications of the B-TRAN are shown below.

THREE PHASE AC POWER CONTROL

The B-TRAN has a unique capability as an AC switch for AC power control (Figure 8), where it would replace SCRs or contactors in controlling the power delivered to a load, such as an induction motor. SCRs are widely used for controlling AC power, but have a significant power loss due to their approximately 1.4 V drop – 7X higher than the 0.2 V drop of the B-TRAN. Contactors are used widely for this application also, and have much lower losses than SCRs, but suffer from a limited life span and environmental degradation. A B-TRAN contactor replacement will also have much lower losses than SCRs, but with an unlimited life and little to no environmental degradation. Both SCRs and contactors cannot control intra-cycle fault currents, which often leads to blown fuses and unsafe conditions, whereas the B-TRAN can both limit and terminate fault currents in microseconds.
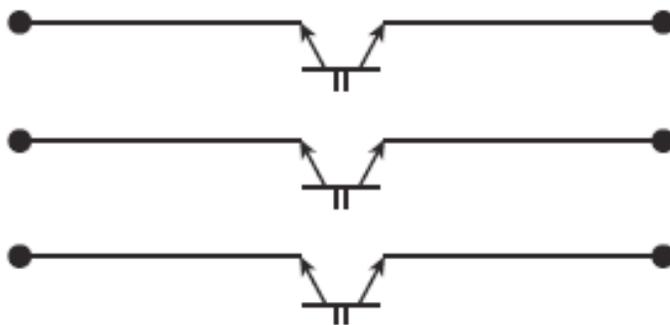

Figure 8 – BTRAN AC Switch

AC VOLTAGE REGULATION

Most electric power worldwide is passed from distribution voltage to low voltage via transformers, but these transformers just step down the voltage without performing any regulatory function. Thus, the end user is subject to voltage variations which may damage equipment and cause excessive power consumption in both lighting and motors.

The power converter of Figure 9 is a simple buck converter, which is easily implemented with B-TRANs, but not so with conventional power switches, since the required switch operation is AC (bi-directional). This converter may be used wherever AC power voltage variations are excessive, or where precise AC voltage control is needed. Calculated switch losses for this low cost B-TRAN circuit are less than 0.3%.

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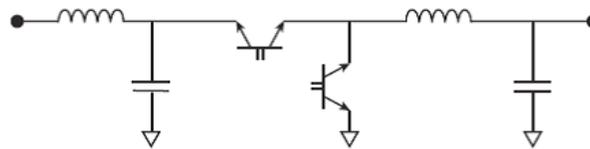
Each of 3 phases

Figure 9 – AC Voltage Regulator

MATRIX CONVERTER VARIABLE FREQUENCY DRIVE (VFD)

Electric Induction Motors consume about 40% of the world's electric power production. Most of these motors could have lower power consumption if the voltage and/or applied frequency were adjustable in order to optimize to load conditions. Existing VFDs are either large, expensive units with relatively low efficiency, or smaller, less expensive units with high line harmonics.

The B-TRAN based Matrix Converter of Figure 10 can adjust both voltage and applied frequency to an induction motor, allowing it to operate at peak efficiency regardless of load conditions and incoming AC voltage. Again, this converter is easily implemented with B-TRANs, but not so with conventional power switches. This converter is expected to be small, compact, low cost, highly efficient, and operate with very low line harmonics. B-TRAN losses are expected to be less than 0.5%.
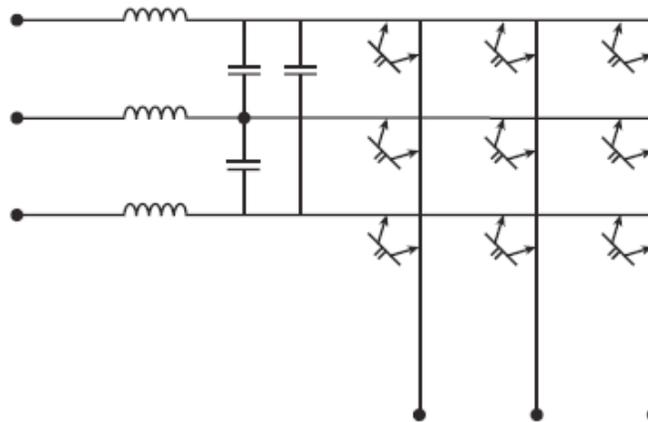

Figure 10 – Matrix Converter Variable Frequency Drive (VFD)

ELECTRIC VEHICLE (EV) DRIVES

The B-TRAN based EV Drive (Figure 7 - above) has an anticipated efficiency of over 99% between any two ports, resulting from the very low voltage drop and low turn-off losses of the B-TRAN, along with a converter topology that eliminates reverse recovery related losses. This high frequency square wave AC link topology (Ideal Power patent pending) also allows for compact, low loss transformer isolation between ports. Other ports may include an on-board generator (hybrid electric) and high power on-board charger. The projected high efficiency may allow low cost air cooling of the drive train on electric vehicles.

WIND/SOLAR/BATTERY CONVERTERS VIA PPSA

The AC switch characteristic of the B-TRAN is well suited for Ideal Power's Power Packet Switching Architecture (Figure 11). Full power conversion efficiency with B-TRANs is anticipated to be better than 99%, resulting in compact, air cooled, low cost converters for renewable energy power generation in wind turbines, solar PV power plants, and such plants combined with battery storage.
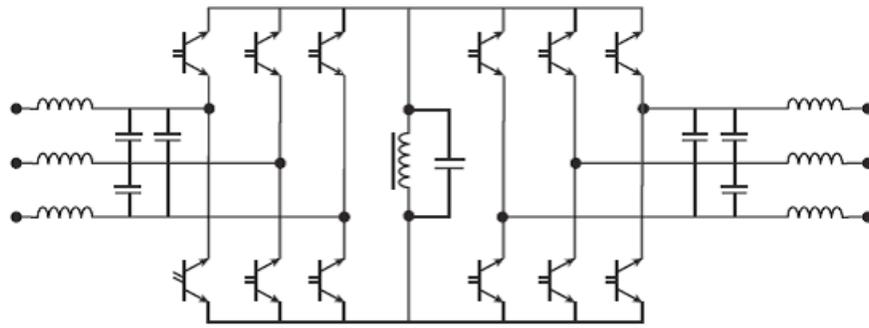
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Figure 11 – BTRAN Based PPSA 3 phase to 3 phase converter

Total Addressable Market (TAM) - Conventional Power Switch replacement

From – "IGBT Markets and Application Trends Report", slide 10, Yole Development, Published on May 23, 2013 the total world market for conventional power switches is about $10B/year. The B-TRAN, with its predicted much lower voltage drop and lower switching losses may be able to replace most SCRs, MOSFETs, diodes, rectifiers, and IGBTs. Additional market expansion for the B-TRAN is possible if the markets for AC Voltage Regulation, VFDs, Renewable Energy, and Electric Vehicles expand.

Manufacture

The B-TRAN manufacturing process is being developed on a conventional silicon process, with steps added for double sided photo-lithography, including temporary "handle" wafers to facilitate double sided processing of thin wafers.

Summary

The B-TRAN topology is a simple, yet radically different topology for power semiconductors. It combines the fast, low loss switching of a MOSFET, the high current density of the IGBT, the low forward voltage drop of the BJT, and a unique bi-directionality, which allows its use in highly advantageous AC link converter topologies. B-TRANs offer the potential to improve efficiency and system economics of a wide variety of power converter applications including Variable Frequency (VFD) motor drives, electrified vehicle traction drives, PV inverters and wind converters.

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