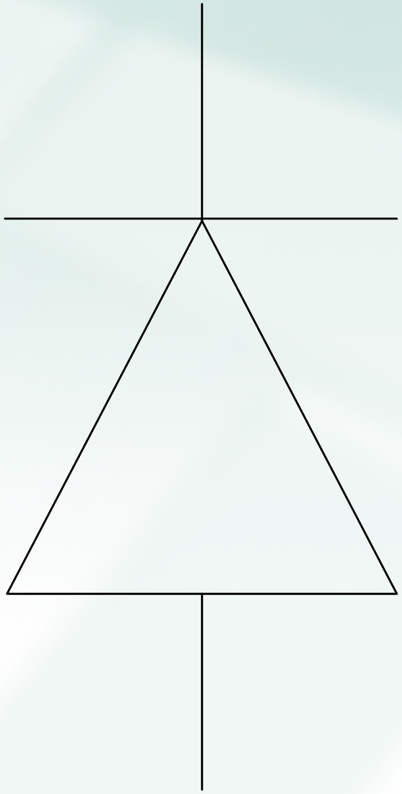
Topics

- Introduction to device families
  - Diodes
    - Rectifier (RD)
    - Fast Recovery (FRD) and Soft Recovery
    - Extra Fast Recovery (XFRD)
    - HP Sonic FRD
  - Thyristors
    - Phase Control (PCT)
      - New Wespack range
    - Medium Voltage (MVT)
    - Distributed Gate (DGT)
      - Fast Turn-off (FTO)

Topics

- Ratings & Characteristics
  - Common to all device types
    - Reverse recovery characteristics
  - Specific to fast (inverter grade) device types
    - Fast Recovery Diodes & Fast Switching Thyristors
  - Specific to slow (converter grade) device types
    - Rectifier Diodes and Phase Control Thyristors
  - Specific to thyristors only
    - Turn-off time test
- Application Issues
  - Snubbers
  - Selection of devices
  - Gate Drives
  - Clamping

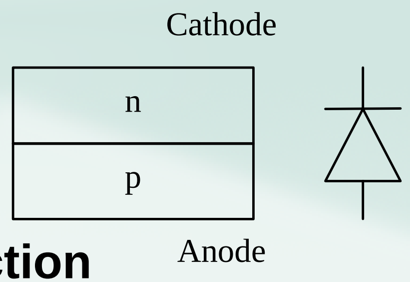
Diodes

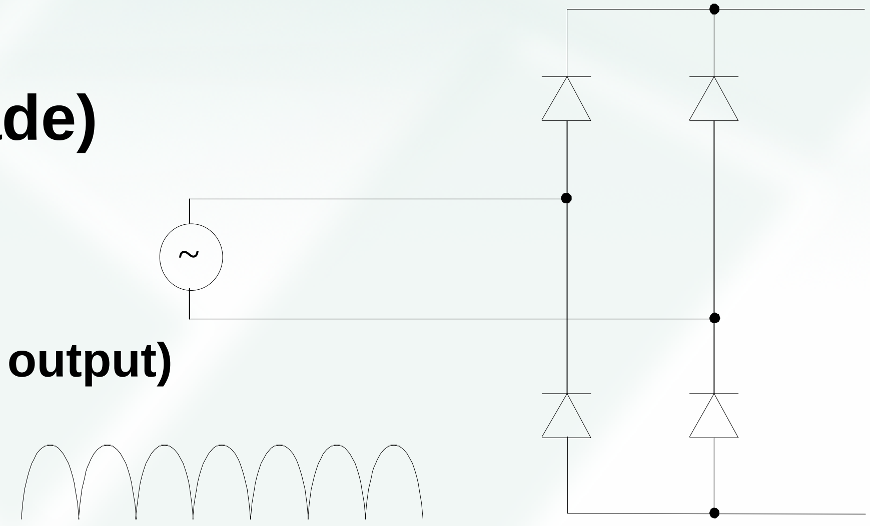


Diode Product Range

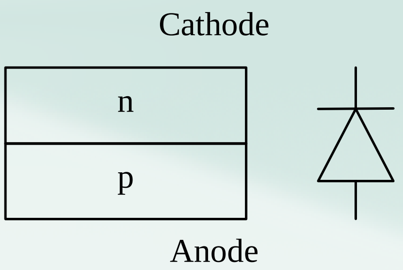
Rectifier Diodes (RD)

- Basic Structure & Symbol
- Device Operation
  - Anode positive w.r.t. cathode = Forward conduction
    - Current flows from anode to cathode
  - Cathode positive w.r.t. anode = Reverse blocking
    - No current flow (leakage)
- Slow device (converter grade)
  - No optimisation
- Application
  - Uncontrolled rectification (fixed output)
  - Traction drives





Fast Recovery Diodes (FRD)
Fast, Soft, Extra Fast and HP Sonic FRDs

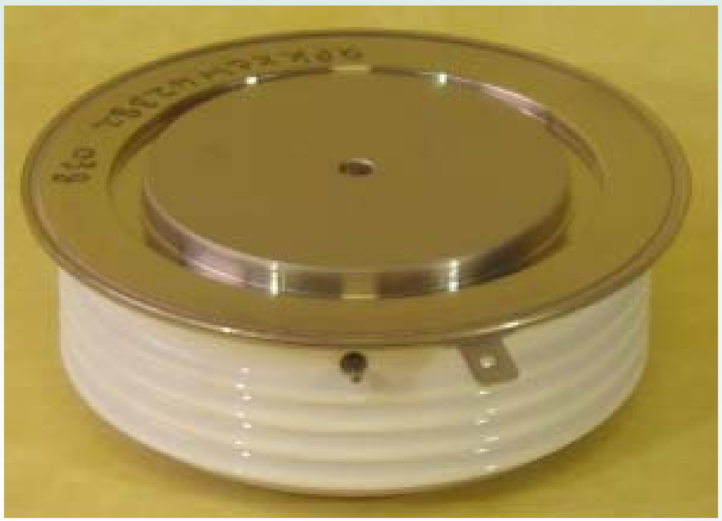


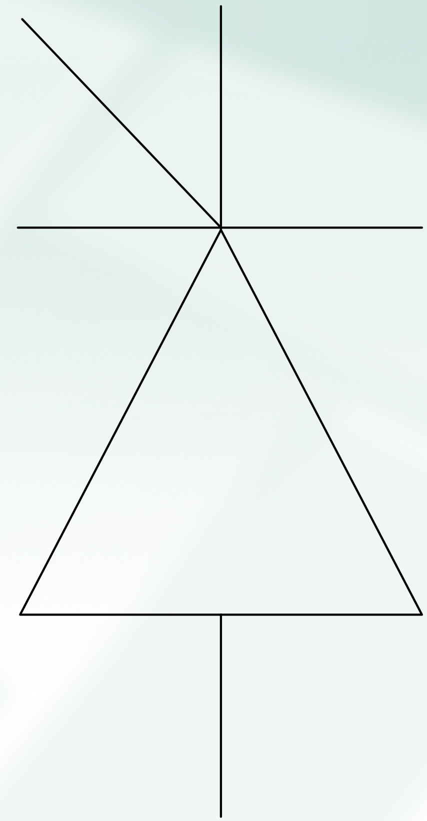
- **Basic Structure & Symbol**
- **Basic operation as per rectifier diode**
  - **FRDs are fast operating devices**
    - **Device optimised for reverse recovery parameters (Lifetime control)**
      - » **Heavy metal doping (e.g. Gold, Platinum)**
        - > **Soft Recovery Diodes**
      - » **Electron irradiation (Fast Recovery Diodes)**
      - » **Ion implantation (e.g. Helium)**
      - » **Combinations also used (Extra Fast and HP Sonics)**
- **FRD Applications**
  - **Anti-parallel (freewheeling)**
    - **Snubber diode for GTO circuits**
  - **Induction heating (often with fast switching thyristors)**
  - **Series diode for asymmetrical operation / choppers**

Fast Recovery Diodes (FRD)
Fast, Soft, Extra Fast and HP Sonic FRDs

- **Soft Recovery Diode applications**
  - RCD snubbers
  - Voltage clamping
  - Snubberless applications
  - Note 125°C is maximum T_j on gold doped soft recovery diodes
- **Extra Fast Recovery Diode applications**
  - When low values of reverse recovery parameters are required
    - In association with IGBTs, GCTs
    - Pulse power
- **HP Sonic FRD applications**
  - Similar to XFRD applications but at higher di/dt
  - When higher operating junction temperature required
    - XFRDs limited to 125°C
  - Lower reverse recovery current than XFRD

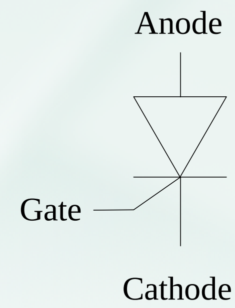
Thyristors

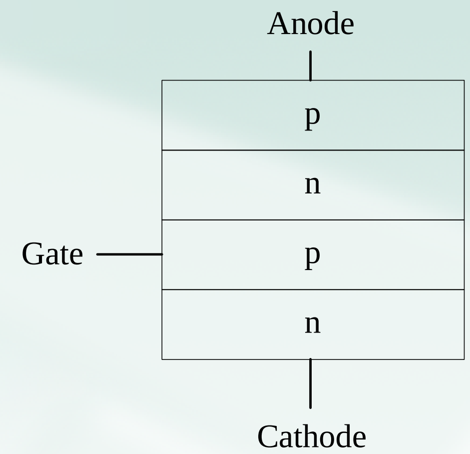




Thyristors

- **Device symbol and basic structure**
  - Three modes of operation
    - Forward blocking (off-state)
      - » Anode positive w.r.t. cathode (no gate potential)
        - > No current flow (leakage)
        - > Negative gate bias required on GTOs
    - Forward conducting (on-state)
      - » Both anode and gate positive w.r.t. cathode
      - » Current flows from anode to cathode
      - » Loss of control - device cannot be <u>commanded</u> to turn off
        - > Core difference between conventional and GTO thyristors
    - Reverse blocking
      - » Cathode positive w.r.t. anode
        - > No current flow (leakage)

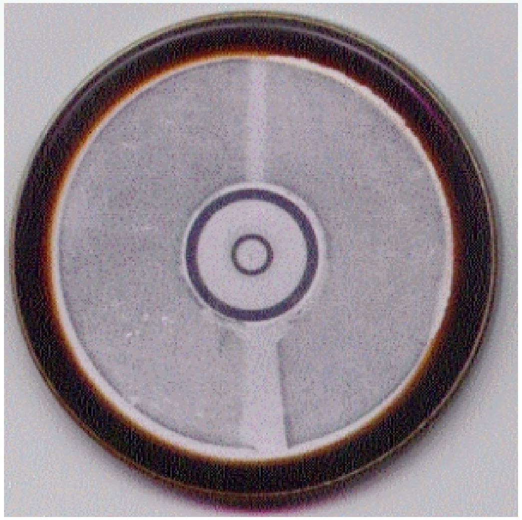


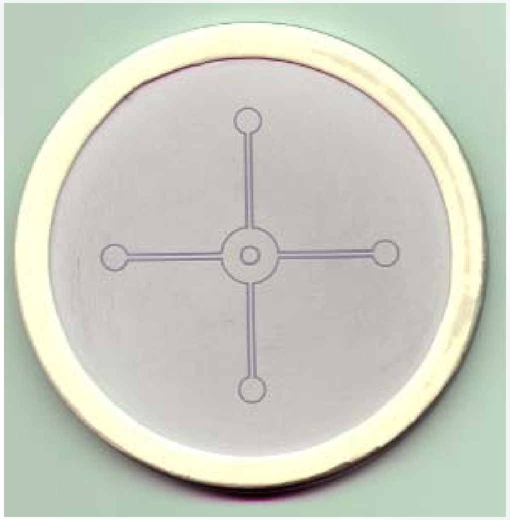


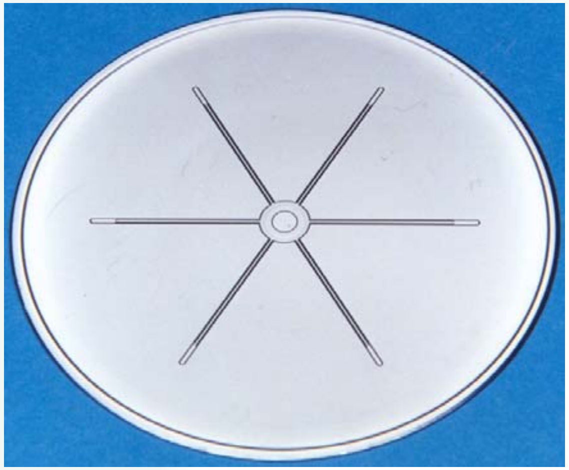
Phase Control Thyristor Product Range

Phase Control Thyristors (PCT) (1 of 2)

- **N series device operation**
  - **Slow device (converter grade)**
    - **Not optimised for reverse recovery (except by special request/requirement)**
    - **Gate pattern not widely distributed**
      - » **Ring pattern (≤ 50mm diameter)**
      - » **Cross pattern (≥ 63mm diameter)**
      - » **Spoke pattern (100mm diameter)**

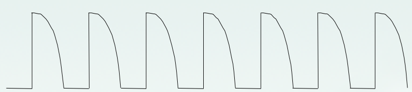


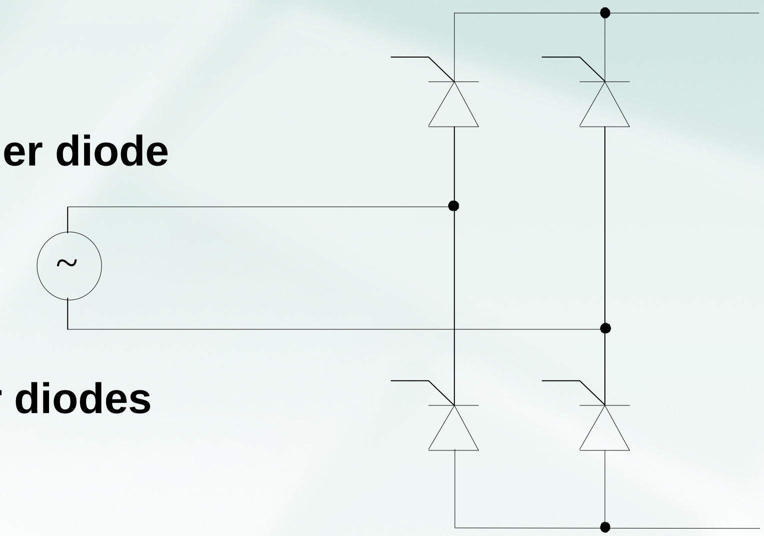




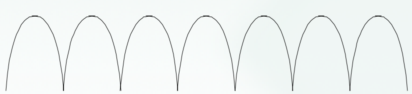
Phase Control Thyristors (PCT) (2 of 2)

- **Applications**
  - **Fully controlled rectification**
    - **Gate controlled device unlike rectifier diode**
    - **Hence, possible output:**

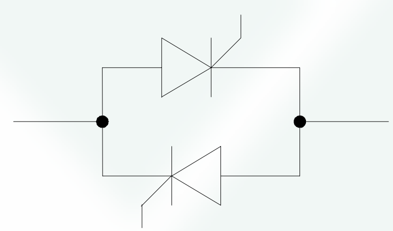




    - **Compare with output using rectifier diodes**

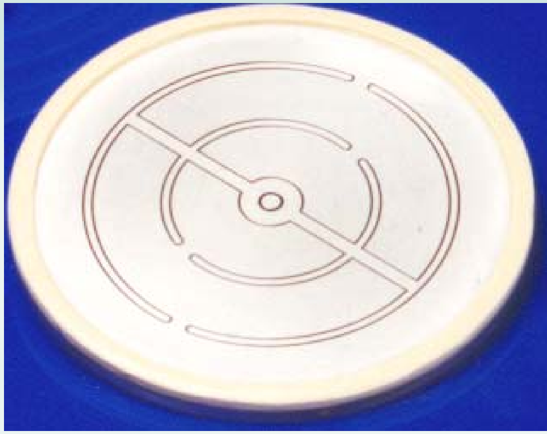


  - **Electro-chemical power supplies**
  - **HVDC projects & utilities**
  - **Cyclo-converters**
  - **Soft start systems**
  - **AC switches**



Medium Voltage Thyristors (MVT) (1 of 2)

- The term ‘Medium voltage’ is derived from target applications
- Not considered a ‘fast’ device
- These are essentially modified PCT’s (Westcode P type)
  - Distributed gate patterns
    - 53mm & 75mm diameter
    - 87mm & 100mm diameter
  - Degree of lifetime control
- Controlled switching characteristics
  - Increased di/dt capability
  - Improved turn-off time
  - Better candidate for series operation



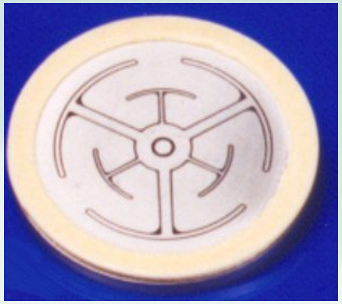
Medium Voltage Thyristors (MVT) (2 of 2)

- **Summary**
  - Essentially PCT with gate distribution
  - P-type gate structure most common in MVT
  - Higher di/dt capability than PCT
  - Controlled recovery and turn-off time (not fast)
- **Applications**
  - Medium voltage utilities
  - High power dc drives
  - Trackside substations
  - Power conditioning
  - Induction melting

Fast Thyristor Product Range

Distributed Gate Thyristors (DGT)

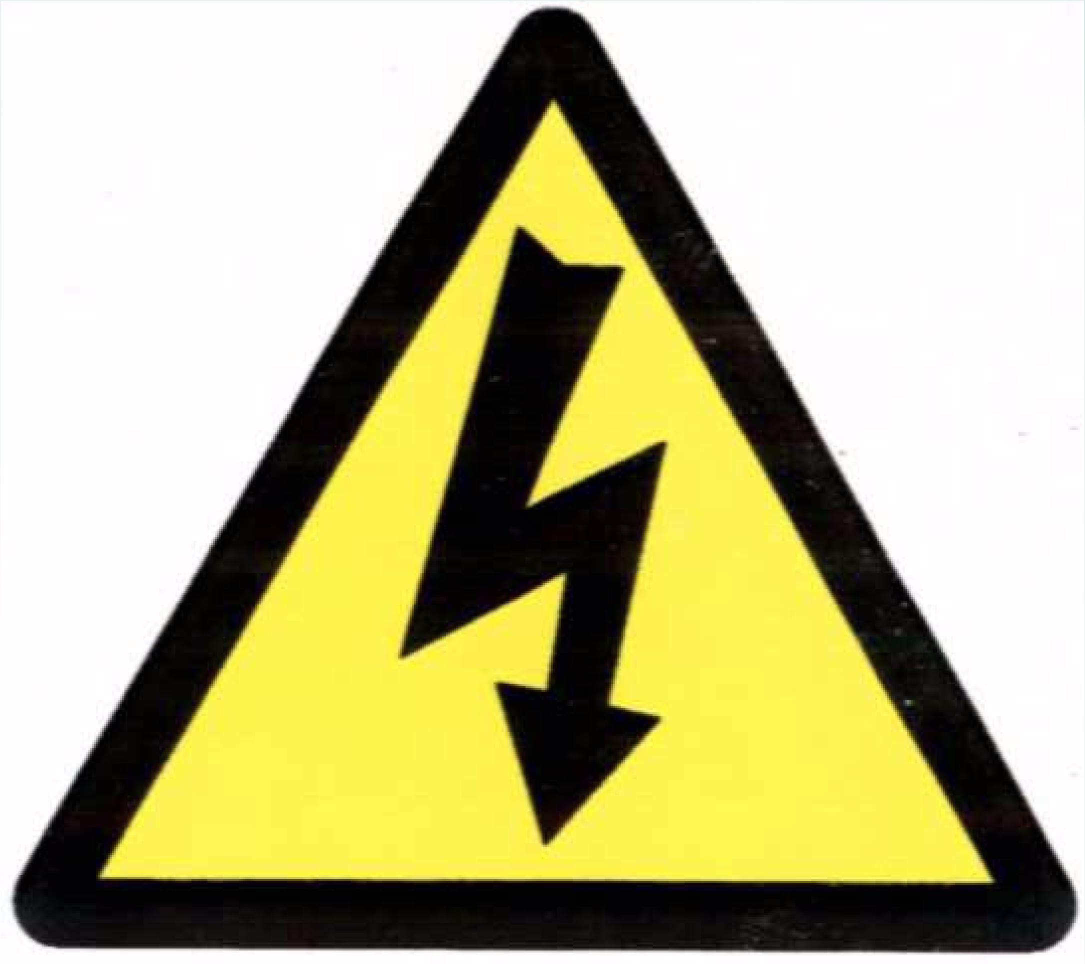
- **R series device operation**
  - Fast switching device (inverter grade)
    - Optimised for recovery parameters
      - » Extensive use of lifetime control techniques
    - Widely distributed gate patterns (more so than MVT)
      - » Up to 50mm diameter inclusive
      - » 53mm diameter
      - » 87mm and 100mm diameter
  - Basic device operation as per PCT and MVT
  - Controlled recovery characteristics and turn-off performance
- **Note: Old ‘D’ series no longer exists as a part number**
  - Such devices are now part of the ‘R’ series



Distributed Gate Thyristors (DGT)

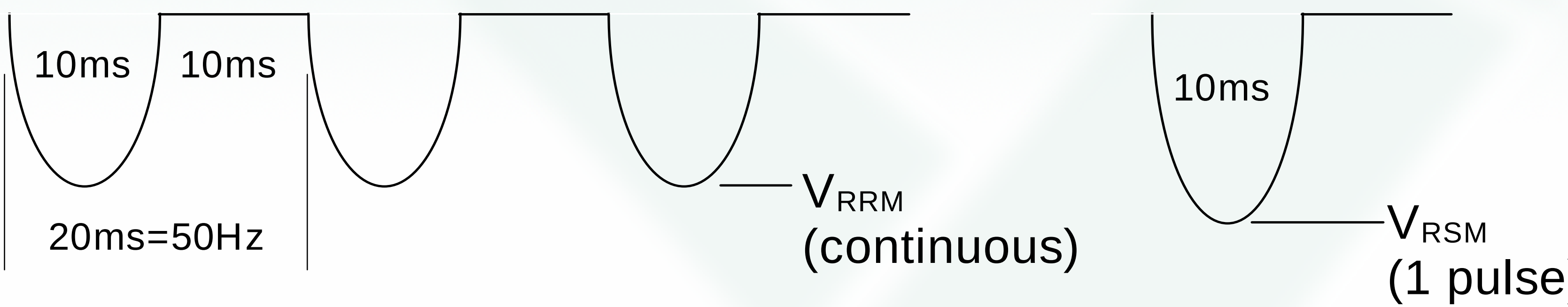
- **Applications**
  - Inverters
  - High frequency welders
  - DC chopper drives
  - Uninterruptible power supplies (UPS)
  - Induction heating
- **Fast turn-off thyristors (FTO)**
  - Regenerative gate structure
  - Used in similar applications to DGT
    - At lower frequencies
  - Most now reassigned as MVT

Ratings & Characteristics



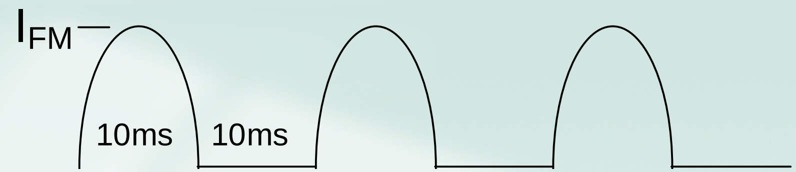
Ratings Common To All Device Types (1 of 3)

- **Maximum ratings**
  - **Maximum operating junction temperature $T_{j\,op}$ ($T_{j\,max}$ T_{vj})**
  - **Maximum storage temperature T_{stg}**
  - **Maximum repetitive reverse voltage V_{RRM}**
    - **Maximum repetitive reverse current I_{RRM} (at V_{RRM})**
  - **Maximum non-repetitive reverse voltage V_{RSM}**
  - **V_{RRM}/V_{RSM} <u>NOT</u> dc values (also applies to V_{DRM}/V_{DSM} on thyristors)**



  - **Values for V_R (dc) is approximately 50% of V_{RRM}**
  - **V_{RSM} typically 100V greater than V_{RRM}**

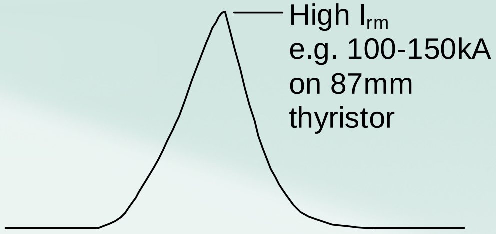
Ratings Common To All Device Types (2 of 3)



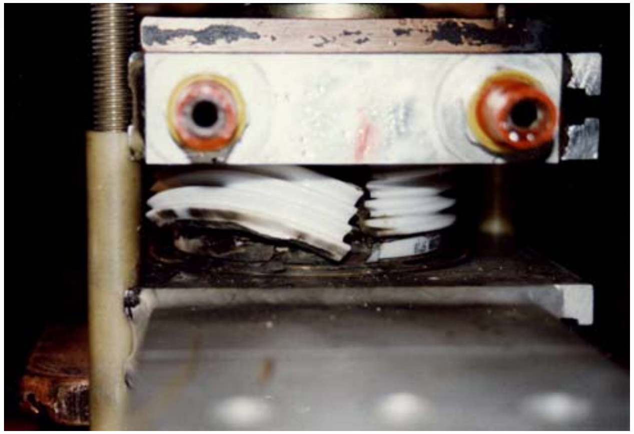
- **Maximum ratings (cont.)**
  - **Forward (on-state) current ratings** **(at specified heatsink temp.)**
    - **Average half sinewave current** $I_{F(av)}/I_{T(av)}$ **($I_{FM} \div \pi$)**
    - **RMS half sinewave current** $I_{F(RMS)}/I_{T(RMS)}$ **($I_{FM} \div 2$)**
    - **DC current** I_F/I_T
  - **Max. non-repetitive forward (on-state) current - Surge**
    - **Overload (fault) condition**
    - **Single cycle of half-sinewave current, 10ms width**
    - **Two separate ratings:**
      - » **Followed by reverse voltage (60% V_{RRM})** $I_{FSM(1)}/I_{TSM(1)}$
      - » **Followed by no reverse voltage (≤10V)** $I_{FSM(2)}/I_{TSM(2)}$
    - **Load limit integral** I^2t **(value for fusing)**
      - » **Calculated by**

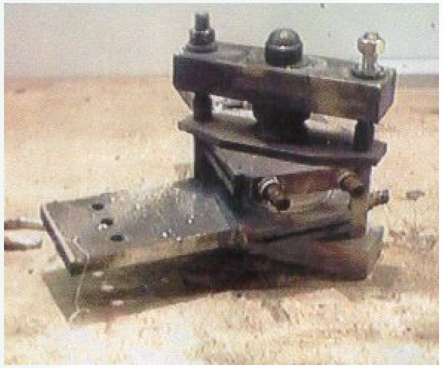
$$I^2t = \int_0^{t_p} I_F{}^2(t)\cdot dt = \frac{I_{FSM}{}^2 \cdot t_p}{2}$$

Ratings Common To All Device Types (3 of 3)



- Explosion rating (Case non-rupture rating)
  - Effectively a test of the housing, not the device
    - » Enhancements (arc-shielding) can be added within housing
  - Simulation of major rectifier fault - device made short-circuit prior to test
  - High level of <u>reverse</u> current passed through failed device and a fuse
  - Pass/fail criteria may vary - usually need to pass a following leak-test
  - Use rating by selecting a fuse with a lower I^2t
  - Important rating as when things go wrong…..



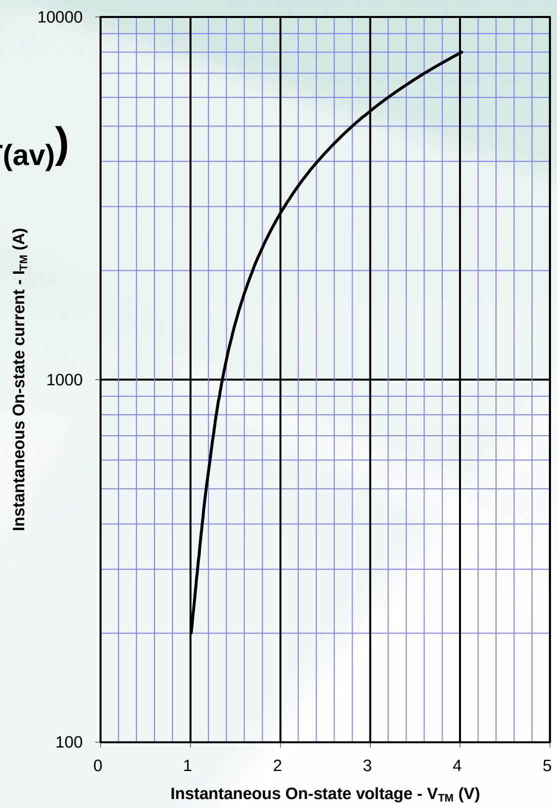


Characteristics Common To All Device Types

- **Characteristics**
  - **Maximum forward (on-state) voltage** V_{FM}/V_{TM}
    - **Test limit V_{FM}/V_{TM} set at I_{FM}/I_{TM} (Usually 3 × $I_{F(av)}/I_{T(av)}$)**
  - **Limit forward (on-state) voltage curves**
    - **ABCD Coefficients**

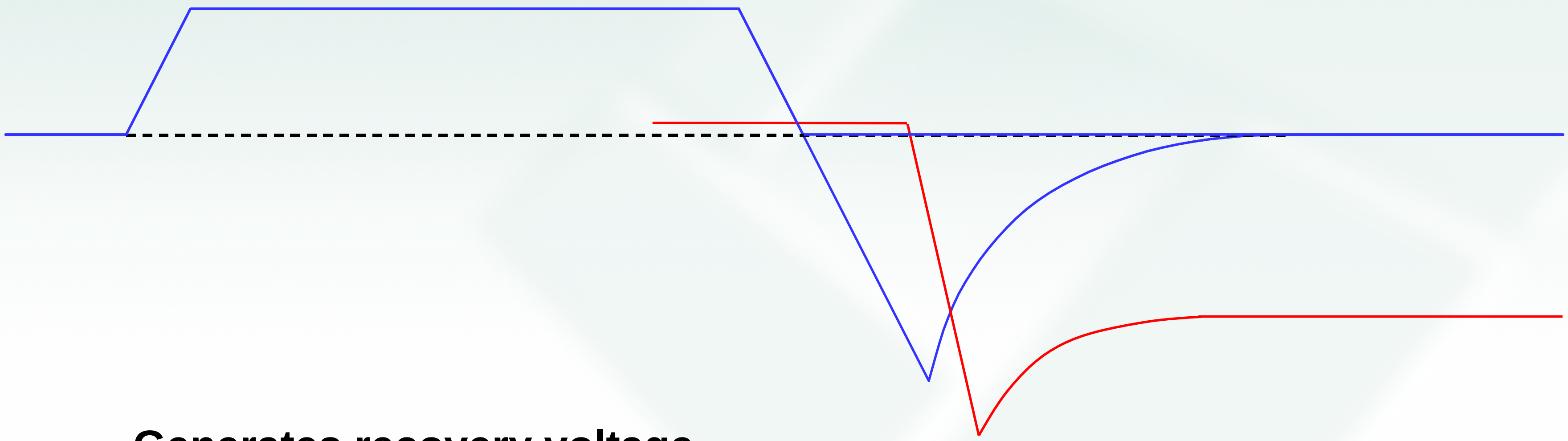
$$V_F = A + B \cdot \ln(I_F) + C \cdot I_F + D \cdot \sqrt{I_F}$$

    - **Threshold voltage** V_{T0} **/ Slope resistance** r_T
      - » **Calculation of max. current ratings**
      - » **Calculation of max. power dissipation**
  - **Thermal resistance**
    - **Steady state value (junction to heatsink)** R_{thJK}
    - **Transient thermal impedance curve**



Reverse Recovery (1 of 5)

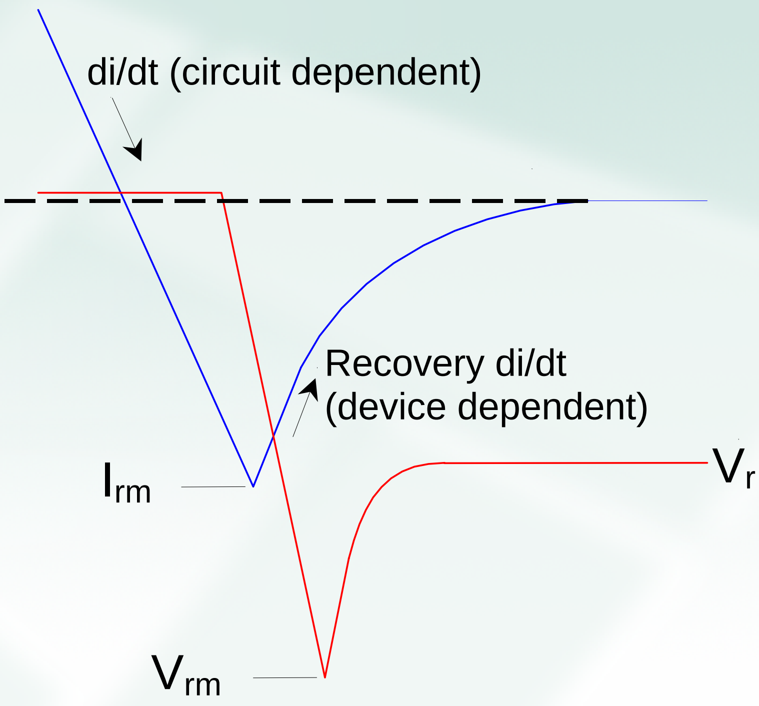
- **What is reverse recovery?**
  - **Consider current waveform**
    - **Ideal situation**
    - **Real situation**



  - **Generates recovery voltage**
  - **Major issue when multiple devices connected in series**
  - **Creates additional power loss ⇒ heat**

Reverse Recovery (2 of 5)

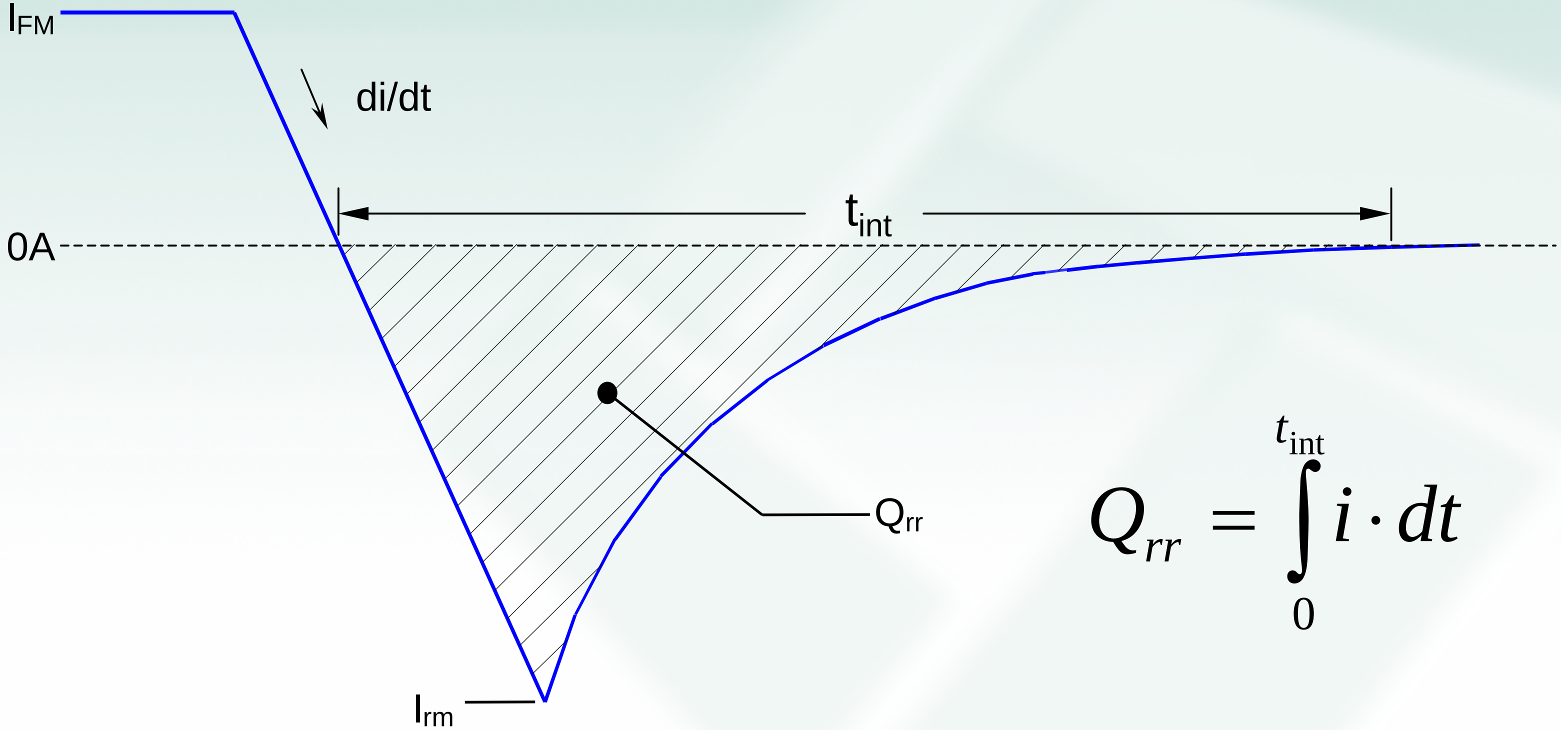
- **Reverse recovery parameters**
  - **Peak reverse recovery current I_{rm} (I_{rr})**
  - **Total recovered charge Q_{rr}**
  - **Recovered charge Q_{ra}**
    - **With specified chord level**
  - **Reverse recovery time t_{rr}**
    - **With specified chord level**



  - **This information is frequently required on ALL product types**

Reverse Recovery (3 of 5)

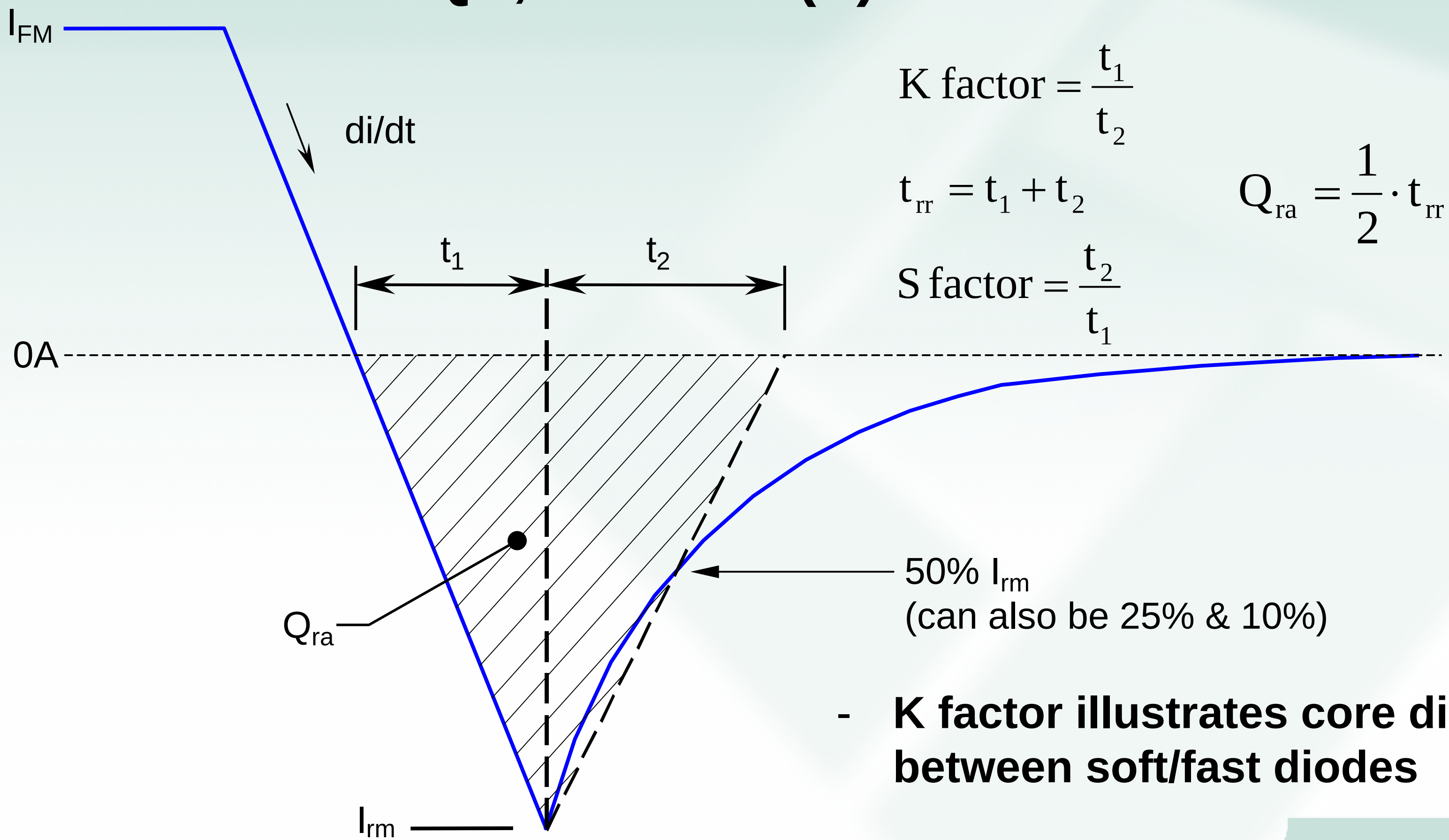
- **Definition of Q_{rr} (total stored charge)**



$$Q_{rr} = \int_{0}^{t_{int}} i \cdot dt$$

- **Area under curve from I=0A to t_{int} (Standard=150µs)**
- **Q_{rr} may appear as Q_s, Q_r, Q_{rec} etc.**

- **Definition of Q_{ra}, t_{rr} and K (S) factor**



$$K\ \text{factor} = \frac{t_1}{t_2}$$

$$t_{rr} = t_1 + t_2$$

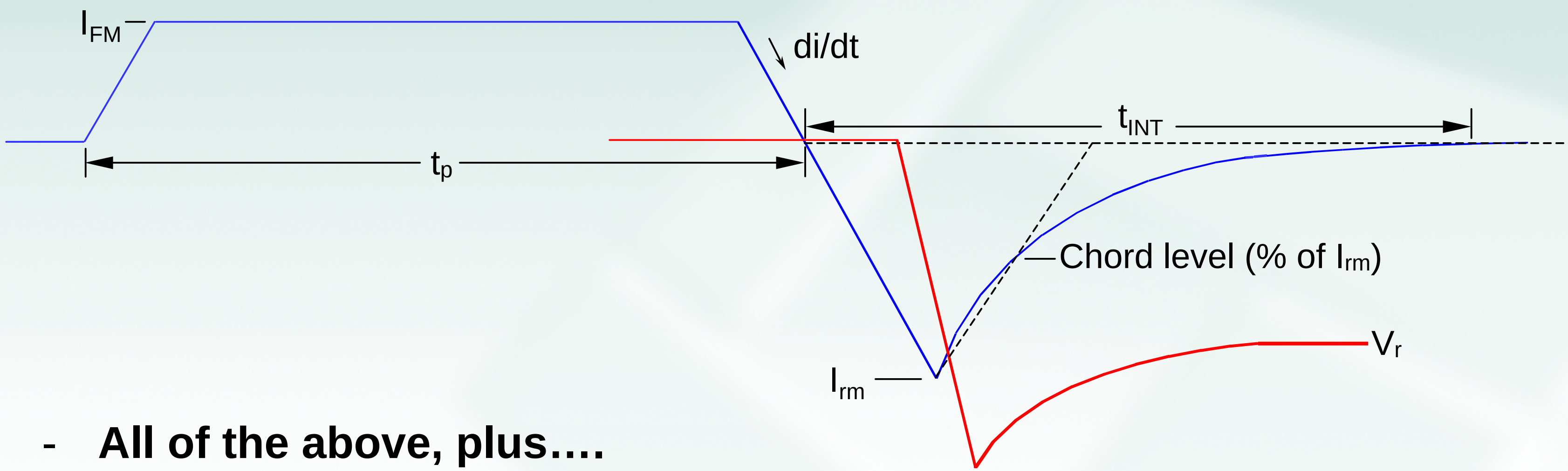
$$S\ \text{factor} = \frac{t_2}{t_1}$$

$$Q_{ra} = \frac{1}{2} \cdot t_{rr} \cdot I_{rm}$$

- **K factor illustrates core difference between soft/fast diodes**

Reverse Recovery (5 of 5)

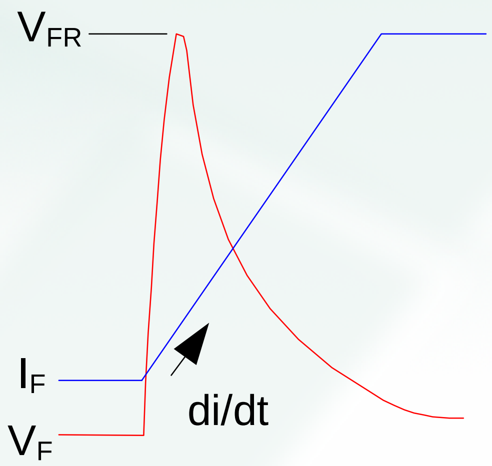
- **Information required for recovery measurements**



- **All of the above, plus….**
- **For Q_{ra}, t_{rr} or K factor, chord level MUST be specified**
  - **Normally 50% but can also be 25% and 10%**
- **For Q_{rr}, specify t_{int}**
- **Test temperature - CRITICAL**
- **Where charge appears only as Q_r, Q_s etc.**
  - **Must clarify whether Q_{rr} or Q_{ra} required**

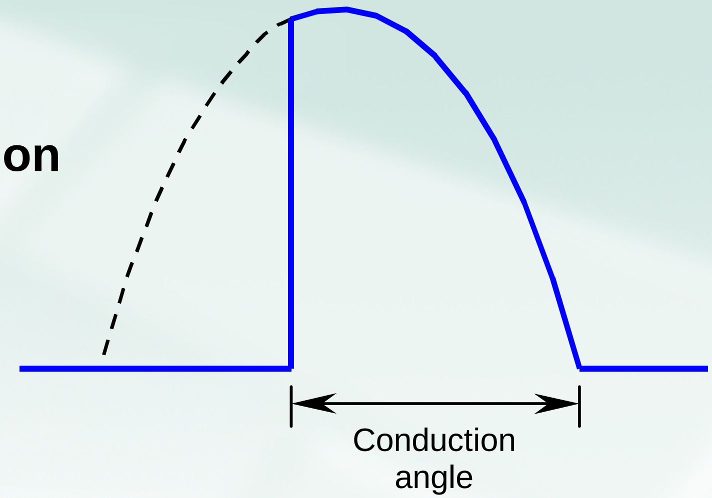
Ratings & Characteristics - Fast Products

- **Fast product ratings**
  - **Frequency/energy ratings**
    - **Energy vs. pulse width $T_j = T_j$ max**
    - **Frequency vs. pulse width**
      - » **55°C / 85°C heatsink temperature**
    - **Square wave (various di/dt's)**
    - **Sine wave**
- **Forward recovery voltage** V_{FR}
  - **Measured exclusively on fast diodes**



Ratings & Characteristics - Converter Grade

- **Power dissipation curves**
  - **Mean forward current vs. power dissipation**
    - **Square wave and sine wave**
    - **Various conduction angles**



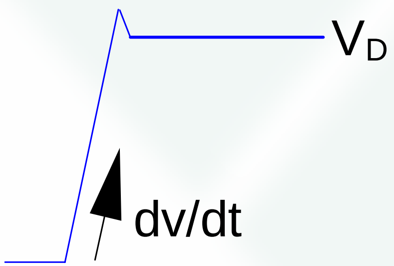
- **Maximum permissible heatsink temperature**
  - **Mean forward current vs. heatsink temperature**
    - **Square wave**
    - **Sine wave**
    - **Various conduction angles**

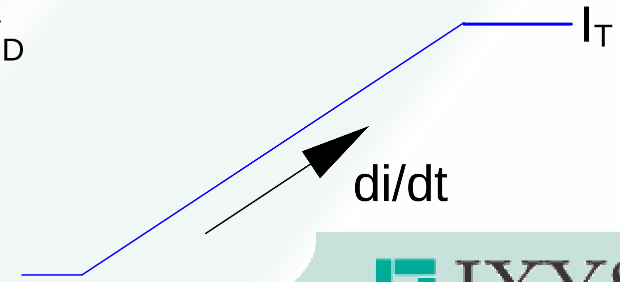
$$P_{\max} = \frac{T_{j_{\max}} - T_K}{R_{thJK}}$$

- **Equivalent shown for dc, ½ wave, 3ph, 6ph on diodes**

Ratings & Characteristics - Thyristors (1 of 2)

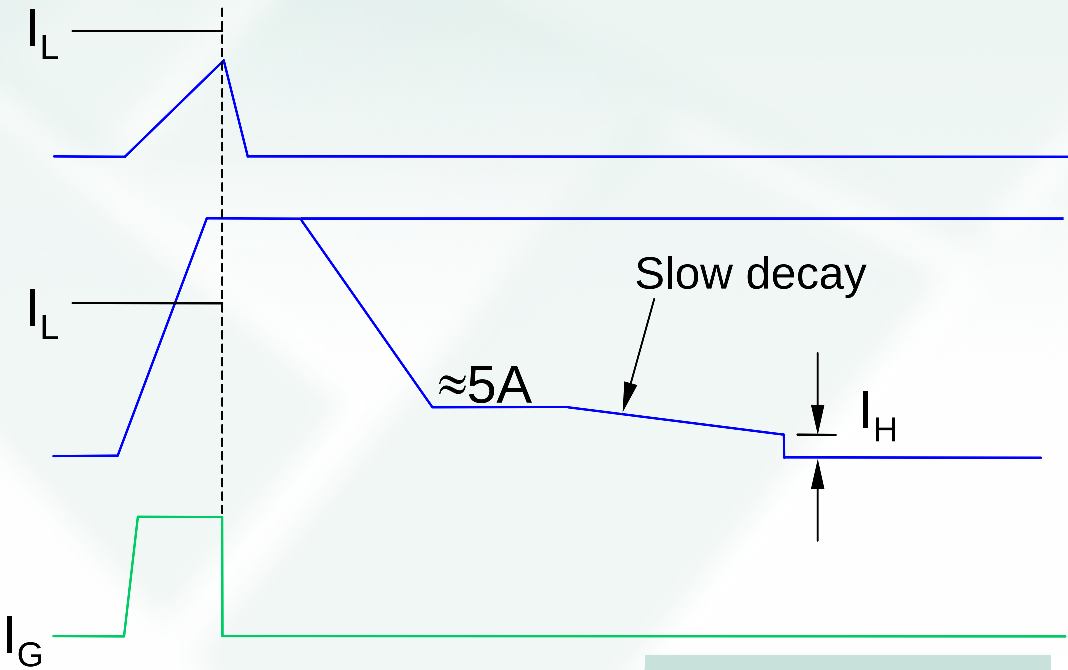
- **Max. repetitive forward (off-state) voltage** V_{DRM}
  - **Maximum repetitive off-state current** I_{DRM} **(at** V_{DRM}**)**
- **Maximum non-repetitive off-state voltage** V_{DSM}
- **Critical rate of rise of off-state voltage** $(dv/dt)_{cr}$
  - **Measured to** V_D**=80%** V_{DRM} **(linear voltage ramp)**
  - **Failure is destructive**
- **Critical rate of rise of on-state current** $(di/dt)_{cr}$
  - **Quoted for repetitive (50Hz) and non-repetitive duty**
  - **Simple turn-on test**
  - **Failure is destructive**





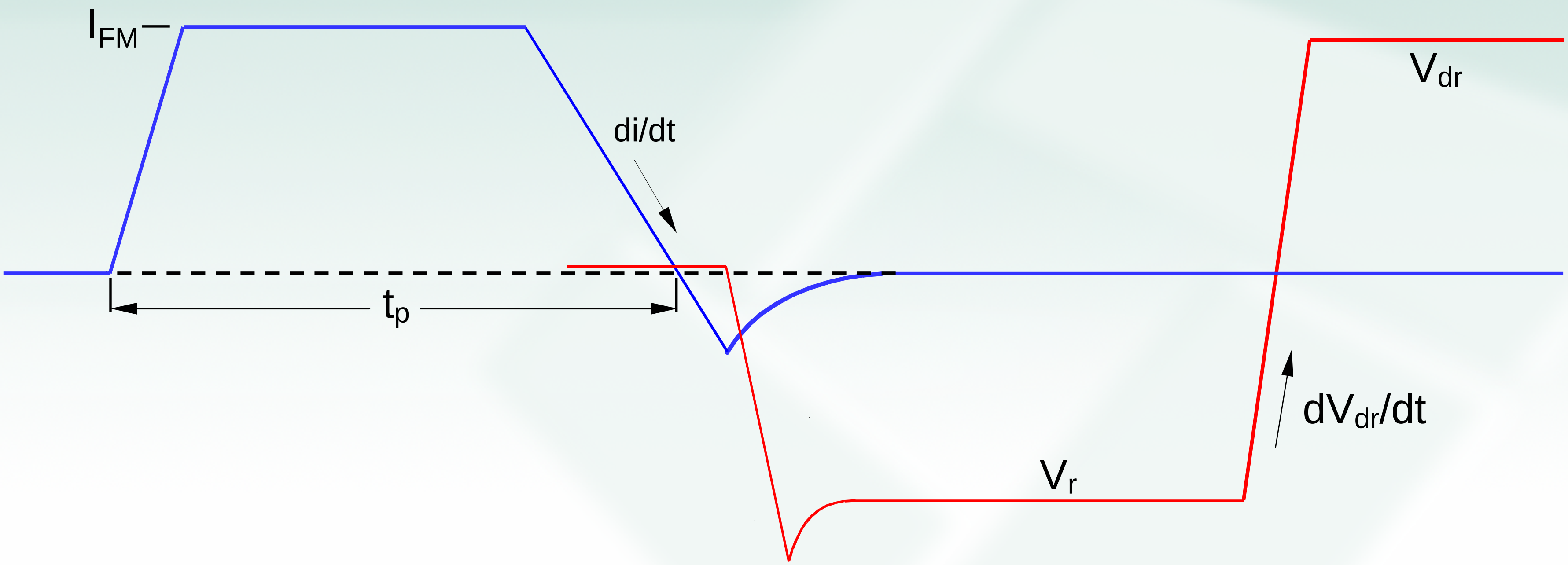
Ratings & Characteristics - Thyristors (2 of 2)

- **Gate trigger voltage** V_{GT} **and current** I_{GT}
- **Gate non-trigger voltage** V_{GD} **and current** I_{GD}
- **Peak forward gate current** I_{FGM}
- **Peak reverse gate voltage** V_{RGM}
- **Mean forward gate power** $P_{G(av)}$
- **Peak gate power** P_{GM}
- **Latching current** I_L
- **Holding current** I_H



Ratings & Characteristics - Turn-off Time (1 of 2)

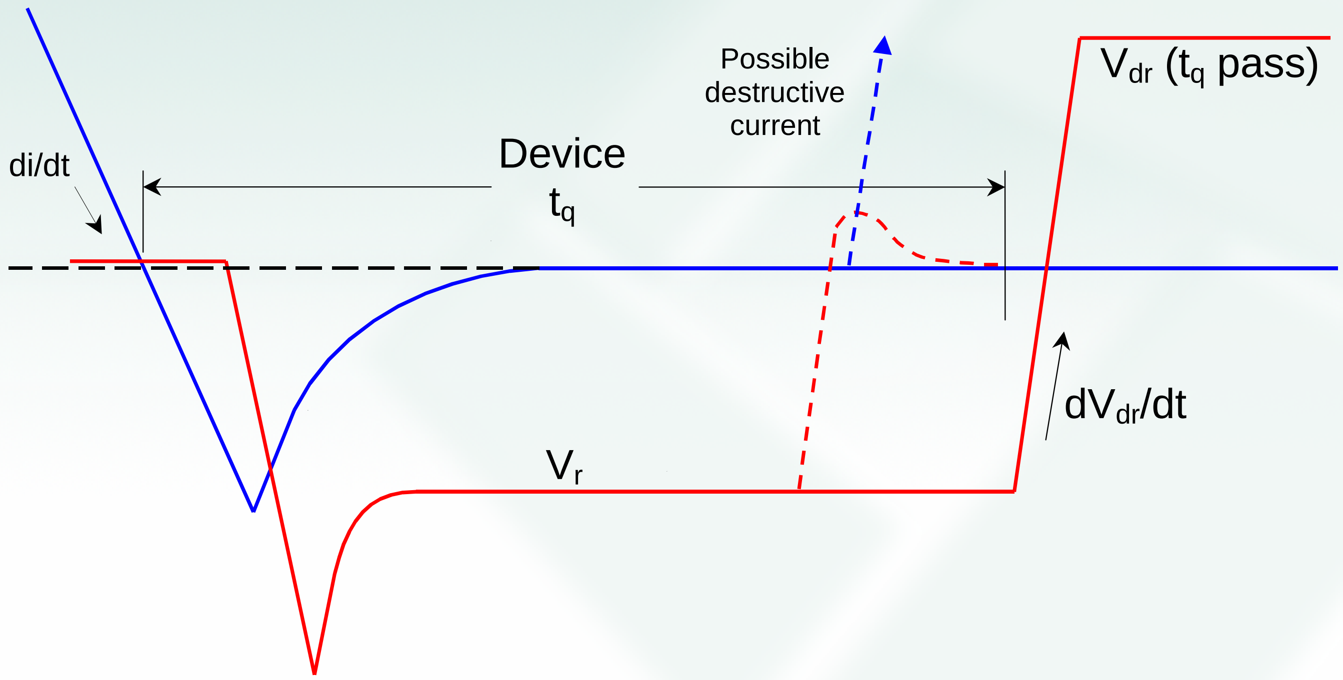
- **Definition of turn-off time test and terms**



- **All of this information is required**
  - **Plus test temperature - CRITICAL**

Ratings & Characteristics - Turn-off Time (2 of 2)

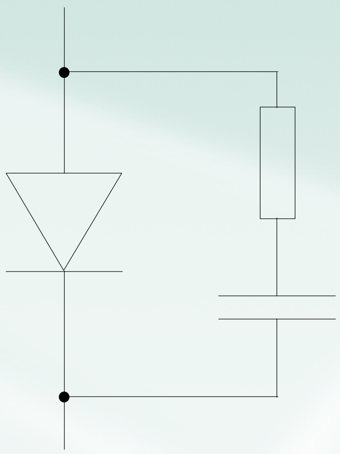
- **Turn-off time t_q**
  - **Time before off-state voltage may be safely re-applied**

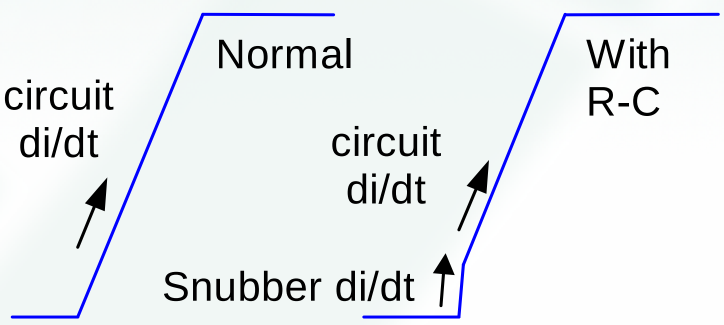


  - **Value of t_q affected by ALL illustrated parameters**
  - **Often asked for on all thyristor types**

Application issues (1 of 5)

- **Snubbers**
  - Resistor and capacitor connected in series
  - Snubber then connected across device anode/cathode
    - Important to minimise inductance
  - Used to restrict dv/dt and V_{rm} to safe values
  - Affects reverse recovery waveform
    - Care needed when devices in series
  - Changes turn-on waveform
    - Implications on di/dt performance
    - Snubber di/dt must be within device rating
  - Careful design calculations
    - Min. resistance/max. capacitance limits



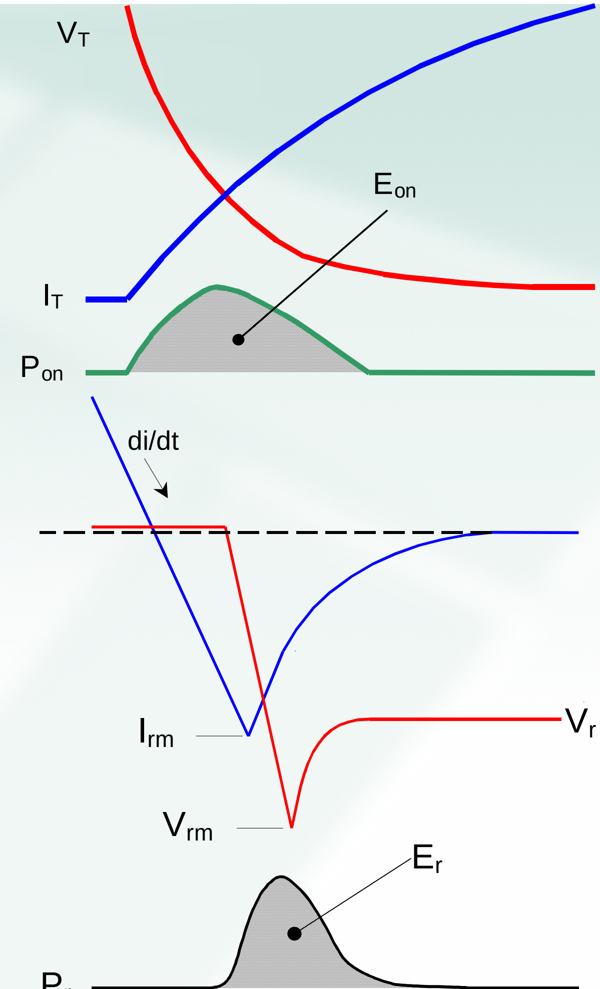


- **Switching energy losses**
  - **Turn-on power** P_{on}
  - **Turn-on energy loss** E_{on}

$$P_{on} = V_T \cdot I_T \qquad E_{on} = \int_0^{t_{on}} V_T \cdot I_T$$

  - **Reverse recovery power** P_r
  - **Reverse recovery energy loss** E_r

$$P_r = V_r \cdot I_r \qquad E_r = \int_0^{t_r} V_r \cdot I_r$$

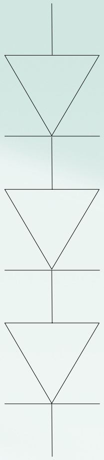


Application issues (3 of 5)

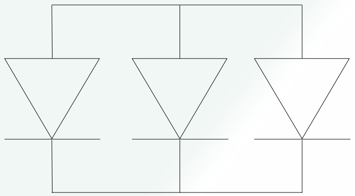
- **Selection of thyristor type**
  - Why select a Phase Control Thyristor (N type)
    - When a low V_T is important
    - High Average Current & Surge Current Ratings are required
    - Low frequency (up to 60Hz) applications and low di/dt
      - » Examples are cyclo-converters and AC switches
  - Why select a Medium Voltage Thyristor (K type)
    - Higher voltage devices/medium voltage applications
      - » Line/power frequency applications (50/60Hz and up to 400Hz)
    - For multiple device operation e.g. series/parallel
      - » N-types are inappropriate due to lack of lifetime control
    - High power drives are a typical application
  - Why select a Distributed Gate Thyristor (R type)
    - When a fast <u>switching</u> device is required (even at low frequencies)
    - R types always considered first for induction heating

Application issues

- **Series operation**
  - Multiple devices required for system voltage rating
  - Considerations needed are:
    - K series device most likely preferable to N series
    - Banding on reverse recovery parameters
    - Matching on leakage current
    - Matching on gate trigger parameters



- **Parallel operation**
  - Multiple devices required for system current rating
  - Considerations needed are:
    - Banding on V_T
    - Banding on delay time (turn-on time)
    - Matching on gate trigger parameters



Application issues (5 of 5)

- **Thyristor gate drive**
  - Important note concerning gate trigger parameters
    - V_{GT}/I_{GT} are the bare minimum amounts required to trigger the device
    - They are absolutely NOT practical values
      - » The full di/dt capability of a device CANNOT be used this way
  - Refer to gate drive note in any thyristor data sheet
    - Most important figures are:
      - » Open circuit voltage
      - » I_G rise time - especially when using device's full di/dt capability
      - » I_{GM} - especially for larger devices
    - Keep to maximum ratings (Voltage & Power)
- **Clamping**
  - Important to clamp at correct force and EVENLY
  - Failure to do this results in higher power dissipation, high V_T and reduced device lifetime