JEDEC STANDARD

Method for Measurement of Power Device Turn-Off Switching Loss

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METHOD FOR MEASUREMENT OF POWER DEVICE TURN-OFF SWITCHING LOSS

(From JEDEC Council Ballot JCB-89-16, formulated under the cognizance of JC-25 Committee on Transistors.)

1. PURPOSE

This method establishes a basic test circuit, provides waveform definitions, and indicates circuit elements for the measurement of the turn-off switching loss of a power device.

2. SCOPE

The approach outlined in this document applies to bipolar, MOS and IGBT device measurements, both N and P type. The device chosen for illustrations is an N channel, enhancement-mode field effect transistor.

3. DEFINITIONS

W_{off} is the symbol used for turn-off switching loss. The units are joules/pulse. The power dissipated in the device during turn-off is $P_{Doff} = W_{off} \cdot f$ in watts and f is the operating repetition rate in pulses/s. The formal definition is:

$$W_{off} \triangleq \int_{t_1}^{t_2} ivdt \qquad \text{joules/pulse}$$

where the instantaneous power at time t is p = iv watts and the symbol " $\triangleq$ " means equal by definition.

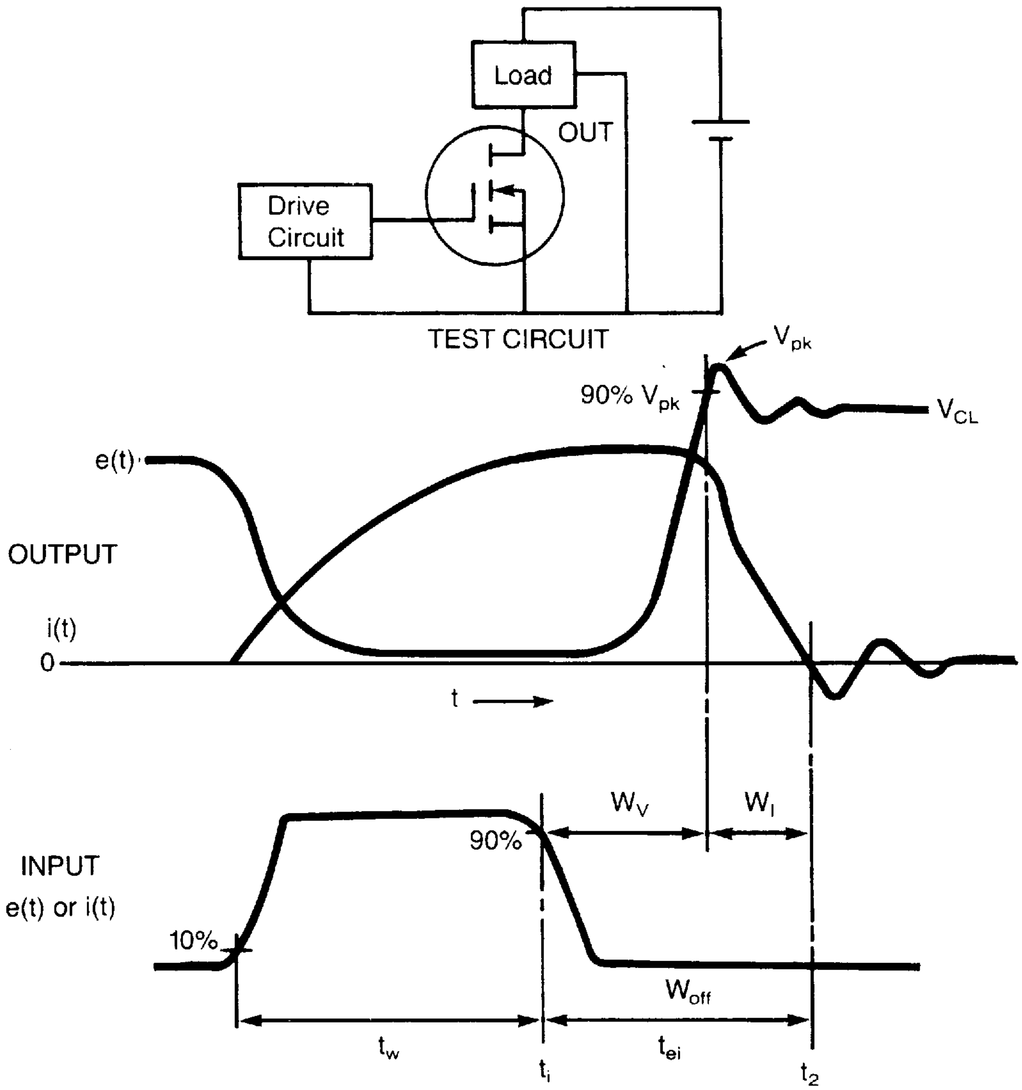
Figure 1 defines the limits of integration. Resistive load waveforms are not precluded by this method; however clamped inductive waveforms are preferred. In general, W_{off} can be separated into component parts W_V and W_I. W_V is that part associated with the rising output voltage during which the output current is reasonably constant. Conversely W_I is associated with the falling current while the output voltage is reasonably constant. V_{pk} has been chosen as the reference rather than the steady state clamp voltage for two reasons:

1. V_{pk} is generally in excess of 50 V higher than the steady-state clamp voltage level. Clamp voltage overshoot is unavoidable in a practicable circuit and is a measure of the clamp circuit effectiveness.

3. **DEFINITIONS** (Continued)

2. The major part of the output current fall occurs during the first V_{CL} overshoot and before a steady-state clamp level is reached.

The end point of W_I has been chosen to be the first output current crossover ($I_{OUT} = 0$). In a high speed switching circuit, turn-off is always accompanied by considerable ringing. The first current crossover is unambiguous and easily detected.



$$W_{off} \triangleq W_v + W_I$$

FIGURE 1
TYPICAL CLAMPED INDUCTIVE WAVEFORMS

4. INPUT DRIVE CONSIDERATIONS

Any configuration of input drive that is appropriate may be used. If specific parts (passive and active) are important for performance they should be listed. If circuit layout is important, this also should be specified, i.e., ground plane, stray capacitance, inductance, etc. The input pulse width, characteristics, and duty factor should also be specified. A duty factor that does not materially raise T_J is preferred. Device T_J is best controlled by external heating rather than by self heating.

5. OUTPUT LOAD CONSIDERATIONS

The comments made about the input drive generally apply to load considerations.

6. INSTRUMENTATION

A modern high speed digitizing system is recommended. The measurement of W_{off} is accomplished by accessing the output e(t) and i(t) waveforms, digitizing them, and transmitting the data to a computer where W_{off} is calculated and the results displayed. Two factors of importance must be considered:

1. Sample spacing must be short relative to transition times for accurate and repeatable results.

2. The relative e(t), i(t) channel delay must be known and accounted for in the computer program that does the point by point multiplication and summation that determines W_{off}. See Figure 2.

7. REQUIREMENTS

In addition to compliance with paragraphs 4, 5 and 6, the following must be specified:

1. T_J - Junction temperature

2. I_{OUT} - On state output current

3. V_{OUT} - Off state output voltage

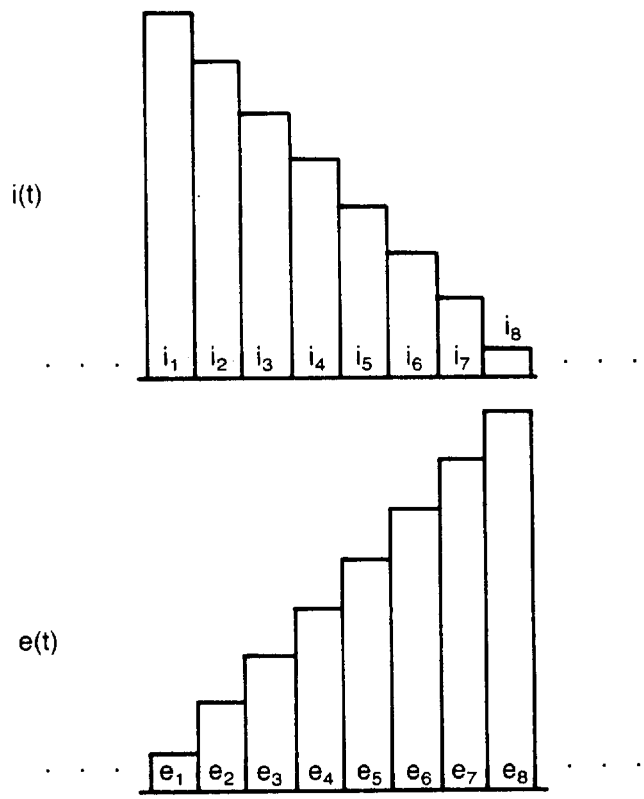
4. V_{CL} - Clamp voltage where applicable

7. **REQUIREMENTS** (Continued)

5. Appropriate input voltage and current values - For example:

bipolar: $I_{BI} = I_{B2}$ = X amperes
Reverse base voltage = V_B volts

MOS/IGBT: $R_{GEN} = R_{GS}$ = X ohms
V_{GS} = X volts



t_{int} = sampling interval
t_d = measured channel delay (see figure 3)
m = number of sample intervals to reach $I_{OUT} = 0$

The computer program calculates:

$$W_{off} = \sum_{n=1}^{n=m} e_n \, i_{n \pm a} \, t_{int}$$

where $a = t_d/t_{int}$ rounded to the nearest integer
use i_{n+a} when i(t) lags e(t)
i_{n-a} when i(t) leads e(t)

FIGURE 2

8. GUIDELINES

The following is recommended:

T_J: The test should be performed at the maximum rated junction temperature.

I_{OUT}: The output current should be the rated device continuous current.

V_{CL}: The clamp voltage should be at least 80% of rated breakdown voltage.

Load: An inductive load is preferred.

Drive Conditions: These should be arranged to minimize W_{off}.

8.1 Measurement Equipment

Current Monitor: Pearson Model 411 or Model 2877 or equivalent

Digitizer: Tektronix 2430A or equivalent

Computer: Tektronix 4041 or equivalent

Page 9 gives a sample printout from this system.

8.2 Channel Delay - Procedure

1. Adjust oscilloscope channel gains so the traces e(t), i(t) have the same display amplitude.
2. Expand the time scale and measure the channel to channel time delay.
3. Figure 3 illustrates the test set up. Equivalent equipment may be used.

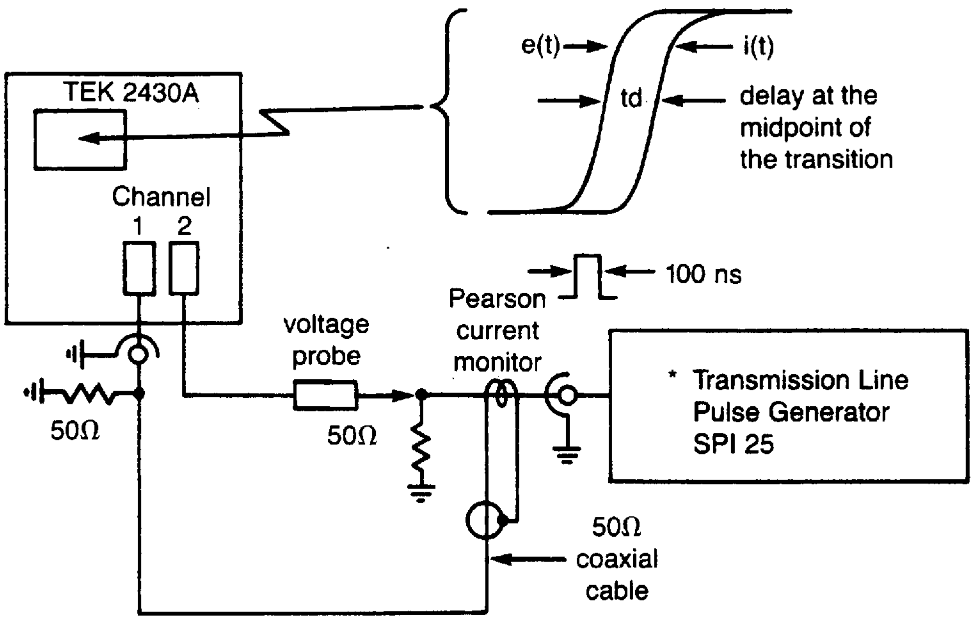


FIGURE 3
TEST SET-UP FOR CHANNEL DELAY MEASUREMENT

* Manufactured by: Spire Corp. (617) 275-6000
Patriots Park
Bedford, Mass.
$t_r = t_f = 500$ ps
0 to 1000 V into a 50 ohm load

Program: Ener4
W_V calculated from trigger position to 90% of V_{pk}.
W_I calculated from 90% of V_{pk} to I_{OUT} = 0.
$t_{d(off)i}$ calculated from trigger position to 90% I_{OUT} maximum.
$t_{d(off)v}$ calculated from trigger position to 10% of V_{pk}.

TRIGGER POINT = 128.0
TIME SLICE = 10 ns
CURSOR POSITION = 486

WFMPRE WFID:"CH1 DC 50V 500ns AVG",NR.PT:1024,PT.OFF:128,PT.FMT:Y,XUNIT:SEC,XINCR:1.000E-8,YMULT:2.000,YOFF:-6.175E+1,YUNIT:V,BN.FMT:RP,ENCDG:BINARY

WFMPRE WFID:"CH2 DC 100mV 500ns AVG",NR.PT:1024,PT.OFF:128,PT.FMT:Y,XUNIT:SEC,XINCR:1.000E-8,YMULT:4.000E-3,YOFF:-6.175E+1,YUNIT:V,BN.FMT:RP,ENCDG:BINARY

Time	Voltage volts	Current amperes	Power watts	Energy microjoules
128	2	8.00	16.00	0.16
178	2	8.00	16.00	0.16
228	2	8.00	16.00	0.16
278	2	8.00	16.00	0.16
328	2	8.00	16.00	0.16
378	2	8.00	16.00	0.16
428	2	8.00	48.00	0.48
478	94	7.76	729.44	7.29
528	290	-0.08	00.00	0.00

W_V = 273.00 microjoules
W_I = 144.64 microjoules
W_T = 417.64 microjoules
$t_{d(off)i}$ = 3590.00 ns
$t_{d(off)v}$ = 3360.00 ns
t_{fi} 90%-10% = 170.00 ns

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