Lecture 10: Field Effect Transistors – Part 2

MOSFETs

MOSFETs have characteristics similar to those of JFETs and additional characteristics that make then very useful.

There are two types of MOSFETs:

Depletion-Type

Enhancement-Type

Depletion-Type MOSFET Construction

The Drain (D) and Source (S) connect to the to *n*-type regions. These *n*-typed regions are connected via an *n*-channel. This *n*-channel is connected to the Gate (G) via a thin insulating layer of silicon dioxide (SiO_2).

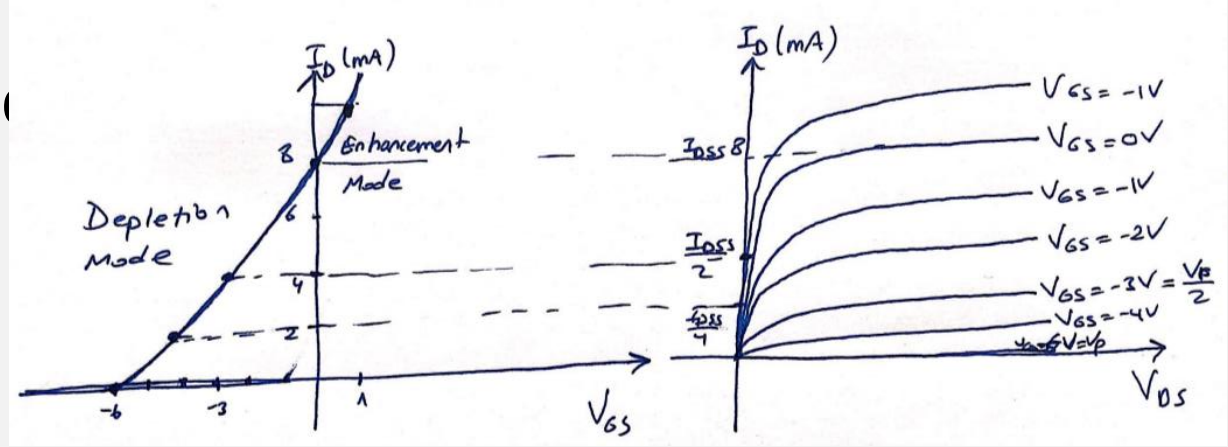
The *n*-type material lies on a *p*-type substrate that may have an additional terminal connection called the Substrate (SS).

Basic MOSFET Operation

A depletion-type MOSFET can operate in two modes:

Depletion mode

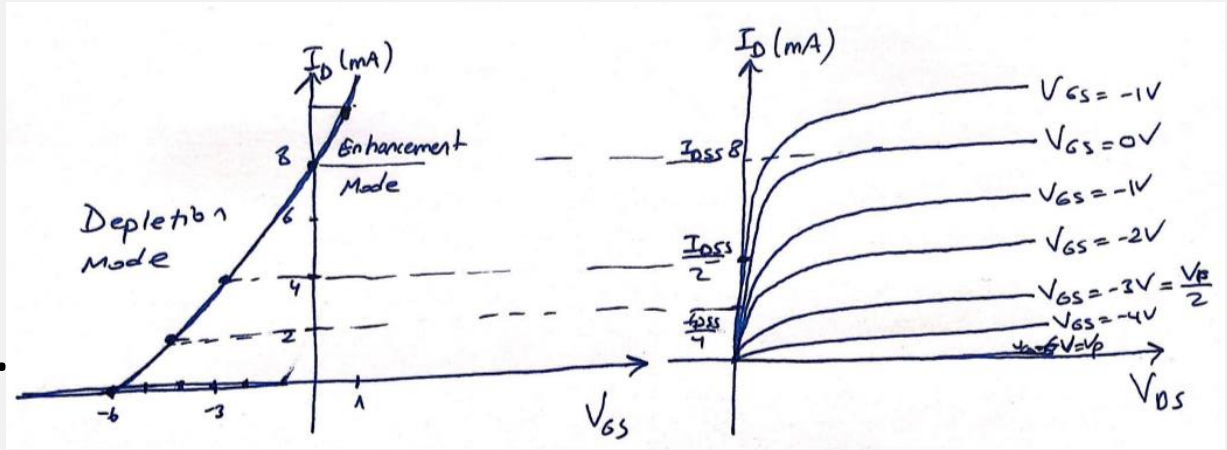
Enhancement mo



Depletion Mode Operation

(D-MOSFET)

The characteristics are similar to a JFET.



when $V_{GS} = 0$ V, $I_D = I_{DSS}$

when $V_{GS} < 0$ V, $I_D < I_{DSS}$

The formula used to plot the transfer curve for a JFET applies to a D-MOSFET as well:

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

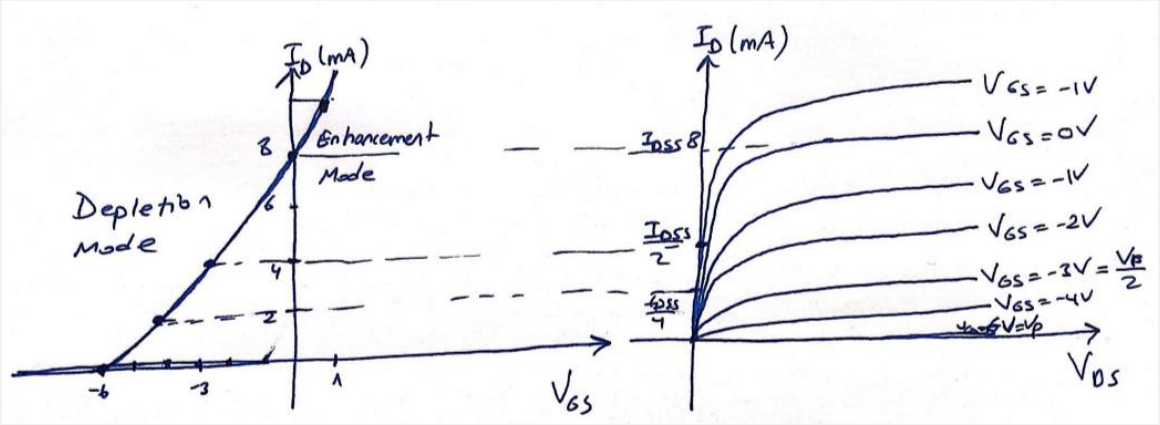
Enhancement Mode Operation

(D-MOSFET)

$V_{GS} > 0$ V, I_D increases above I_{DSS} ($I_D > I_{DSS}$)

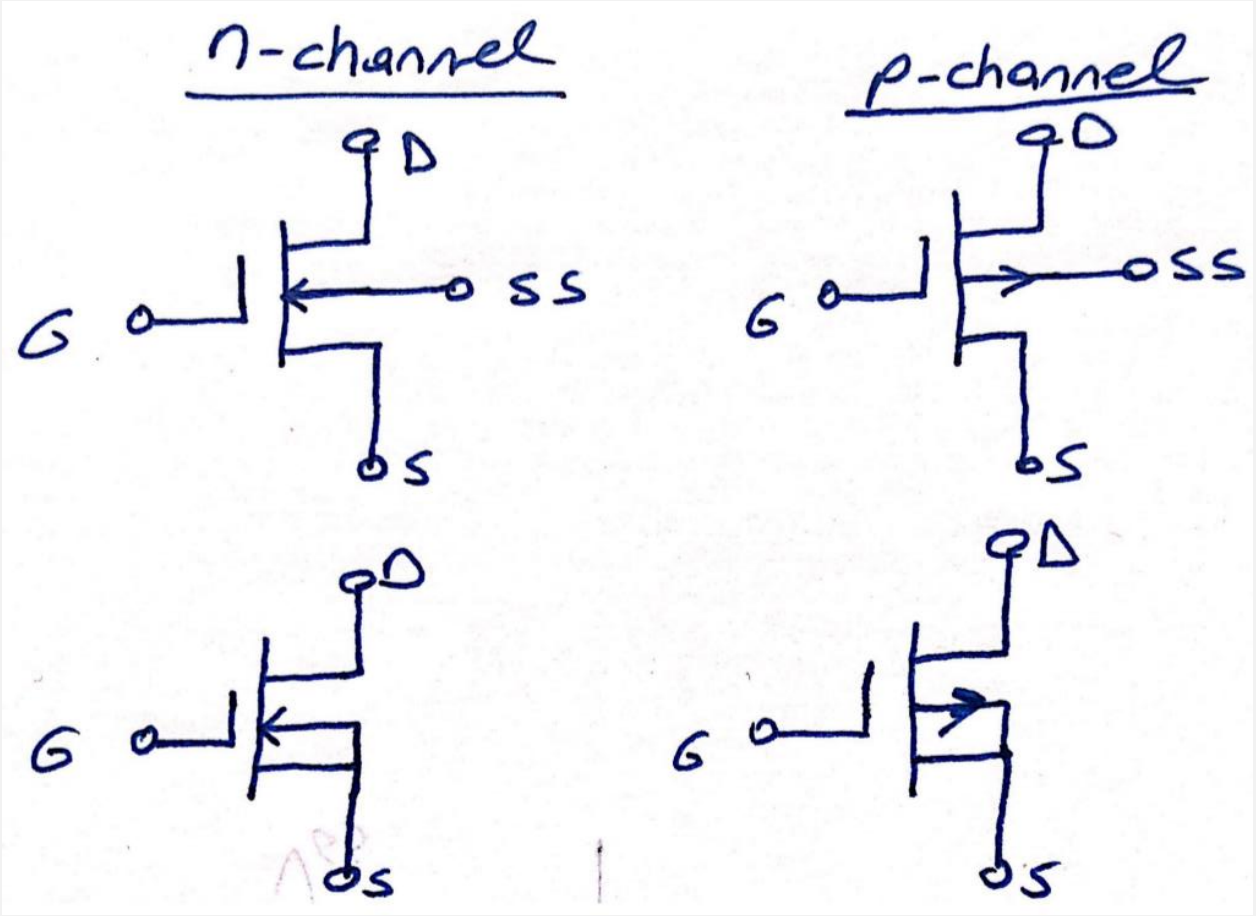
The formula used to plot the transfer curve still applies:

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$



Note that V_{GS} is now positive

D-Type MOSFET Symbols



Specification Sheet

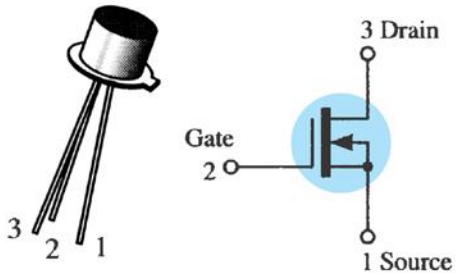
Maximum Ratings

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Drain–Source Voltage 2N3797	V_{DS}	20	Vdc
Gate–Source Voltage	V_{GS}	±10	Vdc
Drain Current	I_D	20	mAdc
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	200 1.14	mW mW/°C
Junction Temperature Range	T_J	+175	°C
Storage Channel Temperature Range	T_{stg}	–65 to +200	°C

2N3797

MOSFET
LOW–POWER AUDIO



N-CHANNEL – DEPLETION

Specification Sheet

Electrical Characteristics

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
OFF CHARACTERISTICS						
Drain Source Breakdown Voltage (V_{GS} = –7.0 V, I_D = 5.0 μA)	2N3797	$V_{(BR)DSX}$	20	25	–	Vdc
Gate Reverse Current (1) (V_{GS} = –10 V, V_{DS} = 0)		I_{GSS}	–	–	1.0	pAdc
(V_{GS} = –10 V, V_{DS} = 0, T_A = 150°C)			–	–	200	
Gate Source Cutoff Voltage (I_D = 2.0 μA, V_{DS} = 10 V)	2N3797	$V_{GS(off)}$	–	–5.0	–7.0	Vdc
Drain-Gate Reverse Current (1) (V_{DG} = 10 V, I_S = 0)		I_{DGO}	–	–	1.0	pAdc
ON CHARACTERISTICS						
Zero-Gate-Voltage Drain Current (V_{DS} = 10 V, V_{GS} = 0)	2N3797	I_{DSS}	2.0	2.9	6.0	mAdc
On-State Drain Current (V_{DS} = 10 V, V_{GS} = +3.5 V)	2N3797	$I_{D(on)}$	9.0	14	18	mAdc
SMALL-SIGNAL CHARACTERISTICS						
Forward Transfer Admittance (V_{DS} = 10 V, V_{GS} = 0, f = 1.0 kHz)	2N3797	$\lvert y_{fs} \rvert$	1500	2300	3000	μmhos
(V_{DS} = 10 V, V_{GS} = 0, f = 1.0 MHz)	2N3797		1500	–	–	
Output Admittance (I_{DS} = 10 V, V_{GS} = 0, f = 1.0 kHz)	2N3797	$\lvert y_{os} \rvert$	–	27	60	μmhos
Input Capacitance (V_{DS} = 10 V, V_{GS} = 0, f = 1.0 MHz)	2N3797	C_{iss}	–	6.0	8.0	pF
Reverse Transfer Capacitance (V_{DS} = 10 V, V_{GS} = 0, f = 1.0 MHz)		C_{rss}	–	0.5	0.8	pF
FUNCTIONAL CHARACTERISTICS						
Noise Figure (V_{DS} = 10 V, V_{GS} = 0, f = 1.0 kHz, R_S = 3 megohms)		NF	–	3.8	–	dB

(1) This value of current includes both the FET leakage current as well as the leakage current associated with the test socket and fixture when measured under best attainable conditions.

E-Type MOSFET Construction

The Drain (D) and Source (S) connect to the to *n*-type regions.
These *n*-type regions are connected via an *n*-channel

The Gate (G) connects to the *p*-type substrate
via a thin insulating layer of silicon dioxide (SiO_2)

There is no channel

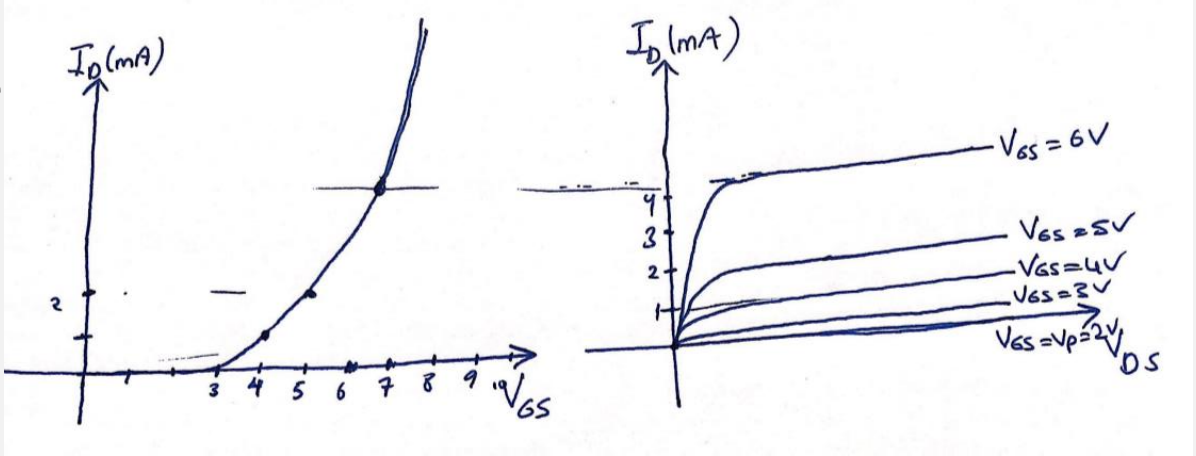
The *n*-type material lies on a *p*-type substrate
that may have an additional terminal connection
called the Substrate (SS)

E-Type MOSFET Operation

The enhancement-type MOSFET (E-MOSFET) operates only in the enhancement mode.

V_{GS} is always positive

As V_{GS} increases, I_D increases



As V_{GS} is kept constant and V_{DS} is increased, then I_D saturates (I_{DSS}) and the saturation level (V_{DSsat}) is reached

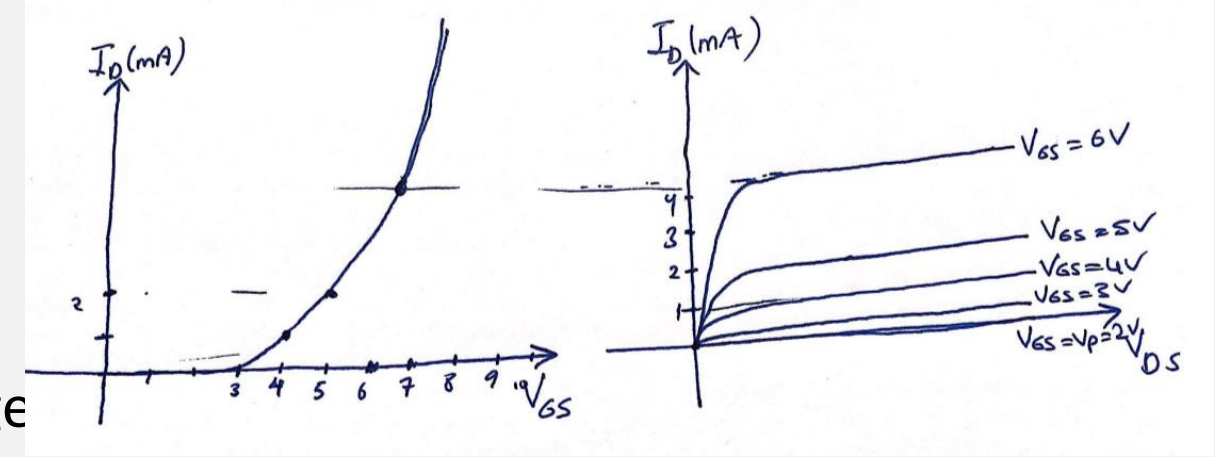
E-Type MOSFET Transfer Curve

To determine I_D given V_{GS}:

$$I_D = k(V_{GS} - V_T)^2$$

where:

V_T = the E-MOSFET threshold voltage



k, a constant, can be determined by using values at a specific point and the formula:

$$k = \frac{I_{D(ON)}}{(V_{GS(ON)} - V_T)^2}$$

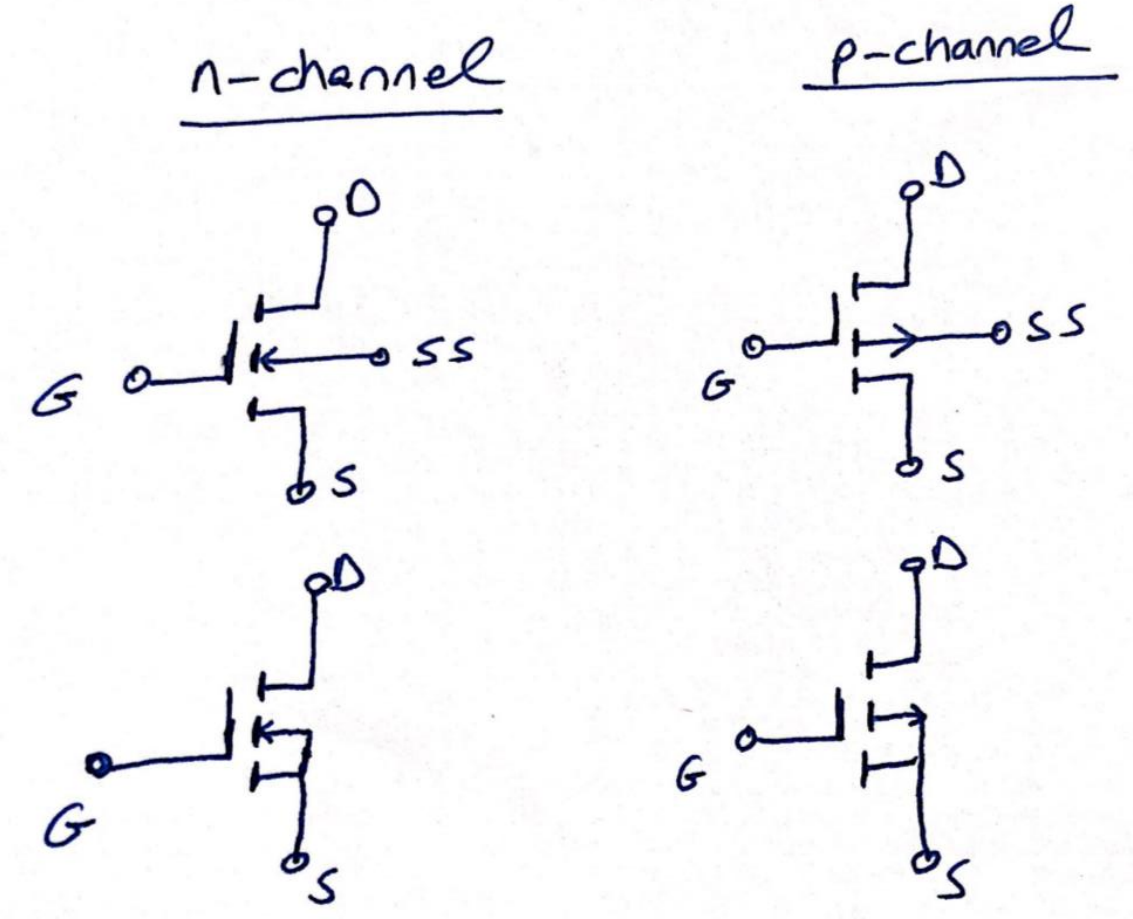
V_{DSsat} can be calculated using:

$$V_{DSsat} = V_{GS} - V_T$$

p-Channel E-Type MOSFETs

The *p*-channel enhancement-type MOSFET is similar to its *n*-channel counterpart, except that the voltage polarities and current directions are reversed.

MOSFET Symbols



Specification Sheet

Maximum Ratings

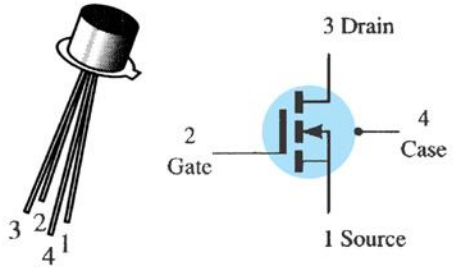
MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Drain–Source Voltage	V_{DS}	25	Vdc
Drain–Gate Voltage	V_{DG}	30	Vdc
Gate–Source Voltage*	V_{GS}	30	Vdc
Drain Current	I_D	30	mAdc
Total Device Dissipation @ $T_A = 25°C$ Derate above 25°C	P_D	300 1.7	mW mW/°C
Junction Temperature Range	T_J	175	°C
Storage Temperature Range	T_{stg}	–65 to +175	°C

* Transient potentials of ± 75 Volt will not cause gate-oxide failure.

2N4351

MOSFET
SWITCHING



N-CHANNEL – ENHANCEMENT

more…

Specification Sheet

Electrical Characteristics

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic	Symbol	Min	Max	Unit
OFF CHARACTERISTICS				
Drain-Source Breakdown Voltage (I_D = 10 μA, V_{GS} = 0)	$V_{(BR)DSX}$	25	–	Vdc
Zero-Gate-Voltage Drain Current (V_{DS} = 10 V, V_{GS} = 0) T_A = 25°C T_A = 150°C	I_{DSS}	– –	10 10	nAdc μAdc
Gate Reverse Current (V_{GS} = ± 15 Vdc, V_{DS} = 0)	I_{GSS}	–	± 10	pAdc
ON CHARACTERISTICS				
Gate Threshold Voltage (V_{DS} = 10 V, I_D = 10 μA)	$V_{GS(Th)}$	1.0	5	Vdc
Drain-Source On-Voltage (I_D = 2.0 mA, V_{GS} = 10V)	$V_{DS(on)}$	–	1.0	V
On-State Drain Current (V_{GS} = 10 V, V_{DS} = 10 V)	$I_{D(on)}$	3.0	–	mAdc
SMALL-SIGNAL CHARACTERISTICS				
Forward Transfer Admittance (V_{DS} = 10 V, I_D = 2.0 mA, f = 1.0 kHz)	$\|y_{fs}\|$	1000	–	μmho
Input Capacitance (V_{DS} = 10 V, V_{GS} = 0, f = 140 kHz)	C_{iss}	–	5.0	pF
Reverse Transfer Capacitance (V_{DS} = 0, V_{GS} = 0, f = 140 kHz)	C_{rss}	–	1.3	pF
Drain-Substrate Capacitance ($V_{D(SUB)}$ = 10 V, f = 140 kHz)	$C_{d(sub)}$	–	5.0	pF
Drain-Source Resistance (V_{GS} = 10 V, I_D = 0, f = 1.0 kHz)	$r_{ds(on)}$	–	300	ohms
SWITCHING CHARACTERISTICS				
Turn-On Delay (Fig. 5)	t_{d1}	–	45	ns
Rise Time (Fig. 6)	t_r	–	65	ns
Turn-Off Delay (Fig. 7)	t_{d2}	–	60	ns
Fall Time (Fig. 8)	t_f	–	100	ns

(I_D = 2.0 mAdc, V_{DS} = 10 Vdc, (V_{GS} = 10 Vdc) (See Figure 9; Times Circuit Determined))

Handling MOSFETs

MOSFETs are very sensitive to static electricity.

Because of the very thin SiO_2 layer between the external terminals and the layers of the device, any small electrical discharge can create an unwanted conduction.

Protection

- Always transport in a static sensitive bag
- Always wear a static strap when handling MOSFETS
- Apply voltage limiting devices between the gate and source, such as back-to-back Zeners to limit any transient voltage.

VMOS Devices

VMOS (vertical MOSFET) is a component structure that provides greater surface area.

Advantages

VMOS devices handle higher currents by providing more surface area to dissipate the heat.

VMOS devices also have faster switching times.

CMOS Devices

CMOS (complementary MOSFET) uses a p-channel and n-channel MOSFET; often on the same substrate as shown here.

Advantages

- Useful in logic circuit designs
- Higher input impedance
- Faster switching speeds
- Lower operating power levels