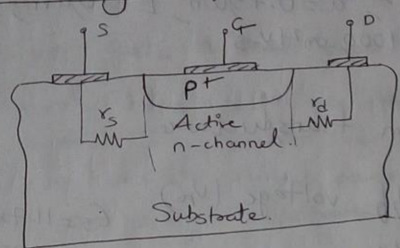
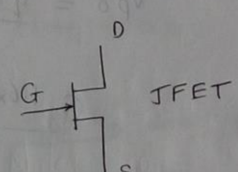
* Small signal equivalent circuit (JFET):-

22/9/14
(12)

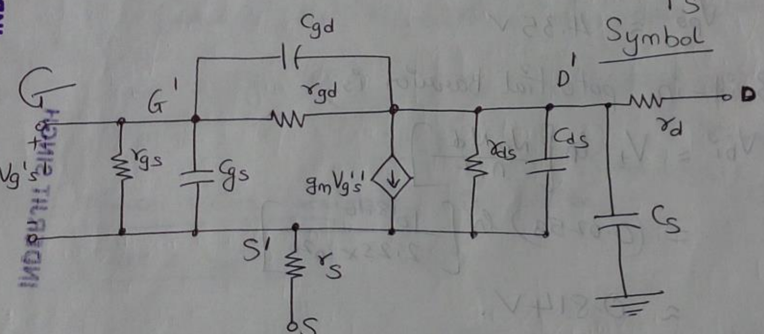


· The cross-section of an n-channel JFET is shown in fig(a), including source and drain series resistance.

fig(a): Cross-section of JFET with source and drain series resistance.



Symbol



fig(b) Small signal equivalent circuit of JFET

· In fig(b), voltage $V_{g's'}$ is the internal gate to source voltage that controls the drain current.

· r_{gs} → Gate to source diffusion resistance
(As Gate-source J^n is R.B ⇒ r_{gs} → very high)

· C_{gs} → Gate to source junction capacitance.

(13)

* r_{gd} ⇒ Gate to drain resistance
* C_{gd} ⇒ Gate to drain capacitance.
* r_{ds} → Finite drain resistance
  ↳ It is a function of Channel length modulation.
* C_{ds} → Drain to source parasitic capacitance.
* C_s → drain to substrate capacitance.

→ Ideal small-signal equivalent ckt. (low frequency)

Ideally, all diffusion (∞) and series (0) resistance's are infinite and zero.

At low frequency, the Capacitances are open ckt.

$\therefore$ $I_{ds} \approx g_m (V_{gs})$ — (1) $I_{DS} \propto$ function[(g_m), V_{gs}] (V_{gs} → i/p vtg signal; g_m → transconductance)

($\because V_{gs} = V_{g's'}$).

If source series resistance's is finite,

$I_{ds} = g_m V_{g's'}$ — (2)

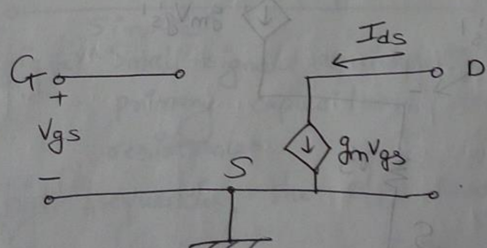


fig c) Ideal low-frequency small-signal equivalent ckt for JFET.

(14)

Now, the relation between V_{gs} and $V_{g's'}$ is,

$$V_{gs} = V_{g's'} + (g_m V_{g's'}) r_s$$

$$V_{gs} = (1 + g_m r_s) V_{g's'} \quad — (3)$$

Thus, equation (2) can be written as,

$$I_{ds} = \left(\frac{g_m}{1 + g_m r_s} \right) V_{gs}$$

$$\boxed{I_{ds} = g_m' V_{gs}} \quad — (4)$$

where, $g_m' = \dfrac{g_m}{1 + g_m r_s}$

Note: g_m is a function of V_{gs}, so does g_m'

The effect of source resistance 'r_s' is to reduce the effective transconductance of JFET

Hence, transistor gain ↓ses

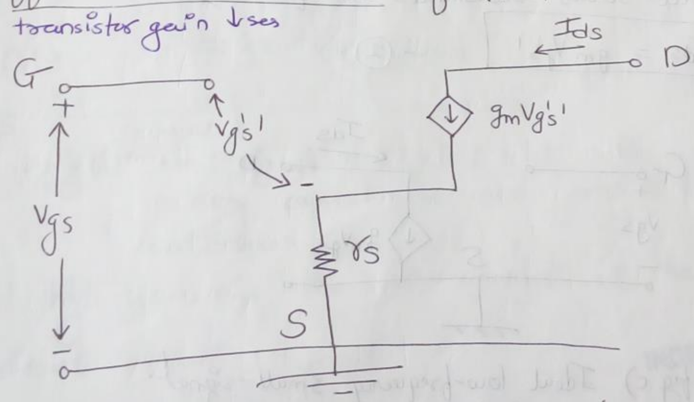


fig d) Ideal equivalent circuit including 'r_s'.

* Frequency Limitation Factors (JFET)

- There are two frequency limitation factors in a JFET
1) Channel transit time 2) Capacitance charging time.

- Channel transit time (τ_t):

$$\tau_t = \frac{L}{v_s}$$

where, L: channel length and v_s: saturation velocity of carriers.

- The channel transit time (τ_t) is the Limiting factor at very high frequencies.

- Capacitance charging time:

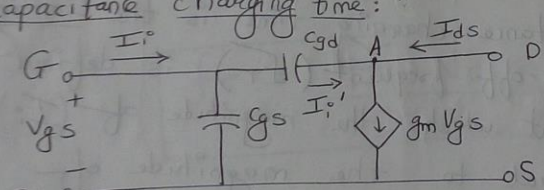


fig (a) Simplied Small-signal equivalent ckt with primary capacitance. and ignoring diffusion resistances.

- At high frequencies, the o/p current is the short circuit current.

· As frequency of I/P signal V_{gs} ↑ses, (16)
Impedance of C_{gd} and C_{gd} ↓ses (ie X_{cgs} & X_{cgd} ↓ses)
∴ More current will flow through C_{gd}.

By KCL at A, we get

$$I_i' + I_{ds} = g_m V_{gs}$$

I_i' → current flowing thr' C_{gd}.

For a constant $g_m V_{gs}$ and I_i' ↑sing
Current I_{ds} ↓ses.

Thus o/p current (I_{ds}) becomes a Function of frequency.

* Cut-off frequency (JFET):-

· If the capacitance charging time is the Limiting factor ; then the cut-off frequent (f_T) is defined as the frequency at which the magnitude of (I_i) I/P current is equal to the magnitude of ideal o/p current $g_m V_{gs}$ of intrinsic transistor.

$$\text{ie} \quad I_i = j\omega (C_{gs} + C_{gd}) V_{gs} \quad \text{—} (1)$$

If $C_G = C_{gs} + C_{gd}$, then at the cut-off frequency, $|I_i| = |I_o|$ ⇒

$$|I_i| = 2\pi f_T C_G V_{gs} = g_m V_{gs} \quad \text{—} (2)$$

$$|I_o| = g_m V_{gs}$$

(17)

ie $$f_T = \frac{g_m}{2\pi C_G} \quad -(3)$$

where, $C_G = C_{gs} + C_{gd}$

We know, $$g_{m_{max}} = \frac{q\mu_n N_d W a}{L} \quad -(4)$$

and $$C_{G(min)} = \frac{\epsilon_s W L}{a}$$; a → maximum space-charge width.

∴ Maximum cut-off frequency is

$$f_T = \frac{q\mu_n N_d W a (a)}{L \times 2\pi \epsilon_s W L}$$

$$f_{T(max)} = \frac{q\mu_n N_d a^2}{2\pi \epsilon_s L^2}$$

Ex: Consider a Si JFET with the following parameters:

$\mu_n = 1000 \, cm^2/V\text{-}s$, $a = 0.6 \mu m$

$N_d = 10^{16} cm^{-3}$, $L = 5 um$

To find the cut-off frequency of given JFET

$$\Rightarrow f_T = \frac{q \mu_n N_d a^2}{2\pi \epsilon_s L^2}$$

$q = 1.6 \times 10^{-19}$ C

$\epsilon_s = 11.7 \times 8.854 \times 10^{-14} \simeq 10^{-12}$

$$\therefore f_T = \frac{(1.6 \times 10^{-19})(1000)(10^{16})(0.6 \times 10^{-4})^2}{2\pi \times 10^{-12} \times (5 \times 10^{-4})^2}$$

$$\boxed{f_T \simeq 3.54\,GHz}$$

↳ Cut-off frequency.