International Journal of Electronics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tetn20

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ANWAR A. KHAN [a] & LALAN SINGH [b]

[a] Electrical Engineering Department , College of Engineering , P.O. Box 800, King Saud University, Riyadh, 11421, Saudi Arabia

[b] Department of Physics , A. N. College , Patna, India

Published online: 24 Feb 2007.

To cite this article: ANWAR A. KHAN & LALAN SINGH (1987) Optimizing the performance of modified field effect transistor, International Journal of Electronics, 62:3, 435-440, DOI: 10.1080/00207218708920994

To link to this article: http://dx.doi.org/10.1080/00207218708920994

INT. J. ELECTRONICS, 1987, VOL. 62, NO. 3, 435–440

# Optimizing the performance of modified field effect transistor

ANWAR A. KHAN† and LALAN SINGH‡

An experimental study of the JFET-BJT combination as reported by Khan and Singh (1985 b) is described with a view to obtain optimum performance against variations in circuit parameters. Important conclusions are drawn which pave the way for easier development of linear instrumentation systems.



## 1. Introduction

A JFET-BJT combination referred to as a modified field-effect transistor (M-FET) has been reported recently in the literature to yield FET-like characteristics with many improvements in transfer curve linearity and temperature stability over a wide dynamic range (Khan 1982, Khan and Singh 1985 a). A detailed experimental study of the M-FET is described in this paper with a view to obtain optimum performance against variations in circuit parameters.

## 2. Basic M-FET equation

The basic M-FET structure is shown in Fig. 1 (a) and its symbol is depicted in Fig. 1 (b). A straight forward analysis of the circuit gives (Khan and Singh 1985 a).

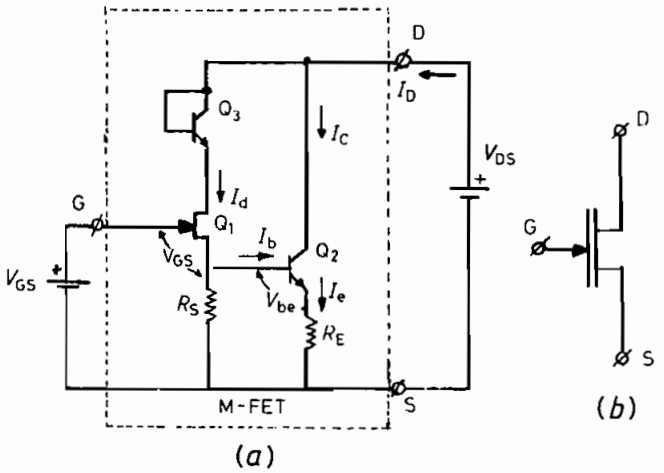


Figure 1. (*a*) Basic circuit schematic of M-FET. (*b*) Circuit symbol.

Received 14 August 1986; accepted 15 September 1986.

† Electrical Engineering Department, College of Engineering, P.O. Box 800, King Saud University, Riyadh 11421, Saudi Arabia.

‡ Department of Physics, A. N. College, Patna, India.

$$I_D = I_{DSS}\left[1 + \frac{V_{GS}}{E_p}\right] \tag{1}$$

with

$$I_{DSS} = \frac{AV_p}{R_{eq}} - \frac{V_{be}}{R_E} \tag{2}$$

$$E_p = AV_p \tag{3}$$

$$R_{eq} = R_E \cdot R_s/(R_E + R_s) \tag{4}$$

$$A = 1 - (I_d/I_{dss})^{1/2} \tag{5}$$

where $V_p$ is the pinch-off voltage of the FET and $I_{dss}$ is its drain-to-source current with its gate-source terminal short-circuited. Note that eqn. (1) is also valid for the negative polarity of $V_{GS}$ which makes the M-FET suitable to accept bipolar input voltage.

The transconductance $g_M$ of the M-FET can be shown to be given by

$$g_M = \left.\frac{\partial I_D}{\partial V_{GS}}\right|_{V_{DS}=\text{constant}} = \frac{1}{R_{eq}} \frac{g_m \cdot R_s}{1 + g_m \cdot R_s} \tag{6}$$

where $g_m$ is the transconductance of the JFET which is given by

$$g_m = \frac{2(I_d \cdot I_{dss})^{1/2}}{V_p} \tag{7}$$

The transconductance $g_M$ of the M-FET, therefore, seems to be least dependent upon the $g_m$ of the JFET so long as $g_m \cdot R_s \gg 1$. In this operating region, $R_{eq}$ dictates the value of $g_m$ of the device and hence ensures constancy against variation in temperature, active device parameters and frequency over a wide dynamic range.

## 3. Results and discussion

The M-FET as shown in Fig. 1(a) was implemented in the laboratory using JFET BFW10. The transfer and the output characteristics as obtained experimentally in common source mode for various values of $R_s$ are shown in Fig. 2(*a*) and 2(*b*) respectively. From Fig. 2(*a*) it is to be noted that the transfer characteristic is linear over a wide range of bipolar input voltage $V_{GS}$. The linearity range, however, is dictated by the FET's pinch-off voltage $V_p$ and the value of $R_s$. The large value of $R_s$ ($> 10\,K\Omega$) is seen to improve linearity in the negative region of $V_{GS}$ whereas the low value of $R_s$ ($< 10\,K\Omega$) greatly extends the linearity range for positive polarity of $V_{GS}$. Also $g_M$ of the M-FET tends to be independent of $R_s$ for its large value. Furthermore, it should be noted that for negative $V_{GS}$ approaching $V_p$, the transfer characteristic tends to exhibit non-linearity. This arises because $g_m$ of the JFET near the pinch-off voltage approaches zero and hence eqn. (6) reduces to

$$g_M \approx \frac{g_m \cdot R_s}{R_{eq}} \to 0 \tag{8}$$

From Fig. 2(*b*) it is to be noted that the slope of $I_D$ versus $V_{DS}$ curve in the active region ($V_{DS} > E_p$) increases with decreasing value of $R_s$. This simply suggests that the output impedance of the M-FET increases with increasing value of $R_s$.

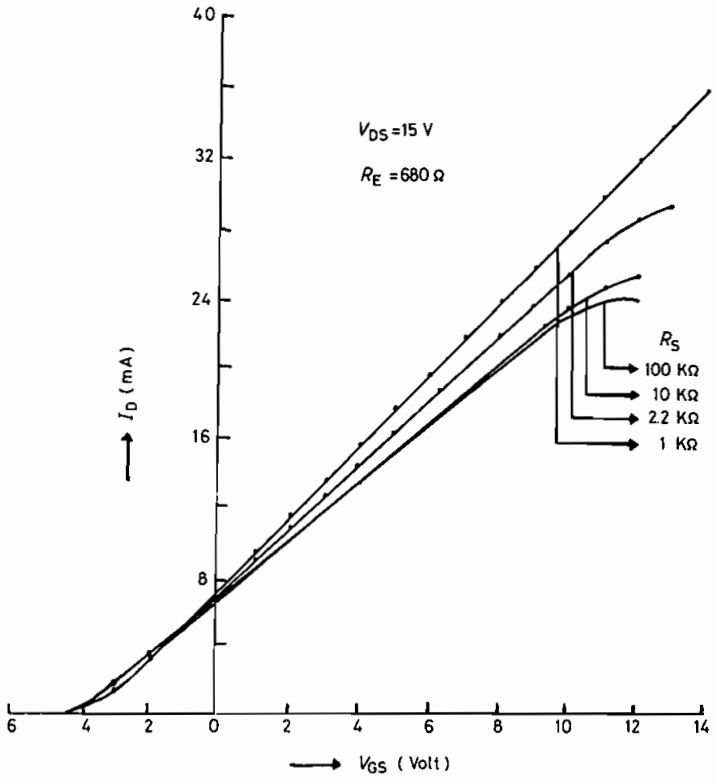


Figure 2. Performance characteristics of the M-FET for various values of $R_s$. (*a*) Transfer curve. (*b*) Output curve.

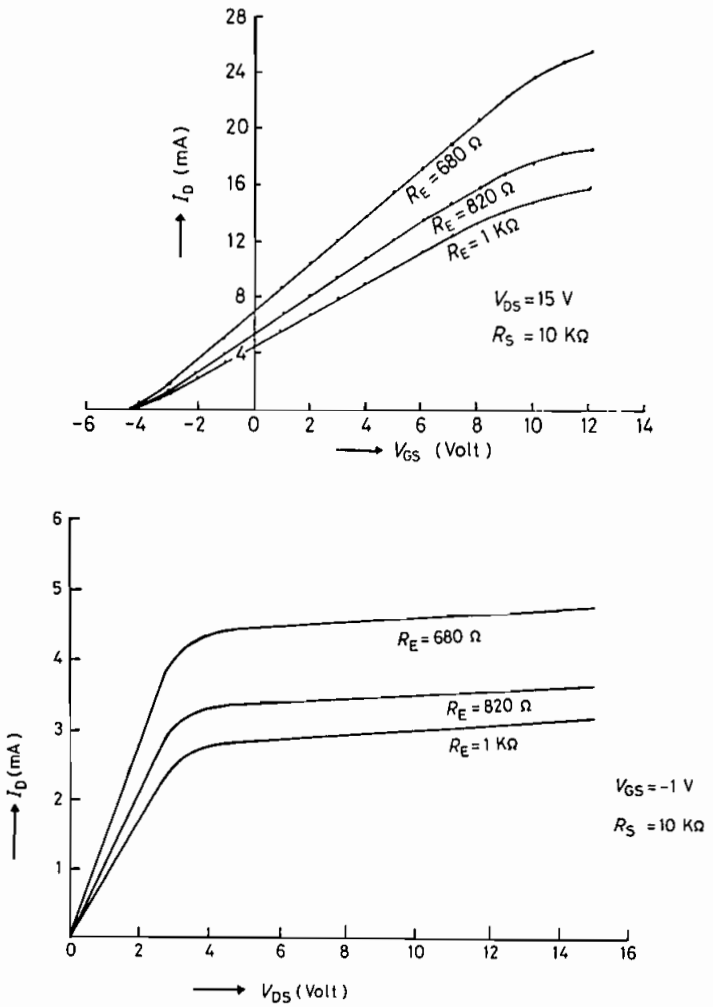


Figure 3. Performance characteristics of the M-FET for various values of $R_E$. (*a*) Transfer curve. (*b*) Output curve.

The transfer and the output characteristics of the M-FET for various values of $R_E$ are shown in Fig. 3(*a*) and 3(*b*), respectively. The response linearity appears to be unaffected, where as $g_M$ of the device is greatly influenced by the value of $R_E$ which is in excellent agreement with the theoretical relation (6). Furthermore, from Fig. 3(*b*) it appears that the slope of $I_D$ versus $V_{GS}$ curve is practically unaffected for various values of $R_E$.

The effect of $\beta$ of the transistor $Q_2$ on the transfer characteristic was also studied experimentally. The transistors were selected to have $\beta$ values in the range 35–195. Results are plotted in Fig. 4. From this plot it may be noted that the $g_M$ of the device increases with increasing value of $\beta$. However, such a relative change amounts to 0·03% per unit change in $\beta$ value. Such a study suggests that if $\beta$ of the transistors comprising the M-FET deteriorates with age, its impact upon the device transfer characteristic is practically insignificant.

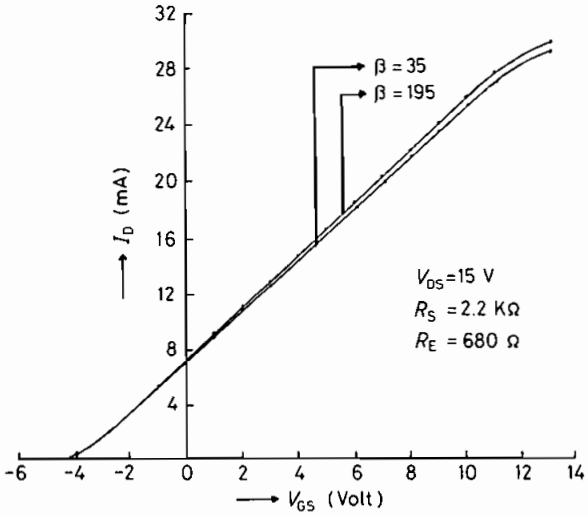


Figure 4. Effect of $\beta$ of the bipolar transistor upon the transfer characteristic of the M-FET.

Figure 5 portrays the way in which $g_M$ of the M-FET for the transistor $Q_2$ having different values of $f_T$ (current gain bandwidth product) varies with frequency. Also shown in Fig. 5 is the effect of the frequency-compensating capacitor $C_E$ connected across $R_E$. Using $C_E$ in the circuit, $g_M$ of the M-FET is modified to

$$g_M(\omega) = \frac{(1 + \omega^2 C_E^2 R_{eq}^2)^{1/2}}{R_{eq}} \cdot \frac{g_m(\omega) \cdot R_s}{1 + g_m(\omega) \cdot R_s} \tag{9}$$

As frequency increases, effective value of $R_{eq}$ decreases because of $C_E$ across $R_E$ and hence this leads to increase in $g_M$ value which compensates the decreasing trend of $g_m$ with frequency. From Fig. 5 it is to be noted that the use of transistor with large

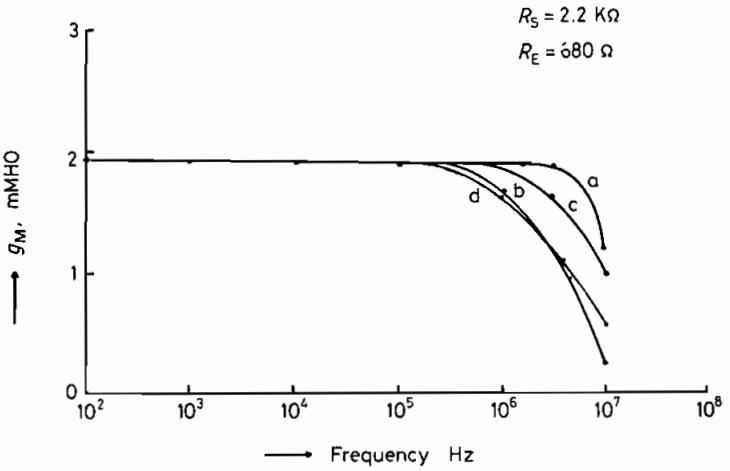


Figure 5. Transconductance ($g_M$) versus frequency plot. (*a*) $f_T$ = 550 MHz, $C_E$ = 200 pF; (*b*) $f_T$ = 550 MHz, $C_E$ = 0; (*c*) $f_T$ = 120 MHz, $C_E$ = 200 pF; (*d*) $f_T$ = 120 MHz, $C_E$ = 0.

$f_T$ value extends the frequency response to a great extent. Also it is to be noted that a suitable value of $C_E$ helps in improving the frequency response.

## 4. Conclusions

A detailed experimental study of the M-FET (Khan and Singh 1985 b) is reported here with a view to obtain its optimum performance against variation in circuit parameters. It is shown that a reasonably good linear transfer characteristic is obtained over a wide range of input bipolar voltage when the resistance in the source leg of the JFET is kept in the range 2·2 KΩ–10 KΩ.

Also its response linearity is shown to be unaffected by variations in the value of $\beta$ of the bipolar transistor constituting the M-FET. The transconductance of the composite unit is, however, shown to be affected which amounts to 0·03% per unit change in $\beta$. This suggests that the performance of the M-FET will be least affected by large spread in the values of $\beta$ arising due to manufacturing processes. Furthermore transconductance of the M-FET practically remains constant over a wide frequency range if one selects a bipolar transistor having large value of current gain bandwidth product.

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