A V.H.F. PREAMPLIFIER USING FET'S

By D. S. KUSHWAH

ABSTRACT

Most transistorized receiving equipment is subject to cross-talk and overload if conventional transistors are used in the r-f stage. F.E.T's resolve this common problem. This amplifier is designed at 240 MHz, for a N.F. of 3 dbs. The designed and observed specifications are compared at the end. It is seen that these tally fairly.

I. INTRODUCTION:

Here, this amplifier is used as a front-end in our FM/FM telemetry receiver. In V.H.F. region, the sensitivity of a receiver is dependent upon the B.W. of the receiver and the noise contributed by the 'front-end'. So the N.F. of the amplifier is very important. This is an r-f amplifier designed expressly to improve the sensitivity(S/N) of the receiver. All the datas of the transistor at the required frequency were not readily available, so an analytical approach has been used throughout. Admittance parameters are used.

II. SPECIFICATIONS:

(1) C.F. 240 MHz
(2) B.W. 35 "
(3) Gain in passband 25 dBs min.
(4) Gain uniformity Within 3 DBs minimum in band
(5) Input/Output impedance 50 ohms nominal
(6) Input/Output VSWR 1.5:1
(7) Dynamic range 25 dBm
(8) Power Requirements 15V, 12 ma max.

Here Motorola J FET's 2N4416 are used.
The following data were available at 240 MHz by the manufacturers.

\[
\begin{align*}
\text{y}_{21}^S &= 6000 \mu \text{V} \\
\text{Re}(y_{21})^S &= 4000 '' \\
\text{Re}(y_{11})^S &= 500 '' \\
y_{22}^S &= 50 '' \\
\text{Re}(y_{22})^S &= 80 '' \\
\text{Im}(y_{11})^S &= 5000 '' \\
\text{Im}(y_{22})^S &= 3000 '' \\
C_{in} &= 4.0 \text{ pf} \\
C_{out} &= 2.0 '' \\
C_{rss} &= 0.8 '' 
\end{align*}
\]

III. DESIGN:

Here the common-source configuration is used for the r-f stage, in order to get the maximum gain. Other advantages of this configuration are:

(i) The optimum noise-source resistance is closest to the optimum-source resistance for best power gain.

(ii) The frequency range of the unconditional stability is wider than that for the common-gate configuration. Common-drain configuration is not used normally as it gives the lowest power-gain out of the three configurations.

Here the Linvill Gibbons technique is used and the amplifier is unilateralized. With the above data the admittance parameters are as follows:

\[
\begin{align*}
(y_{11})^S &= 0.5 + j 5.0 \text{ mV} \\
(y_{12})^S &= - j 1.2 '' \\
(y_{21})^S &= 4.0 - j 4.47 '' \\
(y_{21}^S &= 6.0 '' \\
(y_{22})^S &= 0.08 + j 3.0 '' 
\end{align*}
\]

Now the gain of the R.F. amplifier without unilateralization is given by:

\[
G = \frac{\text{y}_{21}^2}{4 \text{ g}_{11} \cdot \text{g}_{22} - 2 \text{Re}(y_{42} \cdot y_{21})} \quad (1)
\]
Where $g_{11}$ and $g_{22}$ are the real parts of $y_{11}$ and $y_{22}$ respectively. So substituting the proper values we get:

$$G_0 = \frac{6^2}{4(0.5x.08) - 2\text{Re}(-j1.2x4.0-j4.47)} = 3.3 \approx 5.2 \text{ dB}$$

Now the Linvill critical factor "C" is defined as:

$$C = 2 \text{Go} \frac{y_{12}}{y_{21}} \quad \ldots (2)$$

$$= 2 \times 3.3 \times \frac{-j1.2}{4.0-J4.47} = 1.32$$

So "C" is greater than unity, therefore it is conditionally unstable. So the neutralization is required in this case.

For neutralized case (unilateralization), the maximum available gain is given by:

$$G_{oo} = G_{max} = \frac{y_{21} - y_{12}}{4(g_{11} + g_{12}) (g_{22} + g_{12})} \quad \ldots (3)$$

Substituting the values, we get:

$$G_{max} = \frac{4.0 - j4.47 + j 1.2}{4(0.5+0)(.08+0)} \approx 22 \text{ dB}$$

In order to make the stability factor "C" unity, the load should be reduced by a factor of \( \frac{1}{1.32} \)

The configuration of the amplifier will be as follows:

![Fig.1. Common-Source Amplifier]

To calculate the neutralizing inductance

$$y_n = y_{12} = -j 1.2 \text{ mV}$$

As this is negative and imaginary so it is clearly inductive 

$$\therefore \quad \frac{1}{y_{\text{wn}}} = \frac{1}{\text{H}} = \frac{1}{2\pi x 240 x 10^6 x 1.2 x 10^{-3}}$$

\((\text{At 240 MHz})\)

$$= 0.555 \mu\text{H}$$

After connecting this inductance from drain to gate, we can get the maximum stable gain.
To calculate the matching networks:

The nominal impedance at the input and output is 50 ohms. This should match with the input and output admittances of the transistor at the frequency of operation.

For a unilateralized amplifier,

\[ Y_{\text{in}} = Y_{11}' = Y_{11} - Y_{12} \]

and

\[ Y_{\text{out}} = Y_{22}' = Y_{22} - Y_{12} \]

Substituting the above values, we get:

\[ Y_{\text{in}} = (0.5 + j 5.0) + j 1.2 = 0.5 + j 6.2 \text{ mv} \]

& \[ Y_{\text{out}} = (0.08 + j 3.0) + j 1.2 = 0.08 + j 4.2 \text{ mv} \]

At this stage \( Y_L \) and \( Y_S \) are required. These are not given by the manufacturer's sheet so we have to calculate.

For any 4-terminal network

\[ Y_{\text{in}} = Y_{11} - Y_{12} - \frac{Y_{21}}{Y_{22} + Y_L} = Y_{11} - Y_{22} \text{ in this case.} \]

This gives

\[ Y_L = Y_{21} - Y_{22} \ldots \ldots (4) \]

Substituting \( Y_L = (4.0 - j 4.47) - (0.08 + j 3.0) = 3.92 - j 7.47 \text{ mv} \)

Similarly

\[ Y_S = Y_{21} - Y_{11} \ldots \ldots (5) \]

\[ = (4.0 - j 4.47) - (0.5 + j 5.0) = 3.5 - j 9.47 \text{ mv} \]

Let us now design input and output circuits.

![Matching Networks Diagram](image)

\[ R_L = \frac{1}{G_L} = \frac{10^3}{3.92} = 255 \Omega \]

The matching series capacitance is found by:

\[ X_{C4} = X_S = R \frac{\sqrt{R_P - 1}}{R_S} \ldots \ldots (6) \]

Where \( R_P \) and \( R_S \) are the parallel and series resistances respectively.

\[ X_{C4} = 5.0 \sqrt{\frac{355}{50} - 1} \]

\[ = 101 \Omega \]

\[ C_4 = \frac{1}{\pi \times 10^6 \times 240 \times 101} = 6.6 \mu \text{F} \]

The parallel equivalent of this cap. is needed for determining the B.W and resonance.
\[ X_{c4} = X_P = X_S \left[ 1 + \left( \frac{R_S}{X_S} \right)^2 \right] \quad \quad (7) \]

Giving \( X_{c4} = 12.6 \, \text{M} \). This gives \( C_4 = 5.25 \, \text{pF} \)

The equivalent output circuit is:

As calculated above \( y_{out} = 0.08 + j \, 4.2 \, \text{mv} \)

\[ \therefore \quad R_{out} = \frac{1}{G_{out}} = \frac{1}{0.08 \times 10^{-3}} = 12.5 \, \text{k}\Omega \]

\[ C_{out} = \frac{B_{out}}{2 \pi f} = \frac{4.2 \times 10^{-3}}{2 \pi \times 240 \times 10^6} = 2.8 \, \text{pF} \]

Now the total load across the tank is

\[ R_T = \frac{1}{G_{out} + C_{L}} = \frac{1}{(0.08 + 3.92) \times 10^{-3}} = 250 \, \Omega \]

The required B.W. = 35 MHz

Total parallel Cap., CT is given by:

\[ C_T = \frac{1}{2 \pi R_T \times \text{B.W.}} = \frac{1}{2 \pi \times 250 \times 35 \times 10^6} = 18.2 \, \text{pF} \]

\[ \therefore C_2 = C_T - C_{out} - C_4 = 18.2 - 2.8 - 5.2 = 10.2 \, \text{pF} \]

The output inductance resonating with \( C_T \) at 240 MHz is

\[ L_2 = \frac{0.043}{(2 \pi \times 240 \times 10^6)^2} \times 10^{-6} \times 10^{-12} = 0.043 \, \mu \text{H} \]

This completes the design of the output circuit.

Input Circuit:

We have \( y_S = (3.5 - j \, 9.47) \, \text{mv} \)

\[ \therefore \quad y_{in} = 0.5 + j \, 6.2 \]

As done in the output matching circuit

\[ X_{c1} = X_S = R_S \sqrt{\frac{R_P - 1}{R_S}} \quad \quad (8) \]

\[ R_P = \frac{1}{G_S} = \frac{1}{\frac{3.5 \times 10^3}{2}} = 285 \, \Omega \]

\[ \therefore \quad X_{c1} = 50 \left( \frac{3.5 \times 10^3 - 2}{3.5 \times 10^3} \right) = 108 \, \text{k}\Omega \quad \therefore \quad C_1 = 6.2 \, \text{pF} \, \text{at} \, 240 \, \text{MHz} \]

Again the parallel combination of this is required for the resonance B.W. calculations.

\[ X_P = X_S = 108, \]

\[ X_{c1}' = X_S \left[ 1 + \left( \frac{R_S}{X_S} \right)^2 \right] \quad \quad (9) \]

\[ \therefore \quad X_{c1}' = 108 \left[ 1 + \left( \frac{50}{108} \right)^2 \right] = 131 \, \text{M} \]

\[ \therefore \quad C_1' = \frac{1}{2 \pi \times 240 \times 10^6 \times 131} = 5.05 \, \text{pF} \]

Again \( y_{in} = 0.5 + j \, 6.2 \, \text{mv} \)

\[ \therefore \quad R_{in} = \frac{10^3}{0.5} = 2 \, \text{k}\Omega \]
and $C_{in} = \frac{B_{in}}{2\pi f} = \frac{6.2 \times 10^{-3}}{2\pi \times 240 \times 10^6} = 4.1 \, \text{pF}$

$R_T = 250 \, \Omega$, again
B.W. = 35 MHz, again

:. $C_T = 18.2 \, \text{pF}$ as before

:. $L_3 = L_2 = 0.043 \, \mu\text{H}$; $C_5 = 18.2 - 4.1 - 5.05 = 9.1 \, \text{pF}$

This completes the design of the tuned circuits.

Now the loaded "Q" of the coils should be $\frac{f_0}{\text{B.W.}} = \frac{240}{35} \approx 7$.

This can be achieved by coils with ferrite cores.

IV Biasing:

Here the self biasing is used. The source is grounded. We will use here $V_{DD} = +15\, \text{V}$. $V_{GS}$ is adjusted for $I_D = 10.0 \, \text{mA}$. This dissipation is $15 \times 10 = 150 \, \text{mw}$. The maximum ratings for 2N4416 are $V_{DS} = 30 \, \text{V}$. $I_D = 10 \, \text{mA}$. $P_D = 300 \, \text{mw}$. So the final circuit thus becomes:

The final circuit

The values of the components actually mounted are as follows:

$C_1 = 6.2 \, \text{pF}$ (1-12 pf trimmer)
$C_2 = 500 \, \text{pF}$ by pass cap. ceramic
$C_3 = 6.6 \, \text{pF}$
$C_4 = 10.2 \, \text{pF}$ (1-12 pf trimmers)
$C_5 = 9.1 \, \text{pF}$
$C_6 = C_7 = .001 \, \text{uf}$ Ceramic
$L_1 = 0.555 \, \mu\text{H}$ Approx. 8 turns AWG 24

(enameled copper wire, close wound on 7/32" ceramic coil form. Tuning by aluminium slug)

$L_2 = L_3 = .043 \, \mu\text{H}$. 2 turns AWG 16

(Enamed copper wire 3/8" I.D. (air core)

The N.F. of this circuit was measured and found to be 3 dBs.
For our purpose three-stages were cascaded to give maximum gain. The observed data are:

Gain = 25 dBS.
C.F. = 240 MHz.
B.W. = 30 "
Input/Output impedance = 50 ohms
V.S.W.R. = 1.6:1
N.F. = 3 dBS.
Dynamic range = 29 dBm.

Acknowledgements:-

I am very thankful to my colleague Shri S.B.R. Shenoy for suggesting the problem. I am thankful to Shri B. Ramakrishna Rao, Head, ELD(R) for his interest in this work. Finally I am grateful to the Chairman, TCFC for his kind permission to publish this paper.

References:-

FIG. 1: COMMON SOURCE CONFIGURATION

FIG. 2: MATCHING INPUT CIRCUITS

FIG. 3: EQUIVALENT OUTPUT CIRCUIT
FIG. 4: THE FINAL AMPLIFIER CIRCUIT

TABLE I. COMPARISON OF THE DESIGNED AND OBSERVED DATA

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DESIGNED</th>
<th>OBSERVED</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.F.</td>
<td>240MH</td>
<td>240MH</td>
</tr>
<tr>
<td>B.W.</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>GAIN IN PASS BAND</td>
<td>25 dB min</td>
<td>25 dB</td>
</tr>
<tr>
<td>INPUT OUTPUT IMPEDANCE</td>
<td>50 NOMINAL</td>
<td>50</td>
</tr>
<tr>
<td>INPUT OUTPUT V.S.W.R</td>
<td>1.5:1</td>
<td>1.6:1</td>
</tr>
<tr>
<td>DYNAMIC RANGE</td>
<td>25 dBm</td>
<td>29 dBm</td>
</tr>
<tr>
<td>N.F</td>
<td>3 dB</td>
<td>3 dB</td>
</tr>
</tbody>
</table>