Potential Broadband Characteristics of a Microwave Transistor and Realisation Conditions

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Abstact

In this work, the potential broadband characteristics for a microwave transistor are studied together with the realization conditions of the source and the load terminations. For this purpose, firstly the compatible performance (F,V_i,G_T) triplets with $G_{Tmin}\leq G_T\leq G_{Tmax}$ and their (Γ_S,Γ_L) terminations with $|\Gamma_S|\leq 1$ and $|\Gamma_L|\leq 1$ are obtained as a function of the operation parameters (V_{DS}, I_{DS}, f, CT), where V_{DS}, I_{DS} stand for bias voltage and current respectively ; f is the operation frequency and CT is type of the configuration. Then, since the passive termination functions $\Gamma_S(w_i)$ and $\Gamma_L(w_i)$ for i=1,2,…N are given within the operation bandwidth of the active device, the simultaneous realisation conditions of these terminations are investigated using their Darlington equivalences. Finally design of a typical broadband active circuit is given with their (L-C) matching circuits. The gain (G_T), noise (F), input VSWR (V_i) functions are evaluated along the operational bandwidth for the complete broadband active circuit, compared with the corresponding expected performance components and the results are presented.

1. Description of the Work:

The aim of this work is to investigate the potential frequency characteristics of a transistor so that new methods can be proposed to design the active microwave circuits with various operational bandwidths. For this purpose,

(i) Firstly the compatible performance (F,V_i,G_T) triplets with $G_{Tmin}\leq G_T\leq G_{Tmax}$ are chosen among the possible triplets [1],[2],[3]. Although the transducer gain function $G_T(w)$ has a continuous variation between $G_{Tmin}(w)$ and $G_{Tmax}(w)$, there may exist incompatibility among the noise (F), input VSWR (V_i) and gain (G_T) performance components at some operation frequencies within the operation bandwidth.

(ii) Secondly, the systematic procedures [4],[5],[6],[7] are considered so that the simultaneous realisation can become possible for the source and load terminations.

(iii) Thirdly, the whole active circuit is designed, its performance is evaluated along its bandwidth, and the comparison is made between the predicted and achieved performance characteristics.

2. The Possible Performance (F,V_i,G_T) Triplets

The theory based upon the possible performance (F,V_i,G_T) triplets and their passive terminations (Z_S,Z_L) is given in [3] in details. The problem can be described as a mathematically constrained maximization problem which is to find the maximum stable value of $G_T(R_S,X_S,R_L,X_L)$ subject to $\phi_1=F_{req}-F(R_S,X_S)=0$ and $\phi_2=V_{ireq}-V_i(R_S,X_S,R_L,X_L)=0$ and the corresponding values of $Z_S=R_S+jX_S$, $Z_L=R_L+jX_L$ where F_{req} and V_{ireq} are the required noise and input VSWR respectively. The performance measure functions $G_T(R_S,X_S,R_L,X_L)$, $F(R_S,X_S)$, $V_i(R_S;X_S;R_L;X_L)$ can be given for a transistor at the fixed operation conditions:

$$G_T(R_S,X_S,R_L,X_L)=\frac{4R_SR_L|z_{21}|^2}{|(z_{11}+Z_S)(z_{22}+Z_L)-z_{12}z_{21}|^2} \quad (1)$$

$$F(R_S,X_S)=F_{min}+\frac{R_N}{|Z_{opt}|^2}\frac{|Z_S-Z_{opt}|^2}{R_S} \quad (2)$$

$$V_i=\frac{1+|\rho_i|^2}{1-|\rho_i|^2} \quad (3a) \qquad \rho_i=\frac{Z_S-Z_{in}^*}{Z_S+Z_{in}} \quad (3b)$$

$$Z_{in}=z_{11}-\frac{z_{12}z_{21}}{z_{22}+Z_L} \quad (3c)$$

where z_{11}, z_{12}, z_{21}, z_{22} are the open-circuited impedance parameters of the transistor.

3. Design of (Z_S, Z_L) Terminations

Realizability of the passive (Z_S,Z_L) termination is based upon the fundamental theorem of Darlington which expresses that any impedance function $Z(w)=R(w)+jX(w)$ with $R(w)>0$ within the operational bandwidth can be realized by a (L-C) two-port terminated by 1Ω. To simplify the synthesis, the impedance function Z(s) can be divided into two parts: $Z(S)=Z_F(s)+Z_{MR}(s)$ where $Z_F(s)$ is the Foster component which includes only the simple jw poles of Z(s); and then, $Z_{MR}(s)$ is the minimum reactance component. In the w - domain, these components are broken up to their real and imaginary parts. That is, $Z_F(w)=jX_F(w)$, $Z_{MR}(w)=R_{MR}(w)+jX_{MR}(w)$, where $X_{MR}(w)$ is the Hilbert transformation of $R_{MR}(w)$. Here, it should be noted that for our case, we generate the source and load terminations Γ_S, (or Z_S) and Γ_L (or Z_L) point by point. In order to realise source and load impedances we use the following procedure.

Let $Z_D=R_D(\omega)+jX_D(j\omega)$ designate the generated impedance data Z_S or Z_L. In order to break up Z_D in to its Foster and Minimum Reactance parts,

1. Set $R_{MR}=R_D$ which is generated as the real part data of Z_D (ie. real part data of Z_S or Z_L).
2. Since Z_{MR} is a minimum reactance function, X_{MR} is determined using the Hilbert Transformation of R_{MR} as described in [4-7].
3. Having computed X_{MR}, the Foster component $X_F(w)$ of $Z_D(jw)$ is generated as

$$X_F(\omega)=X_D-X_{MR}$$

Here, it should be noted that since $X_F(\omega)$ is a Foster Function, one expects to end up with non-negative $dX_F/d\omega$ over the entire frequency band.

4. At this point, analytic form Z for the computed data Z_D must be obtained to end up with the actual design. This is easy:

(a) First $R_{MR}=R_D$ is fit to an even rational function in w.

$R_{MR}(\omega)=\{A_0+A_1\omega^2+A_2\omega^4+\ldots+A_m\omega^{2m}\}/\{1+B_1\omega^2+B_2\omega^4+\ldots+B_n\omega^{2n}\}$ such that R_{MR} is non negative over the entire frequencies.

Where the integer "n" designates the total number of elements and "m" is associated with the complexity of the lossless Darlington two-port which will be employed either as a front–end or back-end matching network for the transistor under consideration. For realisability, it is required that $m\leq n$.

(b).The analytic form of Z_{MR} is generated from R_{MR}. At this stage, either Gewertz or Bode Procedure is used as described in [4-7].

$$Z_{MR}=(a_0+a_1s+a_2s^2+\ldots a_ns^{n-1})/(1+b_1s+b^2s^2+\ldots+b_ns^n)$$

(c). Finally, analytic form of X_F is obtained as a Foster Function using curve-fitting techniques.

$$X_F(\omega)=-k_0/\omega+k_\infty.\omega+\sum_{i=1}^{p}k_i.\ \omega\ /\ (\omega_i^2-\omega^2)$$

At this step, poles w_i must be chosen outside of the passband while $dX_F/d\omega\geq 0$ is maintained over the entire frequencies. This can easily be achieved by forcing residues $k_i\geq 0$.

(d) Eventually X_F and Z_{MR} are synthesised yielding the desired terminations.

4. Worked Example

Design of a broadband active microwave circuit is given with its specifications below:

The name of transistor: **NE02135**
Bias conditions: I_c=5 mA V_{CE}=10 V
Oparation bandwidth: 0.5-3 GHz
The target compatible performance triplet:
$(F,V_i,G_T)=(4.5dB\ \ 1.5\ \ 5dB)$

Scattering parameters:

f(GHz)	S_{11} mag.-ang (rad)	S_{21} mag.-ang (rad)	S_{12} mag.-ang (rad)	S_{22} mag.-ang (rad)
0.5	0.68 -2.199	7.18 1.85	0.08 0.61	0.51 -0.925
1	0.66 -2.844	4.02 1.41	0.09 0.47	0.34 -1.152
1.5	0.65 3.106	2.75 1.117	0.1 0.47	0.31 -1.291
2	0.65 2.844	2.10 0.907	0.12 0.523	0.31 -1.448
2.5	0.66 2.635	1.68 0.68	0.13 0.453	0.31 -1.658
3	0.66 2.46	1.46 0.47	0.14 0.453	0.33 -1.85

Noise parameters:

f (GHz)	F_{min}	r_{opt} mag	r_{opt}	R_N /50
0.5	1.318	0.36	1.204	0.75
1	1.412	0.31	2.164	0.62
1.5	1.584	0.5	2.879	0.6
2	1.737	0.44	-3.05	0.55
2.5	1.819	0.52	-2.809	0.52
3	2.041	0.68	-2.46	0.5

The required source and load impedances:

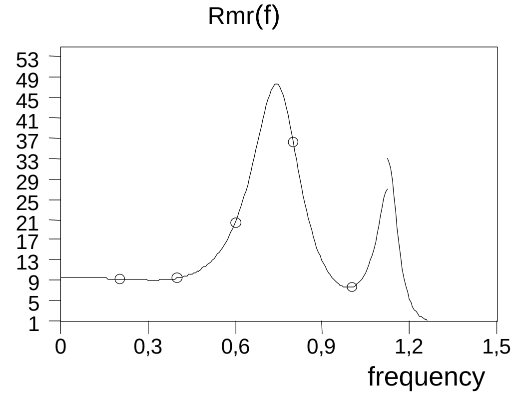
f (GHz)	Z_L	Z_S
0.5	15.352-192.245j	27.783-24.15j
1	15.463-80.20j	24.394-19.45j
1.5	26.397-62.11j	39.478+9.25j
2	42.159-46.7j	34.69-18.88j
2.5	13.659+87.54	8.05-13.199j
3	5.26+26.7719	7.483-7.8549j

Design of the Z_L termination:

Real part of the minimum reactance function:

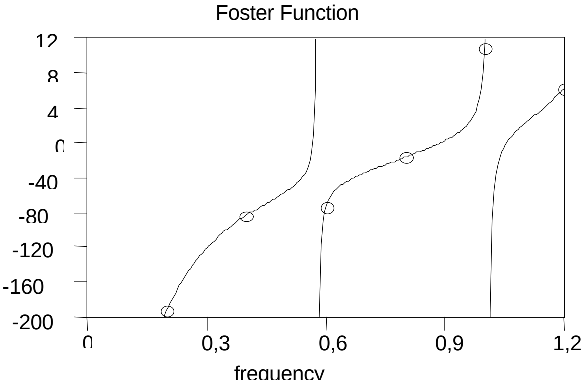
$$R_{MR}(w) = \frac{1.25257}{(0.0808961 - 3.7414.10^3 w^2 + 0.773991 w^4 - 6.73569 w^8 \quad -12.4472 w^{10} + 3.57922 w^{12})}$$

Minimum reactance function which is found from its real part using Gewertz procedure:



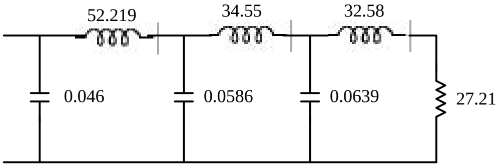
The Foster reactance part:

$X_F(w_i)=X_D(w_i)-x_{MR}(w_i)$

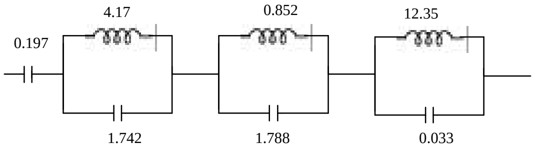


$$X(w)_F = \frac{-39.9807}{w} + 5.24808w + \frac{1.18159w}{(.58^2 - w^2)} + \frac{1.93229w}{(1.01^2 - w^2)} + \frac{51.0013w}{(1.442^2 - w^2)}$$

Similarly minimum reactance circuit for the source termination

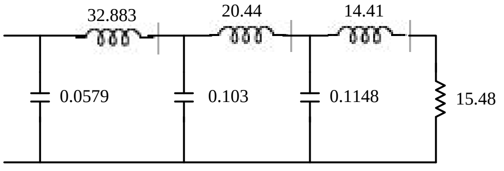


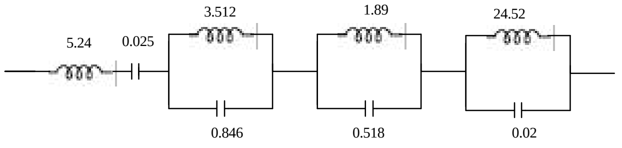
Foster circuit for the source termination is as follows:



$$z(s)_{MR} = \frac{4.404 + 19.26s + 41.995s^2 + 58.696s^3 + 35.275s^4 + 32.653s^5}{.28442 + 1.21662s + 2.60864s^2 + 3.50573s^3 + 4.39364s^4 + 2.04384s^5 + 1.89188s^6}$$

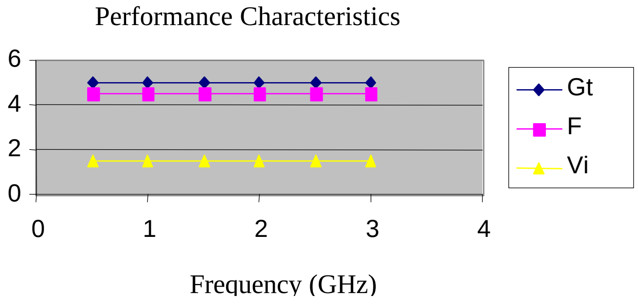
Minimum reactance circuit





The Resulted Performance Values:

f	G_T	F	V_i
0.5	5	4.5	1.5
1	4.99	4.501	1.5
1.5	5	4.5	1.5
2	5	4.499	1.5
2.5	5.00	4.5	1.49
3	5	4.5	1.5



There is no frequencies within the operation bandwidth to cause abrupt in the performance due to the parallel resonance circuit in the Foster parts of both the load and source terminations.

5. Conclusion

As a conclusion, this work suggest a new method design of active microwave circuits with the various bandwidth since of the compatible performance (F,V_i,G_T) triplets with $G_{Tmin} \leq G_T \leq G_{Tmax}$ are known so one can make the active circuit design being aware of the variations of the performance components with the operation bandwidth and of the possibilities for the given bandwidth. This work can be extended to include different data modelling techniques for the load and source terminations.

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