Simple formula for AM-detector transfer factor

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A simple approximate formula for the AM-detector transfer factor, which is valid for small-signal modes as well as for large-signal ones is proposed. This formula allows one to model analytically (or numerically at the behavioural level) an AM-detector in the large-signal and small-signal modes taking into account the nonlinearity of its transfer factor. Formula validation is made by comparison with measurements and PSPICE simulation data.

Introduction: The nonlinearity of the AM-detector transfer factor has a great influence on the performance of a radio system [1, 2]. A polynomial model of the detector transfer factor has been proposed in [1]. This model is based on two-tone measurements in order to determine the polynomial coefficients. It is well-known that a polynomial model works quite well if the input signal does not exceed a certain level. Above this level the model diverges from the real characteristic very quickly so the dynamic range of the model validity is rather small. Furthermore, a lot of two-tone measurements have to be made in order to build a high-order polynomial. A non-polynomial model is therefore desirable.

A non-polynomial model of the AM-detector transfer factor, which is based on theoretical considerations, has been proposed in [3]. As a detailed consideration shows, this model works quite well for the transistor AM-detector or for the diode AM-detector in large-signal mode only (when the diode output impedance is much smaller than the load impedance). This Letter extends the model proposed in [3] for the case of the diode AM-detector operating in small-signal mode (when the diode output impedance is much higher than the load impedance).

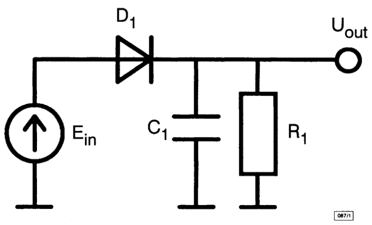

Fig. 1 *AM diode detector*

The basic equation for the detector transfer factor is [3]:

$$\ln(Y+1) + Y\cdot\beta = \ln I_0\left(\bar{A}_{in}\right) \qquad (1)$$

where $\bar{A}_{IN} = (A_{IN}/\varphi_{TE})$ is the normalised amplitude of input signal, A_{IN} is the input signal amplitude, $\varphi_{TE} = \alpha\cdot\varphi_T$ is the effective thermal voltage, α is a correction factor (it depends on the type of detector element, $\alpha = 1, ..., 3$), φ_T is the thermal voltage ($\varphi_T \simeq 25\,\text{mV}$ for room temperature), I_0 is the zeroth-order modified Bessel function of the first kind, $Y = U_{OUT}/(R_1\cdot I_S)$, U_{OUT} is the instant output signal level, R_1 is the load resistance (see Fig. 1), I_S is the diode saturation current, and $\beta = I_S R_1/\varphi_{TE}$. Using eqn. 1, the detector transfer factor can be expressed as follows:

$$k_d = \frac{u_{out}}{A_{in}} = \frac{1}{\bar{A}_{in}}\ln\left(\frac{I_0\left(\bar{A}_{in}\right)}{Y+1}\right) \qquad (2)$$

In the large-signal mode ($\beta \gg 1$) only the second term on the right-hand side of eqn. 1 is essential and eqn. 2 reduces to [3]:

$$k_d = \frac{\ln I_0\left(\bar{A}_{in}\right)}{\bar{A}_{in}} \qquad (3)$$

Unfortunately, this equation can not be used in the small-signal mode, when $\beta < 1$.

Transfer factor in small-signal mode: To find k_D, we must solve eqn. 1 for Y. Unfortunately, this equation is transcendental for Y and it has no analytical solution in general. To find an approximate analytical solution, we use the perturbation theory in a manner similar to [4]. We present Y in the following form

$$Y = Y_0 + \Delta Y \qquad (4)$$

where Y_0 is the solution of eqn. 1 for $\beta = 0$,

$$Y_0 = I_0\left(\bar{A}_{in}\right) - 1 \qquad (5)$$

and ΔY is an addition to Y_0 when $\beta \neq 0$. Then, using eqn. 4, we rewrite eqn. 1 in the form

$$\ln(Y_0 + \Delta Y + 1) + (Y_0 + \Delta Y)\cdot\beta = \ln I_0\left(\bar{A}_{in}\right) \qquad (6)$$

Using eqn. 6 and eqns. 2, 4 and 5, after some manipulation we obtain the following equation for k_D:

$$k_d = \frac{1}{\bar{A}_k}\cdot\ln\left(\frac{1+\beta\cdot I_0\left(\bar{A}_k\right)}{1+\beta}\right) \qquad (7)$$

This equation generalises eqn. 3 for the case of large output detector impedance (when $\beta \le 1$; a typical value of β for a diode detector is $\beta = 0.01, ..., 0.1$). Fortunately, eqn. 7 reduces to eqn. 3 when the output impedance is small ($\beta \gg 1$) so it also works for large values of β. (Note that, as a rule, perturbation series work well for a small value of an expansion parameter but it is difficult to obtain a good approximation for large value of the expansion parameter).

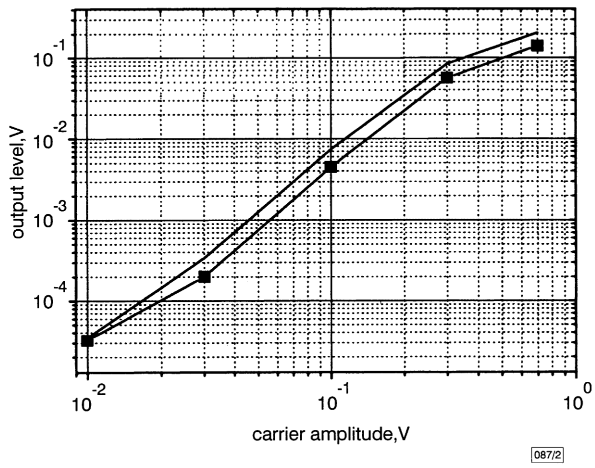

Fig. 2 *Diode AM-detector transfer characteristic*

——— proposed formula
—■— measurement

Formula validation: To validate the proposed formula, an extensive circuit-level simulation of diode and transistor AM-detector and measurements have been carried out. The circuit-level simulation has been made by means of the well-known simulator PSPICE [5]. The input signal used in the simulation is an AM-modulated signal (modulation index = 0.3). Fig. 2 shows the diode detector transfer characteristic (output level at the modulating frequency against carrier amplitude at the input) calculated using eqn. 7 and the measured one. As can be seen from this Figure, the formula predicts the transfer characteristic quite well in a wide dynamic range.

Conclusion: A simple formula has been proposed for the calculation of the AM-detector transfer factor in the small-signal mode, as well as in the large-signal one. The comparison between calculations and measurement shows quite a good agreement. We should also note that the diode AM-detector transfer factor in the small-signal mode depends substantially on the diode saturation current (i.e. β) which in turn reveals large technological dispersion. Thus, the prediction accuracy is not very good in this case if we do not know the saturation current of the specific diode used in the detector. If the values of I_S and α are extracted from the measurement of the diode volt-ampere characteristic (as in PSpice, for instance), only the small- signal part of this characteristic should be taken into account in order to achieve good accuracy for these values. The large-signal part of this characteristic can reduce the accuracy substantially.

26 November 1998
Electronics Letters Online No: 19990091

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