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The method of compensating non-linear effects due to disturbing signals in the military operations theatres

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The multitude of disturbing signals from the military operations theatres and battle platforms can lead to the nonlinear operation of radiofrequency (RF) modules in radio receivers with unfavorable effects on the processing of the useful signal. The authors propose in this paper a new way to compensate the operating effects of RF amplifiers in the nonlinear area by introducing a feedback loop based on signal decomposition in reverse power series.

Keywords: *perturbations, interference, nonlinear, amplifier, compensation, series of powers*

1. Introduction

In the modern electronic warfare there are impressive amounts of electronic devices, with increasingly sophisticated performances. Thus, in command centers, 60 - 80 transmitter-receiver equipments can be found and on board of military ships 60 – 80 electronic systems are allocated [1].

As a consequence a supra – saturation of electromagnetic spectrum and electromagnetic disturbances or electromagnetic interferences (EMI) may occur.

In electromagnetic compatibility analysis of communication systems a particular focus should be paid to radio receivers because they are the main victims of EMI.

The authors bring up the EMI which affect (harm) radio frequency amplifier (RFA), which is the first amplifier stage from a radio receiver and therefore is very important as the form of the signal being received must not be deformed because, in the case of nonlinear distortions in the amplified signal new components appear with different frequencies besides of the input active signals. These new components are added to the following stages of the radio receiver and can change both the structure and the shape of the useful signals.

The main cause of the useful signal deformation is the changes of the operating conditions from the linear to nonlinear RFA area:

a) Pulse disturbances (periodic or aperiodic), which have a high occupancy frequency band, and which transmit a certain amount of energy to the input circuit due to which damp free oscillations with frequency equal to the resonant frequency of the circuit, tuning frequency of the receiver. Thus, in the input circuit, disturbing oscillations with the frequency equal to that of the desired signal are obtained, oscillations which will be amplified normally with the useful signal [Vladescu]. Hence, these disturbances come to act as interference on a common channel or EMI co-channel.

b) disturbances from other transmitters with frequencies that are inside or near the radio bandwidth of the receiver and which, after frequency change, fall outside the bandwidth of the intermediate frequency amplifiers (IFA). These disturbances are called adjacent – signal EMI.

It is obvious that the radiofrequency amplification stage may enter into the nonlinear operating range if the amplitude of the disturbing signals described above (a, b) is high. In practice, there may also be situations where the plurality of low-level disruptive signals taken individually would not produce significant disturbing effects on radiofrequency levels, but together can combine in the worst – case so that the final result is still removing RFA or other electronic stages from the linear to nonlinear operating area.

2. The analysis of the nonlinear effects from a RFA

In order to make the analysis of the nonlinear effects from a RFA the case of a bipolar NPN transistor in common emitter connexion is taken into consideration. The Ebers-Moll equations are [2-4]:

$$i_E = I_{ES}\left(e^{\frac{qu_{BE}}{kT}} - 1\right) - \alpha_R I_{CS}\left(e^{\frac{qu_{BC}}{kT}} - 1\right) \tag{1}$$

$$i_C = \alpha_F I_{ES}\left(e^{\frac{qu_{BE}}{kT}} - 1\right) - I_{CS}\left(e^{\frac{qu_{BC}}{kT}} - 1\right) \tag{2}$$

where:

I_{ES} emitter saturation current when collector is shorted to the base,

I_{CS} collector saturation current when emitter is shorted to the base,

α_F forward transfer ratio,

α_R reverse transfer ratio.

By combining above mentioned Eqs. (1), (2) the following relation is deducted:

$$i_E - \alpha_R i_C = I_{ES}\left(e^{\frac{qu_{BE}}{kT}} - 1\right) - \alpha_F \alpha_R I_{ES}\left(e^{\frac{qu_{BE}}{kT}} - 1\right) = I_{ES}(1-\alpha_F\alpha_R)\left(e^{\frac{qu_{BE}}{kT}} - 1\right) \quad (3)$$

The collector current is given by $i_C = \alpha_F i_E + I_{CB0}$ where I_{CB0} represent the current from collector to base when emitter is not connected. By inserting the collector current eq. in (3), yields:

$$i_C = \frac{I_{CB0}}{1-\alpha_F\alpha_R} - \alpha_F I_{ES} + \alpha_F I_{ES} e^{\frac{qu_{BE}}{kT}} \quad (4)$$

If an input signal $u(t)$ is applied, the base – emitter voltage u_{BE} can be written as:

$$u_{BE} = U_{BE} + u(t) \quad (5)$$

where: U_{BE} represent the polarisation voltage.

The collector current signal contains both continuous and alternative (variable) components:

$$i_C = I_C + i_{C\sim} \quad (6)$$

where

$$I_C = \frac{I_{CB0}}{1-\alpha_F\alpha_R} - \alpha_F I_{ES} \quad \text{and} \quad i_{C\sim} = \alpha_F I_{ES} e^{\frac{qu_{BE}}{kT}} \quad (7)$$

By noting $\frac{kT}{q} = U_T \cong 26mV \; at \; 36\ ^oC$ - thermal voltage, the alternative component of the collector current $i_{C\sim}$ becomes:

$$i_{C\sim} = \alpha_F e^{\frac{U_{BE}}{U_T}} I_{ES} e^{\frac{u(t)}{U_T}} . \quad (8)$$

For general case, the input signal $u(t)$ is as follows:

$$u(t) = u_1(t) + u_2(t) + ... + u_n(t) \quad (9)$$

the voltage base-emitter u_{BE} can be written:

$$u_{BE} = U_{BE} + u_1(t) + u_2(t) + ... + u_n(t) \quad (10)$$

and Eq. (8) becomes:

$$i_{C\sim} = \alpha_F I_{ES} e^{\frac{qu_{BE}}{kT}} = \alpha_F I_{ES} e^{\frac{q}{kT}\left(U_{BE}+u_1(t)+u_2(t)+....+u_n(t)\right)} \quad (11)$$

$$i_{C\sim} = \alpha_F \, e^{\frac{U_{BE}}{U_T}} I_{ES} \, e^{\frac{u_1(t)+u_2(t)+....+u_n(t)}{U_T}} \tag{12}$$

The Eq. (12) can be expressed in Taylor series through $i_{C\sim}$ decomposition:

$$i_{C\sim} = \alpha_F \, e^{\frac{U_{BE}}{U_T}} I_{ES} \{1 + \frac{u_1(t)+u_2(t)+....+u_n(t)}{1!\cdot U_T} + \\ \frac{[u_1(t)+u_2(t)+....+u_n(t)]^2}{2!\cdot {U_T}^2} + ... + \frac{[u_1(t)+u_2(t)+....+u_n(t)]^m}{m!\cdot {U_T}^2} + ...\} \tag{13}$$

By making the following notation:

$$c_0 = \alpha_F \, e^{\frac{U_{BE}}{U_T}} I_{ES} \; ; c_1 = \frac{c_0}{1!\cdot U_T} \; ; c_2 = \frac{c_0}{2!\cdot {U_T}^2} \; ; ...... \quad c_m = \frac{c_0}{m!\cdot {U_T}^m} \; , \tag{14}$$

the forthcoming equation is obtained:

$$i_{C\sim} = c_0 + c_1 u(t) + c_2 u(t)^2 + ... + c_m u(t)^m + ... \; . \tag{15}$$

The Eq. (15) represents a large level of generalisation, and can be used for any nonlinear devices. The factors show nonlinear level can be determined in the same mode for nonlinear used device (diodes, unipolar transistors, etc.). Non-linearity distortions are as bigger as that proportion of factors is bigger.

3. Proposed solution to decrease the non-linearity effects

Because the RFAs have a bandwidth larger than the signal processing, they can be considered as nonlinear systems without memory. By applying post distortion method [5-14] the effect of the nonlinearity on these systems can be compensated.

In order to reduce the operating effects of RF amplifiers in the nonlinear area a new approach has been proposed by the authors: introducing a feedback loop based on signal decomposition in reverse power series (Figure 1).

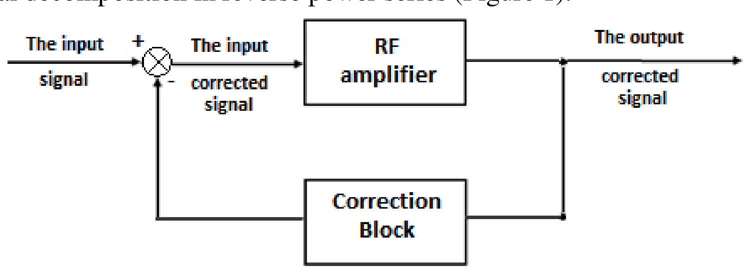

Figure 1. Compensate the operating effects of RF amplifiers in the nonlinear area by introducing a feedback loop

From Eq. (15) by using the reverse power series the input voltage can be written according to the current output:

$$u(t) = C_1 i(t) + C_2 i(t)^2 + C_3 i(t)^3 + C_4 i(t)^4 + C_5 i(t)^6 + \ldots\ldots \tag{16}$$

where:

$$C_1 = \frac{1}{c_1}\ ,\ C_2 = -\frac{c_2}{c_1^3}\ ,\ C_3 = \frac{2c_2^2 - c_1 c_3}{c_1^5}\ ,\ C_4 = \frac{5c_1 c_2 c_3 - 5c_2^3 - c_1^2 c_4}{c_1^7} \tag{17}$$

$$C_5 = \frac{7c_1^3 c_2 c_5 + 84 c_1 c_2^3 c_3 + 7c_1^3 c_3 c_4 - 28 c_1^2 c_2 c_3^2 - c_1^4 c_6 - 28 c_1^2 c_2^2 c_4 - 42 c_2^5}{c_1^7}$$

Thus, from the input voltage, can be deducted the components of higher order that lead to distortion of the useful signal.

Figure 2 shows the Matlab – Simulink developed block diagram to simulate the effect of introduction of a feedback loop based on signal decomposition in reverse power series.

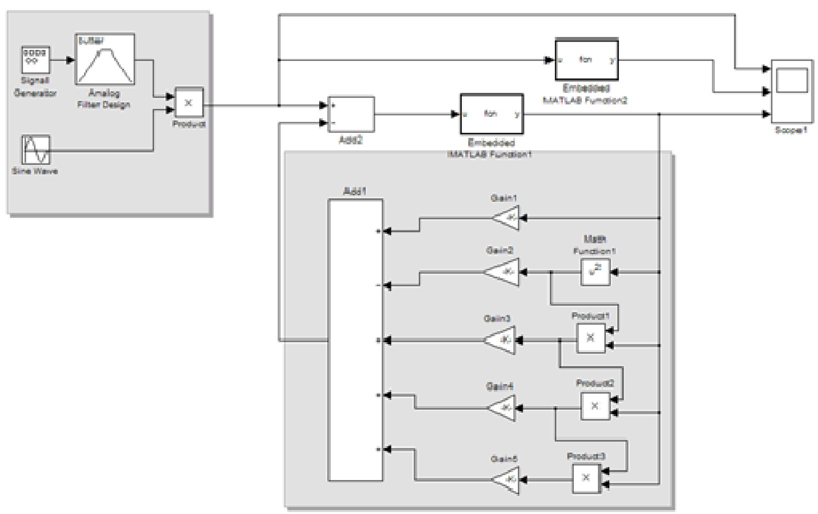

Figure.2. Matlab Simulink developed file to simulate the reduction of non-linearity of radiofrequency stages by introducing a feedback loop based on the reverse power series

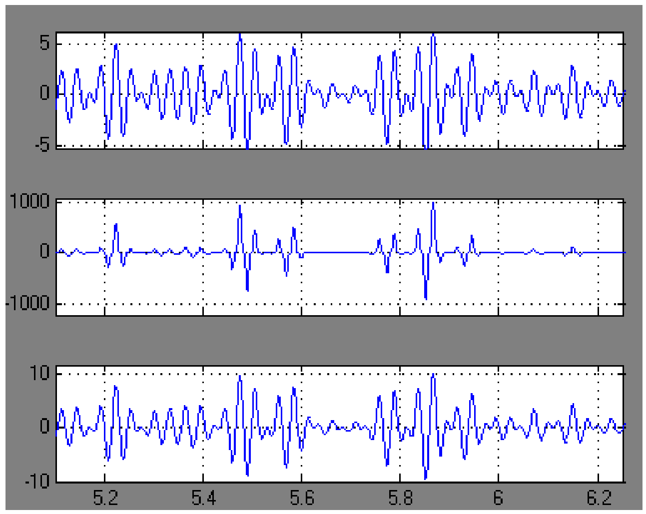

Figure.3. The signals obtained from the Matlab-Simulink simulation according to Fig.1: a) the original signal b) the amplified signal without compensating for the nonlinearity c) the amplified signal by feedback loop introduction based on the reverse power series

4. Conclusion

In order to compensate the nonlinearity of the RFA systems due to disturbing signals in the military operations theatres, the feedback loop based on signal decomposition in reverse power series has been proposed by the authors. The appropriate Matlab – Simulink block diagram has been developed by the authors to simulate the effect of feedback loop. The simulation results show the effectiveness of the proposed solution.

However, from the stability point of view the price paid is decreasing in amplification. In order to achieve a high rate of amplification, the authors propose the use as methodology two RFAs steps: the first step with the feedback loop to increase immunity to disturbances (interferences), and the second step without the feedback loop, to achieve a high rate of amplification.

References

[1] Mincu C-tin., Gruia T., *Compatibilitatea sistemelor radioelectronice*. Editura Olimp, Bucureşti, 1999.

[2] Constantin I., Marghescu I., *Transmisiuni Analogice şi Digitale*, Editura Tehnică, Bucureşti, 1995.

[3] Căleanu C.D., *Dispozitive şi circuite electronice: Experimente şi simulare*. Editura Politehnica, Timişoara, 2003.

[4] Vlădescu A., Nicolescu V., *Radioreceptoare,* Editura Tehnică, Bucureşti, 1970.

[5] Jialu Huang, Hong Ma, Jiang Jin, Hua Zhang, Nonlinear Blind Compensation for Array Signal Processing Application*, Sensors,* 18(4), pp. 1286, 2018.

[6] Vansebrouck R., Jamin O., Desgreys P., Nguyen V.-T., *Digital distortion compensation for wideband direct digitization RF receiver*, IEEE 13th International New Circuits and Systems Conference (NEWCAS), Jun. 2015, Grenoble France.

[7] Mwangi Stanley Njenga: *Band Limited Digital Predistortion of Wideband RF Power Amplifiers,* MSc Thesis, 2017.

[8] Vansebrouck R., Jabbour C., Desgreys P., Jamin Ol, Nguyen V.-T., *Performance study of nonlinearities blind correction in wideband receivers*, ICECS, Dec. 2014, Marseille, France.

[9] Golara, Soheil, Identifying Mechanisms of AM-PM Distortion in Large Signal Amplifiers, 2015, https://escholarship.org/uc/item/4jp786z8

[10] Morris KA & McGeehan, Gain and Phase Matching Requirements of Cubic Predistortion Systems, *IEEE Electronics Letters*, 36(21), pp. 1822-1824.

[11] Tsai J.-H., Chang H.-Y., Wu P.-S., Lee Y.-L., Huang T.-W., Wang H., Design and analysis of a 44 GHz MMIC low-loss built-in linearizer for high-linearity medium power amplifiers, *IEEE Trans. Microw. Theory Tech*., 54(6), 2006, pp. 2487–2496.

[12] Jeng-Han Tsai, *A 60 GHz CMOS Power Amplifier with Built-in Pre-Distortion Linearizer*, IEEE Microwave and wireless components letters, 21(12), 2011.

[13] Gary Hau, Takeshi B. Nishimura, A Highly Efficient Linearized Wide-Band CDMA Handset Power Amplifier Based on Predistortion under Various Bias Conditions, *IEEE Trans. Microwave Theory Tech*., 2001, 49(6), pp. 2487–2496.

[14] Solcanu V., Călueanu D., *Calculul neliniarității curentului în cazul unui dispozitiv electronic*, A XXI-a Sesiune de Comunicări Ştiințifice cu Participare Internațională „NAV.MAR.EDU”, 2007.

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