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Prevention of Intermodulation Interference and its Products in Communication System

Ezebuiro, I.I[1] and Udo, E.U[2]*
[1, 2]Department of Electrical/Electronic Engineering, Michael Okpara University of Agriculture, Umudike, Abia State.
*Corresponding author's email: thought.umoren@gmail.com

Abstract
This paper focuses on the prevention of intermodulation interference and its products in communication system. In radio communication system, the presence of intermodulation products at intercept points make the system unreliable and intermodulation products are spurious frequency components generated when two or more signals pass through a non-linear device. The presence of noise in the system generates interference in the signal transmitted and this ultimately causes errors in the communication system. Intermodulation distortion enhance difficult challenge for requirements on components and sub system linearity which lead to increase in spectrum congestion. The method adopted involves intermodulation programmed calculation for interference which reduces interference effects and provides useful ways of promoting efficient spectrum utilization. The results calculated shows that at a particular at frequency of $2f_w$*-*f_z *for third order products, the intermodulation index level,* P_e*-in = -57dBm, frequency of component,* P_{imp} *= -135dBm, the recalculated equivalent intermodulation product level,* P_{ino} *= -147dBm and signal interference ratio, R = 41dBm. Again, several ways of prevention of intermodulation interference that are created at the output of a receiver due to non-linearity is presented. In conclusion, it is recommended that the probability of occurrence of intermodulation interference due to high level of unwanted signals is reduced to the barest minimum.*

Keywords: *Intermodulation interference, Noise, Spectrum congestion, Prevention, Communication system*

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1. Introduction

The radio frequency spectrum can be compared with raw materials. The major difference between the two items is that the radio frequency is not limited. It can be used or misused but not wasted. If misused, this can lead to interference. If not used, the frequency returns to its original stage. It is this misusing aspect of the radio frequency spectrum utilization that is of great concern to telecommunications operators and frequency regulators. The necessity of efficient and effective spectrum usage cannot therefore be over-emphasized (Delise, 2014). Intermodulation noise is produced by nonlinearities in the transmitting, receiving or intervening transmission medium. These components behave as linear systems which is equal to the input times a constant. Excessive non-linearity can be caused by component malfunction from excessive signal strength. It is under these circumstances that the sum and difference frequency terms occur (Jin et al., 2018).

Improper frequency management will result in operators using unauthorized frequencies, thereby giving rise to different forms of interferences and their products. Interference is the effect that occurs when two or more radio frequencies arrive the same point simultaneously. This includes undesired noise or other unwanted radio signals. With the electromagnetic spectrum being populated with ever increasing input from man-made devices and processes, the problem of radio interference is becoming a great concern especially to communication and radio astronomy (Kearney and Steven, 2017). Apart from atmospheric causes, the main sources of noise are from man-made devices such as electric-arc welding (the source of impulse noise), noise spikes of short duration and of relatively high amplitude, galactic noise from fridges and external electromagnetic disturbances, such as lightning and flaws in the communication system. On the national level, there are at least six major user groups namely, broadcasting, security service, telecommunications operators, ministry of defence, civil aviation, private users such as closed mobile radio operators and radio amateurs.

The interest of these various user groups is different and conflict in many situations in the same part of the spectrum due to interference. The mixing of various radio frequencies by operators and especially those from unauthorized users result in complex inter-modulation problems thus giving rise to inter-modulation products (Ezebuiro and Udo, 2010). Inter-modulation products are the result of mixing between two or more radio frequency signals in a non-linear medium such as the collector of a class C power amplifier transistor, a pre-amplifier that is operating at or near the gain compression point, a receiver's first mixer or antenna system joint. The mixing can occur between fundamental frequency signals or the harmonics of one or the entire transmitters involved (Shitvov et al., 2014). Consider the example of transmitters at frequencies f_1 and f_2. The fundamentals can mix and produce products at $f_1 + f_2$ and $f_1 - f_2$. These products are referred to as two-frequency second order. These are also known by the form of the equation from which they are derived (1) f_1 + (1) f_2 and (1) f_1 – (1) f_2. The (1) in the latter form is the implied coefficient of f_1 and f_2 and is normally not written when their value is one. The researchers observed that these frequencies are second order products because the sum of the coefficients is two. These products are not likely to cause much problem because of frequencies on which they fall. However, consider the two frequencies, third order given by $2f_1 - f_2$ and $2 f_1 + f_2$. The mixing would therefore result in various products such as $2^* f_1 + f_2$, $2^* f_2 + f_1$, $2^* f_1 - f_2$ and $2^* f_2 - f_1$.

All these results are quite significant because they fall right in the frequency bands where many of other mobile radios operate. One of those intermodulation frequencies could easily fall on one of any customer's communications. These examples also point out that not all intermodulation equations produce any significant results and cannot be solved. Algorithms can be developed that eliminate as many as unnecessary calculations and comparisons as possible such as double precision floating point addition, subtraction and multiplication. These processes can be done by the central processing unit (CPU), clock cycles, thereby cutting down the number of unnecessary equations to be solved with greater speed and accuracy especially when many frequencies are involved (Kozlov et al., 2015).

2. Materials and methods

2.1 Mathematical modelling of the generation of intermodulation noise in the transmitter

There are two classical methods for the analysis of non-linear system, namely the first order and second order method. The first order employs the expansion of signal in Volterra series and the second order make use of the Wiener base function expansion, the Wiener functions are orthogonal if the white Gaussian noise excites the system. The non-linear system output signal y(t) can be expressed by a Volterra seris as shown in Equation (1) (Kearney and Steven, 2017).

$$y(t) = H_o + H_1 + H_2 \tag{1}$$

where H_i is the Volterra operator operating on the input x(t) of the system. The first three operators are given in Equations (2) to (4).

$$H_o[x(t)] = h_0 \tag{2}$$

$$H_1[x(t)] = \int h_1(\tau)x(t-\tau)d\tau \tag{3}$$

$$H_2[x(t)] = \iint h_2(\tau_1,\tau_2)x(t-\tau_1)x(t-\tau_2)d\tau_1 d\tau_2 \tag{4}$$

The kernels of the integral operators can be measured by the variation of the excitation time of input pulses where h_1 and h_2 represent the first order and second order kernel. Therefore,

$$\varphi_{nn}(\tau) = A\delta(t) \tag{5}$$

Equation (5) is the autocorrelation function of the input signal x(t) = n(t), where A is the noise power spectrum density. The first three kernels are given in Equations (6) to (8).

$$h_0 = \overline{y_{0\,(t)}} \tag{6}$$

$$h_1(\sigma) = \frac{1}{A}\overline{y_{1\,(t)n(t-\sigma)}} \tag{7}$$

$$h_2(\sigma_1,\sigma_2) = \frac{1}{2A^2}\overline{y_{2\,(t)n(t-\sigma_1)n(t-\sigma_2)}} \tag{8}$$

The first three Wiener G- functional are shown in Equations (9) to (12).

$$G_0[x(t)] = k_0 \tag{9}$$

$$G_1[x(t)] = \int k_1(\tau_1)x(t-\tau_1)d\tau_1 \tag{10}$$

$$G_2[x(t) = \iint k_2(\tau_1,\tau_2)x(t-\tau_1)x(t-\tau_2)d\tau_1 d\tau_2 - A\int K_2(\tau_1,\tau_1)d\tau_1 \tag{11}$$

$$G_3[x(t)] = \iiint k_3((\tau_1,\tau_2,\tau_3)x((t-\tau_1)x(t-\tau_2)x(t-\tau_3)d\tau_1 d\tau_2 d\tau_3 - 3A\iint k_3(\tau_1,\tau_2,\tau_2)x(t-\tau_1)d\tau_1 d\tau_2 \quad ,(12)$$

For imperfect square law second order device, the input-output relation of a non-linear device is given in Equation (13).

$$z(t) = y(t) + ay^2(t) \tag{13}$$

The input signals $x_1(t)$ and $x_2(t)$ are originated from a single signal x(t), because of the spectral separation from the filters $h_a(t)$ and $h_b(t)$. The output signal z(t) in the transmitter is determined using Equation (14).

$$z(t) = \int [h_a(t) + h_b(t)] x(t-\tau) d\tau + a\{\int [h_a(\tau) + h_b(\tau)] x(t-\tau) d\tau\}^2 \quad (14)$$

For imperfect square law third order device, the input-output relation of a non-linear device is as shown in Equation (15).

$$z(t) = y(t) + ay^3(t) \quad (15)$$

If only the intermodulation term which distorts the signal in its own frequency band is considered, the kernel transform of the third Voltera $Z_3(w_1, w_2, w_3)$ is given in Equation (16).

$$Z_{(3)}(w_1, w_2, w_3) = a \prod_{i=1}^{3} [H_a(w_i) + H_b(w_i)] \, x(w_i) \quad (16)$$

The intermodulation part in the spectrum of z(t) is as shown in Equation (17) (Jokinen, 2016).

$$Z(w) = \frac{1}{(2\pi)^2} \iint Z_{(3)}(w - \mu_1, \mu_1 - \mu_2, \mu_2) d\mu_1 \, d\mu_2 \quad (17)$$

2.2 Materials

The materials used in this study are transmitters, receivers, transmission medium, active antennas, radio system, telephone system, non-linearity of passive circuits, amplifiers and mixers.

2.3 Method

The method employed make use of intermodulation programmed calculation which involves the determination of attenuation of incoming signals acting at the input of the receiver by input filters, β and intermodulation product levels at the output of the mixer, P_{imp}. However, it also utilizes the calculation of levels of the incoming signals acting at the input of the pre-selector, $P_{J.}$ and signal interference ratio at the input of the receiver, R. Similarly, estimation of the equipment of intermodulation product level was recalculated to the input of the receiver, P_{ino} Intermodulation programmed calculation also compares the signal interference ratio with the protection ratio for determination of compatibility condition of the receiver with other radio systems in the specified electromagnetic environment. However, when a satellite transponder is operated in the nonlinear region to amplify several input signals at different frequencies, the intermodulation products among input signals causes interference with the output signals. The use of wideband deviation frequency modulation helps to economize transmitter power at the expense of an increase in bandwidth and it is immune to the effects of interference and intermodulation.

2.4 Innovative engineering practices for prevention of intermodulation interference

Fifteen innovative engineering practices has been considered and recommended for prevention in order to minimize intermodulation interference. These include the following:

1. Use of intermodulation programmed calculation for interference analysis before applying for a new frequency or accepting a customer with existing frequency assignment involves the following preventions.
2. By considering the use of single section ferrite isolator and band pass filters on every transmitter. These components can eliminate a multitude of potential interference troubles.
3. Interference can be minimized by considering the use of master receive antenna with pre-selector filters spaced vertically from all transmitting antennas.
4. Intermodulation interference can be avoided by always using double shield or solid jacket cable for connecting all radios and filtering devices
5. Ensuring that all incoming control audio and power lines are well by-passed and properly grounded. Intermodulation problems have been traced to inability coupling of radio frequency from one radio to another through telephone lines.
6. Realize that one watt of spurious output and one watt of the desired frequency energy affect most watt-meters the same way. This means that the power output of a transmitter when measured with wattmeter contains larger quantities of spurious energy.
7. Consider the use of low noise preamps on mobiles and higher gain antennas at the base station end before increasing transmitter power.
8. Keep abreast with the latest regulatory and technical developments that will allow a greater number of users per channel or a greater number of channels per megahertz.
9. Keep radio system to operate at their best by checking frequency, power output and deviation regularly with well calibrated test equipment.
10. Exercise great discipline in the use of frequency by ensuring the use of authorized frequencies with proper co-ordination and correlation (Jokinen, 2016).
11. The bolted metal to metal joints always have enough oxidation to turn them into excellent diode

junctions. Therefore, avoid bolted or riveted type towers. The heavy flow of current in the tower sections that results from this practice can pass through dissimilar metal joints and generate broadband for radio frequency noise (Jin et al., 2018).

12. Avoid close spacing of Omni-directional antennas to metal lower than directional antenna patterns.

13. Avoid over driving external power amplifiers used with lower power transmitters. An overdriven amplifier can be a great source of spurious radiation.

14. Avoid routine operation of radio without the shield covers in place and doors closed or without the cabinet being properly grounded.

15. Avoid the use of unauthorized frequency and never attempt to use any frequency not authorized by the regulator (Jackson et al., 2015).

3. Results and discussion

The results obtained shows that the calculations of intermodulation product levels should be made for the same distribution of index of frequencies of their components. Also, different levels of incoming signals at the output for the same order have various levels which can be calculated. Again, to attenuate unwanted incoming interfering signal, bandpass filter is usually installed at receiver inputs before pre-selectors. Also, the reduction of intermodulation products produced in the output stages of different transmitters can be done by minimizing the coupling rather than reducing the level at the mixing junction. However, the results revealed that if the input of the wanted signal is high enough, additional variable radio frequency attenuator should be inserted between the antenna feeder and receiver inputs. This will always permit the reduction of the incoming interference signal.

(1) The determination of intermodulation interferences of 2nd and 3rd orders for two unwanted incoming signals was realized through the following parameters The order and type of product for 2nd and 3rd orders are stated as: 2(1;1) and 3(2;1).

(2) Frequency of components, f_{imp} for two unwanted signals at 2nd and 3rd orders are $f_w + f_z$ and $2f_w + f_z$

(3) The intermodulation index level P_e-in for 2rd and 3rd orders are given as $\frac{P_w+P_z}{2}$ and $\frac{2(P_w+P_z)}{3}$

(4) The equivalent intermodulation level recalculated to the input of the receiver $P_{ino} = P_{imp} - G$

(5) The signal interference ratio at the input of the receiver R is given as $R = P_s - P_{ino}$

For example, the determination of intermodulation interference at a specified frequency of $2f_w + f_w$ for 3rd order of product 3(2;1) in the receiver can be calculated to reduce it harmful effect using the following parameters: P_w = -60dBm, P_z = -50dBm, Ps = -106dBm, G = 12dB.

Intermodulation index level, $p_{e-in} = \frac{(2P_w+p_z)}{3}$

$$p_{e-in} = \frac{(2 \times -60 + (-50))}{3}$$

$$p_{e-in} = \frac{-120\ -\ 50}{3} = \ -57\text{dBm}$$

Power in the intermodulation product, $P_{imp} = 3(P_{e-in} + G) = 3(-57\ + 12)$

$P_{imp} = 3 \times (-45) = -135\text{dBm}$

Equivalent intermodulation level, $P_{ino} = p_{imp} - G$

$P_{ino} = -135\ - 12 =\ -147\text{dBm}$

Signal interference ratio, $R = P_s\ - P_{ino}$

$R = -106\ - (-147)\ = 41\text{dBm}$

4. Conclusion

Predicting and physically solving intermodulation interference problems are only measures of frequencies interference control. But knowing how to prevent the occurrence of intermodulation products provides a better cure, which the researchers have demonstrated together with some innovative engineering practices to adopt in order to avoid intermodulation interference problems. However, non-linearity noise is due to non-linear distortion in the demodulated signal between the various channels comprising the signals. The provision of a pre-demodulator band pass filter to limit the thermal noise in the earth's station receiver causes truncation noise due to intermodulation among the baseband channels. Many telecommunication operators should adopt accepted engineering practices and all new preventive measures to check interference and its damaging effects. Intermodulation distortion has incapacitating effect on the performance telecommunications networks. The resulting decreased system capacity and degraded call quality at cell sites results in reduced revenue for the wireless service provider. Controlling the generation of intermodulation is the key to maintain capacity and service quality, therefore receivers need to have minimized intermodulation distortion in order to maintain call quality in a congested network.

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