# Gorbhani Amplifier and Doppler Issues for Inter-Satellite Data Links

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***Abstract*** — This paper attempts to present the relation between Gorbhani type of Amplifier distortion and doppler for varying levels of normalized signal. The Intersatellite links are subjected to doppler phenomenon due to relative motion between the satellites. Doppler and Amplifier distortion together significantly degrade the data transmitted on the Inter-Satellite links. The cumulative degradation is presented via Error Vector Magnitude (EVM) metric as it helps to understand both qualitative and quantitative signal degradation. In view of significant number satellite constellations being deployed around the globe for data transmission ,the results presented in this paper helps satellite constellation designers to understand and estimate the cumulative distortion. An expression for the Error Vector magnitude is derived and presented for a PSK(I/Q) modulated signal. The results presented corelates two different types distortions component induced Amplifier distortion and physical(channel) distortion Doppler. The results present in this paper helps Satellite Constellation/System designers in the selection of components( Amplifier) whose distortion is less sensitivity to doppler.

**Index Terms— Amplifier Distortion, Satellite Communication,**

## I. Introduction

1.0 Satellite constellations and their impact on providing enhanced remote sensing products have been discussed in [1]. Two types of Intersatellite links have been discussed.

- Intersatellite links between satellites which are in the Orbital frame. (Intersatellite links between Low Earth Orbiting Cube satellites and Low Earth Orbiting Microsatellites)
- Intersatellite link between Satellite which are in different Orbital frame (Intersatellite links between cube/Microsatellites and Geostationary Satellite).

1.1 The performance of the communication links mentioned above is affected by various impairments. The impairments affecting the links are:

a) Non-Linearity of the amplifiers

b) Doppler shift in frequency /Phase due to relative motion between satellites.

c) Phase Noise distortion of the Local oscillator

d) IQ imbalance

e) Noise Temperature

In this paper an attempt to correlate amplifier Non-linearity and Doppler shift due to satellites in the Low Earth Orbit( with relative velocity being a maximum of 1000 m/s) is done.

1.2 The Non-Linearity exhibited by various power amplifiers have been modeled by various researchers. The predominant models are:

a) Saleh Model

b) Rapp Model,

c) Gorbhani Model

If X(t) represents a Phase modulated signal and depicted by the equation $X(t)=r(t)\cos(\omega(t)+\Psi(t))$

Where ω represents the carrier frequency

r(t) Modulated envelope

Ψ(t) modulated Phase

The signal x(t) when fed to an amplifier with Saleh Type Amplitude and Phase Distortions then the output response signal can be represented as

$$Y(t)=A[r(t)]\cos\{(\omega(t)+\Psi(t)+\phi(r(t))\} \quad (1)$$

Where A[r(t)] represents AM-AM conversion

ϕ(r(t)) represents the AM-PM conversion

The Gorbhani model[4][5] is suitable to GasFET type of amplifiers. The Gorbhani model relates the input signal with the output signal by the following equations.

$$y(t)=A(r(t))\cos(\omega_o t+\psi(t)+\phi(t))$$

$$A(r)=x_1 r^{\frac{x2}{1+x3r^{x2}}}+x_4 r \quad (2)$$

$$\phi(r)=y_1 r^{\frac{y2}{1+y3r^{y2}}}+y_4 r$$

(3)

Where $x_1,x_2,x_3,x_4,y_1,y_2,y_3,y_4$ are variables and are selected to approximate to the Input-Output characteristics of GasFET amplifiers.

## II EVM EXPRESSION FOR THE DISTORTED SIGNALS

The effect of Amplifier Non-linearity has been discussed in [6].N.K,Ekanayake and similar analysis has been adopted below for studying the effect of doppler and Amplifier non-linearity

If $a_k$ represents a binary data assuming the values of +1 and -1 with equal probability and with binary data of period 1/Ts. Here Ts represents the bit duration.

The signal S(t) is represented as

$S(t)= \Sigma$ k even $a_k$ p(t-kT) $Cos(w_c t)$- $\Sigma$ k odd $a_k$ p(t-kT) $Sin(w_c t)$ (4)

k=0,1,2…………M. k represents the bit sequence.

M=4 for QPSK

M=8 for 8 PSK

For ease of analysis let S(t) be represented as

S(t) = x(t)+y(t)

Where x(t) is the in-phase component and equals

$x(t)=\Sigma$ k even $a_k$ p(t-kT) Cos $(w_c t)$

and y(t) is the Quadrature component and equals

$y(t)=\Sigma$ k odd $a_k$ p(t-kT) Sin $(w_c t)$

John LibertrueRiccardo De Gaudenzietalreported in IEEE Document No 802.16.1pp-00/15 (http://ieee802.org/16/phy/docs/80216pc-00_15.pdf) and N.K,Ekanayake in [5] the effect AM/AM and AM/PM type of distortion on a signal amplified by an amplifier can be represented as two different components in amplitude and phase component.

Accordingly, the signal S(t) which when passed through amplifier with Saleh type of Non-linearity undergoes both AM/AM and AM/PM type of distortion and is represented as $S_1(t)$.

Accordingly

$S_1(t)=x_1(t)+y_1(t)$

For Simplicity the effect of amplifier on the signal S(t) is done separately for in phase and Quadrature phase components.

The amplified/distorted in phase component can be written as

$x_1(t)= \Sigma$ k even $a_k$ A(r) p(t-kTs) Cos $(w_c t+\Phi(r))$

(5)

The amplified/distorted in quadrature phase component can be written as

$y_1(t)= \Sigma$ k odd $a_k$ A(r) p(t-kTs) Sin $(w_c t+\Phi(r))$

(6)

The Inphase component can be represented as

$x_1(t)= \Sigma$ k even $a_k$ A(r) p(t-kTs) Cos $(w_c t+\Phi(r))$

(7)

Replacing Ts with $1/f_s$ the equation $x_1(t)$ becomes

$x_1(t)= = \Sigma$ k even $a_k$ A(r) $p(t-k/f_s)$ Cos $(2\pi f_c t+ \Phi(r))$

(8)

The pulse shape p(t) shall be represented as

$p(t)= A \, Cos(\pi t/2T_s)$ for $-T\leq t\leq T$

= 0 elsewhere

$x_1(t)= \Sigma$ k even $a_k$ A(r) A Cos $((\pi t)/ 2T_s)$ Cos $(2\pi f_c t+ \Phi(r))$

(9)

$x_1(t)= \Sigma$ k even $a_k$ A(r) A Cos $((\pi t)*f_s/ 2)$ Cos $(2\pi f_c t+ \Phi(r))$

(10)

The NASA Technical Report, No NASA/TM-2001-210595[7].states that the doppler phenomena affects both the carrier frequency and symbol period equally by a factor N where $N=f_d/f_c$ where $f_d$ represents the doppler frequency and $f_c$ represents the carrier frequency. For the case of simplicity, the effect of doppler is calculated individually for the Inphase and Quadrature phase components .

Accordingly replacing $f_s$ with $f_s(1+N)$ and $f_c$ with $f_c(1+N)$ the equation 10 becomes

$x_1(t)= \Sigma$ k even A(r) A Cos $((\pi t)f_s(1+N) / 2)$ Cos $(2\pi f_c (1+N)t+ \Phi(r)))$ (11)

For a k th Symbol the above expression becomes

$x_1(t)= a_k$ A(r) A Cos $((\pi t) f_s (1+N) / 2)$

Cos $(2\pi f_c(1+N) t+ \Phi(r))$ (12)

For a k th Symbol the quadrature component becomes

$y_1(t)= a_k$ A(r ) A Cos $((\pi t)f_s(1+N) / 2)$

Sin $(2\pi f_c(1+N)t+ \Phi(r))$ (13)

The in-phase component Equation 12 becomes

$x1(t)= a_k$ A(r) A Cos $((\pi t) f_s (1+N) / 2)$

Cos $(2\pi f_c(1+N)t+ \Phi ( r)))$ (14)

The Quadrature component Equation 13 becomes

$y1(t)= a_k \ A(r)\ A\ \cos((\pi t) f_s(1+N)/2)$

$\sin(2\pi f_c(1+N)t+ \Phi(r))$ (15)

Let

P=πtfs/2

Q=πtfs(1 + N)/2

For ease of calculation ,the definition of N= fd/fs is substituted in the above equations.

$x_1(t)= a_k\ A(r)\ A\ \cos(Q)\ \cos(2\pi f_c(1+N)t+ \Phi(r))$

$x_1(t)= a_k\ A(r)\ A\ \cos(Q)\ \cos(2\pi t\ (f_c+f_d)+ \Phi(r))$

$x_1(t)= a_k\ A(r)\ A\ \cos(Q)\ \cos(2\pi t f_c + 2\pi t f_d + \Phi(r))$ (16)

The quadrature component becomes

$y_1(t)= a_k\ A(r)\ A\ \cos(Q)\ \sin(2\pi t\ (f_c+ f_d)+ \Phi(r))$

$y_1(t)= a_k A(r)\ A\ \cos(Q)\ \sin(2\pi t f_c + 2\pi t f_d + \Phi(r))$ (17)

In the subsequent steps $x_1(t)$ and $y_1(t)$ are individually simplified and added together to obtain the value of $S_1(t)$ .

Let $X=2\pi f_c t$

$Y=2\pi f_d t+ \Phi(r)$

$\cos(X+Y)=\cos(2\pi f_c t+(2\pi f_d t+ \Phi(r))$

$\cos((X+Y)=\cos(X)\cos(Y)-\sin(X)\sin(Y)$

$x1(t)= a_k\ A(r)\ A\ \cos(Q)\ \cos(2\pi t f c + 2\pi t f_d + \Phi(r))$

$x1(t)= a_k\ A(r)\ A\ \cos(Q)\ [\cos(2\pi t f_c)\cos(2\pi t f_d + \Phi(r)) -\sin(2\pi t f_c)\sin(2\pi t f_d + \Phi(r))]$ (18)

Applying the same steps as done for In-phase component to quadrature component

$y1(t)= a_k A(r)\ A\ \cos(Q)\ [\sin(2\pi t f_c)\cos(2\pi t f_d + \Phi(r)) + \cos(2\pi t f_c)\sin(2\pi t f_d + \Phi(r))]$ (19)

Now $S_1(t)$ can be written as

$\{ a_k\ A(r)\ A\ \cos(Q)\ (\cos Y+ \sin Y)\}\ \cos(2\pi f_c t)$

+

$\{ a_k\ A(r)\ A\ \cos(Q)\ (\cos Y- \sin Y)\}\ \sin(2\pi f_c t)$

(20)

From the definition of EVM in [8]

$$EVM_{rms} = \sqrt[2]{\frac{1/M\sum_1^M [Ik-Iok]^2 + [Qk-Qok]^2}{1/M\sum_1^M [Ik]^2 + [Qk]^2}} \quad (21)$$

From equation 4

$S(t)= \Sigma\ k\ even\ a_k\ \ p(t-kT)\ \cos(2\pi f_c t)- \Sigma\ k\ odd\ a_k\ \ p(t-kT)\ \sin(2\pi f_c t)$

For a $k^{th}$ Symbol

$S(t)= \Sigma\ k\ even\ a_k\ p(t)\cos(2\pi f_c t)- \Sigma\ k\ odd\ a_k\ p(t)\sin(2\pi f_c t)$

The pulse shape p(t) for representing the bits shall be represented as

$p(t)= A\cos(\pi t/2Ts)$ for $-T\leq t\leq T$

= 0 elsewhere

That is

$p(t)= A\cos(\pi t f_s/2)$ for $-T\leq t\leq T$

= 0 elsewhere

$S(t)= \{ a_k \cos(\pi t f_s/2)\}\cos(2\pi f_c t) -\{ a_k\ A\ \cos(\pi t f_s/2) \} \sin(2\pi f_c t)$ (22)

To evaluate the EVM as mentioned in the equation mentioned above the components $[Ik - Iok]$ and $[Qk - Qok]$ are computed independently ,squared and then added together to obtain the resultant EVM expression. From equations 20 and 22

$[Ik - Iok]^2= [a_k \cos(\pi t f_s/2)- a_k\ A(r)\ A\ \cos(Q)\ (\cos Y+ \sin Y]2$

$[Qk - Qok]^2 =[ a_k \cos(\pi t f_s/2)- a_k\ A(r)\ A\ \cos(Q)\ (\cos Y- \sin Y)]2$

$[Ik - Iok]^2 + [Qk - Qok]^2$ equals

$\{ 2\ ak2\ A2 \}\ [\cos 2(P)+ A(r)\cos 2 Q-2 A(r)\cos P\cos Q\cos Y]$ (22)

$[Ik]^2 + [Qk]^2$ equals $\{ 2\ a_k^2\ A^2 \}\ \cos^2(P)$ (23)

Substituting the values of $[Ik - Iok]^2 + [Qk - Qok]^2$ and $[Ik]^2 + [Qk]^2$ in the expression of EVM yields (i.e., substituting equations 22 and 23 in equation 21

EVM=sqrt( Nr/Dr) (24)

Where $Nr=\cos^2(\pi tfs/2)+A(r)(\cos^2(\pi tfs(1+N)/2)-2\cos(\pi tfs/2)\cos(\pi tfs(1+N)/2)\cos(2\pi fdt+ \phi(r))A(r)$

$Dr=\cos 2(\pi tfs/2)$

$$EVM = \sqrt[2]{\frac{\left[\left(Cos^2\left(\frac{\pi tfs}{2}\right) + A(r)Cos^2\left(\frac{\pi tfs(1+N)}{2}\right) - 2\,Cos\left(\frac{\pi tfs}{2}\right)Cos\left(\frac{\pi tfs(1+N)}{2}\right)\right)\left(Cos\left(2\pi fdt + \varphi(r)\right)A(r)\right)\right]}{Cos^2\left(\frac{\pi tfs}{2}\right)}} \quad (25)$$

### III RESULTS AND DISCUSSION

To understand the impact or correlation between Doppler and Amplifier nonlinearity simulations have been carried out using equation 25. The choice of frequencies and data rates are drawn from the ITU regulations for Intersatellite communication links. Amplifier parameters have been derived from[2],[3]and [4] . Results have been presented via various figures below.

| | Carrier Freq | Relative velocity (Max)Between satellites | Expected Fixed Doppler frequency (Max) |
|---|---|---|---|
| ISL 23 | 23.55GHz | 1000m/s | 78.5 KHz |
| ISL 25 | 27.5 GHz | 1000 m/S | 90 KHz |
| ISL 32 | 33 GHz | 1000m/S | 110Khz |

Table 1: ISL- Carrier Frequencies and expected doppler frequency

The values of Saleh parameters considered are:

$\alpha_a$=1.66238 $\beta_a$=0.0552 $\alpha_\Phi$= 0.1533$\beta_\Phi$=0.3456

The choice of these parameters is taken from [2] and [3] and [4]

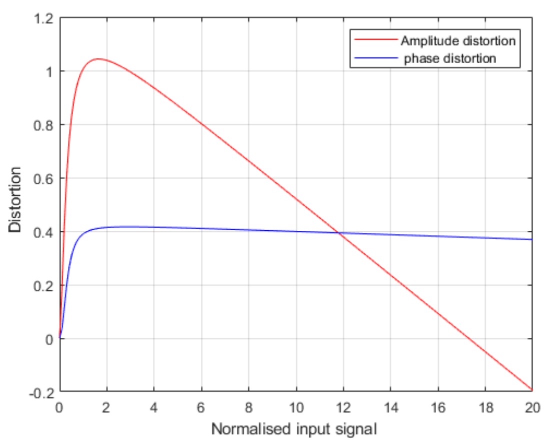


Figure1. Gorbhani Amplifier Distortion Curve

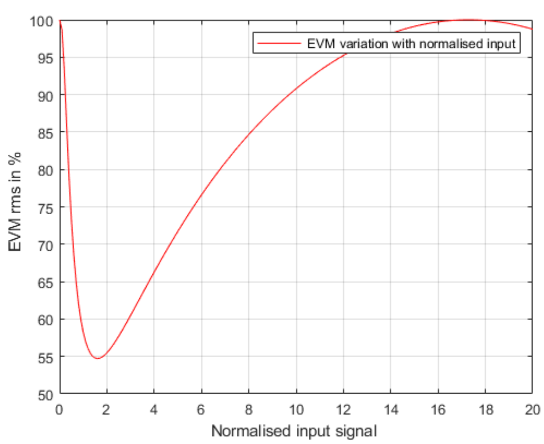


Figure2. Varaition of EVM with Normalised input value at 500 Mbps data transmision rate with doppler frequency -100 kHz for a carrier frequency of 27 GHz

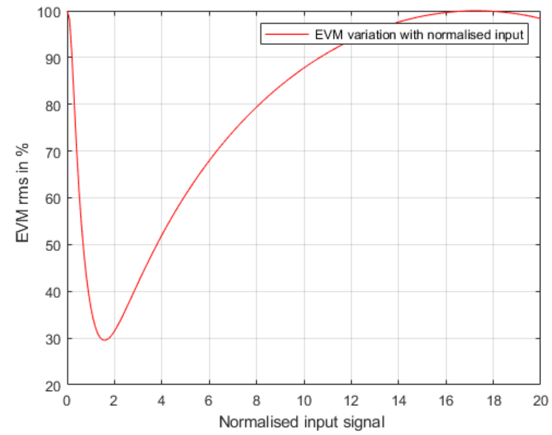


Figure3. Varaition of EVM with Normalised input value at 500Mbps data transmision rate with doppler frequency +100 kHz for a carrier frequency of 27 GHz

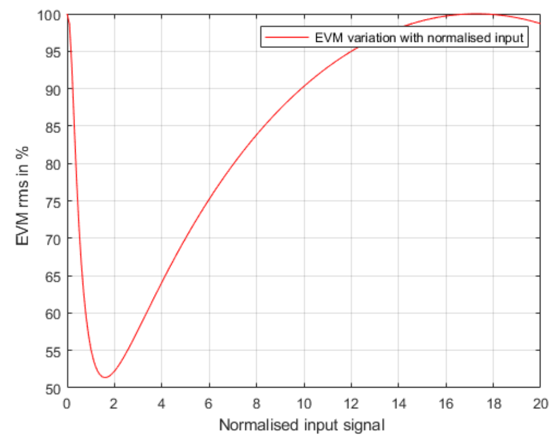


Figure4. Varaition of EVM with Normalised input value at 200Mbps data transmision rate with doppler frequency -100 kHz for a carrier frequency of 27 GHz

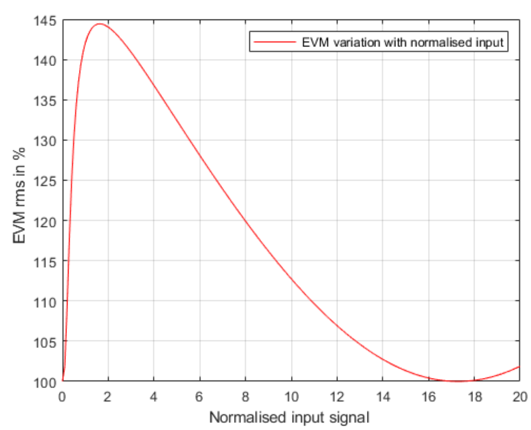


Figure5. Varaition of EVM with Normalised input value at 200Mbps data transmision rate with doppler frequency 100 kHz for a carrier frequency of 27 GHz

From the figures 1,2 3 4,and 5 the following conclusions are drawn:

a) The direction of doppler affects the EVM. For Saleh Set 1 parameters -100 KHz doppler yields a maximum EVM of 112 whereas as +100 KHz doppler yields a maximum EVM of 240.

b) For an amplifier with distortions shown in figure 1( Saleh Set 1 parameters), the total EVM is significantly driven by Amplitude distortion curve. For Saleh Set 2 parameters the EVM is not driven by Distortion curve. This solidifies the fact that selection of Amplifier for a known doppler helps to minimize signal distortion.

c) Amplifiers with Set -2 Saleh parameters yield lower value of EVM as compared to Set -1 Saleh parameters.

d) Amplifiers with Set -2 Saleh parameters also have sensitivity to doppler direction .( Comparing figure 7 and 8. )

## REFERENCES

[1] Kishore Pasi,“ Constellation Proposal for Remote Sensing with UAV interleaved with CubeSat/Smallsat Networks”, 2018, 69th International Astronautical Congress(IAC),Bremen, October 1-5th Proceedings.

[2] Costa, M. Midrio, and S. Pupolin, “Impact of amplifier
IEEE Commun. Lett., vol. 3, no. 2, pp.37-39, February 1999.

[3] Ghorbani and M.Sheikhan, “ The effect of solid-state power amplifiers (SSPAs) nonlinearities on MPSK and M-QAM signal transmission,” in Proc. Int. Conf. on
Digital Processing of Signals in Communications, pp. 193-197, September 1991.

[4] Kishore Pasi,” Cumulative Amplifier and Doppler Effect on PSK modulated signals in Inter-Satellite Communication," 2018 IEEE International Conference on Advances in Computing, Communications and Informatics (ICACCI), 2018, pp. 1890-1895, doi: 10.1109/ICACCI.2018.8554554.

[5] K. Pasi, "Interrelationship between Amplifier and Doppler phenomenon in Inter-Satellite Communication links," 2019 URSI Asia-Pacific Radio Science Conference (AP-RASC), 2019, pp. 1-4, doi: 10.23919/URSIAP-RASC.2019.8738425.

[6] N .K .Ekanayake ”MSK and Offset QPSK Signal transmission through Non-linear Satellite Channels in the presence of ISI”,IEE Proceedings,VolNo:130,Part F,No:6,October 1983.

[7]FuginXiong,MartyAndrio,” The effect of Doppler frequency Shift ,Frequency offset of the Local Oscillator, and the Phase Noise on the performance of Coherent OFDM Receivers”. NASA Technical Report No: NASA/TM-2001-210595 www.ntrs.nasa.gov/archive/nasa.gov/20010049375 [www.gltrs.grc.nasa.g/gltrs]

[8] Rene Schmagrow, Bernd Nebendhal, Marcus Winter etal “ Error Vector Magnitude as a performance measure for advanced Modulation Formats”, IEEE Photonics Technology Letters, Vol No:24, No:1,Jan 1,2012,PP 61- 63.