Interrelationship between Amplifier and Doppler phenomenon in Inter- Satellite Communication links

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Abstract—
Doppler phenomena are one of the distorting factors in Inter-satellite links. Various Techniques are in use for compensating the phenomena of Doppler. Amplitude distortion is another physical phenomenon affecting the performance in Satellite links. The distortion exhibited by an amplifier varies by operating signal level and the effect of distortion can be minimized by changing the operating signal level. No studies have been done to study the inter-relationship between amplitude distortion and amplifier phenomena. The inter-relationship study helps a satellite system designer to optimize the system parameters. The interrelation between the two is brought out in this paper. The inter-relationship study helps minimize the effect of Doppler by selection of an amplifier and its operation characteristic. It also helps in selection of an amplifier for an expected Doppler to obtain sufficient margin in the links. In this paper results are presented for variation of EVM with doppler frequency.From the results it can be observed that a) The EVM varies non-periodically with the Doppler frequency. b) The EVM value changes for different Gorbhani Parameters and changes with the Doppler frequency.

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Key Words: Cube Satellite-microsatellite constellation, Doppler and Phase error, Intersatellite Links, Types of Amplifier Non-linearity

I.INTRODUCTION

A constellation of Cube Satellites and a Micro Satellite [1] for the enhanced remote Sensing as shown on the figure 1. A number of cube Satellites are placed in different orbits performing Remote sensing of the earth[1]. The cube satellites with payload perform the task of acquiring the remote sensing data. The remote sensing data from the various cube satellites shall be transmitted to the microsatellite[1]The microsatellite will be performing the task of formatting the data, processing the data before transmitting the data to the ground station/users Via Geo Satellite Intersatellite link as shown in figure 1.

In the constellation proposed there are two categories of Inter-satellite links[2]:

a) Intersatellite links between Cubesatellies and Microsatellites

b) Intersatellite link between Microsatellite and GeoSatellite

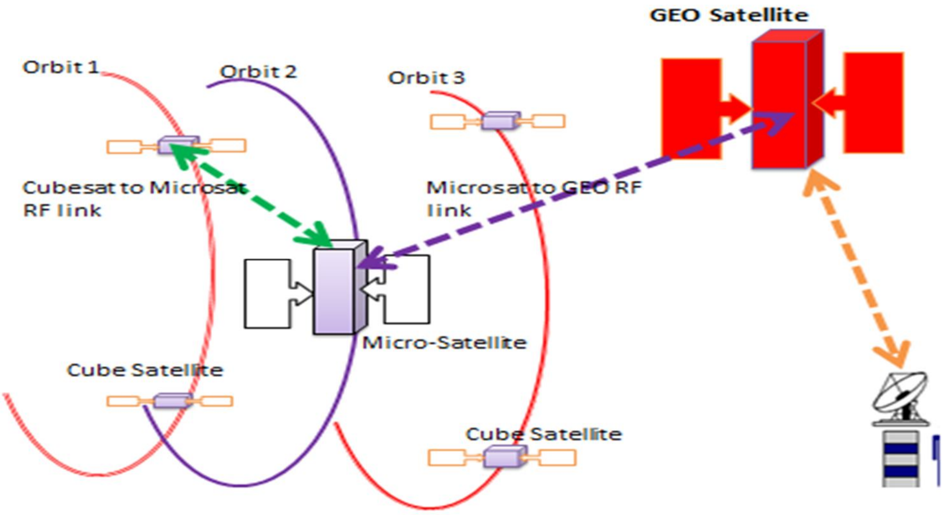

Figure:1 Cubesat-Microsat LEO-LEO constellation and Intersatellite links

II. LIMITING FACTORS FOR INTER-SATELLITE LINKS

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 freq/Phase due to relative motion between satellites.

2.1 Amplifier Non linearity

The Non-Linearity exhibited by various power amplifiers [4] have been modeled by various researchers. The predominant models are :

a)Saleh Model

b) Rapp Model,.

c) Ghorbani Model

The Commercial amplifiers used in satellite communications amplifiers have Amplitude and Phase distortions similar to the amplifier Non-Linear models mentioned above.

2.1.1 Gorbhani Model: The Gorbhani model proposed by Gorbhani is suitable to GasFET type of amplifiers. The Gorbhani model relates the input signal with the output signal by the following equations.

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

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

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

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.

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

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

Where A(r) represents AM-AM conversion (2)

$\phi(r)$ represents the AM-PM conversion (3)

III EVM EXPRESSION FOR THE DISTORTED SIGNALS

The effect ofAmplifier Non linearity have been discussed in [6]. N.K,Ekanayakeetal 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 $1/T_s$. Here T_s represents the bit duration.

The signal S(t) is represented as

$S(t)= \Sigma_{k\ even}\ a_k\ p(t-kT)\cos(w_ct)- \Sigma_{k\ odd}\ a_k\ p(t-kT)\sin(w_ct)$ (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

$x(t)=\Sigma_{k\ even}\ a_k\ p(t-kT)\ \text{Cos}w_ct$

and y(t) is the Quadrature component and equals

$y(t)=\Sigma_{k\ odd}\ a_k\ p(t-kTs)\ \sin w_ct$

John Libertrue reported in IEEE Document No 802.16.1pp-00/15 (http://ieee802.org/16/phy/docs/80216pc-00_15.pdf) and reported by Riccardo De Gaudenzietal 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 Gorbhani type of Non-linearity undergoes both AM/AM and AM/PM type of distortion and is represented as S1(t).

Accordingly S1(t)=x1(t)-y1(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

$x1(t)= \Sigma_{k\ even}\ a_k A(r)\ p(t-kT_s)\cos(w_ct+\Phi(r))$ (5)

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

$y1(t)= \Sigma_{k\ odd}\ a_k A(r)\ p(t-kT_s)\sin(w_ct+\Phi(r))$ (6)

The Inphase component can be represented as

$x1(t)= \Sigma_{k\ even}\ a_k\ A(r)\ p(t-kT_s)\cos(w_ct+\Phi(r))$ (7)

Replacing T_s with $1/f_s$ x1(t) becomes

$x1(t) = \Sigma_{k\ even}\ a_k A(r)\ p(t-k/f_s)\cos(2\pi f_ct+\Phi(r))$ (8)

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

$p(t)= \text{Cos}(\pi t/2T_s)$ for $-T\leq t\leq T$

= 0 elsewhere

For a OQPSK signal with t=T/2 the pulse shape becomes

$p(t) = A/1.4141 \quad -T \leq t \leq T$

$\quad = 0$ elsewhere

$$x1(t)= \Sigma_k \text{ even } a_k A(r) A \cos((\pi t)/2Ts)\cos(2\pi f_c t+ \Phi(r)) \quad (9)$$

Replacing T_s with $1/f_s x1(t)$ becomes

$$x1(t)= \Sigma_k \text{ even } a_k A(r) A \cos((\pi t)*fs/2) \cos(2\pi f_c t+ \Phi(r)) \quad (10)$$

In the NASA Technical Report No NASA/TM-2001-210595[7] ,it is stated 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 represents the carrier frequency. N can also be represented as (V_r/C) .Cos(Angle) ,where Vr represents the relative velocity between the satellites ,C a constant (Velocity of light in free space) and " Angle" being the angle between the axis of the Satellites.

For the case of Simplicity the effect of doppler is calculated individually for the Inphase and Quadrature phase components .

Accordingly replacing fs with fs(1+N) and fc with fc(1+N) the equation 10 becomes

$$x1(t)= \Sigma_k \text{ even } a_k \; A(r) A \cos((\pi t)f_s(1+N)/2) \; \cos(2\pi f_c(1+N)t+ \Phi(r))) \quad (11)$$

For a kth Symbol the above expression becomes

$$x1(t)= a_k \; A(r) A \cos((\pi t)f_s(1+N)/2) \; \cos(2\pi f_c(1+N)t+ \phi(r))) \quad (12)$$

The term x1(t) in the above equation represents a in phase component of a QPSK modulated signal affected Gorbhani type Non linearity and fixed doppler. The constellation diagram is a pictorial /graphical representation of the Inphase and Quadrature phase components of a group of symbols.

Applying similar analysis to the Quadrature component ,the critical values where the Quadrature component can become zero shall be obtained.

$$y1(t)= \Sigma_k \text{ odd } a_k A(r) p(t-kTs) \sin(w_c t+ \Phi(r))$$

$$y1(t)= \Sigma_k \text{ odd } a_k A(r) p(t-k/f_s) \sin(2\pi f_c t+ \Phi(r)) \quad (13)$$

The pulse $p(t-kT_s)$ can be represented as $A\cos((\pi t)/2Ts)$ accordingly y1(t) can be represented as

$$y1(t)= \Sigma_k \text{ odd } a_k A(r) \; (A\cos((\pi t)/2T_s) \; \sin(2\pi f_c t+\Phi(r))$$

$$y1(t)= \Sigma_k \text{ odd } a_k A(r) A \cos((\pi t)f_s/2)) \sin(2\pi f_c t+\Phi(r)) \quad (14)$$

Replacing fs with fs(1+N) and fc with fc(1+N) the equation becomes

$$y1(t)= \Sigma_k \text{ odd } a_k A(r) A \cos((\pi t)f_s(1+N)/2) \quad \sin(2\pi f_c(1+N)t+ \phi(r))$$

For a kth Symbol the above expression becomes

$$y1(t)= a_k A(r) A \cos((\pi t)f_s(1+N)/2) \; \sin(2\pi f_c(1+N)t+ \phi(r)) \quad (15)$$

From equation 12 and 15 the QPSK signal can be represented as

$$S(t)=x(t)-y(t); \quad (16)$$

The signal S(t) represents a totally distorted QPSK signal with amplifier non-linearity and Doppler.

The EVM measurements or calculations of a signal can be referenced with respect to reference signal, average constellation power or Peak constellation power.

In this paper it is attempted to calculate the EVM of the QPSK signal by the reference signal method.

From equation 6 and equation 16, and using the equation for the EVM above ,the expression for the EVM can be given as

EVM=sqrt(Nr/Dr) (17)

Where Nr$=\cos^2(\pi t f_s/2)+ A(r)\,(\cos^2(\pi t f_s(1+N)/2)-2\cos(\pi t f_s/2)\cos(\pi t f_s(1+N)/2)\cos(2\pi f_d t+ \phi(r))A(r)$

Dr$=\cos^2(\pi t f_s/2)$

V RESULTS AND DISCUSSION

In the figure 2 ,the AM/AM distortion and AM/PM distortion for Gorbhani model parameters are plotted. The distortions are plotted against the normalized input signal amplitude. The values of Gorbhani parameters considered are :

x1=8.1081;x2=1.5412;x3=6.5202;x4=-0.0718;
y1=4.6645;y2=2.0965;y3=10.88;y4=-0.003

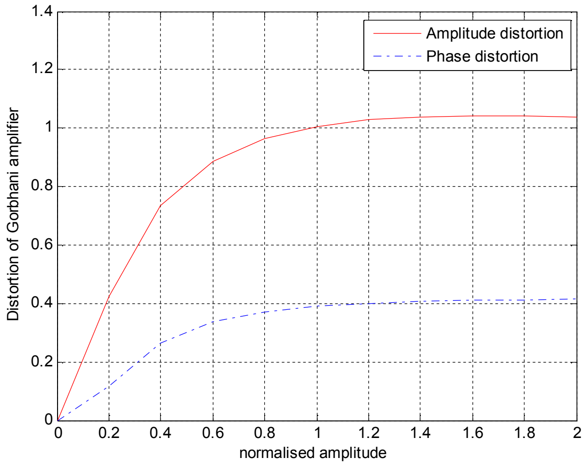

Figure:2 Amplitude and Phase response of Amplifier with Gorbhani Type Non-Linearity

From figure 2 ,it can be noticed that the AM/AM (Amplitude Distortion) increases with a slope and attains maximum value at a input amplitude of unity and decreases after the input amplitude of unity, whereas the AM/PM(Phase distortion) attains maximum value at a input amplitude of unity and remains constant thereafter.

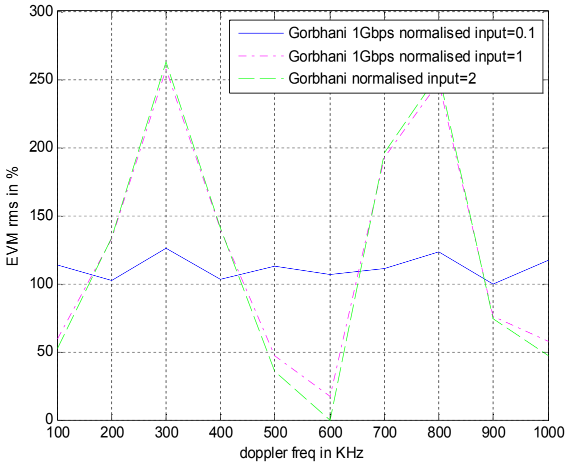

Figure:3 Variation of EVM for Gorbhani Type Non linearity for various doppler frequencies with various input signal levels

In Figure 3 the variation of Error Vector Magnitude (EVM) is plotted against the Dopplerfrequency,as per the derived equation No:17 ,for a normalized input amplitudes of 0.1,1 and 2.0 . The carrier frequency is chosen to be 27.00 GHz(Inter-Satellite Frequency) and rate is chosen to be 1Gbps(based on the worst case payload data generation). From the figure 3 the following conclusions can be drawn:

- For a normalized input amplitude of 0.1,the variation of EVM with Doppler frequency is very minimal or less. For this level the EVM varies non-periodically with doppler frequency. A straight relation cannot be established between the EVM and doppler frequency.
- For normalized input amplitude of unity, there is a pre-dominant variation of EVM with doppler frequency. The value of EVM is peak at a doppler frequency of 300KHz, and attains the minimum value at a doppler frequency of 600KHz.For this amplitude it can be observed EVM values are a maximum as compared to other normalized input amplitudes which is in match with the distortions presented in Figure 2. (AM/AM distortion is highest for this input amplitude level).
- For a normalized input amplitude of 2, the variation of EVM with doppler is lesser in magnitude compared to normalized input amplitude of unity, except for the value of EVM at the doppler frequency of 600 KHz .At this doppler frequency the EVM value is higher compared normalized input amplitude of unity.

This clearly establishes the Sensitivity with Doppler frequency i.e. for a given Type of Amplifier Non Linearity model and input amplitude, the Doppler frequency plays a pivotal role on the EVM.

As Dopplerfrequencies in the proposed constellation is a function of relative velocities between the satellites in the constellation, the relative velocities can be optimized for minimal or zero EVM. This helps a system engineer to optimize the Energy/Power generated on Satellite and achieve energy balance in the spacecrafts.[10]

V.CONCLUSION

The paper brings out the cumulative effect of Doppler frequencies on **Gorbhani** type non-linearity for a PSK (Phase Shift Keying) modulated signal in Intersatellite communication link. The distortion introduced is measured by taking Error Vector Magnitude (EVM) as metric of evaluation.. The Doppler frequency changes with the frequency of operating signal. The PSK type considered is QPSK and the effect of amplifier linearity is first derived and then the effect of Doppler is applied onto it. The EVM expression derived is the power reference type.

The paper brings the effect of Doppler frequencies on the satellites for a given Amplifier Non Linearity.

The paper also helps in determining the values of Doppler frequencies that can make the EVM value to zero. As Doppler frequencies are a function of Relative velocities between the satellites in the proposed constellation, the results of this paper can be used for optimization of velocities between the satellites.

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