I- INTRODUCTION
The error increasing demand for satellite Communications capacity and the crowded conditions prevailing in many regions of the radio spectrum combined with the emphasis on digital satellite transmission has created a need for improved spectrum utilisation techniques.
From the spectral efficiency point of view 16-ary QAM, and 16-ary offset with a theoretical maximum efficiency of 4 bits/S/Hz are a very attractive modulations techniques[1]. In satellite communication, nonlinearities are encountered in both transmitting earth station and the satellite repeater power amplifiers. The travelling wave tube (TWT) power amplifiers exhibits AM-to-PM and AM-to-FM effects and cause distortion of signals having large envelope fluctuations; such as 16-QAM.

The performance analysis of 16-QAM signalling through two-link nonlinear satellite channels in the presence of additive Gaussian noise is discussed in [2]. Reference [3] evaluate the performance of 16-QAM scheme in the same environments considered in [2], in addition to the effect of intersymbol interference (ISI) introduced by filters in the up-link channel. In this paper the performance of 16-ary-offset QAM with sinusoidal shaping scheme in the satellite nonlinear channel is evaluated analytically for nonlinear satellite channel in a narrowband case considering the up-link and down-link noise on-board TWT power amplifier nonlinearity, and ISI effect by filters in the up-link channel.

II- MATHEMATICAL ANALYSIS OF SEP
The digitally modulated signals (Fig.1) which incorporate in-phase and quadrature channels offset by one half symbol duration (T₂ = T/2) as in MSK signal may be expressed as:

\[ S'(t) = \sum_{p} a_p (t-KT_1) \cos \omega_0 t + \sum_{k} \frac{a_k}{k} \]

\[ (t-KT_1) \sin \omega_0 t \quad \ldots \quad (1) \]

\[ S''(t) = \sum_{p} b_p (t-KT_1) \cos \omega_0 t + \sum_{k} \frac{b_k}{k} \]

\[ (-K \sin \omega_0 t) \quad \ldots \quad (2) \]

The pulse \( p(t) \) is defined for MSK signal as:

\[ p(t) = \begin{cases} \cos \pi t / 2T_1 & 0 \leq t \leq T_2 \\ 0 & \text{elsewhere} \end{cases} \quad \ldots \quad (3) \]
The transmitted signal \( s(t) \) which is the sum of the two signals \( s'(t) \) and \( s''(t) \) that are 6-dB difference in power takes the form (NLA=150 QAM/ASK) that can be expressed as:

\[
S(t) = \sum_{k} d_{\text{even}} p(t-kT_{\text{c}}) \cos w_{c} t + \sum_{k} d_{\text{odd}} p(t-kT_{\text{c}}) \sin w_{c} t
\]

where \( d_{k} \) is a random variable related to \( \left\{ a_{k} \right\} \) and \( \left\{ b_{k} \right\} \) by the relation \( d_{k} = a_{k} + 2b_{k} \).

The signal \( s(t) \) is bandlimited by a filter whose impulse response is:

\[
H(t) = h(t) \cos w_{c} t
\]

signal \( s(t) \) is even by:

\[
S_{1}(t) = \sum_{k} d_{\text{even}} q(t-kT_{\text{c}}) \cos w_{c} t - \sum_{k} d_{\text{odd}} q(t-kT_{\text{c}}) \sin w_{c} t
\]

where,

\[
q(t) = p(t) \ast h(t)
\]

After corruption with up-link narrowband gaussian noise, the signal \( S_{2}(t) \) is:

\[
S_{2}(t) = R(t) \cos \phi(t)
\]

where:

\[
R(t) = x_2(t) + y_2(t), \quad \phi(t) = \arctan \left[ \frac{y(t)}{x(t)} \right]
\]

\[
x(t) = x_{uc}(t) + \sum_{k} d_{k} q(t-kT_{c})
\]

\[
y(t) = \sum_{k} d_{k} q(t-kT_{c}) + n_{us}(t)
\]

\( n_{uc} \) and \( n_{us} \) are independent gaussian processes with zero mean and variance \( \sigma_{u}^{2} \). The signal \( S_{2}(t) \) is amplified by the TWT amplifier on board of the satellite, thus:

\[
S_{3}(t) = R(t) \cos \left[ \theta(t) + \varphi'(R) - \theta' \right]
\]

where \( R(t) \) and \( \varphi'(R) \) denote the AM-AM and AM-FM conversion. The signal \( S_{3}(t) \) is now corrupted with the down-link noise, thus:

\[
S_{4}(t) = F(R) \cos \left[ \theta(t) + \varphi'(R) - \theta' \right] + n_{dc}(t)
\]

\[
\cos w_{c} t = n_{dc}(t) \sin w_{c} t
\]

where \( n_{dc}(t) \) and \( n_{us}(t) \) are the in-phase and quadrature components of narrowband down-link noise. The receiver coherently demodulates the input signal \( S_{4}(t) \) with the reference carrier, to get the inphase and quadrature baseband components:

\[
x_{4}(t) = F(R) \cos \left[ \theta(t) + \varphi'(R) - \theta' \right] + n_{uc}(t)
\]

\[
y_{4}(t) = F(R) \sin \left[ \theta(t) + \varphi'(R) - \theta' \right] + n_{us}(t)
\]

The ISI due to up-link filtering is taken into consideration. Omitting the time variable, the random variables \( x \) and \( y \) may be written as:

\[
x = d_{0} q_{c} + \alpha + n_{uc}, \quad y = \beta + n_{us}
\]

where \( \alpha \) and \( \beta \) are the ISI in the in-phase and quadrature channels, respectively.

The symbol error probability SER can be expressed as:

\[
Pe = \left[ P_{e} + 0.75 P_{e} \right] \quad \text{where} \quad P_{e} = \frac{1}{P_{1/2}} \left[ \frac{1}{P_{1/2}} \right]
\]

\[
\frac{1}{P_{1/2}} = \frac{1}{P_{1/2}} \left[ \frac{1}{P_{1/2}} \right] \quad \text{and} \quad P_{e} = \frac{1}{P_{1/2}} \left[ \frac{1}{P_{1/2}} \right]
\]

\[
\frac{1}{P_{1/2}} = \frac{1}{P_{1/2}} \left[ \frac{1}{P_{1/2}} \right] \quad \text{and} \quad P_{e} = \frac{1}{P_{1/2}} \left[ \frac{1}{P_{1/2}} \right]
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\[
\frac{1}{P_{1/2}} = \frac{1}{P_{1/2}} \left[ \frac{1}{P_{1/2}} \right] \quad \text{and} \quad P_{e} = \frac{1}{P_{1/2}} \left[ \frac{1}{P_{1/2}} \right]
\]

The computation of expressions of \( P_{e} \) and \( P_{e} \) require the knowledge of \( F \), \( \varphi'(R) \), \( \sigma_{u}^{2} \), \( q_{c} \), \( b_{c} \), \( s_{c} \), and \( c^{*} \). Each double integral defining the conditional error probabilities \( P_{e} \) and \( P_{e} \) is numerically evaluated using the Cartesian products of gauss-Hermite quadrature formulas [4].

Figs. (2) & (3) show the dependence of SER on the down link SNR for different values of 2\( P_{e} \) (normalized bandwidth). The up-link SNR \( P_{e}^{2} = 18 \text{dB} \), and the back-off values are \( P_{0} = 9 \text{dB} \).

III-CONCLUSIONS

The NLA=16 QAM/ASK signal is shown to be less sensitive to the nonlinear operation of the on-board satellite travelling wave tube power amplifier (TWT). This is due to signal shaping and the one half symbol duration overlapping between the in-phase and quadrature components of the generated signal. The comparison of the NLA=16 QAM/ASK and NLA=16 OQPSK/ASK signals from the point of view of spectral shaping is performed on the basis of spectral subband of QPSK and ASK signals, respectively. The conclusion of that study shows that the rate of spectral decay of NLA=16 OQPSK/ASK signal is too much higher than NLA=16 QAM/ASK, also higher power is included in smaller bandwidth.
exceeds 1.5 the normalized bandwidth. The results of comparison reveal that the performance of NLA-16-QAM/MSK system is superior than that of NLA-16-QAM/QPSK at all values of back-off i.e. at all nonlinear regions of operations of the on-board satellite TWTA.

REFERENCES


