PHASE NOISE MODELLING FOR KA-BAND VERY HIGH-THROUGHPUT SATELLITE SYSTEMS

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With ever increasing demand for higher data rate, traditional Ka-band satellite services are constantly being upgraded for denser very high-throughput satellite (VHTS) systems which can also accommodate 5G and 6G backhaul communication systems. Phase noise in VHTS systems is usually perceived as the most critical limiting factor. Driven by higher-order modulation schemes, the phase noise mask initially determined in DVB-S2X standard serves the starting point in evaluation of system performance. Phase noise characterization is often carried out by empirical, mathematical, simulation or combination of these platforms. Starting from the empirical model, we present a simple characterization method based on mathematical description of the modulated signals. Measured results in a Ka-band satellite test loop translator system are presented.

Keywords*:* HTS, VHTS, phase noise, Ka-band*.*

INTRODUCTION

High Throughput Satellite (HTS) and Very High Throughput Satellite (VHTS) systems offering transmission rates from 1000 Mb/s to Tb/s are gradually replacing traditional broadband satellite systems [1-3]. Demand for higher data rates together with reduced launch and operational costs of satellites progressively push for VHTS systems. Furthermore, next generation communication systems that will offer higher data rates are expected to utilize satellite systems as their backhaul or even as a complementing system to terrestrial network. All these exciting developments introduce new challenges in system design. One key area among all the challenges is the impact of phase noise on system performance.

Phase noise has always been recognized as one of the most critical point in degradation of system performance. Especially, in satellite communications it's been long known to be the limiting factor [4-6]. With the demand for higher data rates, higher frequencies are being utilized in the satellite communication systems, which, in turn, results in higher phase noise. Higher data rate not only demand higher carrier frequencies but also higher order modulation and coding (MODCOM).

Although component and module level phase noise degradation has been determined for original equipment manufacturers (OEM's), system level total degradation is still a key parameter for achieving the desired data rates with pre-defined bit error rates (BER's).

THEORETICAL BACKGROUND

The signal at the output of a signal source can be simply modelled as

$$v(t) = A(1+\varepsilon(t))\sin(\omega_o t + \phi(t)) \tag{1}$$

where $v(t)$, A, $\varepsilon(t)$, ω_o, and $\phi(t)$ represent signal voltage, signal amplitude without distortion, amplitude distortion, radial frequency, and phase error. Phase error term can be further broken down to:

$$\phi(t) = \phi_{random}(t) + \phi_{deterministic}(t) \tag{2}$$

where $\phi_{random}(t)$ and $\phi_{deterministic}(t)$ represent the random and deterministic parts of the phase errors. Deterministic part of the phase errors is identifiable in the form of spurs and mixing products, but random variation cannot be represented in closed form. Thus, we assume all phase errors are non-deterministic. Through trigonometric identities, it's easy to show that (1) can be simplified as

$$v(t) = A(1+\varepsilon(t))\sin(\omega_o t) + A(1+\varepsilon(t))\phi(t)\cos(\omega_o t) \tag{3}$$

if $|\phi(t)| \ll 1$. Power spectral density of the signal can be expressed as

$$S_v(f) = \frac{A^2}{4} S_\phi(|f - f_o|) \tag{4}$$

for $\forall f \neq f_o$. Now, if we define one-sided power spectrum as.

$$L(f) = \frac{S_v(f + f_o)}{A^2/2} \tag{5}$$

for all $f > 0$. In terms of phase error power spectral density, we can simply restate as:

$$L(f) = \frac{1}{2} S_\phi(f) \tag{6}$$

where $S_\phi(f)$ represents the phase errors power spectrum for all $f > 0$.

Phase noise errors tend to smear the signal along the expected reference point and the compression errors tend to pull the measured signal inward whereas additive white Gaussian noise (AWGN) smear the measured signal in all direction relative to the expected signal level. Spurs on received signal also create larger circles of error on the demodulator.

Error vector magnitude (EVM) as displayed in Fig. 1, can be expressed as,

$$EVM = \sqrt{\frac{\int\left[v_{ref}(t) - v_{meas}(t)\right]^2 dt}{\int\left[v_{ref}(t)\right]^2 dt}} \tag{7}$$

where $v_{ref}(t)$ and $v_{meas}(t)$ represent expected and measured signals, respectively. For $|\phi(t)| \ll 1$, this expression can be further simplified to

$$|E|^2 = 2R^2 - 2R^2\cos(\phi) \approx R^2\phi^2 \tag{8}$$

and EVM can be represented as

$$EVM_{rms} \approx \phi_{rms} = \sqrt{2 \times \int L(f)\, df} \quad . \tag{9}$$

Hence, given EVM maximum allowed phase error can be found readily.

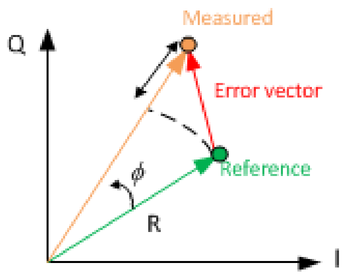


Figure 1. Depiction of error vector magnitude.

Phase noise in traditional Ku-band systems has been well studied and the performance metrics were captured in IESS-308 standard [7]. Military satellite communication systems phase noise spec has been stated in MIL-STD-188-164C [8-9]. Both specs are shown in Table I.

Table I. Common Phase Noise Standards

Offset Freq	IESS-308 (dBc/Hz)	MIL-STD-188-164C (dBc/Hz)
10 Hz	-30	-32
100 Hz	-60	-62
1 kHz	-70	-72
10 kHz	-80	-82
100 kHz	-90	-92
1 MHz	-90	-102
10 MHz	-90	-102

For 256 APSK with minimum C/N of 24 dB, EVM should be better than -30 dB. With a typical 20 MBaud/s transmission rate, standards given in Table I produce approximately -21.7 and -32.68 dB EVM values, respectively. While MIL-STD seems to satisfy this criterion for single source, in a typical chain there are more than several uncorrelated signal sources that contribute to total phase noise. Clearly, specifications in Table 1 will be inadequate for wideband, high data rate VHTS systems.

. SATELLITE LINK AND MEASUREMENTS

A typical satellite link is shown in Fig. 2. The modulator and demodulator are assumed to have their own respective local oscillators to create the modulated signal.

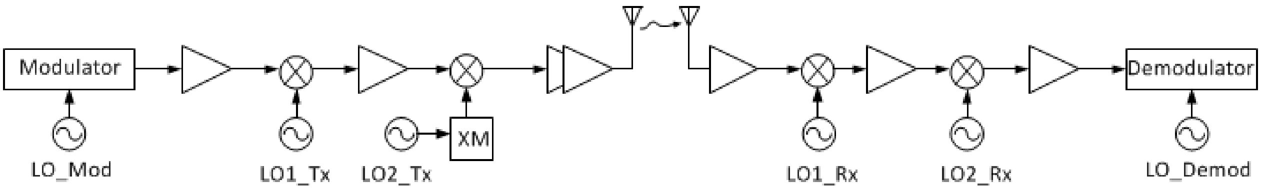


Figure 2. Typical satellite link.

Excluding the satellites, it is observe there are usually at least three signal sources involved in a typical satellite communication link. A measurement setup based on this link where the satellite is replaced with Ka-band satellite test-loop-translator (TLT) is shown in Fig. 3.

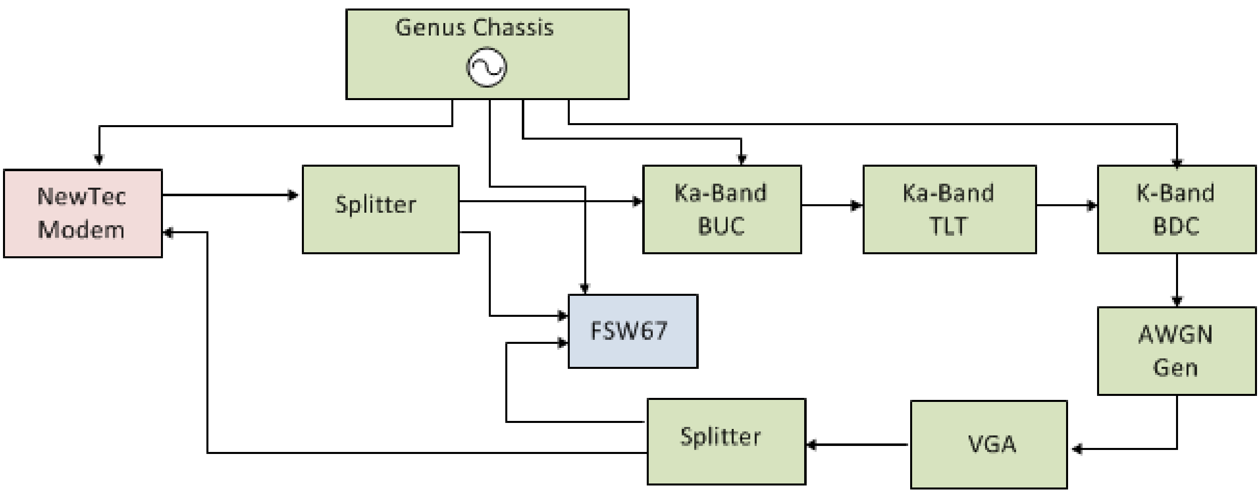
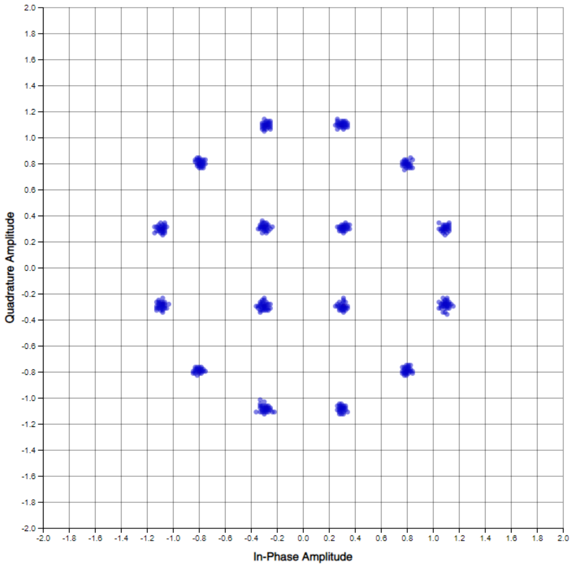
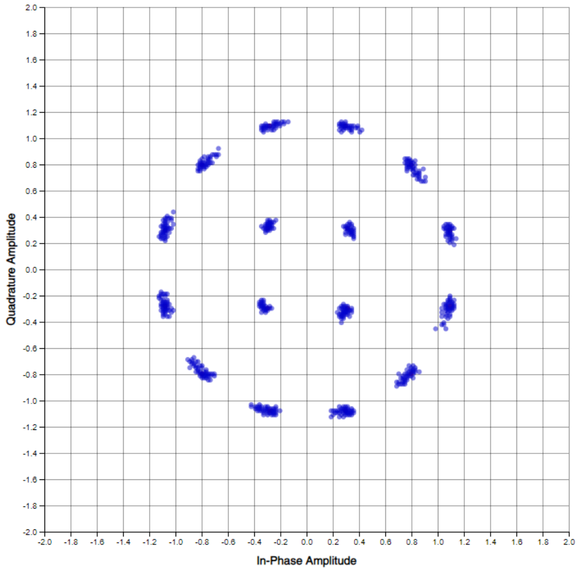


Figure 3. Measurement system.

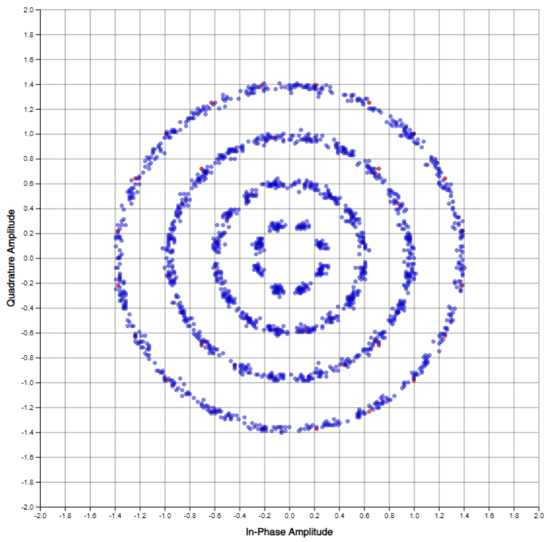
Received signal test results for 16 APSK, 64 APSK and 256 APSK are shown in Fig 4. Modem-to-modem without the satellite link is also illustrated for 16 APSK in Fig 4a.



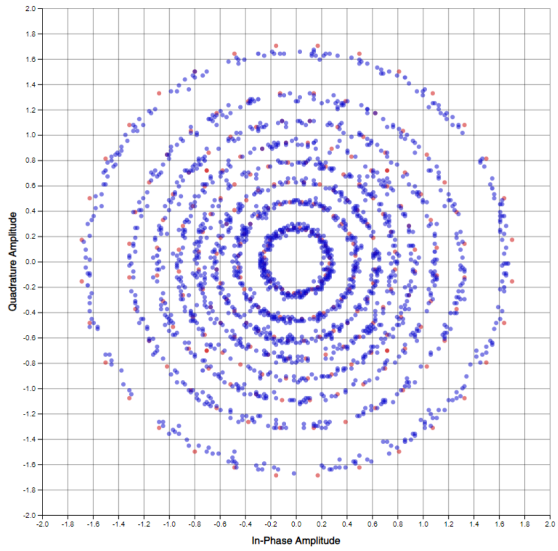
(a)



(b)



(c)



(d)

Figure 4. Measurement results with a modem a) 16 APSK with modem-to-modem test, b) 16 APSK with Ka-band satellite linl, c) 64 APSK with satellite link, d) 256 APSL with satellite link.

CONCLUSION

Phase noise modelling at the system level is critical for HTS and VHTS systems. The flexible payload that these system employ is modelled as a satellite-test-loop-translator, and MODCOM results for narrowband and wideband transmissions are presented. Phase noise model of the cascade system is essential for demanding target link targets.

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