Mitigating Photon Jitter in Optical PPM Communication

Compensation based partly on photon-arrival statistics would yield gain.

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A theoretical analysis of photon-arrival jitter in an optical pulse-position-modulation (PPM) communication channel has been performed, and now constitutes the basis of a methodology for designing receivers to compensate so that errors attributable to photon-arrival jitter would be minimized or nearly minimized. Photon-arrival jitter is an uncertainty in the estimated time of arrival of a photon relative to the boundaries of a PPM time slot. Photon-arrival jitter is attributable to two main causes: (1) receiver synchronization error [error in the receiver operation of partitioning time into PPM slots] and (2) random delay between the time of arrival of a photon at a detector and the generation, by the detector circuitry, of a pulse in response to the photon. For channels with sufficiently long time slots, photon-arrival jitter is negligible. However, as durations of PPM time slots are reduced in efforts to increase throughputs of optical PPM communication channels, photon-arrival jitter becomes a significant source of error, leading to significant degradation of performance if not taken into account in design.

For the purpose of the analysis, a receiver was assumed to operate in a photon-starved regime, in which photon counts follow a Poisson distribution. The analysis included derivation of exact equations for symbol likelihoods in the presence of photon-arrival jitter. These equations describe what is well known in the art as a matched filter for a channel containing Gaussian noise. These equations would yield an optimum receiver if they could be implemented in practice.

Because the exact equations may be too complex to implement in practice, approximations that would yield suboptimal receivers were also derived. One

Symbol-Error Rates were computed for a PPM receiver not subject to jitter and for PPM receivers subject to photon-arrival-jitter-induced inter-time-slot interference (neglecting inter-symbol interference), all for the case of 16-time-slot PPM words with an average of 0.2 noise photons per time slot and $\alpha = 0.2$ in a jitter-offset exponential distribution $f(\delta) = [1/(2\alpha)]e^{-|\delta|/\alpha}$, where $\delta$ is the jitter offset in units of one slot duration.

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Refer to NPO-43070, volume and number of this NASA Tech Briefs issue, and the page number.
A fiber-optic sensor system has been developed that can remotely measure
the concentration of molecular oxygen (O₂), nitrogen (N₂), hydrocarbon
vapor, and other gases (CO₂, CO, H₂O, chlorofluorocarbons, etc.) in the ul-
lage of a liquid-fuel tank. The system provides an accurate and quantitative
identification of the above gases with an accuracy of better than 1 percent by
volume (for O₂ or N₂) in real-time (5 seconds). In an effort to prevent airc-
raft fuel tank fires or explosions similar to the tragic TWA Flight 800 explo-
sion in 1996, OBIGGS are currently being developed for large commercial
aircraft to prevent dangerous conditions from forming inside fuel tanks by
providing an “inerting” gas blanket that is low in oxygen, thus preventing
the ignition of the fuel/air mixture in the ullage.

OBIGGS have been used in military aircraft for many years and are now stan-
dard equipment on some newer large commercial aircraft (such as the Boeing
787). Currently, OBIGGS are being de-
v eloped for retrofitting to existing com-
mercial aircraft fleets in response to
pending mandates from the FAA. Most
OBIGGS use an air separation module
(ASM) that separates O₂ from N₂ to
make nitrogen-enriched air from com-
pressed air flow diverted from the engine
(bleed air). Current OBIGGS systems do
not have a closed-loop feedback control,
in part, due to the lack of suitable
process sensors that can reliably measure
N₂ or O₂ and at the same time, do not
constitute an inherent source of ignition.

Thus, current OBIGGS operate with a
high factor-of-safety dictated by process
protocol to ensure adequate fuel-tank in-
erting. This approach is inherently ineffi-
cient as it consumes more engine bleed
air than is necessary compared to a
closed-loop controlled approach. The
reduction of bleed air usage is important as
it reduces fuel consumption, which
translates to both increased flight range
and lower operational costs.

Numerous approaches to develop-
ing OBIGGS feedback-control sensors
have been under development by
many research groups and companies.
However, the direct measurement of
nitrogen (N₂) is a challenge to most
OBIGGS ullage sensors (such as tun-
able diode laser absorption) as they
cannot measure N₂ directly but de-