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A COMPARISON BETWEEN COHERENT AND NONCOHERENT MOBILE SYSTEMS IN LARGE DOPPLER SHIFT, DELAY SPREAD AND C/I ENVIRONMENT

KAMILO FEHER
University of California, Davis; Davis, CA 95616
916-752-8127 or 916-752-0583; FAX 916-752-8428

ABSTRACT

The performance and implementation complexity of coherent and of noncoherent QPSK and GMSK modulation/demodulation techniques in a complex mobile satellite systems environment, including large Doppler shift, delay spread and low C/I, are compared. We demonstrate that for large $f_d T_b$ products, where f_d is the Doppler shift and T_b is the bit duration, noncoherent (discriminator detector or differential demodulation) systems have a lower BER floor than their coherent counterparts. For significant delay spreads, e.g., $\tau_{rms} > 0.4\ T_b$ and low C/I coherent systems outperform noncoherent systems. However, the synchronization time of coherent systems is longer than that of noncoherent systems.

Spectral efficiency overall capacity and related hardware complexity issues of these systems are also analyzed. We demonstrate that coherent systems have a simpler overall architecture (IF filter implementation-cost versus carrier recovery) and are more robust in an RF frequency drift environment. Additionally, the prediction tools, computer simulations and analysis of coherent systems is simpler. The threshold or capture effect in low C/I interference environment is critical for noncoherent discriminator based systems.

We conclude with a comparison of hardware architectures of coherent and of noncoherent systems, including recent trends in commercial VLSI technology and direct baseband to RF transmit, RF to baseband (0-IF) receiver implementation strategies.

MODEM/RADIO ARCHITECTURES

In Fig. 1 a Quadrature (QUAD) modulator, nonlinearly amplified (NLA) modulator radio architecture is illustrated. The Baseband Processor (BBP) could implement conventional QPSK [6] $\pi/4$-DQPSK [1, 7] or Gaussian MSK, GMSK functions [6, 8]. In the baseband to RF implementation, a slow Frequency Hopped Spread Spectrum-TDMA application is illustrated. The demodulation could be coherent or differential (discrimination detection) as illustrated in Fig. 2 and Fig. 3, from Ref. [1].

DEFINITIONS

QPSK	Conventional QPSK [6]
$\pi/4$-QPSK	$\pi/4$-shifted QPSK - The standard modulation technique for IS-54-EIA standard [7] as well as for the Japanese digital cellular system.
GMSK	Gaussian filtered MSK [6] used in the DECT European standard [8] with noncoherent receivers and the GSM European system with coherent receivers.
F-QPSK	Feher's filtered QPSK [5, 6] for nonlinearly amplified systems. This modem/radio [2] doubles the capacity of European GMSK standard cellular/wireless systems.

PERFORMANCE

The $P(e) = f(E_b/N_o)$ performance in a Rayleigh faded channel is illustrated in Fig. 4. Note that the coherent F-QPSK system has a 7dB advantage over the noncoherent GMSK system filtered with $BT_b = 0.5$ [2]. The integrated out-of-band spectrum (ACI = adjacent channel interference), Fig. 5, indicates that F-QPSK is about 50% more spectrally efficient than GMSK. In Fig. 6 and Fig. 7 the performance in large Doppler $\log(f_D T)$ and large delay spread environment is illustrated. Coherent and differential $\pi/4$-QPSK results are presented, based on [9]. These illustrative sample results are summarized in Table 1, based on Ref. [1]. In this Table, a comparison of coherent-noncoherent GMSK and F-QPSK systems is presented.

REFERENCES

[1] K. Feher, *Cellular Digital Personal Communications*, (working title), A forthcoming book under contract with Prentice Hall, Inc., Englewood Cliffs, NJ, USA. Expected publication year: 1994.

[2] P. Leung, K. Feher, "Low Cost F-QPSK Modem Radio Solutions for Doubling the Capacity of European Standard Cellular/PCS Systems," *Proc. of the Wireless Symposium and Exhibition*, San Jose, CA, Jan. 1993.

[3] T. Le-Ngoc, S. Slimane, "IJF-OQPSK Modulation Schemes with MLSE Receivers for Portable/mobile Communications," *Proc. IEEE 42nd Veh. Tech. Conference*, pp. 676-680, Denver 1992.

[4] Y. Guo, K. Feher, "Frequency Hopping F-QPSK for Power and Spectrally Efficient Cellular Systems," submitted to IEEE Vehicular Technology Conference, 1993.

[5] K. Feher, "Filter: Nonlinear Digital," US Patent No. 4,339,724, issued July 13, 1982; Canada No. 1130871, August 31, 1982.

[6] K. Feher, Ed., *Advanced Digital Communications Systems and Signal Processing Techniques,*" Prentice-Hall, Englewood Cliffs, NJ, 1987.

[7] EIA IS-54 Dual-mode subscriber equipment - Network equipment compatibility specification, December 1989.

[8] DECT Specification. Physical Layer, CI SPEC Part 1, Rev 06.0.

[9] K. Feher, "Modems for Emerging Digital Cellular-Mobile Radio Systems," *IEEE Trans. on Vehicular Technology*, May 1991.

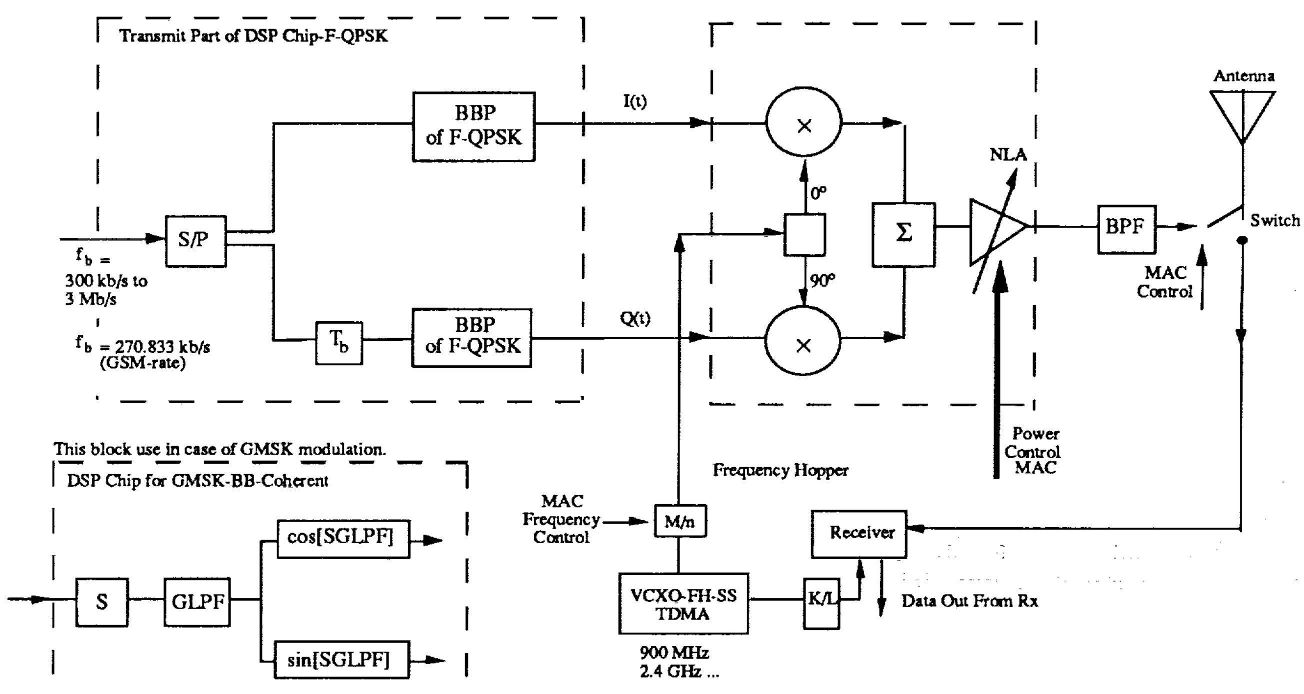

Fig. 1 Transmitter of a BB to RF radio for F-QPSK or GMSK nonlinear amplifier applications (slow frequency hopping-spread spectrum SFH-SS-TDMA) Ref. [1].

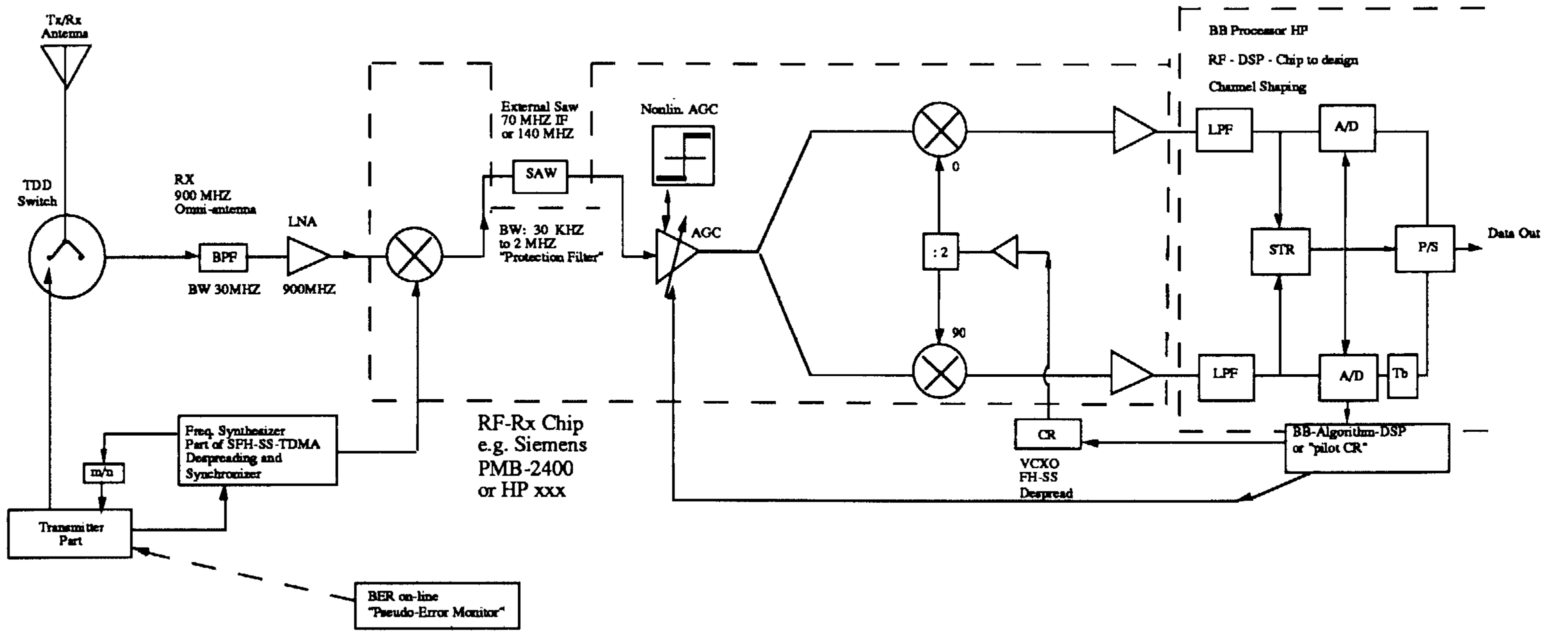

Fig. 2 Receiver with one IF stage for Coherent F-QPSK or GMSK systems (TDMA-TDD-SFH-SS) [Ref. 1].

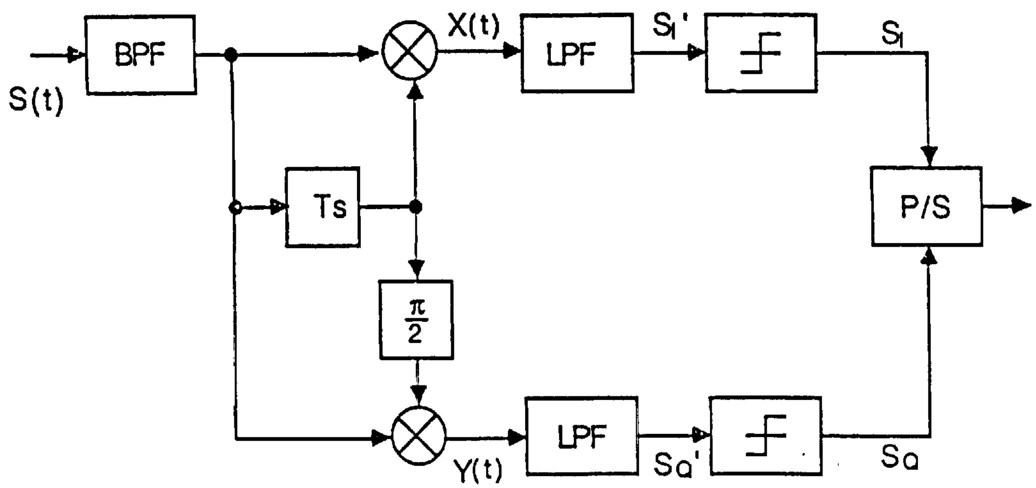

Fig. 3 Differential Demod of a QPSK modem.

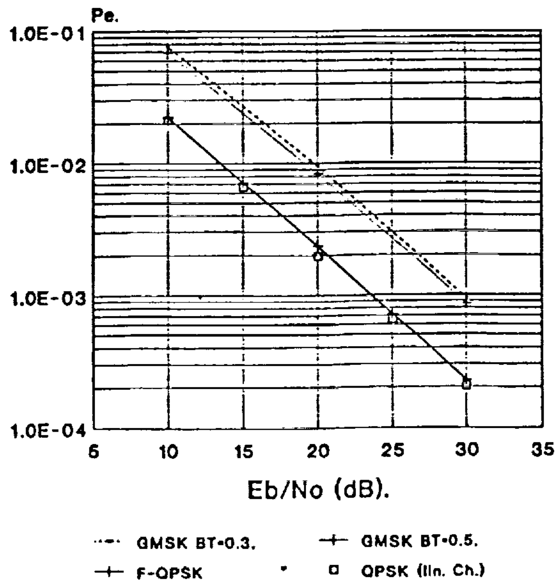

Fig. 4 BER of coherent F-QPSK and noncoherent GMSK BT=0.5 (DECT) in Rayleigh fading.

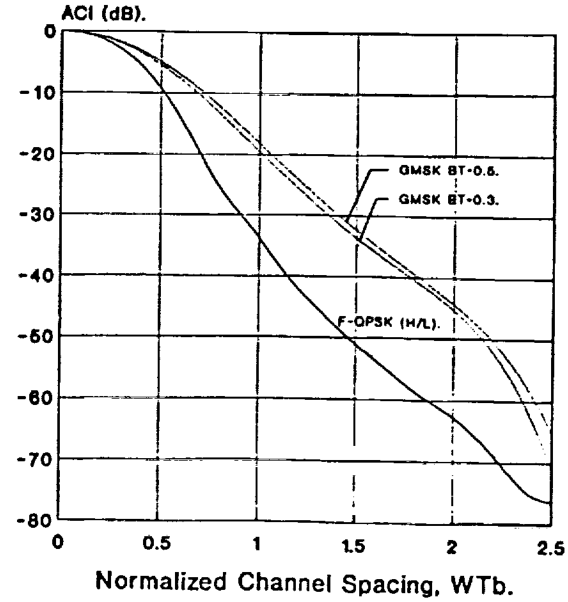

Fig. 5 ACI of F-QPSK and GMSK.
F-QPSK: Butterworth BPF (4 ord), BiTb=.55
GMSK: Gaussian BPF (4 ord), BiTb=0.6.

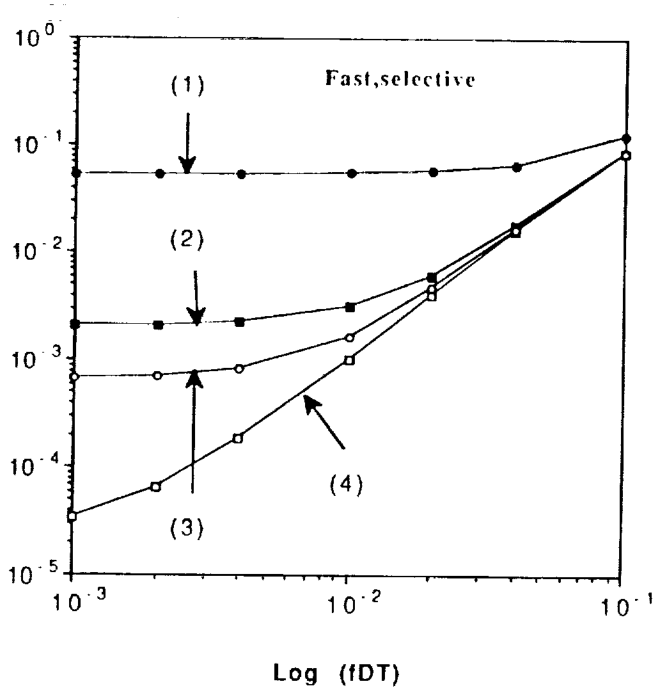

Fig. 6 P(e) vs. f_DT of π/4-DQPSK in a frequency-selective fast fading channel. f_c=850 MHz, f_s=24 kBaud, α=0.2, C/I=∞ dB. (1) τ/T=0.1, C/D=10 dB, (2) τ/T=0.1, C/D=30 dB, (3) τ/T=0.5, C/D=10 dB, (4) τ/T=0.5, C/D=30 dB.

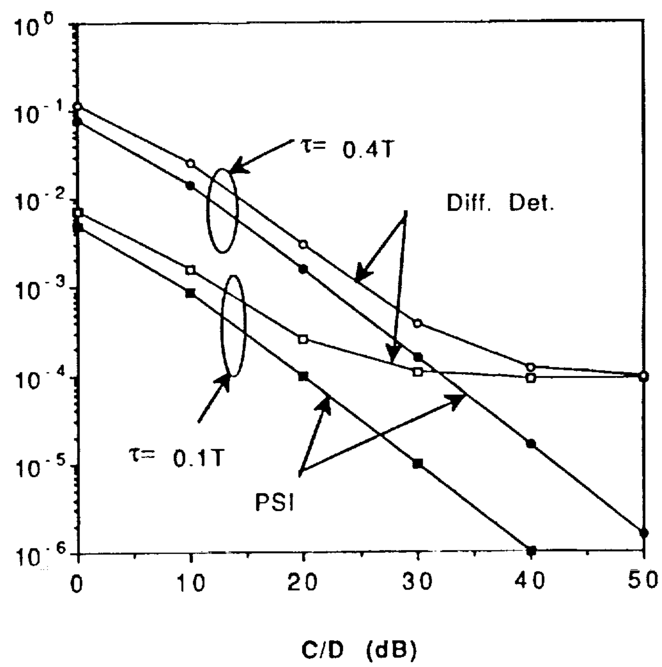

Fig. 7 Error-floors of the fade compensated π/4-QPSK and π/4-DQPSK in a frequency-selective fading channel as functions of C/D for τ=0.1T and 0.4T. The fading rate is assumed to be $f_DT=3\times10^{-3}$.

Table 1 Coherent-Noncoherent GMSK and F-OPSK Comparison. Ref. [1].

Maximal bit rate and delay spread τ_{rms} issues	**COHERENT QPSK OR F-QPSK** (or GMSK-similar, however worse performance.)	**DIFFERENTIAL DQPSK** (or DGMSK)
τ_{rms} "worst case" 1μs		
τ_{rms} = 200 ns		
BER = 10^{-2} floor due to τ_{rms}/T_s	$\tau_{rms}/T_s = 0.2$	$\tau_{rms}/T_s = 0.15$
$P_{(e)}$ = C/I degrad(addit) of 1dB due to τ_{rms}/T (4*more sensit. than for "floor"	$\tau_{rms}/T_s = 0.075$ QPSK F-QPSK is higher abut 50%	$\tau_{rms}/T_s = 0.05$
Maxim. bit rate f_b		
for 10^{-2} Error Floor 1μs[200ns]	600 kb/s [3 Mb/s]	300 kb/s [1.5 Mb/s]
for 1dB τ_{rms} caused degr. 1μs[200ns]	150 kb/s [750 kb/s]	75 kb/s [375 kb/s]
CAPACITY ISSUES BASED ON C/I = 3 dB (CCI advantage)	BER=10^{-2} C/I-15dB (Rayleigh)	BER=10^{-2} C/I=18dB
NORMALIZED RELAT. CAPACITY		
Based on k = 9 to k = 7 reuse	100%	70% (30% loss)
Based on WER and throughput	100%	20% (80% loss)
Spectral efficiency ACI and BPF versus LPF caused advantage, i.e., lower noise BW-coherent receiver (normalized to coherent)	100%	60%
Increased Bit Rate or Cell Coverage/Adaptive Equalization	Relatively simple/low cost DSP/SW adaptive equalizer could increase rate (coverage)	Very costly if at all feasible adaptive equalization technology (theory not well understood-requires original new research).

Table 1 (continued) Coherent-Noncoherent GMSK and F-QPSK Comparison.

	COHERENT QPSK	DIFFERENTIAL DQPSK
Bit rate (PHY) change, without loss of performance (within range)	Automatic SW (software controlled) in BBP	Very difficult could require change of IF-BPF
Spectral Efficiency for ACI=-20dB nonlinearly amplified radio	F-QPSK = 1.42 b/s/Hz GMSK = 0.94 b/s/Hz $BT_b = 0.5$ and 0.98 b/s/Hz for $BT_b = 0.3$	Approx. 0.7 b/s/Hz depending on BPF complexity
Synchronization Time (CR) (relative to no CR - differential loss of frame efficiency for 1000 or 10,000 bit word (packet)	50 bits:1000 = 5% (max 100 bits = max 10% 50 bits:10,000 = 0.5% max 100 bits for CR=max.1% - a disadvantage. Parallel CR and STR design could eliminate this drawback.	Potential of 1% to 10% packet/synch time advantage(?). However, could be lost due to BPF transient ringing. Synch. Time advantage could be lost due to DC comp. to sat. time requirement.
Threshold capture effect (discriminator-impulse noise)	No problem	Potential problem in the critical BER = 10^{-2} range with discriminator.
Tools (prediction)	Well known.	Much more involved as IF-BPF imperfect; impact of frequency tolerance GMSK $BT_b = 0.3$ very difficult.
RF-oscillator drifts include synthesizer - impact on BER - DC restoration.	Simple.	Very costly - potential danger like in DECT.
Additional down conversion/filters	Not required.	Very costly, extra stage could be required due to lower IF and BPF problems.
Carrier Recovery Requirements	Yes. Simple pilot in band and other Costas . . . well-known techniques. No Doppler problem. Low power solution. GSM, ADC other cellular have it.	No need for CR. Advantage
DC power-extra for CR	Could be marginally higher for demand alone.	Discriminator power requirement is smaller than coherent. However, DC battery power advantage could be lost due to LO or synthesizer-DC compensation requirement.
IC Chips-Trend	Most manufact. companies developing QUAD (coherent struct.)	Noncoherent discrim. today cheaper however overall radio extra IF, BPF, DC compensation not evident.
Overall Cost/DC Power estimate	About same as noncoherent receiver (total radio) with new technology.	About same.
RF Frequency 900MHz 1.9GHz, 2.4GHz Bit Rate Variation	Same architecture for both RF frequencies Flexible bit rate	Could require in some applications extra expensive IF stage (space/cost) does not lead to software driven bit rate change