Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [ISM and Worldwide Band Modulation for Mandatory 50kbps]
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Re: []

Abstract: [Supporting presentation for 15.4g FSK 50kbps mandatory mode. Background and elaboration.]

Purpose: [Proposed resolution to TG4g comment #324. Presented to the 802.15.4g SUN Task Group for consideration.]

Modulation for Mandatory Mode

- A comment has been made to replace FSK with GFSK for the 15.4g PHY 50kbps mandatory data rate mode, alleging it offers better performance

- The argument that GFSK is a better modulation type than FSK for reasons of performance, harmonization, and coexistence is debatable

  - FSK can actually offer better performance than GFSK

  - Harmonization involves many parameters (data rate, modulation, modulation index, etc.), not just modulation….

  - Coexistence is a complex topic, not just a discussion about sidelobes and spurs
    - FSK systems can be designed to coexist as well as GFSK systems

- Modulation index and tolerance are as important as modulation type

Sensitivity

- It is standard practice to compare sensitivity numbers for a specific datarate by including the <u>modulation index</u> and, ideally, the receiver IF bandwidth…

Datarate = 50kbps   Measured Data in the ISM Band 902-928MHz

Modulation	Mod Index	IF bandwidth	Sensitivity (dBm)
FSK	1	100kHz	-107.2
GFSK	1	100kHz	-107.4
FSK	1	150kHz	-107.2
GFSK	1	150kHz	-107
FSK	0.8	100kHz	-107.4
GFSK	0.8	100kHz	-106.9
FSK	0.8	150kHz	-107.2
GFSK	0.8	150kHz	-106.5
FSK	0.5	100kHz	-107
GFSK	0.5	100kHz	-104.6
FSK	0.5	150kHz	-106.8
GFSK	0.5	150kHz	-104.6

Here, FSK shows better sensitivity than GFSK for 5 of the 6 profiles…

Does the FSK spectral mask <u>really</u> look like this when implemented in silicon?
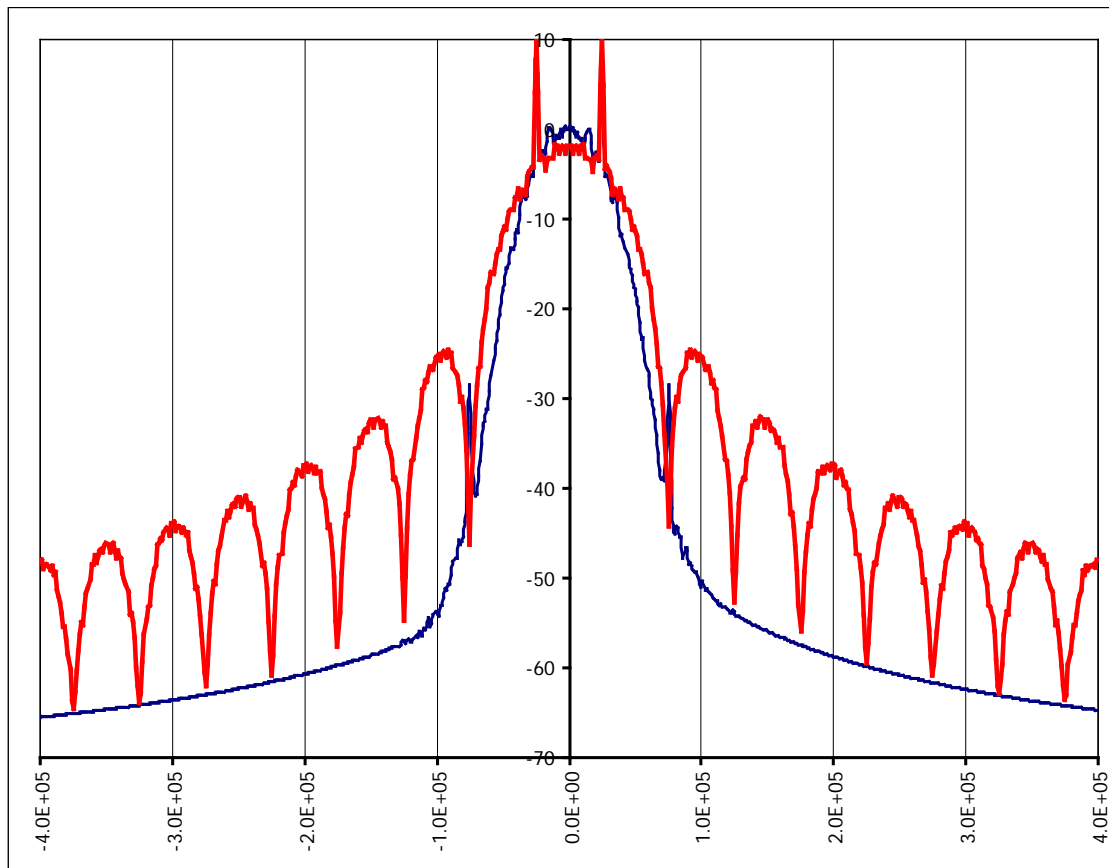
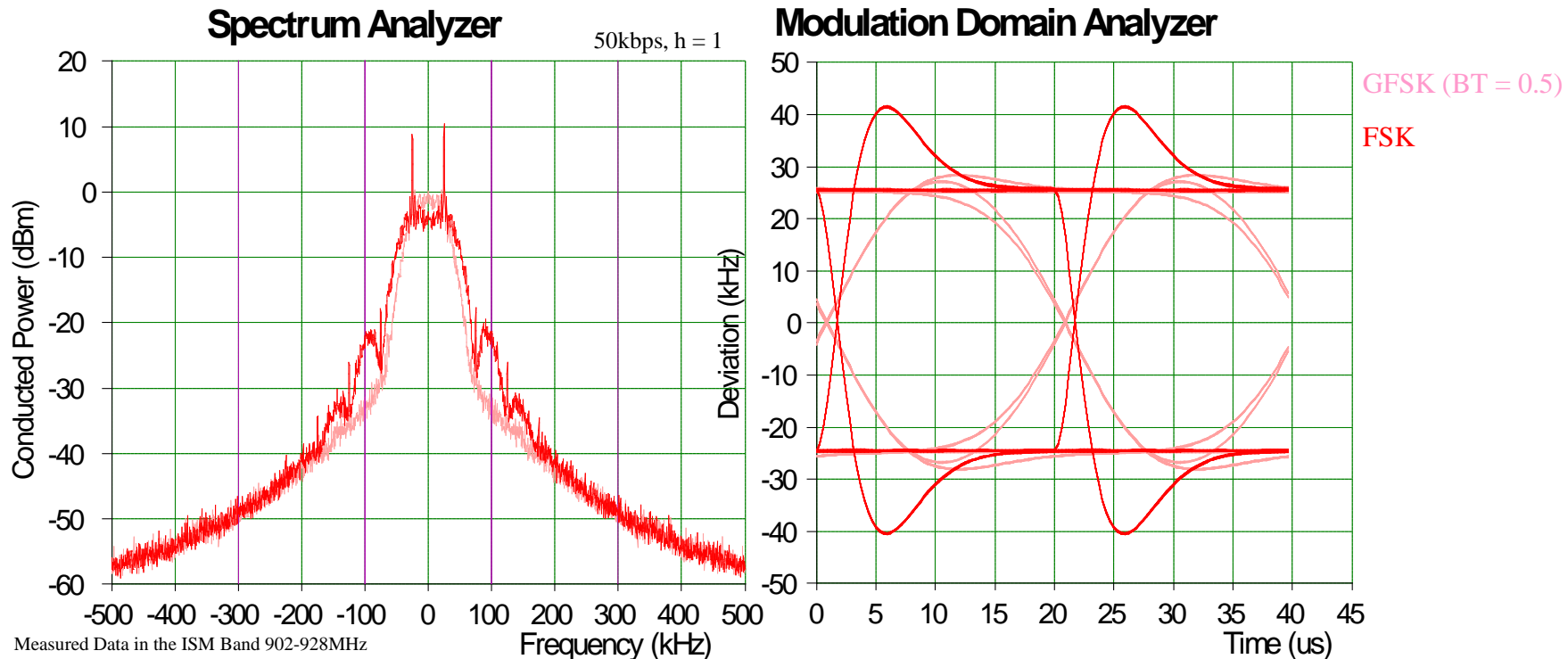Data Rate: 50 kbps
Modulation Index: 1.0
— 2-FSK
— 2-GFSK BT=0.5

from IEEE 802.15-10-0096-01-004g

FSK on silicon is not FSK in simulation…

Current FSK radios all incorporate some level of inherent filtering…

1) This might be:
    1) a low pass filter e.g. a Butterworth (maximally flat response) or
    2) a simple 2 stage RC Filter that replaces a Gaussian Filter
2) The low pass filter can be:
    1) inserted at baseband (we low pass filter the digital bit stream) before FSK modulation or
    2) it can be done at RF (with the RF Tx PLL Loop bandwidth)

Spectrum Analyzer

50kbps, h = 1

Modulation Domain Analyzer

GFSK (BT = 0.5)

FSK

Measured Data in the ISM Band 902-928MHz

Modulation Index Tolerance

- In order to allow low cost radio designs, it is common to see modulation index tolerances on the order of the +/- 20% currently specified in 15.4g
- Bluetooth, for example, specifies h = 0.28 to 0.35
- 802.15.4d (Japanese 950MHz band) specifies +/- 30%!
- As the modulation index:

$$h +/- \Delta h = 2 * f_{dev} / DR$$

for a fixed datarate changes, the deviation frequency and, hence, GFSK ISI and sensitivity will vary, too…

  – FSK systems can be designed to have much lower ISI than GFSK systems, hence sensitivity is not as much a function of modulation index

Variations in modulation indexes adversely affect GFSK

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GFSK	0.5	150kHz	-104.6

~3dB!

Modulation index tolerance is currently specified in 15.4g as +/- 20%...

FSK sensitivity only varies about <u>0.3dB</u> from h = 0.5 to 1.0…

Coexistence is Complex

1) Coexistence depends on differences in frequency, time, space, modulation or coding or a combination of these
2) Coexistence depends on topologies and operating conditions of networked nodes in the impacted frequency band
3) Coexistence depends on parameters such as peak power, modulation type, modulation index, receiver threshold, propagation channel, inter-nodal spacings and distances, etc.

FSK systems can be designed to co-exist as well as GFSK systems

FSK is a better option than GFSK for .4g

1) FSK has equal or superior sensitivity compared to GFSK
2) FSK presents lower ISI compared to GFSK
3) FSK has negligible variation in sensitivity as a function of modulation index compared to GFSK
4) FSK is currently deployed in utility applications at much higher volumes than GFSK…
5) Current FSK radios all incorporate some level of inherent filtering which assists the spectral purity of FSK with lesser ISI than that of GFSK

Summary

	FSK	GFSK
Proven in the Field for (>=50kbps) Utility Applications (Volumes > 5Mu)	☺	
Best overall sensitivity	☺	
Lowest variation in sensitivity to changes in mod index	☺	
Lowest Intersymbol Interference (ISI)	☺	
Sufficient Spectrally Efficiency given .4g Channel Spacing Definitions (>= 200kHz) and -90dBm Sensitivity Specification	☺	☺
Lowest Complexity & Lower Power (Gas/Water)	☺	
Harmonization of The Mandatory Data Rate	?	?
Conclusion	FSK is the best option for .4g with many advantages over GFSK!	