DISCUSSION OF MODULATION PARAMETERS FOR THE 2.4 GHz FREQUENCY HOP PHYSICAL LAYER

Jim McDonald
Motorola, Inc
JULY, 1993

SCOPE OF PAPER

- Discuss the relative merits of four level and two level FSK modulation.
- Propose selection of BT product and modulation index.

DISCUSSION OF 4 LEVEL AND 2 LEVEL

- Identify systems of comparison
- Identify the basis of comparison
- Present side by side performance comparison
- Discuss issues of relative economic viability
- Summarize
- Present conclusions

SYSTEMS OF COMPARISON

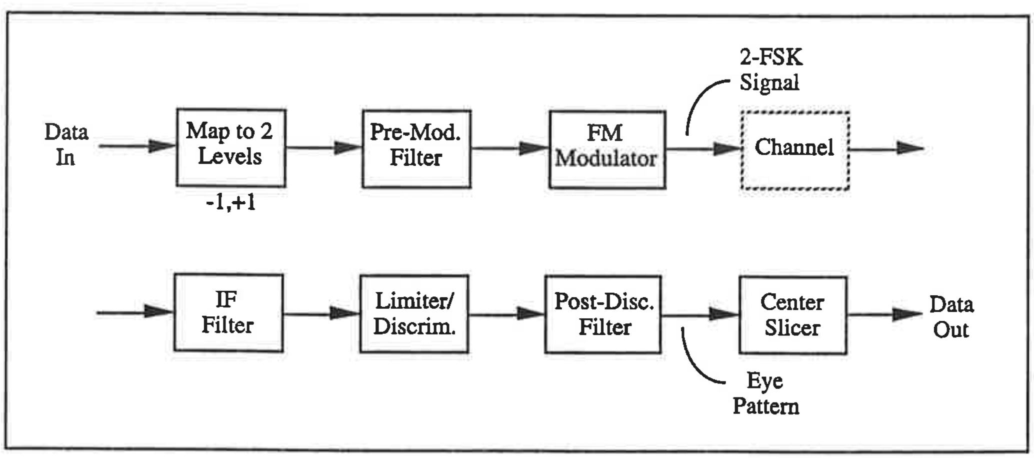
- Comparable restraints for both the 4 level and 2 level systems.
  - Same data rate
  - Same bandwidth
- For this exercise the occupied 99% power bandwidth of both the 4 level and 2 level systems will be set to 1 MHz.
- Relative conclusions would also apply if the 20 dB bandwidth criteria were used.

2 LEVEL SYSTEM (0.39 GMSK)

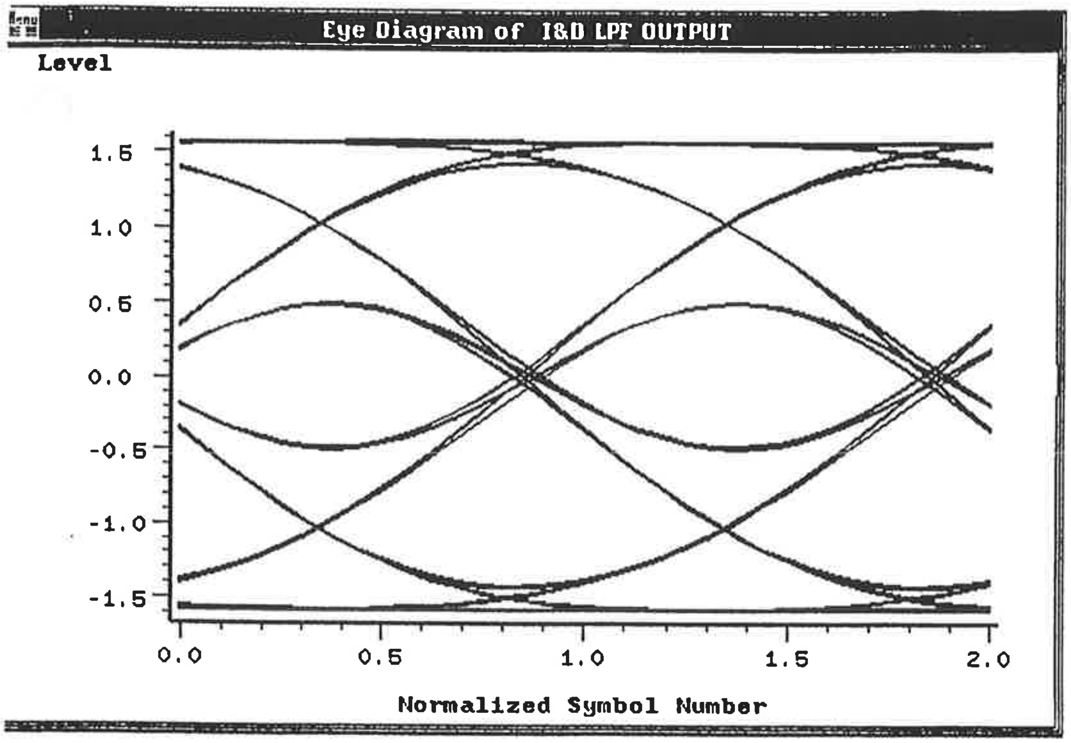
- Uses Gaussian premodulation filter.
- Deviation set to 250 kHz.

4 LEVEL SYSTEM

- Uses square root raised cosine premodulation filter.
- Deviation set to 275 kHz.



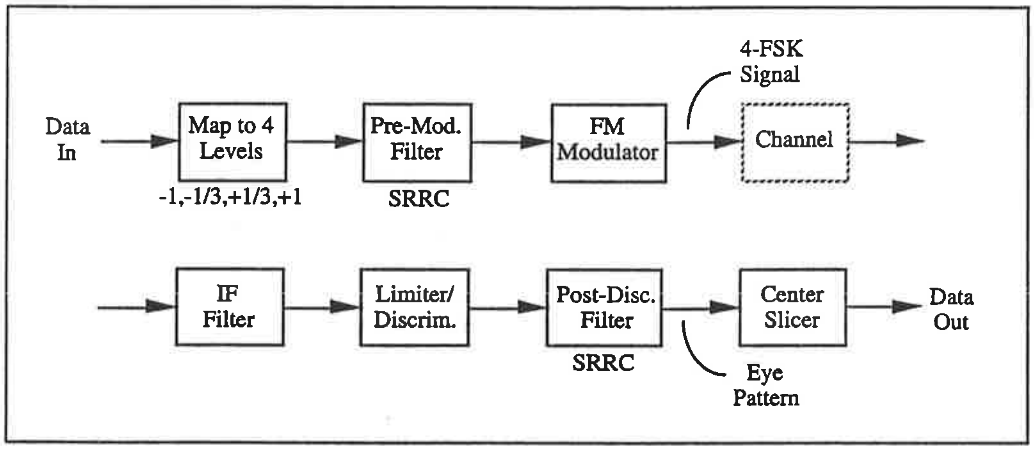
Block Diagram of the Two-Level System



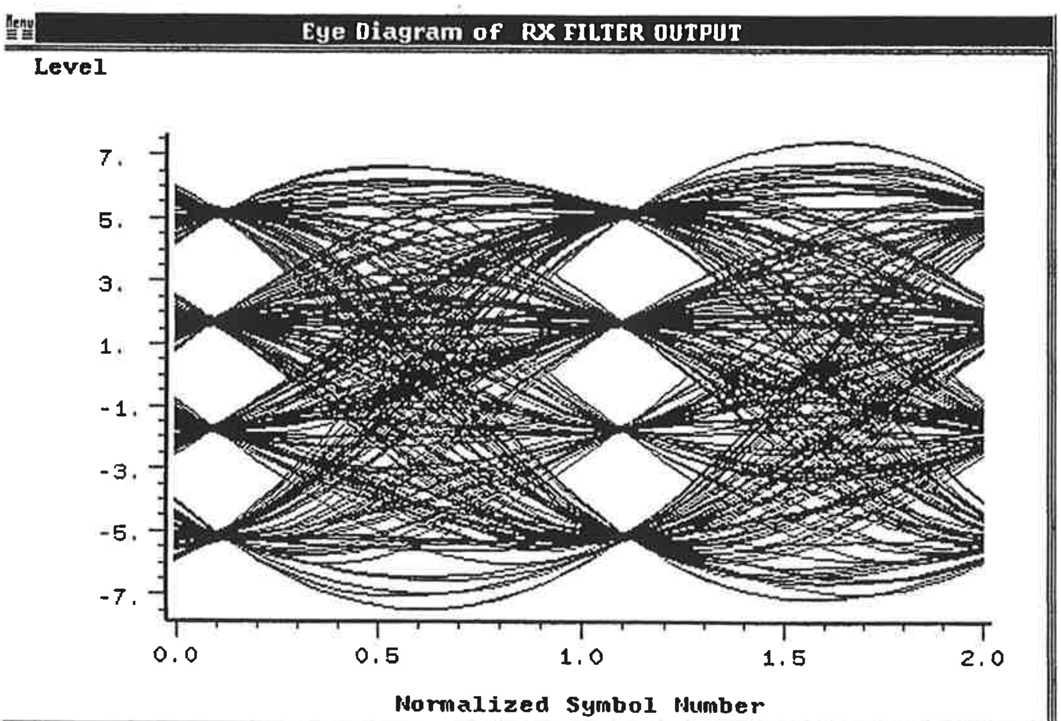
Eye-Pattern of Two-Level System

RAISED COSINE FILTERS

- Used in communications systems because they have the property of no intersymbol interference, i.e., the eyes are fully open.
- One square root cosine filter is used at transmitter for splatter protection and another at the receiver for post demodulation filtering.
- The combined effect is raised cosine.
- Used on four level systems such as U.S. Digital Cellular with $\pi/4$ QPSK, Japan Digital Cellular with $\pi/4$ QPSK, and RD-LAP with FSK.
- Refer to K. Feher, Digital Communications; Satellite / Earth Station Engineering, Prentice-Hall, New Jersey, 1983.



Block Diagram of the Four-Level System



Eye-Pattern for the Four-Level Raised-Cosine System

SYSTEM COMPARISON

System	Bit Rate	Modulation Filter	Deviation	IF Filter
2 Level	1 MB/S	Gaussian	250 kHz	SAW*
4 Level	1 MB/S	SRRC	275 kHz	SAW*

--SAW Filter: 3 dB BW > 1.0 MHz, 20 dB BW < 2.5 MHz
ote: Power outside 1 MHz bandwidth is -21.3 dB/2 level, -21.2/4 level.

SIMULATED SENSITIVITY- Eb/No

SYSTEM	SIMPLE DEMODULATOR	COMPLEX DEMODULATOR
2 LEVEL	1 BIT INTEGRATOR AND SLICER 18 dB	2 BIT INTEGRATOR AND 4 LEVEL SLICER 13 dB*
4 LEVEL	SIMPLE DEMODULATOR NOT APPLICABLE	SRRC AND 4 LEVEL SLICER 11 dB

--Based on actual measurement. It is expected that longer integration eriods would improve performance 1 dB or more.

TRANSMITTER SPLATTER IN ALTERNATE CHANNEL

- Simulations were done with a brickwall filter having a passband from F_C + 1.5 MHz to F_C +2.5 MHz

- There are two primary sources of noise:
    1. Modulation splatter
    2. VCO Noise

- Modulation Splatter

    With 2 Level (0.39 GMSK) noise is -72 dBc

    With 4 level SRRC deviation at 275 kHz noise is -87 dBc

- VCO noise floor of commercial modules measures to be -140 dBc/Hz or -80 dBc in 1 MHz BW. Assuming tolerance for practical issues and the observation that the floor is not reached at the alternate channel, a relative noise power of -70 dBc is estimated.

ALTERNATE-CHANNEL NOISE POWER FROM TRANSMITTERS dBc in 1 MHz BAND CENTERED at + 2 MHz

SYSTEM	MODULATION SPLATTER	VCO NOISE	TOTAL
2 LEVEL	-72 dBc	-70 dBc	-68 dBc
4 LEVEL	-87 dBc	-70 dBc	-70 dBc

Conclusion: Improved splatter performance of 4 level SRRC modulation has limited benefit because of the sideband noise of practical VCO's

ISSUES OF ECONOMIC VIABILITY

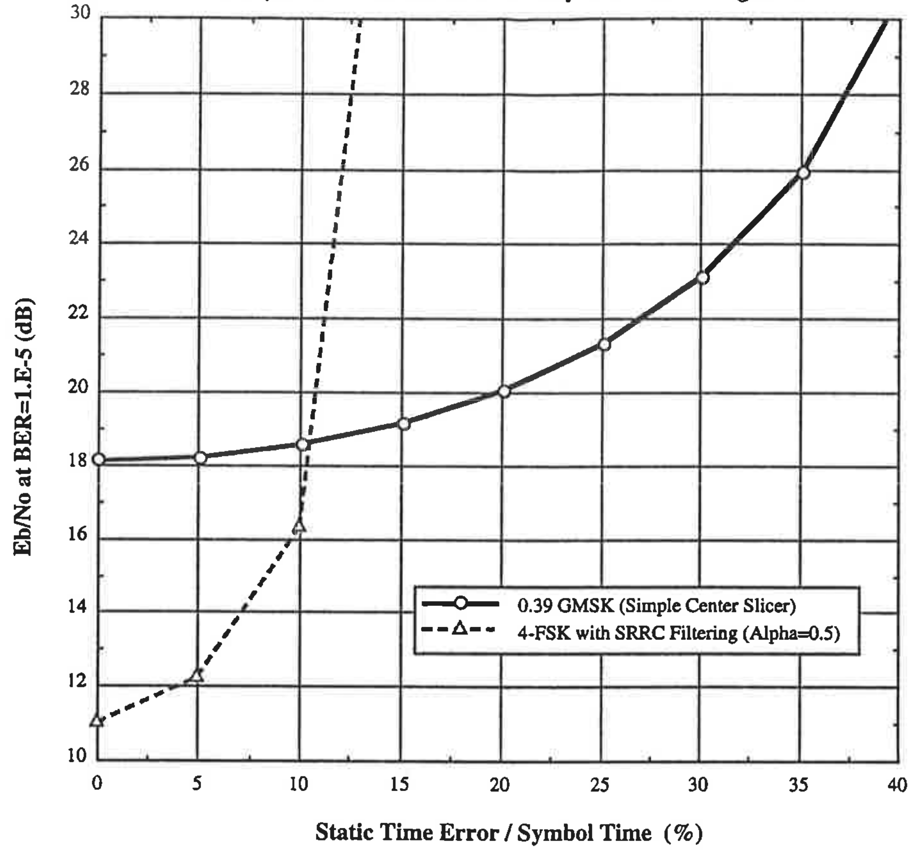
With respect to a two level system, four level FSK systems impose the following issues relating to economic viability.

- SRRC filters in both receivers and transmitters.
- A 4 level slicer and related automatic compensation for variations in levels.
- DSP or very large gate array is appropriate for demodulation.

ISSUES OF ECONOMIC VIABILITY
CONTINUED...

- Center frequency tolerance is more critical.
- Deviation control is more of an issue.
- Phase distortion is more critical.
- Longer preamble and sync required.
- Greater sensitivity to recovered clock error.

Binary and 4-Level FSK Sensitivity to Static Timing Error



SUMMARY

- With DSP or complex ASIC demodulator, BER performance of 2 level and 4 level CPFSK at 1 Mb/s is very close.
- DSP or complex ASIC demodulators raise issues of viability.
- Issues of tolerance susceptibility with 4 level also raise issues of economic viability.
- DSP or complex ASIC demodulators raise issues of power consumption in small battery operated equipment.
- A 2 level system provides the opportunity to operate with adiscriminator and simple slicer at about 5 or 6 dB more Eb/No.
- The apparent advantage of alternate channel selectivity available with 4 level is negated by VCO sideband noise.

CONCLUSION

Binary is the appropriate modulation for IEEE 802.11.

- It meets the data rate requirement.
- It provides for economically viable implementation.
- It provides for the options of more complex high performance demodulators.
- Binary is more forgiving of system tolerance issues.
- The option of a gear shift to a higher data rate option using four level is left in place with a baseline 1 Mb/s binary system.

SELECTION OF BT PRODUCT AND MODULATION INDEX

General Form of Modulation is:

- Binary 1 Mb/s
- CPFSK
- Premodulation filter is Gaussian
- 3 dB point of premodulation filter is BT. Three options mentioned are:
  - 0.39
  - 0.50
  - 0.70

- With a given BT product, the deviation is set to provide a 20 dB bandwidth of 1 MHz

INTERPRETATIONS OF THE FCC 1 MHz RULE

- Aggressive Interpretation

  99% of the power within 1 MHz bandwidth

- Conservative Interpretation

  20 dB bandwidth defined relative to center frequency with a narrow resolution filter

- Based on the conservative interpretation of the FCC bandwidth rule:

  What is the impact of BT and deviation on system performance?

BT AND DEVIATION OPTIONS CORRESPONDING TO THE CONSERVATIVE INTERPRETATION OF THE FCC BANDWIDTH RULE IN TERMS OF Eb/No in dB

BT	Deviation --kHz	Attenuation @ ±500 kHz --dB	Sensitivity with 1 Bit Integrator & Slicer	Sensitivity with 2 Bit Integrator & 4 Level Slicer
0.39	190	20.3	20.6	15.5
0.50	175	20.5	19.3	15.5
0.70	160	20.3	18.5	16.5

BT AND DEVIATION OPTIONS CORRESPONDING TO THE CONSERVATIVE INTERPRETATION OF THE FCC BANDWIDTH RULE

ALTERNATE-CHANNEL PROTECTION in dB

BT	Deviation --kHz	Composite of Modulation and VCO Noise in Alternate-Channel--dBc	Alternate-Channel Protection in dB (simple slicer)
.39	190	-69	48.4
.50	175	-69	49.7
.70	160	-63	44.5

PROPOSAL

EE 802.11 specifies a minimum deviation based on the nservative interpretation of the FCC bandwidth rule.

sume for instance that the committee selects a BT product of 0.50.

e conservative interpretation implies that the deviation is 175 kHz. owing for tolerance, the IEEE might specify the deviation as "at st 160 kHz".

e regulating agency imposes the upper limit. Noting that the gressive interpretation has a deviation of 210 kHz, only 20% her here is no problem with interoperability.