*To:* FCC Technological Advisory Council

*From:* Dr. Arthur Ross, Independent Telecommunications Consultant

*Subject:* Comments on Spectrum Management/Software Radio Question

The Commission's charter to the Technological Advisory Council requested, in part:

> "Please assess and report to the Commission the current state of the art for software defined radios, cognitive radios, and similar devices and, to the extent possible, predict future developments for these technologies. Please also suggest ways that the availability of such devices might affect the FCC's traditional approaches to spectrum management, as well as ways the agency could facilitate experimentation and commercial deployment of such devices."

This is, in a sense, the wrong question. It is more appropriate to ask what effect spectrum management will have on the development of such devices. Due to the realities of semiconductor device physics, an enlightened regulatory policy will be *necessary* if such devices are to be practical. The products will follow from the policy, not the other way around.

I fully agree with Lucent Technologies' comments[1] about the properties of wideband spread spectrum technologies – paraphrasing briefly:

- The software radio is not a fundamentally new notion. It's performance is limited by the A-to-D converter, and the dynamic range of the signals it encounters.
- As spreading gain increases, ultimate capacity suffers, going to zero in the extreme for high mobility systems, because of the characteristics of the real communication channel, such as multipath, fading (multipath in a different guise), and Doppler.
- The semiconductor technologies that increase density and speed conspire to reduce dynamic range, thus harming the ability of the system to detect and decode weak signals.

I also support the Lucent comments about the trend toward allocations in large blocks and establishment of general sharing rules. But I would go a bit farther. My view amounts to a slightly different spin on the same facts, based on the following additional premises:

- Future high data rate applications are most likely going to be fixed or low mobility (nomadic), and vice-versa – high mobility applications are likely to remain low data rate, such as the ever-present voice and intelligent vehicle applications.
- The rich functionality of very dense semiconductor devices *can* be utilized if the electromagnetic environments that will be encountered by the devices can be controlled.

The negative view is that the electromagnetic environment, as it currently exists, precludes the practical application of digital radios due to the high dynamic range of signals and interference. However, I would promote the alternative positive view: that digitally implemented radios *are* possible and practical, provided the regulatory focus is on management of the electromagnetic environment with the specific goal of *facilitating* them.

This management entails not only the obvious traditional considerations like:

- Ambient noise levels
- Transmitter power and antenna patterns

- Out-of-band emissions

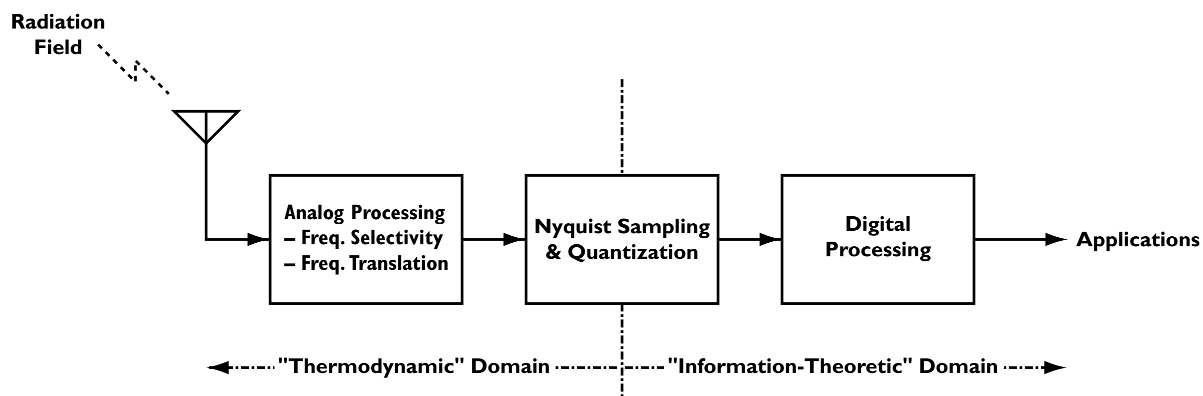
but also:

- Spectrum sharing rules
- Power management rules used by intelligent radiators.
- Geographical distribution of radiators, their proximity to one another, and their mobility

Prior to the introduction of mass-market spread spectrum systems, the separation of users and services was spectral and geographic. Specific bands were assigned in specific areas to specific licensees. Frequency reuse was in accordance with minimum spatial separation. But spread spectrum multiple access (SSMA) technology reduces the need for spectral and geographical separation. As has been shown in the cellular and PCS services, universal frequency reuse is possible and practical.

Shannon's principles are, by now, well-understood. They show the way to high capacity reliable multiple access communication using noise-like signals. Issues such as the power radiated by each user, and where it is radiated, are important considerations in achieving that high capacity. But the realization of those principles in low-cost, commercially viable products can be difficult due to the properties of real receivers – specifically dynamic range and linearity – the issue raised by Lucent[1].

A generic digital receiver front end might be abstracted as shown in the figure.




The sampling and quantization step divides the physical, or, as I sometimes call it, the thermodynamic world from the information-theoretic (IT) world. The well-known principles of discrete-time digital signal processing are used on the right side of the figure to separate SSMA signals in code space. However, departures from idealized behavior on the left side of the figure impair the ability of the receiver to carry out this mathematical separation. Large out-of-band interfering signals that are not rejected sufficiently by passive filtering generate, via device nonlinearities, in-band distortion products. Those distortion products act like excess noise to SSMA systems, thus reducing coverage and capacity – to the point of inoperability if large enough. These phenomena are inevitable; it is only a question of their magnitude. Design features that mitigate them tend to result in undesirable product attributes, such as excessive size, weight, complexity, and power consumption.

I suggest that the Commission take modest steps to mitigate these adverse receiver phenomena through regulatory policy. Such policy would create service(s) in which there is a demonstrably small likelihood that very large interferers will impact consumer devices when those devices are used as intended. This will require some sort of benchmark models of usage and of receiver characteristics. While the interference experienced by mobile devices obviously cannot be regulated with iron-clad certainty, modest efforts to do so would have substantial benefits to both the communicating public and manufacturers. Such rule changes are desirable due to the advent of SSMA technology.

I also suggest that the Commission concentrate its efforts on the left side of the figure – the thermodynamic aspects – signal levels, spectral distributions, and power control rules. Regulation of the right side of the figure – the IT world – should be minimal. What should count, as far as the commission is concerned, is the spectrum “pollution” ascribable to each station/signal/user, without regard for what information it conveys. Other details of the air interface should be either laissez faire, or mandated only at a minimalist level.

My general recommendations are:

- Take a “polluters pay” philosophical view of spectrum use, that is, try to incentivize the use of spectrally efficient signals and low power.

- Solicit industry input on benchmark service models and receiver properties that can guide future spectrum policy.

- Take steps that further facilitate the use of unlicensed consumer devices, as the Part 15 rules do now.

For additional view on this issue, see my monograph[2] on this topic that was submitted to the Commission in September of 1998.

These comments are filed only on behalf of myself, as a telecommunications industry technologist, in the public interest. They do not necessarily represent the opinion of any client.

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[1] “Input on Spectrum Management,” Lucent Technologies contribution to TAC Focus Group on Spectrum Management, September, 1999.

[2] “Maxwell, Shannon, and Economics,” Dr. Arthur H. M. Ross, submitted in response to FCC Notice DA 98-1703, September, 1998.