BEFORE THE
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Authorization and Use of Software Defined Radios	)	ET Docket No. 00-47
	)	
	)	

COMMENTS BY HYPRES, Inc

HYPRES, Inc., a member of the Software Defined Radio (SDR) Forum, is submitting these comments in response to requests for relevant information related to security provisions for equipment using software defined radio (SDR) technology as stated in paragraph 32 of the First Report and Order, ET docket No. 00-47, adopted September 13, 2001.

HYPRES, Inc. is a manufacturer of exceptionally high-performance and cost-effective electronic equipment using Superconductor Technology. HYPRES has demonstrated digital circuit capabilities that far exceed those currently available and forecasted with semiconductors and other implementations. The performance of these circuits enables real-time processing of RF signals in the digital domain at frequencies previously unattainable. HYPRES technology, called **Digital RF**, brings the power of digital processing in the RF domain.

Introduction

As recently indicated by Chairman Powell,[1] the solution to many of the issues facing the commission lies in "more innovative use of existing technologies, such as Software Defined

[1] FCC News, Federal Communications Commission, August 9, 2002, FCC Chairman Michael K. Powell Outlines Critical Elements of Future Spectrum Policy

Radio (SDR)." One of the deterrents to use of SDR has been the constraints placed on equipment designs by performance limitations of current and projected semiconductor devices. While there are several issues, these constraints are particularly severe in two specific areas. One is the need for sensitive analog to digital converters (ADC) with high resolution output and extremely high sampling rates. The other is the difficulty of suppressing intermodulation products generated by non-linear power amplifiers when processing the multiple waveforms created by SDR digital processing of multiple-channel transmissions.

HYPRES **Digital RF** technology, described in Appendix A, provides the performance necessary to relieve such constraints and enables fielding equipment with vastly improved performance and lower cost for all forms of wireless networks. Appendix B describes the capabilities and performance enhancements possible with implementations of **Digital RF** technology.

In this document HYPRES describe how the performance and cost improvements realized with **Digital RF** addresses issues of interest to the commission, including an economic basis for decision making, FCC license compliance, SDR security, and spectrum availability. We will also make recommendations on how Commission actions can facilitate introduction of new operational concepts based on these substantial performance improvements to achieve its goals.

The need for wireless innovation

Appendix C describes applications of HYPRES **Digital RF** and SDR to the wireless service. These technologies support general goals for wireless communications and enable certain new capabilities that solve problems and introduce new capabilities. Of course, **Digital RF** is not the only emerging technology likely to promote development of personal connectivity through wireless communications. It is a good example of an innovation that brings substantial benefit to design of wireless systems. It is also an example of the problems faced during insertion of technology into products in the field. .

Technology Insertion is the field of study that describes how technological changes are accepted or rejected. Replacement of an existing technology by a new one is often "perceived" as a complex process, a function of the nature of the new ideas, the nature of the receiving community, and the characteristics of the adoption process, as described in Appendix F.

One of the most influential types of incentives to adopt a new way of doing things is called the authoritative decision. Resistance to adoption is reduced, and implementation takes place much more rapidly under regulatory impetus than when it is optional. The best decision making, however, occurs when economic considerations prevail. Using regulatory power to set the stage for economic decision making is an ideal combination. As implemented by Commission policy, this combination has demonstrated promise as a major tool for constructive change.

Wireless communications promise to play a critical role in the high level of personal connectivity envisioned for the future. Mobile telephone service has seen one of the fastest adoption rates in the history of communications systems. The acceptance of mobile phones has clearly demonstrated that people will pay for services they find valuable, and that there is a viable economic justification for wireless services. This emerging market has also demonstrated that bandwidth in the RF spectrum, at one time considered abundant and free, has a definite economic value that must be recognized.

There are a large number of stakeholders in the area of wireless systems, and as discussed in Appendix C, they have differing perspectives. Some want to change legacy access to spectrum and accelerate introduction of new systems. Others have a vested interest in extending the effective life of existing capital investment and avoiding the expense associated with change, even though that change is critical to realizing needed improvements.

It is a HYPRES concern, based on the concepts of Technology Insertion, that there will be a great deal of reluctance to move beyond the status quo by a substantial portion of those in a position to support the innovation necessary to fulfill the promise of wireless communications. Timely introduction of new technology and an economic basis for decision making are keys to meeting the challenges faced in optimal use of RF spectrum.

In this document HYPRES, Inc makes the following recommendations to reflect our view that the Commission has an opportunity to be the change agent responsible for rapid development of wireless technology:

A. The commission should undertake a leadership role in defining and implementing emerging wireless personal communication technology.

HYPRES applauds the recent steps to establish a Spectrum Policy Task Force. Its report in October should be a beginning, not an end. Just as DoD has undertaken a major initiative to incorporate new technology in a solution to the myriad problems of its legacy radios, the Commission should continue its proactive role to make a similar transition for commercial wireless.

The task is not an easy one, particularly in the face of conflicting interests and perspectives of current and prospective participants. It is imperative that the process involve the stakeholders from all the constituencies, require that their positions be made known and placed on the table, and that compromise rather than rigidly held positions prevail.

HYPRES recommends that the Commission implement its leadership by establishing a series of goals to be obtained in the near, mid, and longer term, with regulatory powers and economic incentives used to ensure attainment. Then coordinated work by the various stakeholders, encouragement for needed technology developments, coordination with other executive agencies, and appeal to legislative action where necessary, can evolve a program that is a major step forward and a benefit to all.

B. Spectrum pollution and radio system economics

Operators of radio transmitters often radiate energy outside their assigned frequency bands due to inherent non-linearity in commercially available equipment. This situation is potentially exacerbated by the introduction of SDR technology. An SDR radio can combine a number of different transmission channels in the digital domain prior to digital to analog conversion (DAC). The output of the DAC is used as an exciter input to a high power amplifier (HPA) which increases the power level to that needed to drive the antenna.

Operating parameters of the HPA include bandwidth, power output, and linearity. As out-of-band intermodulation products appear in the output signal as a function of linearity, the design must trade off these parameters to obtain the desired transmitter performance at an acceptable level of intermodulation emissions. The result is low HPA operating efficiency, and higher cost to reach needed power levels.

A very cost effective solution to this problem is to effectively improve HPA performance. Interference is reduced with the use of spectrally pure carriers and ultra-linear power amplifiers.
HYPRES **Digital RF** capability, based on superconductor circuits, has the ability to provide real-time digital pre-distortion to compensate for non-linearity in HPAs.

Spectrally pure carriers begin with multi-GHz clocks with clock jitter measured in sub-picoseconds, followed by inherently-perfect DACs, to generate the "near-perfect sine wave". Fast digital circuits, using superconductor technology, enable digital pre-distortion on a multi-GHz RF waveform, greatly simplifying the algorithms and the complexity of signal processing over working at baseband. This performance enables a new linearization capability, a Digital RF pre-distorter, with much greater linearity, bandwidth and efficiency than conventional baseband pre-distorter schemes and other approaches such as "feed forward" linearization

If the ultra-linear HPAs were in wide use, spectrum pollution would be substantially reduced, and the ambient noise floor would be generally lowered. But system operators have little incentive to operate their transmitters more cleanly in areas other than in-band interference, where they are interfering with their own services. They will operate just inside regulatory limits on out-of-band emissions in order to reduce cost and improve service.

We propose a solution similar to that used in regulating air pollution. There are certain minimum levels of acceptable pollution, but in some cases factory operators have an option of either installing scrubbers or buying emission rights from other local factories who have lowered emissions. The course of action is their economic decision, but the end result is a controlled level of pollutants without the negative economic impact of shutting down older facilities.

We propose that system operators be provided with an economic incentive to operate their transmitters with a cleaner signal. One such approach in areas where spectrum is auctioned is to offer a substantial discount from the auction price for lowered interference. The operator could pick any one of a number of improved signal characteristics. The better the signal they agree to use, the greater the discount from the final auction price of spectrum. The discount should be economically sufficient to incentivize the operator to transmit with a cleaner signal, and should have graduating scale depending on spectral purity. Alternatively or in combination, a periodic fee could be assessed depending on the purity of the transmission signals and the degree of implementation.

The means to monitor conformance to their agreed-upon performance is provided by the monitoring capability proposed above. We suggest that spectrum monitoring can be another service offering provided by network operators with their existing infrastructure and available background processor time.

We also suggest that the Commission adopt a more holistic position with regards to RF links than it has assumed in the past. Link operation involves both transmitters and receivers, and the performance of both impacts spectrum utilization, link effectiveness, and the potential for interference. Specifications for receiver performance should be included in the Commission's economic purview.

We suggest that this is a win-win situation. Operators win because they make their own economic trade-offs, with prospects of lowered cost, and have the side benefit of better performance in their networks. Regulators win because the overall quality of spectrum usage is improved and the monitoring system provides much improved data on current spectral conditions. Equipment manufacturers win because a market arises for improved equipment performance, generating the cash flow needed to develop new technology.

C. Commercial and civil use of wireless communications should have an economic basis. Spectrum bandwidth has an economic value, and all users should pay for the bandwidth per unit time they consume. If it is found necessary to subsidize certain uses, then other users should have surcharges to cover the subsidies.

Much of the present use of RF spectrum is strongly conditioned by the history of existing services, and reluctance to change by legacy holders of licensed access to spectrum. Some services, such as UHF TV, occupy substantial amounts of spectrum with relatively low utilization and marginal economic return. The PCS bands, in contrast, are substantially more spectrally efficient, generate substantial revenue streams, and have demonstrated effectiveness auctions as a means of spectrum allocation.

HYPRES recommends that a policy be established that encourages services to migrate to networks operated as a public utility that provides shared-spectrum access to all participants. In the case of emergency services, they would be given priority access on demand to as much bandwidth as needed in an emergency. They, like all users, should pay for the services consumed in order to provide an incentive to minimize their priority override. .Just as we provide highway access for emergency vehicles, not by building special roads but by pulling over for a siren, spectrum access can be shared rather than dedicated.

Because these proposed future networks will be engineered to provide extreme flexibility, large amounts of spectrum will be available to meet the offered channel demand and take advantage of potential revenue generation. Strong security is required to make sure that no service is used without paying, and that the content of the traffic is kept private.

Network operators should pay a fee and be granted a franchise for specified blocks of spectrum and designated geographic areas. They should also collect fees from their users to subsidize use of the network by civil government and other designated users. The networks should be required to provide a suitable level of coverage throughout their geographic area. They should also be given incentive to offer spectrum monitoring as a service.

D. The Commission should facilitate Technology Insertion for emerging innovation.

As described in Appendix F, Technology Insertion is an uncertain process. Adoption of an innovation proceeds, often slowly, through steps of awareness, interest, commitment, and acceptance. A graph of rate of adoption over time is characterized by an S curve. It starts with a long period as a new technology with little adoption, gradually begins to rise until it assumes a steep slope, and then proceeds up to another slow period when most users have adopted it. The exact parameters of adoption vary enormously, and it is very difficult to predict when the rapid growth of the middle phase will start. Those factors are a function of relative advantage over the technology being displaced, compatibility, complexity, ease of trial, observability, and economic payback.

Introduction of many proposed innovations is dependent on installation of next-generation RF equipment with substantial performance improvements over existing systems. Incumbent system owners, however, may not see the economic incentive they need to plan such replacement. The resulting market forecasts are lower than their potential. Combined with the current uncertainty is the investment community, investment in innovation is being inhibited to an alarming degree.

The Department of Defense is moving out to meet its needs. But the commercial market is much larger, and operates with economic drivers that make it more efficient. There is a need to balance use of the single RF spectrum, with its wireless mobile capability, against the myriad spectra represented by newly installed fiber connections with fixed terminations. The Commission has an opportunity to move more aggressively to introduce "sunset" provisions in the near term that will clear the way for new approaches to communication. The commission also has an opportunity to be proactive in publishing requirements for new capabilities that will stimulate innovation and introduction of higher performance next-generation technology.

Conclusion

HYPRES has presented a picture of a new paradigm of wireless communications. We have also made a set of recommendations for actions by the Commission to realize those improvements.

HYPRES is confident that its technology, as part of the emerging hardware and software performance improvements, will enable the performance needed for innovative systems using software defined radios to change the basic approach to radio technology. **Digital RF** and system improvements built on it, will permit implementation of new services, functions, and capabilities to provide new capabilities, business opportunities, improve system security, improve performance, lower cost, and enhance reliability.

Respectfully submitted,

Jack Rosa
CEO and President
Vice Chairman, Board Of Directors
HYPRES, Inc. ***September 10, 2002***

APPENDIX A
Digital RF

Digital RF Capabilities

HYPRES Digital RF technology is based on the unique properties of superconductors. Under the physics of superconductivity, an induced current will flow indefinitely. Further, very small loops of current, called fluxons, can be used with a technique called Rapid Single Flux Quanta (RSFQ) to form binary logic circuits with extreme accuracy and very high speed. RSFQ digital circuits operate with two streams of fluxons. One, the clock, has a fluxon present at time intervals precisely defined by quantum mechanics. The corresponding data stream represents binary data with the presence (1) or absence (0) if a fluxon at each time slot. These circuits exceed equivalent silicon implementations in performance by orders of magnitude.

RSFQ circuits can be used in a very innovative way to construct extremely high performance analog to digital converters (ADC). Operating with clock rates from 8 to 50 GHz, they directly measure $\Delta v/\Delta t$, the first derivative of the received signal. After integration, a range of spectrum from 100 KHz to 2.5 GHz is accurately digitized with 14 to 24 bits of resolution. This dynamic range allows unfiltered input at the antenna to be digitized directly, and the resulting information processed with digital signal processing (DSP) techniques rather than analog filters and synthesizers. With Digital RF capability, a base station can accurately process a wide range of channels from a variety of services. It is no longer necessary to install a separate infrastructure for each of the services operating in a geographic area.

A further advance in receiver technology with Digital RF is the Cross-Correlation Receiver. In this application it is not necessary to write detailed DSP programs for each waveform or air interface to be recognized by a base station. Instead a template of the desired signal is derived from the corresponding modulator, and used by very fast real-time Digital RF processors to identify, synchronize with, and demodulate the incoming signal.

Another example of HYPRES **Digital RF** precision functionality is in the construction of digital to analog converters (DAC). This proven capability is used in one of the HYPRES products, the NIST-approved voltage standard. In a transmitter using **Digital RF**, information from a large number of channels is combined in digital form, and then accurately transformed into a composite analog exciter signal free of harmonics and intermodulation products for amplification and transmission.

The high power amplifiers (HPA) needed to boost the exciter signal developed by the DAC for transmission are a problem because their non-linear characteristics lead to signal distortion. These distortions can be eliminated by running the amplifier at lower levels of gain, or by a negative feedback loop. The former leads to higher equipment cost for a given transmitted power level. Implementation of digital feedback loops is difficult because of the high speed processing required. **Digital RF** circuits are fast enough to compare a digitized sample of the transmitted signal with the DAC input in real time to create an error, or distortion, signal. That signal, when inverted and combined with DAC input, precompensates for HPA anomalies, resulting in a very pure transmitted signal, free from energy outside the desired signals. The impact of drift in component values and distortion from overdriving is eliminated. In addition to the obvious advantages in transmitter precision, the economics of this solution are compelling. HPA cost is one of the major elements of base station economics. With **Digital RF** and this predistortion scheme, fewer HPAs are needed, and acceptable performance can be achieved with less expensive designs.

ADC, DAC, transmitter predistortion, and the cross-correlation receiver are examples of high-performance capabilities enabled by **Digital RF** implemented with RSFQ technology. HYPRES integrates these capabilities into a single package combining cold and warm sections with a service module providing cold and power busses. This **Digital RF** Module (DRFM) can be integrated into system designs as a high-performance front end using “white box” techniques, where functionality is determined by software loaded into the box..

APPENDIX B
HYPRES Technology Performance

HYPRES, Inc. has demonstrated a superconductor technology that is fundamental to the performance requirements needed to implement the suggested operations, and also provides a number of operational benefits to system operators. HYPRES technology is able to produce the following:

Simultaneous wideband and high-fidelity digitization — Capability of producing 14 to 24 effective (true) bits with 100 to 160 dB Spur Free Dynamic Range (SFDR) over the 100 kHz to 2 GHz range (a 20,000 to 1 bandwidth).

Ultra-high Analog to Digital Converter (ADC) resolution — Capability of producing over 20 effective (true) bits with an SFDR exceeding 130 dB for 3G/4G bandwidths (60 to 100 MHz) at > 2 GHz level carrier frequencies.

Extremely Low-noise, High-sensitivity, and ultra low Bit Error Rate (BER)— Noise-free **Digital RF** front-ends (<< 1^{o} K noise temperature) with sensitivities 30 to 50 dB better than conventional technologies and Bit Error Rates (BER) less than 10^{-15}.

Extreme sensitivity enabling unprecedented flexibility for monitoring the digital environment — A combination of extreme sensitivity and very fast processing capability adequate to examine designated portions of spectrum, defined dynamically by software directives, in real-time. Thus the infrastructure is capable of detecting the spectral footprint of in-band and out-of-band emitters, identifying inappropriate transmissions and providing real-time notification of violations and spectral anomalies.

Spectrally-pure carriers –HYPRES high stability multi-GHz clocks coupled with our inherently-perfect Digital to Analog Converters (DAC) provide spectrally-pure GHz-frequency carriers for transmission via a single or multiple high-power amplifiers (HPA).

Ultra-Linearized Single HPA – Capability to directly synthesize digitally pre-distorted wideband waveforms for transmission, enabling multi-carrier operation via a single HPA, simultaneously optimizing in-band performance and minimizing out-of-band spurious effects far beyond current (or forecasted) technologies can achieve. This also represents a significant reduction in initial and operating cost, due to much higher HPA efficiencies.

Low-power Tera-OPS DSP – Execution of Digital Signal Processing operations at clock speeds greater than 100 GHz, including picosecond RAM/ROM access operations and programmable digital filtering, while dissipating only 1 mW/chip.

Ultra-high Reliability & Durability – Similarly packaged products currently deployed in wireless communication base stations have exhibited up-times in excess of 99.997%.

Compatibility with Existing Systems – Although revolutionary in operation, HYPRES **Digital RF** products can occupy existing 19 in. racks (or other configurations) and interface to any standard bus configuration at a maximum speed limited only by bus performance.

"The technology is so accurate it defines the volt,
so sensitive it can measure brain currents,
and so fast it can directly convert RF signals"

HYPRES technology offers many benefits to users in a variety of application areas. The following benefits accrue to operators of wireless networks and the FCC:

Lower Capitalization per Base Station – One digital radio performs the tasks of many conventional protocol-and frequency-specific base station radios. For example, the critical communication equipment is reduced by about 90% to about 10% of a traditional GSM base station. A single universal platform can be configured dynamically and/or periodically (in the factory or in the field) to suit many different services, independent of communication bandwidth or standard. This versatility significantly reduces the cost of base stations and the infrastructure provider's spares inventory needed to accommodate multiple protocols.

Reduced Infrastructure Capital Expenditures – HYPRES technology significantly expands base station range coverage, enabling a significant reduction of the total number of base-station sites required, thereby reducing total network capitalization by an order of magnitude. Our technology enables wideband 3G performance with 2G base-station range.

Reduced Operating Expenses – Fewer base stations translates into fewer (costly) connected landlines and less power consumed. Less power consumed per base station is a significant further reduction. High reliability and nearly maintenance free operation further reduces operating cost. Resistance to surges and lightning strike effects means far less repair cost.

Enhanced Revenues and Margins – Because of the higher receiver sensitivity, resolution, and processing speed enabled by the HYPRES technology, more traffic for a given bandwidth allocation is possible, allowing additional users and/or services to be added at will, without upgrading the infrastructure. Our superior interference rejection results in higher call quality, few dropped calls, and, in turn, increased customer usage.

Boost Spectral Efficiency – Current state-of-the-art wireless systems only provide 0.5 to 0.8 bits/sec/Hz, in terms of their ability to exploit (i.e. generate revenue from) an allocated bandwidth. In contrast, the HYPRES approach can provide more than 8 bits/sec/Hz, a 10-fold improvement, vastly accelerating the return on investment for costly spectrum licenses.

Adaptability – Because the HYPRES technology enables universal interoperability among legacy, current, and future wireless protocols, it enables an agile business model that can quickly adapt to meet changing market environments and rapidly accommodate new initiatives (such as spectrum sharing, etc). Our hardware will accommodate generations of software upgrades and changes.

Extended Mobile Battery Life -- HYPRES base station products significantly extend the life of the battery of the mobile terminals**.** Transmit function consumes most of the power in a mobile terminal. The ultra high performance enabled by the HYPRES base station technology enables adequate link margin at a lower level of transmit power from the mobile units.

These performance characteristics permit the location of the ADC to a position adjacent to the antenna for reception and the corresponding DAC adjacent to the PA for transmission. This enables the next generation of true Software Defined Radio (SDR) technology throughout the base station, and facilitates development of near real-time frequency agile performance.[2] HYPRES technology totally supports the objectives of the commission[3]

HYPRES technology is an advanced superconductor technology, where electrical current flows indefinitely and fundamental performance characteristics are derived from quantum principles. Digital logic building blocks using this technology provide digital circuits with much higher performance than can be achieved with semiconductor circuits. The first ADC produced by HYPRES, using relatively crude 3-micron lithography technology, outperformed the best semiconductor ADCs in every aspect.

Superconductor technology has already been embraced by the wireless community for RF filters demonstrating excellent performance characteristics and outstanding reliability. We are confident that HYPRES technology is essential to widespread use of SDR, and the basis for substantial improvements in wireless security and spectral efficiency.

[2] FCC 00-41, Policy Statement In the matter of Principles for Promoting the Efficient Use of Spectrum by Encouraging the Development of Secondary Markets, Adopted November 9, 2000 (hereafter 'PS'), Par. 35, 36.
[3] FCC 00-401, WT Docket No. 00-230, Notice of Proposed Rulemaking in the same matter, Adopted November 9, 2000 (hereafter 'NPRM'), Par. 3,4

APPENDIX C
Application of Digital RF and SDR to Wireless Service

HYPRES **Digital RF** technology is an ideal vehicle for integrating antenna systems into an SDR implementation. It provides the RF accuracy and digital precision necessary to solve many of the problems now faced by existing services. It also extends performance to enable new paradigms for operational flexibility, improved security, increased spectral efficiency, better service levels, and economic gains as new applications and new service concepts evolve. **Digital RF** enables base stations capable of detailed monitoring of ambient spectrum utilization by geographic area. In the paragraphs that follow we present some of the concepts for system improvement, service extension, new wireless applications, and expanded system architectures offered by **Digital RF.** .

A. Improved RF environment. Digital RF transmitter predistortion capability provides dramatic improvement in the quality of transmitted signals, improving the ratio of signal to interferer (S/I) for other signals in range. Its correlation-based receiver has sensitivity to extract signals in the face of noise, interferers, and multipath. The result is far more precise operation of the wireless links, resulting in improved spectral efficiency, more data delivered per unit bandwidth, and flexibility to enable spectrum sharing. **Digital RF** also includes timing control to synchronize transmitter, receiver, and antenna operations.

B. Incremental system changes. Digital RF has operational flexibility to permit system changes to be introduced gradually rather in large steps. This capability can be used for simple error corrections, or to introduce new systems and applications slowly, with capacity growing as demand builds. Operating in an SDR environment, incremental system upgrades can be introduced to effect continual improvement in the ambient RF environment.

The capital investment needed to build out new infrastructure is a major limitation on introduction of new services. A network operator with **Digital RF** capability can phase in a new service incrementally, initially allocating small amounts of capacity at low cost, and increasing bandwidth as demand improves. Such an approach gets away from a need for additional dedicated spectrum for emerging services, and also facilitates reallocation of bandwidth from services with declining demand.

C. Network Oriented Base Station (NOBS)[4]. As initially implemented in cellular telephone systems, the base station was little more than a simple terminus for the RF link to user terminals. Under the concept of a **Digital RF** Network Oriented Base Station, the base station becomes a connecting node between remote terminals of multiple services and their respective network infrastructures. All of the simultaneous incoming traffic, operating on multiple frequencies, is extracted digitally from the received waveform, and delivered to the appropriate terrestrial network connection. Similarly, all of outgoing traffic for supported services is combined digitally, converted to an analog signal, and transmitted.

C. Spectrum monitoring. Digital RF gives network operators capability to monitor the RF environment in the geography covered by their station sites (See Appendix B). Base stations are aware of the normal operational patterns of nearby emitters, and can flag unusual operational conditions. Types of situations that can be detected by a change in traffic include accidents, emergencies, new sources of interference, illegal transmitter operation, tower failure or power outage, and new services starting up.

Government agencies or commercial organizations can subscribe to a service for monitoring specific portions of spectrum. The monitoring program receives either information about specified signals, and, if authorized, the content of those signals. Such a facility provides a means of identifying interferers, measuring traffic volume, locating illegal transmissions, and documenting actual spectrum utilization.

D. Spectrum sharing. The cellular model, where links are operated with controlled power and frequencies are reused many times over a geographic area, has proven the concept of spectrum sharing within the context of a single service. Operators of cellular PCS services

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[4]See SDRF Document SDRF-02-S-0015-V2.01, Wireless Network Architectures

are now of adding services to provide their users with internet access, data delivery, and messaging.

A broader form of spectrum sharing, enabled by **Digital RF**, involves enabling heterogeneous services to operate in the same spectral space. For example, personal communications services (PCS) display a strong diurnal pattern, with peaks in the late morning and early afternoon, and very low usage at night. There is a substantial amount of off-peak capacity available. Meter reading is one example of an application that can be done at any time of day. With **Digital RF** capability, base stations can time-share spectrum, diverting part of their off-peak capacity to an air interface optimized for meter reading, and fill in the available time.

The ability to dynamically reallocate spectrum across dissimilar services is a capability offered by **Digital RF**. The cross-correlation receiver can go beyond other types of equipment to support real-time use of common channels by dissimilar services.

E. Business case economics. An economic model, operating with appropriate controls, has proven effective as a way of allocating resources. Networks implemented with **Digital RF** capability provide the flexibility to implement new spectrum allocation models based on economics. For example, much of the spectrum used by civil government has a very low level of utilization. That fallow capacity also has a substantial economic value due to scarcity of bandwidth needed to handle the wireless load offered by personal communications services. One scenario is to rent public safety channels to network operators, with priority preemption. The operators would pay for use of the spectrum as their traffic demand supported it. The owning organization would be motivated to control its preemption because doing so would interrupt its revenue stream. Alternately, the spectrum could be owned (and paid for) by the network operator, while organizations with priority access would be charged for their use by the minute. The underlying argument is that organizations needing bandwidth, including civil government and broadcasters, pay for services and equipment they consume. So, as access to spectral bandwidth has value, they should pay for that also, with higher rates for higher priority. **Digital RF** provides the spectral agility to make these models feasible.

F. Last mile. Personal communications services have demonstrated how efficiently bandwidth can be utilized under economic pressure. As call volumes build up, new cell sites are added, and operate with less power. Frequency reuse over a large area is a more efficient use of spectrum than a single central site.

To take the cellular concept to a logical extreme, the highly precise and higher capacity wireless links offered by **Digital RF** can be established as a wireless utility, offering generic bandwidth from existing cell sites for local connections with backhaul provided by the extensive fiber capacity now in place. Such a network is a potential solution to the "last mile" problem of providing infrastructure connectivity to homes and businesses.

G. Emergency services. Emergency services have benefited from mobile radio systems since the first installation of radio receivers in police cars. Many such services still operate with a single high-powered central base station covering a large area. In many cases, trunking systems are used, where groups of remote terminals are directed to tune to an available channel when one member of a group wants to talk. These systems are typically half-duplex, meaning only one station at a time can transmit. The ten code system is often used for net control ("ten-four"). Based on statistical distribution of traffic patterns, communications systems can accommodate users without dedicating a channel to each user group. In a municipality many services will often share a trunking system, with emergency services given a preemption priority over lower precedence traffic such as Parks and Recreation or Public Works.

An alternative model, supported by **Digital RF**, is to develop a new service with a half-duplex trunking model or full-duplex "conference call" supported on a cellular network. The service could operate either in the existing cellular bands (freeing up spectrum currently allocated to those services) or continue in the same spectrum with additional capacity provided by the frequency reuse cell plan. Calls would be billed to users on an as-used basis, providing an additional revenue source for network operators. Municipalities would no longer need to fund their own base stations, relieving them of the problem of how often to upgrade to new technology.

An additional benefit of such a system is the ability to dynamically alter trunking assignments and provide interoperability in an emergency. A remote or onsite network control center can trunk together terminals from units responding to an emergency without needing access to the terminals.

APPENDIX D
Spectrum Monitoring

Spectrum monitoring is a step beyond type approval in ensuring proper use of RF spectrum. It has a potential to improve understanding of how spectrum is being utilized, and to improve security by alerting the proper authorities when rule violations are occurring.

Monitoring Proposal

We describe a monitoring system capable of providing both a historical documentation of spectrum usage and a monitoring capability that can generate an alert when certain circumstances arise. HYPRES proposes that the FCC consider implementation monitoring capability in the wireless system or other appropriate infrastructure to provide the data necessary for spectrum management, confirm compliance of stations to their certification, and provide security improved measures. HYPRES' technology provides the accuracy and resolution necessary to perform these functions in real time, and also improves the performance and lowers the cost of the infrastructure. Although there are many possible variations, this approach permits consideration of a number of the attributes of such a system.

A SPECTRUM MONITORING SCENARIO

The city of Smalltown, USA has 31 PCS base stations, operated by three service providers. Two of those operators have applied to provide State of the Spectrum (SOS) service from 18 of those sites. SOS is a service offering that monitors ambient spectrum usage, developing usage data and reporting anomalies.

Each of the SOS-equipped sites has radio equipment with a very sensitive RF front end and software defined radio (SDR) capability. These sites perform a number of monitoring services in the background of performing normal PCS. Some of those services are under contract the US Government while others are part of the service providers internal security program.

In order to implement SOS, every emitter operating under FCC license is assigned a 128 bit IPV6 Internet address. The organization holding the license under which that emitter operates is responsible for responding to IP traffic sent to that address. Content addressable central directories of service, spectrum authorization, IP address, and geographical location are available with an internet connection. SOS sites receiving a signal can send a message to the IP address of an emitter, obtained from their data base of identified local systems or a central site. The content of the message contains, at minimum, the time and frequency on which the transmission was received, and indication as to whether a response is requested. Other signal characteristics are defined and may also be sent. Several protocols are defined for a response. One simply provides contact information for the equipment owner. A static protocol acknowledges with ACK, that the transmitter associated with that channel does transmit on the specified frequency, or NAK, that it does not. Emitter location information is also returned. A third offers a dynamic response, indicating that, at the precise time specified in the message the designated transmitter was radiating. The dynamic response, suitable for use in base stations, involves local buffering of transmit times to permit response to a delayed inquiry of up to 24 hours.

1. Baseline State of the Spectrum (BSOS)

Establishing the BSOS involves each SOS monitoring the received spectrum from 106 MHz to 2.9 GHz (or segments as desired or needed) for some period (<30 days) to built a data base of normal RF activity at that location. The BSOS is a one-time activity to develop a baseline database, so the spectrum can be monitored in a series of steps, where a convenient bandwidth is monitored for a short time. The result is a repeated sweep of the entire bandwidth adequate to develop a statistically significant pattern of the ambient RF environment.

This search for signals is conducted to the extent of processor time available after servicing normal system traffic. When an emission pattern is identified as statistically significant, an internet message is sent to the central site where the emitter database is located. The central site returns the IP address associated with relevant emission patterns at that geographic location.

The intent of the baseline period is to identify as many local emitters as possible, and to build a local baseline database of local spectral use. Statistical data is also maintained to indicate the fraction of the time when the channel was seen to be active. That indication would vary from 1.00 for a full-time broadcast station to 0.00 for an emergency channel that was allocated, but never used during the baseline period.

This process "introduces" all of the regular communication services in Smalltown to all of the SOS monitoring basestations, and, when the individual databases are merged, provides an RF map of the area.

2. Current State of the Spectrum (CSOS)

After the baseline is built, routine spectrum scanning is conducted on a regular basis. Each monitoring station camps on a specific frequency band range for a defined period to analyze the activity there. If a known emitter is active, the analysis looks for interfering signals.

Two types of monitoring are performed. One is the *activity monitor*, using a scanning algorithm coordinated so that each of the 18 active monitors is looking at a different band at any point in time. Signals not conforming to the pattern developed in the BSOS are flagged for further investigation.

Emissions found from CSOS scan are also recorded, and used to maintain the baseline scan in the case of new services being introduced in the area, such as a new basestation or broadcaster coming on the air. Other emissions may be classified as noise, or identified as suspicious and reported for further investigation.

This is a scan that uses known local traffic patterns to identify CSOS anomalies in the area. Using statistical sampling techniques, it looks for high levels of usage on normally low utilization channels or sudden activity where there are no known emitters. Such activity can be an early indicator of an emergency or other activity that warrants attention.

The other type of monitoring is the *designated service monitor*, applied to specific bands where known services are operating. The characteristics of that service determine the details of the scan and what specific characteristics are reported. For example, interfering emitters might be identified in one specialized search pattern, while stations transmitting with excessive power are identified in another.

Any service active in the area can have a monitoring program tailored to its needs, such as system security. One PCS attack is a perpetrator who imitates the network to attract user telephones in an attempt to initiate a fraudulent connection. Legitimate base station sites in the vicinity can detect transmissions from the illegal one, and initiate a warning. Similarly, unauthorized rogue terminals may attempt to gain access, and can be detected. The features of these dedicated systems are specific to the security and monitoring needs of the service, but implemented in ways similar to the SOS monitors.

3. SIGNALS OF INTEREST

There are a number of circumstances where a law-enforcement, regulatory, of government authority want to know if a specific type of emitter becomes active. With an SOS network in place, a signal description can be sent to all of the active stations, and a continuing watch posted. If that emitter is detected, an Internet message is immediately sent to the originator of the request who takes appropriate action.

One of the key applications of HYPRES technology is improved analog to digital converter (ADC) performance. Receivers implemented with this technology are able to use digital signal processing techniques to monitor signals of interest as a byproduct of their primary function as a receiver in a standard service. HYPRES technology features uniquely wide bandwidths, and uniquely high sensitivity and speed. Further, because of these attributes, the use of simple and inexpensive ancillary equipments are allowed, such as broadband omni antennas for the monitoring functions. HYPRES is submitting these suggestions to suggest how the application of such technology to the function of spectrum monitoring can provide empirical data to support detailed assessment of the actual state of spectrum usage. The result is a data base that reflects both the CSOS and historical data suitable for statistical analysis.

APPENDIX E
Wireless Participant Perspectives

The radio frequency (RF) communications over the air interface give wireless systems their major advantage, mobile voice and data communications without a wired connection. The popularity of mobile communications has led to substantial increased demand for spectrum. That demand has, in turn, increased market, legislative, and political pressures to revise the basis for allocation of spectrum, particularly to services whose operation is not efficient in its use of available spectrum. Efficiency is actual realization of bits per unit area per unit time (e.g. bits per second per km^2) or equivalent measure.

There are differing major perspectives on spectrum utilization, held by market participants whose different interests cause them to have differing concerns. These concerns lead them to emphasize different aspects of how the spectrum is used.

REGULATORS

RF spectrum is a shared and scarce resource. Regulators are concerned with mechanisms for selection of applicants for spectrum use, technical specification of regulations for spectrum use, and confirmation of conformant use of allocated spectrum by users.

Mechanisms for licensee acceptance and spectrum allocation are subject to change with evolving market demand, new technology, and political consideration of achieving the common good. Recent developments have also raised the level of concern about security issues associated with radio operation.

Operational conformance involves transmission only on designated frequencies within an approved envelope of radiated power levels. Different services have varying means of verifying conformance. In mobile communications certification of terminal equipment is the primary control on user terminals. In the infrastructure, base stations propagation patterns are routinely field tested.

HYPRES **Digital RF** technology offers a step function in performance, particularly for base stations, that can serve as a tool for regulatory oversight of how spectrum is actually used, and a means to identify violators. The monitoring capability from base stations equipped with **Digital RF** represents a major new opportunity for spectrum management.

LICENSEES

Licensees have two primary considerations in the operation of radio equipment and any needed supporting infrastructure. One is the service provided to the user community and the other is their economic model. These parameters interact in different ways in different services.

Personal communications service network operators have profitable operation as a primary objective, and tailor their service offerings to increase revenues and optimize profit. They use sophisticated technology to deploy geographically dispersed systems that maintain high spectral efficiency by localizing transmissions and minimizing transmitted power. Network operators are also intensely interested in detecting anyone attempting to access services without paying, or attempting to steal the identity of a legitimate customer.

Public safety systems are typically operated by local government organizations or their contractors to support local operations. Their primary objective is efficient execution of the service provided. Although the cost of operation is considered a normal part of tax-funded services, they strive to keep costs low. One approach to optimizing their requirements is to put spectrum on a paid basis. In the event of an emergency they would have priority access to large amounts of spectrum, configured to meet the demands of the occasion, including interoperation with other agencies not normally needed. In other times they would have a low cost level on the basis of low actual usage levels.

Licensees in other services have varying motivations, but each must balance economic viability against service issues. Many licensees have a stake in their operations that may be threatened by moves to make spectrum more efficient or efficient.[5] They may be reluctant to make new investment, and reluctant to take on new technology because they have late adopter characteristics (see Appendix D.) Their needs must be taken into account, and any changes imposed on them done so in the least intrusive way.

But in every case, the licensee has a vested interest in rapid identification of interfering emitters, and eliminating the source of interference. Monitoring capability makes such identification conveniently possible.

In some circumstances, a licensee may be inclined to push or exceed the constraints imposed by license conditions. Self-regulation by licensees is now the rule, but just as police radar units mitigate highway speed, knowledge that the local spectrum is monitored is a strong incentive to be diligent in operating properly.

HYPRES technology has a dual role in meeting the needs of licensees. One is improving the spectral efficiency achieved by installed radio systems, allowing more communication capability in a given bandwidth. The other is an improved ability to detect and reject attempts to penetrate the system and to reduce non-revenue traffic.

USERS

Users are individuals and organizations that purchase communication services, usually as a commodity, without needing detailed knowledge of how the service is provided. Users want good system performance, privacy of information, and freedom from theft of identity. Some users place a great deal of importance in priority access to communications, and will pay for the right to preempt lower priority subscribers.

Users desires may be in conflict with other participant's interests. For example, a desire for high performance may lead a user to attempt to operate at higher power levels than the

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[5] See Spectrum Study of the 2500-2690 MHz Band, Final FCC Staff Report, dated March 30, 2001. It describes the inconvenience imposed on incumbents in accommodating this proposed UMTS band for worldwide roaming.

minimum necessary by installing rogue software in a terminal. The monitored environment can provide information to deter such inappropriate terminal behavior.

Identity theft may be attempted by a perpetrator imitating a base station, and enticing a user terminal to camp there. Doing so involves transmitting pilot channel information, and can be detected as a spectral anomaly in a monitored environment.

HYPRES technology supports these needs by providing improved system performance, and by improving overall system robustness in the face of attempts to compromise user privacy.

ORIGINAL EQUIPMENT MANUFACTURERS (OEM).

The OEM has the highly developed capability to make equipment for the network operator. Historically most new technology has been introduced into wireless markets through these organizations. An exception has been the use of superconducting filters to improve base station operation. That capability has been largely installed by operators on their own, and has shown dramatic improvement in wireless operations.

The OEMs have the problem that equipment is sold in large blocks as network operators build out their systems. Then orders drop off as the operators work to recover their capital investment. This puts operators in tension with their suppliers, as the OEMs are motivated to build new and better equipment, and to promote introduction of new protocols and systems to continue their sales.

SUMMARY.

The wireless community has many participants, each with a specific set of interests. Any change in the status quo will benefit some and inconvenience others. Clear goals in place for the near, medium, and long term are a great benefit to all players as they consider their actions in the economy. For example, a position that new technologies are to be encouraged, and a record of supporting that position, helps both the innovators and those who would resist change evaluate their chances in a realistic way.

APPENDIX F
Technology Insertion

There is a field of academic study called "Diffusion of Innovations" which studies how new ideas find their way into acceptance (or rejection).[6] Everett Rogers' definition is "Diffusion is the process by which an innovation is communicated through certain channels over time among members of a social system…"[7] Technology Insertion is a subset of the field dealing with how new technologies emerge from laboratories to displace older ones in specific applications. Insertion is also the first part of a product life cycle.

Understanding the structure of Technology Insertion and the role it plays in development of Wireless markets is important because its parameters vary substantially between different services and different parts of the spectrum. Policy development and rule making must take into account the often conflicting forces coming to bear on a particular issue, and how those forces vary from one issue to the next.

There are three major dimensions to describe displacement of an existing way of doing something with something new. They are the characteristics of the invention, structure of the adopter community, and the stages of the adoption process. We will discuss them sequentially.

Characteristics of the innovation. In some cases a new technology is replacing an older one, and in other cases several new technologies are competing for market share. Some innovations are really better than others, but perceptions of prospective adopters also play an important part in insertion. The following characteristics have been found to be important, although no one of them operates independently of the others.:[8]

> **Relative advantage.** An innovation representing a substantial improvement or a new capability will be accepted faster than one seen as a minor improvement. For

[6] Rogers, Everett Diffusion Of Innovations, Fourth Edition, The Free Press, 1995, Chapter 1.
[7] Ibid, Pg. 5
[8] Ibid, Pg. 15. Complexity has been dropped from Rogers list because innovation in this market are rarely simple. Economic payback has been added to Rogers list based on work in the SDR Forum on document SDRF-02-W-0008-V1.00, Business Model for Wireless PCS.

example, FM radio has not displaced AM, while color TV programming has prevailed over black and white. Perception of improvement has been found to be more important than any measureable difference in terms of accelerating adoption.

Compatibility. If the new technology is seen as compatible with existing ways of doing things it will be less disruptive, and more likely to be adopted. HDTV technology, for example, is a more difficult transition than the change from black and white TV to color.

Ease of Trial. If the new technology can be tried out on a limited basis without disrupting use of the old, a smoother transition will possible. Trials will face less resistance if they are easy to implement.

Observability. Seeing others in similar circumstances make use of a technology is an incentive to adopt it. We will see below that the use of a technology be early adopters is a powerful incentive for those in the majority to adopt. This characteristic is probably important in determining the steepness of the adoption curve.

Economic payback. A business case is associated with most insertion of new technology. A large payback in a short period is not only attractive in its own right, but it also reduces fear of incorrect projections.

Structure of the adopters. In a community some individuals introduce new ideas while others prefer to continue to use the known and familiar. The characteristics of adopters and how they are confronted with the new technology can influence the adoption process.

Innovators. These individuals seek out new ways of doing things, and sometimes are the inventors of the new technology. They enjoy trying out something new, but often cannot be relied upon to follow through by supporting the new technology as it is put to use. They are very likely to be distracted with the next new thing.

Early adopters. Individuals interested in solving problems and improving the state of affairs. They are willing to evaluate the risk involved in inserting a new technology, and proceed, taking precautions to minimize the exposure. They are opinion leaders and change agents, instrumental in initiating the first steps toward adoption. They listen cautiously to the innovators, and are role models for the majority.

Majority. This group follows the lead of the early adopters during the steep part of the acceptance curve. They want to be sure that use of the new technology will not present an unacceptable level of problems before electing to adopt. If the innovation is economically viable it will be generated during this phase as the initial investments are paid back and economies of scale set in to ongoing operations.

Late Adopters. These individuals are reluctant to change because they want to extend the economic life of existing investment and avoid new expenditure. They prefer to avoid the effort involved with change. In dealing with late adopters it has been found that the arguments they advance for not adopting may not be their real objection, so techniques for isolation of objections may be needed.

Stages of adoption. Many studies of diffusion show a variety of adoption curves with a common S shape.[9] The chart of percent adoption over time starts with zero. Rises slowly during the early phases, then increases abruptly at a point called the take-off. Then saturation starts, and the last hold-outs are slowly converted.

Awareness. Knowledge that the technology exists, prior to any serious consideration of it. Much advertising and trade show activity is aimed at providing awareness.

Consideration. Serious interest starts with an impression that the technology might be applicable to solution of problems at hand or result in an improvement in operations or service that help justify the cost of acquiring it. A key point in this phase is making a decision to evaluate the technology. The phase ends with a decision to adopt or not to proceed.

Commitment. Following a favorable decision, preparation is made to proceed. In the case of communication systems, this point marks the start of designing and integrating the technology into the system. For the recipient of the technology, this point represents the beginning of serious investment and commitment of funds. The phase ends when the resulting system is operational or, if a product, is ready to deliver to customers.

[9] Ibid, Pg. 11

Acceptance. This phase is characterized by successful operation under field conditions. The system is installed and operational, usually with some number of early-life problems. System responsibility passes to the user or operator.

Technology Insertion is normally considered complete after acceptance, although the full product life cycle continues on through maintenance, upgrade, and end-of-life.

Summary.

An understanding of Technology Insertion is important to setting and achieving goals for long-range improvement in use of spectrum and the secure use of SDR technology. Each participant in the wireless market has to make daily decisions on how to proceed. If a badly needed new technology is realized because its prospects were encouraged by goals set forth by the Commission, then the entire economy benefits. The technology serves operators and users, the developers and investors see a return on their investment, and the Commission has a more orderly field to regulate, and is recognized as forward thinking.