The "Ham And SDR Sandwich": Innovation and Enforcement Issues for Free and Open-Source Software on Software-Defined Radio Devices

James Miller, Esq.[1]

3-4-2 Shibaura, Grand Park Heights 303, Minato-ku, Tokyo, 108-0023 JAPAN
JamesMillerEsquire@gmail.com, www.nihonlinks.com/news (BLOG)

Abstract. This paper proposes a novel approach to resolving concerns by independent developers of cutting edge technology regulated under the FCC's emerging "Cognitive Radio" and "Software Defined Radio" ("Smart Radio") rules. These Smart Radio rules balance a need for flexibility to innovate new radio technology, against necessary limitations to ensure that radios will not be misused to cause harmful interference. These rules achieve balance by, *inter alia*, enumerating the conditions under which software modifications and installations are permitted. The rules necessarily rely on assumptions about the nature of users and devices in making this balance. An important assumption of the Smart Radio rules is that devices are ubiquitous and users lack specialized spectrum expertise, thus requiring regulatory checks on how software may be accessed and modified. In the case of amateur licensing, the testing requirements for "ham" radio operators ensure users have a minimum level of technical sophistication and understanding of FCC rules. This paper explores how the Smart Radio rules and their assumptions impact Free and Open-Source Software (FOSS) and other small non-commercial developers and why their goals and motivations make the amateur licensing regime an attractive complement to development under the FCC's Smart Radio rules. The paper explores the limitations for development under both the smart radio rules and amateur licensing models, other brewing controversies, and proposes the adoption of amateur licensing models to address the specific concerns of independent radio technology developers. With the adoption of "Smart Radio" rules, developers may find a "Ham and SDR sandwich" is precisely what they were hungry for.

I. Introduction

This paper proposes a novel approach to resolving concerns by independent developers of cutting edge technology regulated under the FCC's emerging "Cognitive Radio" and "Software Defined Radio" ("Smart Radio" and SDR) rules.[2] These Smart

1 Mansfield Fellow 2004-2006, on detail from the Federal Communications Commission, Office of Engineering and Technology, Policy and Rules Div., Spectrum Policy Branch., currently placed with the Japanese Ministry of Communications.

2 Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies, ET Docket No. 03-108, *Report and Order*, FCC 05-57 (rel. Mar. 11, 2005), available at http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-05-57A1.pdf (making significant changes to rules for Software Defined Radios first adopted in FCC 01-264 R&O).

Radio rules balance a need for flexibility to innovate new radio technology, against necessary limitations to ensure that radios will not be misused to cause harmful interference. These rules achieve balance by, *inter alia*, enumerating the conditions under which software modifications and installations are permitted.[3] These rules necessarily rely on assumptions about the nature of users and devices in making this balance. An important assumption of the Smart Radio rules is that devices are ubiquitous and users lack specialized spectrum expertise, thus requiring regulatory checks on how software may be accessed and modified. In the case of amateur licensing, the testing requirements for "ham" radio operators ensure users have a minimum level of technical sophistication and understanding of FCC rules. Thus the historically the rules for amateur licensees are more liberal, and seek to encourage broad experimentation and technical innovation. This paper explores how the Smart Radio rules and their assumptions impact Free and Open-Source Software (FOSS) and other small non-commercial developers and why their goals and motivations make the amateur licensing regime an attractive complement to development under the FCC's Smart Radio rules.

Today radios are increasingly composed of highly modular components that function under the direction of "software" that directs the parts to perform their respective radio functions. This design offers tremendous benefits for consumers, developers, and regulators alike. However, like similar questions plaguing these players in the online and portable media market, how to accommodate not only traditional commercial developers but the independent emerging technology developer is a particularly vexing problem. For example, the FOSS community has produced a variety of technical contributions that offer benefits for consumers and commercial development of Smart Radio technology. However, FOSS developers may not be involved in traditional commercial radio development and in many cases are not seeking any commercial gain from their contributions. Moreover, FOSS developers often seek to make modifications primarily for their own use. Nevertheless, these developers are subject to the same development overhead that commercial manufacturers are.

For these and other reasons the amateur licensing regime's fundamental policy goals of promoting technical experimentation align well with the needs and motivations of these developers. Moreover, the FCC's rules for Smart Radio have made changes in how development of software-defined radios can be done lawfully. Thus there is pressing need to explore how these rule impact this vibrant and growing sector. Developers making use of the amateur licensing model can overcome thorny issues independent developers may experience under the existing Smart Radio rules without sacrificing key motivational goals. The paper explores the limitations for development under both the Smart Radio rules and amateur licensing models, other brewing controversies, and proposes the adoption of amateur licensing models to address the specific concerns of independent radio technology developers. With the adoption of "Smart Radio" rules, developers may find a "Ham and SDR sandwich" is precisely what they were hungry for.

3 "We neither wish to have our processes inadvertently be a barrier to the development and deployment of these technologies nor wish to permit the widespread deployment of radios easily susceptible of being misused to cause harmful interference to others." R&O para. 4.

II. SDR, FOSS, and Amateur Background and Motivational Goals

This section of the paper explores the particular role of FOSS development under the new regulatory and technical paradigm introduced by the appearance of software-based (also software-defined) radios. In the same way the use of general purpose computing machines, Personal Computers (PC), radically changed office automation and consumer electronics, radios that work by using software instead of specialized hardware chips are poised to bring dramatic improvements in the use of spectrum. Likewise, the contributions of FOSS development to internet software infrastructure have revolutionized the world of communications. Before discussing the nexus of these topics, this section of the paper explores the background of what software-based radios are, and the background of amateur radio and FOSS development.

A. SDR Background

The home PC is generally viewed as something very different from other "electronics equipment," such as TVs and toasters. In fact, much of what comprises the hardware "parts" of many modern electronics, can be found in many PCs. The emergence of software-based radios is also the story of a shift from specialized chip-based solutions to systems using generalized chips and specialized software to execute similar tasks. The topic can be thought of as the "pc'ization" of the embedded computing market.

Electronic devices all function by exploiting the natural properties of materials (today predominately silicon) utilizing logic and mathematics to accomplish logical tasks. In this regard, electronic devices are all similar. However, identical functions, say opening and closing a circuit in a predetermined way (say a "blinkie circuit"), can be accomplished in limitless ways.[4]

The hardware-oriented design is fundamentally concerned with how the physical nature of a device is organized to achieve the logical task. The approach focuses on how the flow of electricity through "circuits" can achieve the goal, under various development constraints. For example a hardware-oriented design of our "blinkie circuit" on paper might focus on how the orientation of the wires achieved the appropriate timing and minimized the amount of electricity needed to accomplish the task. The design might suffer from certain trade offs such as, it would only last a few weeks, wasn't very reliable and cost $50,000. Despite such limitations the design might still be a perfect match for some "blinkie" products for business and design reasons.

4 There are a variety of logical tasks that opening and closing a circuit may accomplish. The example used here is a "blinking" function where a circuit might need to open for a certain period of time before closing and remaining closed for a period of time. A "blinkie" function might repeat in complex ways to do such things as send light to TV screen to display and image, or even emit electromagnetic waves in a predefined way so as to send a voice call from a cellular phone.

Thus, such a hardware designer's focus and ability to create the "blinkie" function are closely coupled with considerations of how best to correlate the flow and timing of electricity to achieve a logical task. Naturally, certain logical functions can be packaged together to form higher order functionality. For example, transistors, and diodes can all provide low-level logical functions that can likewise be incorporated in the design of even higher-order "chips" such as hardware components that perform specific functions or operations, such as filters, mixers, amplifiers, and detectors.[5]

Among these higher-order chips there are two broad categories, very roughly “hardware” and “software” chips. Special purpose chips, such as application-specific integrated circuits (ASIC), utilize lower-order electrical circuits to provide functionality that is solely fixed by the physical nature of the chips.[6] These chips provide for only specific functionality. That functionality can't be altered without the altering physical nature of the chip.

The other variety of software "programmable" chips provide a set of performance characteristics that can be manipulated using symbolic constructs, commonly known as "code" or software. These software-enabling chips come in a variety of forms, but from a development perspective all offer developers the ability to focus on higher-order logical tasks rather than physical electrical properties.

Various performance considerations such as form factor, performance, development expertise, and, of course, price influence the direction development of a particular project may take. In the past these performance and business considerations tilted many sectors towards the use of specialized hardware solutions that relied heavily on non-programmable semiconductors. However, as Gordon E. Moore observed in an article in 1965 that the number of transistors in integrated circuits had doubled every year, the trend in the computer industry demonstrates that computational capacity of machines generally doubles every 18 months.[7] This phenomenon is widely known today as “Moore’s Law.” The impact of Moore’s Law in the business computing sector was to shift the development and business balance in favor of developing devices that execute “software” to accomplish desired tasks.

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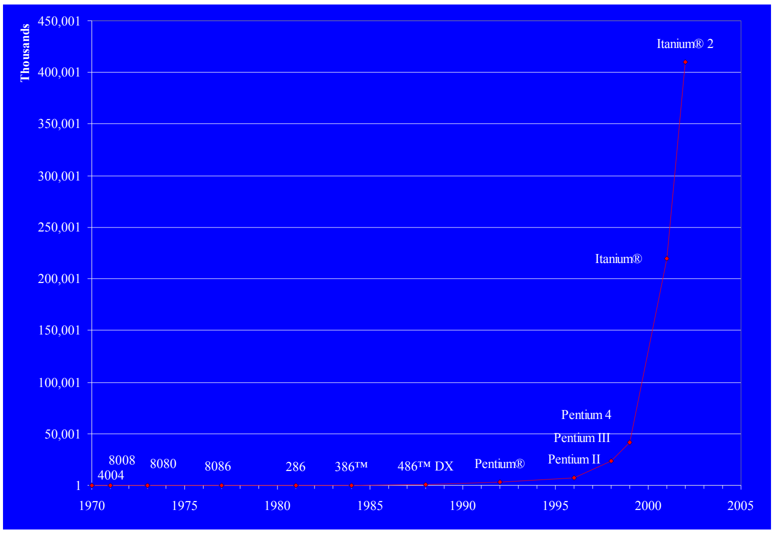
5 Some electrical components function by manipulating the “analog” properties of materials but as components become more complex they tend to rely solely on the “digital” boolean logic properties of other components. http://en.wikipedia.org/wiki/Digital. Engineers tend to specialize in either analog or digital signal engineering, but “mixed-signal” engineering that deals with translation of signals between the digital and analog domain is an important part of SDR development. *See* Wikipedia, Mixed-signal circuit, *available at* http://en.wikipedia.org/wiki/Mixed-signal_circuit.

6 Wikipedia defines an ASIC as “an integrated circuit (IC) customised for a particular use, rather than intended for general-purpose use.” *See* Wikipedia, Application-specific integrated circuit, *available at* http://en.wikipedia.org/wiki/Asic.

7 *Cramming more components onto integrated circuits*, Electronics, Volume 38, Number 8, April 19, 1965.

Intel Pentium Processors 1970-2005



Source: Intel

However, the effect of Moore's Law is pervasive and today reverberates in every sector of development. The author experienced the impact of Moore's Law in the construction aggregate controls market in the late 90's. At the time, concrete, asphalt and other construction aggregate plant controls were solely the domain of embedded hardware systems. At first glance, the selling of rock, "mud," and road materials seems as "low-tech" a comparison to the late 90's Internet economy as conceivable. However, the processing of such materials involves sophisticated chemical scientific computing that demands advanced industrial real-time processing. The real-time controls of the industry were dominated by the same Process-Ladder-Logic controls (PLC) used pervasively in the industrial control sector.[8]

However, the guaranteed response times and processing capabilities of off-the-shelf PC hardware began to approach a level acceptable for many "soft" real-time tasks at the time back-office information systems capable of bringing significant business benefits entered the mainstream PC market.[9] For example, a typical Asphalt or

8 While Wikipedia and other web sources define "PLC" more generally as a "programmable logic controller," the use of "ladder-logic" in logic controllers is dominant, as well as the definition of the term used most commonly in the author's experience. The author directs readers to Wikipedia's respective definitions at http://en.wikipedia.org/wiki/Programmable_logic_controller and http://en.wikipedia.org/wiki/Ladder_logic.

9 These response times remain a focus of concern for PC based controls, and were recently identified as a source of concern in a recent review of the major Amateur SDR device cur-

Concrete plant may process daily thousands of tons of materials amounting to huge gross sales. Regardless of the existence of extremely sophisticated control systems, many plants conducted their administration all on paper. Any given public works project could amount to millions of dollars and take more than 90 days to invoice. Merely having sales data available to billing facilities made possible firms closing a 60 day gap of significant outstanding capital.

Today, Moore's Law is poised to revolutionize the capabilities of radio-frequency devices. Not only are cellular telephones an inexpensive daily accessory, RF components are now bundled in many household electronic devices. The RF enabled toaster is not far off. More importantly, Moore's Law and the role of software-oriented approaches for radio design stand ready to increase spectrum access opportunities, optimize use of spectrum and make it possible to avoid and reduce potential interference between users.

While in the past software-based radio processing was beyond the reach of most off-the-shelf components, RF processing is now possible in software. The history of hardware to software transition in other sectors would suggest that RF radio design and spectrum use stand on the verge of significant change. The role of FOSS software development in enabling these new opportunities is thus of significant interest to many developers who have experienced this transition in other sectors. The motivational focus of FOSS developers is explored below to better understand certain concerns and solutions for FOSS development of SDR software and how synergies with the Amateur licensing system can promote both group's goals in SDR development.

B. FOSS and Amateur Background and Motivational Linkages

i. Significance of FOSS and Amateur Radio for SDR Development

As discussed above, SDR offers broad new flexibility in the development of radio devices. Both FOSS and Amateur Radio can play a significant role in the evolution of SDR.

Amateur Radio has a long history that is tightly woven in the technical advancements of radio technology.[10] The FCC amateur licensing system has provided an environment where hobbyists, amateur scientists and students of radio engineering can gain expertise from real-world application of radio engineering concepts. This experi-

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rently available. *See* Rick Lindquist, *Product Review: FlexRadio Systems SDR-1000 HF+VHF Software Defined Radio Redux*, QST Magazine, October 2005, *available at* http://www.flex-radio.com/articles_files/2005-10_QST_Review.pdf.

10 Many radio pioneers around the world, but particularly in the U.S. and Japan, were first exposed to radio engineering through amateur radio. *See generally*, Thomas H. White, United States Early Radio History § 15, *available at* http://earlyradiohistory.us/sec015.htm; conversations with Dr. Isamu Nagano, Professor, Kanazawa University, Faculty of Engineering

ence often translated into significant work opportunities. Amateurs having acquired valuable experience with radio engineering often transitioned into professional positions in government industry and academia. In Japan for example roughly half of space research academics gained their first experience with radio engineering with amateur radio.

However in Japan, the US, and the rest of the world, amateur radio no longer plays the same role in attracting new talent and preparing potential engineers for work in radio technology. This controversial point was first raised by Johan Costas, with the rise of SSB transceivers.[11] Costas warned that amateur radio was significant because amateurs acquired valuable skills putting together their own radio "shacks." He argued that because SSB transceivers were too difficult to be made generally, amateur radio risked losing its engineering focus.

The continued decline in numbers of amateurs worldwide may be attributed to this concern as much as the rise of the Internet as a communications medium.

ii. The Internet, FOSS, and Wireless

The rise and current prominence of the Internet can be largely attributed to broad proliferation of technology that was easily malleable and an excellent vehicle for teaching. Many computer scientists learned much of the fundamentals of software development through lens of the TCP/IP protocol stack. Low level device drivers, client-server application development, and sophisticated routing technologies all provide abundant examples of hobbyist and student work that blossomed into technologies today supporting billions of dollars of commerce. The blueprint for the IP protocol itself is the quintessential example of education and learning as an impetus for technological growth.

Much of this educational learning was possible because software was made available on terms that permitted free (read freedom) modification and copying. These "free" or “open source” software (“FOSS”) licenses played a significant role in the Internet becoming the vehicle for modern communications systems.[12]

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11 Johan Costas, noted pioneer in CDMA and SSB development, urged the adoption of suppressed carrier double-sideband use by Amateurs because such transceivers were much easier to manufacture. Johan Costas, “Poisson, Shannon and the Radio Amateur,” Proc IRE, Dec. 1959.

12 The Free Software Foundation defines free software as a matter of the users' freedom to run, copy, distribute, study, change and improve the software. Specifically it defines four necessary freedoms to satisfy as “Free Software.” The freedom to run the program, for any purpose (freedom 0). The freedom to study how the program works, and adapt it to your needs (freedom 1). Access to the source code is a precondition for this. The freedom to redistribute copies so you can help your neighbor (freedom 2). The freedom to improve the program, and release your improvements to the public, so that the whole community benefits (freedom 3). Access to the source code is a precondition for this. The Free Software Foundation (FSF) is the principal organizational sponsor of the GNU Project launched in 1984 to develop a

The pedigrees of amateur radio and FOSS have many things in common. In the second part of this paper we explore why FOSS development under the Amateur Radio licensing system not only makes FOSS transition into the wireless world easier, but can revitalize amateur radio itself.

III.Commission Rules and the FOSS Wireless Developer

Above all else SDR and related technologies offer the potential for radios to use radio spectrum more intensively and more efficiently than in the past. This technology comes at just the right time, as the existing system of spectrum use seems to bust at the seams with demand for available spectrum driven by a highly diverse marketplace of devices and uses. The Commission has emphasized consistently that the benefits of these technologies over traditional hardware-based radio systems are important for all the Commission's regulatory models, namely both licensed (exclusive use) and license-exempt (unlicensed commons) spectrum use models. The technologies have been identified as important elements of the spectrum reform efforts of the secondary markets proceedings.[13] The technologies have also been a central feature of the cutting edge unlicensed proceedings in the 5 GHz (DFS), 3 GHz and other proceedings.[14]

The goal of Smart Radio Rules described in the collective Software-Defined Radio and Cognitive Radio proceedings was to achieve a balance of flexibility to innovate new radio technology, and necessary limitations to prevent harmful interference from misuse of the technology.[15] The rules establish a framework of conditions for

complete free software UNIX style operating system. GNU is frequently used synonymously with Free Software.

The Open Source Initiative (OSI) is a non-profit corporation promoting the Open Source Definition through a certification mark program. The “Open Source” definition requires the following features for compliant licenses:

1. Free Redistribution; 2. Source Code; 3. Derived Works; 4. Integrity of The Author's Source Code; 5. No Discrimination Against Persons or Groups; 6. No Discrimination Against Fields of Endeavor; 7. Distribution of License; 8. License Must Not Be Specific to a Product; 9. License Must Not Restrict Other Software; 10. License Must Be Technology-Neutral.

The Open Source Definition Version 1.9, available at http://www.opensource.org/docs/definition.php

13 *See Report and Order and Further Notice of Proposed Rule Making* in WT Docket No. 00-230, 18 FCC Rcd 20604 (2003) and *Second Report And Order, Order On Reconsideration, And Second Further Notice Of Proposed Rulemaking* in WT Docket No. 00-230, 19 FCC Rcd 17503 (2004).

14 *See Notice of Proposed Rule Making* in ET Docket No. 04-186, 19 FCC Rcd 10018 (2004) and *Notice of Proposed Rule Making* in ET Docket No. 04-151, 19 FCC Rcd 7545 (2004); 3650-3700 MHz band *Report & Order* , FCC 05-56, ET Docket No. 04-151 (adopted March 10, 2005).

15 “We neither wish to have our processes inadvertently be a barrier to the development and deployment of these technologies nor wish to permit the widespread deployment of radios

permissible software modification and installation to SDR devices.[16] Ultimately, SDR devices are radios that use the RF spectrum and like any other are subject to the regulatory constraints of the Commission's RF regulatory policies.[17] The Commission's spectrum regulatory policy is composed of rules and policies that, generally, "allocate" spectrum for specific services, describe specific rules governing use of spectrum under various services, and the specific licensing arrangements for spectrum use under the rules of a given service.[18]

As discussed in more detail below changes to this framework regarding the certification aspects for SDR, work together with other existing rules for licensed services, such as the Amateur service, and the Part 15 technical rules to strike the desired balance of flexibility and prevention.[19] The paper explores below this balance, specifically the relative strengths of development under Part 15 and Amateur licensing rules, and recommends the use of the Amateur rules for some FOSS development.

A. SDR Rules Background and the Collective "Smart Radio" Proceedings on Software Defined Radio and Cognitive Radio Technologies

Changes to the equipment authorization rules adopted in the 2001 "Software Defined Radio" proceeding were the Commission’s first attempt to accommodate this balance of flexibility for the developing software defined radio (SDR) technology. The Commission adopted rules defining software defined radio as a transmitter in which the operating parameters of frequency range, modulation type or maximum output power (either radiated or conducted) can be altered by making a change in soft-

easily susceptible of being misused to cause harmful interference to others.” R&O para. 4.

16 Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies, ET Docket No. 03-108, *Report and Order*, FCC 05-57 (rel. Mar. 11, 2005), available at http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-05-57A1.pdf (making significant changes to rules for Software Defined Radios first adopted in FCC 01-264 R&O).

17 47 C.F.R. § 2.801 (“As used in this part, a radio frequency device is any device which in its operation is capable of emitting radio frequency energy by radiation, conduction, or other means.”).

18 The Commission's spectrum policy is complex and a complete introduction is beyond the scope of this paper. A variety of sources provide very useful introductions to the

19 The rules describe the role of these technical rules together with the rules governing the regulation of radio devices. The rules explain:

(a) In order to carry out its responsibilities under the Communications Act and the various treaties and international regulations, and in order to promote efficient use of the radio spectrum, the Commission has developed technical standards for radio frequency equipment. The technical standards applicable to individual types of equipment are found in that part of the rules governing the service wherein the equipment is to be operated. In addition to the technical standards, the rules governing the service may require that such equipment receive an equipment authorization from the Commission as a prerequisite for marketing and importing this equipment into the U.S.A. The marketing rules, § 2.801 et seq., were adopted pursuant to the authority in section 302 of the Communications Act of 1934, as amended (47 U.S.C. 302). 47 C.F.R. § 2.1201.

ware that controls the operation of the device without making any changes in the hardware components that affect the radio frequency emissions.

The definition was a permissive one that did not require but instead *permitted* manufacturers the choice of declaring a device an SDR. Manufacturers electing to file for certification of an SDR could take advantage of other rule changes intended to accommodate SDR development, and avoid the need to physically re-label a device with a new FCC identification number in the field.

The most significant among the rules changes created the "Class III change" a streamlined procedure for obtaining approval for changes to the software in approved SDR devices affecting the RF characteristics of the device.[20] There are in fact three classes of permissive changes. Class I permissive changes do not "degrade" the RF characteristics of a device as it was certified, and no filing is required. Class II permissive changes modify a device such that they do degrade the characteristics of the device as it was certified, but remain in compliance with the applicable technical rules. A Class II change requires an acknowledgment from the party who certified the device that the changes are acceptable.[21]

Class III permissive changes modify approved SDR software in a way that affects the frequency, modulation type, output power or maximum field strength beyond what was previously approved. The Commission requires a filling describing the changes supported by test data demonstrating compliance of the device with the applicable rules, and prohibits the marketing of the equipment until after the changes deemed acceptable. Currently, the Commission is the only party who may certify SDR devices.

Additional changes to the rules allowed labeling of SDR equipment with the same FCC identification number to be used with these changes, and allowed FCC identification numbers to be displayed electronically, rather than with a physical label.

The other significant rule change required that SDRs incorporate security features to ensure that only approved software could be loaded into an SDR, and required that manufacturers supply a copy of software controlling the operating parameters of a radio to the Commission upon request.

i. Cognitive Radio Proceeding

In the follow-on "Cognitive Radio" proceeding, the Commission expanded the scope of the inquiry into SDR and related technologies to explore more thoroughly the potential benefits of sophisticated software for improving the spectrum marketplace.

The Commission adopted a Notice of Proposed Rule Making and Order ("Notice") December 17, 2003, seeking comment on various proposals and inquiries

20 *See* 47 C.F.R. § 2.1043(b).

21 The Commission is in many cases the party granting a device certification but in some cases [TCBs] are permitted to grant certifications for devices.

for the use of cognitive radio technology to facilitate improved spectrum access. Specifically, the Notice sought comment on: 1) the capabilities of cognitive radios, 2) permitting higher power by unlicensed devices in rural or other areas of limited spectrum use, 3) enabling the development of secondary markets in spectrum use, including interruptible spectrum leasing, 4) applications of cognitive radio technology to dynamically coordinated spectrum sharing, and 5) software defined radio and cognitive radio equipment authorization rule changes. The Notice garnered broad interest from industry, academia, and governmental interests with a total of 56 parties filing comments and 14 parties filing reply comments. Comments varied in content with highly technical contributions richly interspersed with those of a pure economic or policy nature.

In response to the record, the Commission adopted a Report and Order in March 2005, to modify and further clarify the authorization requirements for software defined and cognitive radios. The adopted changes now require that radios in which:

> software that controls the RF operating parameters is designed or expected to be modified by a party other than the manufacturer to comply with the rules for software defined radios, including the requirement to incorporate security features to prevent unauthorized modifications to the software.[22]

Changes to the rules now also substitute the certification requirement that applications include software "source code" with the more relaxed requirement manufacturers supply a high level operational description of the software controlling the radio's RF characteristics. In addition the new requirements require a description of the software security measures employed to prevent unauthorized modifications.[23]

B. Certifications Rules and Background to Device-Oriented Regulatory Approach

This framework for manipulation of SDR software elements enforced through device certification expresses the Commission's current desired balance of flexibility and prevention. Naturally, this balance rests on a variety of assumptions. Two significant concerns are who the intended users will be and the scope of the market for the devices. In fact, concerns about user base and market scope are at the core of both the certification process and its basis in statutory marketing rules. Thus it is important to understand the background and process of certification in order for FOSS development to lawfully proceed in the SDR world.

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22 Cognitive Radio R&O para. 20, at 8.

23 *See id.* In addition to the changes to the certification rules, the Order also clarified the rules to permit manufacturers to market radios that have the hardware-based capability to transmit outside authorized United States frequency bands, and concluded that there are technical measures that cognitive radios can employ that will allow reliable secondary use of spectrum without adopting any particular technical model for interruptible spectrum leasing or rules.

The modern device certification rules responded to Congressional action amending the Communications act to provide the Commission greater authority to address interference problems. This feature is crucial to understanding the Commission's approach to the regulation of SDR and related devices. In the late 1960's the Congress deliberated the negative impact of harmful interference emitting from malfunctioning or manipulated devices. As a prominent example of the seriousness of RFI involving unlicensed devices, the Report cited interference caused to air-safety-related emergency communications and other frequencies at a California facility by 58 garage door openers, which were then, as well as now, RF devices subject to technical standards set out in Part 15 of our rules.[24] These concerns in fact lead to the adoption of amendments in 1968 to section 302 of the Communications Act of 1934, expanding the FCC's authority to address harmful interference concerns from non-compliant devices. The amendments authorized the FCC to make regulations to ensure that before RF devices enter the stream of commerce, they could be checked for compliance with the appropriate technical rules that ensure their use would not cause harmful interference.[25] The Commission adopted "marketing rules" pursuant to this authority, and established the current Commission's device authorization regulatory policy.[26] The statute and subsequent rules thus created a "pre-check" on the harmful interference potential of devices. Thus these device authorization rules work together with the technical rules to prohibit the use of equipment or apparatus which causes interference to radio communications.[27]

Today most radio transmitters that "intentionally radiate" radio waves are required to be certified before they can be marketed within the United States. The Commission rules in Part 2 specify the procedures for certifying for both licensed and unlicensed radios.[28] The certification procedures require tests that demonstrate a device's compliance with the applicable technical rules. The process also requires an application, test report and certain exhibits be filed.[29] In most cases changing the frequency range, modulation techniques, or power of an device that has already completed the process tees up the need to file a new application for certification, and in some cases a new label bearing a new FCC id number.[30] Certain changes to an approved device can be handled through the permissive changes discussed above, which require either a streamlined filing or no filing and do not require a new identification number on a device.

24 *See* 1968 Senate Report at 2488.

25 *See* 1968 Senate Report at 2488-91.

26 47 U.S.C. 302 (codifying section 302 of the Communications Act of 1934, as amended); 47 C.F.R. §§ 2.1201, 2.801 et seq.

27 *See* S. Rep. No. 1276, 90th Cong., 2d Sess. 1968, 1968 U.S.C.C.A.N. 2486, 2487 (1968 Senate Report)(recording the Senate's deliberations on the need for expanding the FCC's regulatory authority to address harmful interference from non-complaint devices in the field); *see generally* 47 C.F.R §§ 2.901, 2.1033, 15.5 et seq (defining the FCC's equipment certification and RFI requirements)

28 *See* 47 C.F.R. Part 2, subpart J.

29 *See* 47 C.F.R. §§ 2.1033 and 2.960.

30 *See* 47 C.F.R. § 2.1043(a).

The legislative history of the marketing rules and statutory changes demonstrate Congress' concern for controlling potential harmful interference when devices are "ubiquitous" and users lack specialized expertise, despite the existence of technical rules that if observed would prevent harmful interference. Thus, the harmful interference potential of devices is in large part evaluated in light of the potential scope of the market for the devices and the spectrum users not solely whether the appropriate rules are in place for real time spectrum use.

The certification rules shift some of the enforcement risk of devices from the field where it is costly and difficult to resolve, to the lab where advance review can allay the risk of potential interference occurring in the field.[31] The technical or other rules adopted to address concerns for harmful interference during actual operation, are enforced via the certification process that confirms conformity with the relevant rules.[32]

Thus, working under this statutory structure the Commission prohibits the sale, lease, or other transfer, or the advertising, importation, or distribution, of any new device that emits radio frequency energy by radiation, conduction, or other means unless it has complied with the applicable Commission equipment rules.[33] In the case of intentional radiating devices, which includes most applications of SDR, devices must be certified by the Commission or a designated third party.[34] Generally the certification of a new device is approved when it is found to operate in accordance with the technical standards of the rule part(s) under which the device is to be operated.

In addition to the certification policies, the Commission authorizes devices under other more lenient rules reflective of the various devices harmful interference potential. For example, simple digital devices are subject to a self approval process, called Verification. Under the verification rules manufactures need only perform tests on the devices, maintain test data that demonstrates compliance with the FCC technical rules, and properly label the device. Handheld games, calculators, and musical equipment with digital electronics or midi ports for connections between musical equipment are examples recently reviewed by the Commission.[35] Computer peripherals marketed for use in residential areas (Class B devices), can opt to use yet another

31 The Commission charges the Enforcement Bureau and the Office of Engineering and Technology with the shared responsibility for enforcement of radio frequency equipment and device complaints. *See* 47 CFR § 0.111(a)(4) and accompanying note.

32 The Commission in a recent order reviewed this history. *See Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, FCC 04-285, *Second Report and Order and Second Memorandum Opinion and Order*, ET Docket No. 98-153 [UWB R&O]. The Commission, inter alia, responded to a broad challenge to the statutory authority for its unlicensed regulatory, and discussed the relationship of device certification and its other spectrum use rules in preventing harmful interference.

33 *See* 47 C.F.R. § 2.803.

34 While many other intentional radiators may be certified by third-parties, only the Commission may currently certify software-defined radios.

equipment approval process similar to verification. Under the Declaration of Conformity (DoC) or certification process a "self-approval" requires that tests be performed by an accredited test laboratory.

C. Exceptions to the Certification SDR Requirements

Limited exceptions exist to the general authorization requirement discussed above, both in the statute and the rules that offer FOSS developers flexibility in developing certain SDR.[36]

For example, devices used for Part 97 Amateur Radio Services are subject only to limited Part 2 requirements, and home-built devices are excluded from equipment authorization requirements.[37] The Amateur device authorization procedures are discussed in more detail below, but the home-built provisions provide:

> (a) Equipment authorization is not required for devices that are not marketed, are not constructed from a kit, and are built in quantities of five or less for personal use.
> (b) It is recognized that the individual builder of home-built equipment may not possess the means to perform the measurements for determining compliance with the regulations. In this case, the builder is expected to employ good engineering practices to meet the specified technical standards to the greatest extent practicable. The provisions of Sec. 15.5 apply to this equipment.[38]

In short, an individual employing solely their own technical resources, not simply assembling a prepackaged kit, can in limited numbers manufacture and utilize home-built devices. Moreover presumably the builder is expected to have sufficient engineering expertise to manufacture and evaluate the home-built device to meet the technical standards required by the rules. This rule at first glance seems to offer much for an aspiring FOSS wireless developer. On closer review there are both practical and theoretical concerns for the FOSS developer.

35 FCC Clarifies Equipment Authorization Policy for Approving Music Devices that Connect to a Personal Computer, DA 04-2253, October 12, 2004.

36 *See* 47 U.S.C. § 302c (Statutory exceptions); 47 C.F.R. § 2.1202, et seq.; 47 C.F.R. § 2.807 (excluding public utilities, Federal Government users, export manufacturers and transporters from 2.803 requirements); 47 C.F.R. § 2.811 (excluding part 73 Radio Broadcast Services transmitters from 2.803(a)-(d) requirements); 47 C.F.R. § 2.813 (excluding part 74 Instructional Television Fixed Service from 2.803(a)-(d) requirements provided transmitters satisfy conditions in 74.952).

37 47 C.F.R. §§ 2.1060, 15.23. Amateur radio equipment is generally exempt from a certification requirement, except for certain external power amplifiers. *See* 47 C.F.R. §§ 97.315 and 97.317.

38 47 C.F.R. § 15.23.

Development of wireless hardware is not an easy task. Even in the Amateur community today, most radios in use are manufactured "shacks" not those designed and assembled by individual amateurs. In fact at the time of the early adoption of the single-side band (SSB) transceiver in the Amateur community, noted electrical engineer, Johan Costas, cautioned that because development of SSB transceivers was out of reach of most Amateurs, SSB's adoption in that community would negatively impact the hardware oriented experimentation nurtured by the Amateur system.[39]

As a practical matter, design and manufacture of sophisticated SDR's may well be beyond the reach of many novice FOSS wireless developers. However, there are a variety of interesting radio projects readily available to software developers new to the radio field. For example, several technical articles in the amateur community describe in detail both the theoretical mathematics's at the core of the project, as well as practical soldering iron skills needed to assemble the project.[40] Nevertheless such projects are directed at Amateur radio licensees who are permitted use of the spectrum that lacking a license FOSS developers would not be legally permitted to use. Moreover, these projects would not usable in the frequencies the Commission's Part 15 rules permit use without an individual license. Thus as a practical matter FOSS wireless developers hoping to use the home-built exemptions for design of devices under the Part 15 rules face practical issues.

The use of the home-built rules pose another theoretical concern raised above in the discussion of a what an SDR is and why the technology garnishes such current interest. In short, innovative hardware design is nothing new to radio. However, It is the use and technical potential of *software* that makes SDR so important to spectrum reform and new innovative design approaches. FOSS wireless developers naturally must have some understanding of the hardware engineering aspects of radios, but much of the goal of SDR is the possibility of abstracting the software process from hardware tinkering. In short, undue focus on hardware development robs SDR software development of its central strength.

Thus requiring FOSS developers to first acquire expert hardware wireless engineering fabrication skills before entering the wireless software development world is not consistent with the Commission's policies for encouraging SDR development. Unfortunately, as a practical matter home-built designs are out of reach of most developers, and as a regulatory matter off-the-shelf or kit development approaches are not permitted without teeing up Commission certification requirements for SDR radios.

D. "Catch-22" Certification Issues for FOSS SDR Development Using Off-the-shelf Equipment or Self-Assembly Kits

39 Johan Costas, noted pioneer in CDMA and SSB development, urged the adoption of suppressed carrier double-sideband use by Amateurs because such transceivers were much easier to manufacture. Johan Costas, "Poisson, Shannon and the Radio Amateur," Proc IRE, Dec. 1959.

40 Articles are cited and discussed in more detail in Part III.G below.

As discussed above, SDRs are now required to have technical measures to prevent manipulation of SDRs RF oriented software. In addition, FOSS developers would not be exempt from certification under the home-built exception for assemble of the many kits that are entering the market for Amateur SDR development.[41] The SDR rules now require radios using software "designed to be, or expected to be, modified by a party other than the manufacturer" to employ security mechanisms to "prevent unauthorized software modifications" that would touch the RF operating characteristics of the radio. This would seem to put the individual FOSS developer in a "pig in a poke" being subject to a rule that lacking permission of the manufacturer prohibits the very modifications wireless software development attracts. In any event, FOSS developers unable to design a modern SDR hardware apparatus themselves would not be able to make "unauthorized software modifications," which would presumably be the point for development of any air-interface oriented wireless oriented software.

Absent the Commission rules requiring "hardening" of SDR equipment against unauthorized modifications, these hardening mechanisms would very likely invoke other legal barriers to SDR FOSS development. As has been demonstrated in various court reviews of the Digital Millennium Copyright Act, individual software experimentation that circumvents "copyright protection schemes" are subject to strict legal sanctions.[42] In the case of SDR software, a hardening scheme would likely involve a protection scheme that *by definition* is not only designed, but Commission rule *required*, to protect the software of the device. Thus SDR software modifications naturally raise certain DMCA legal interpretation concerns.

Naturally the rules provide certain avenues for enterprising FOSS developers to seek certification for software modifications of off-the-shelf SDRs. The rules do

41 *See* 47 C.F.R. § 15.23(a) ("Equipment authorization is not required for devices that are not marketed, are *not* constructed from a kit, ...") [emphasis added].

42 *See* Digital Millennium Copyright Act ("DMCA"), 17 U.S.C. § 1201 et seq. (Supp. V 1999). The Second Circuit has ruled on that software that circumvents a DVD protection scheme may not be distributed and is not lawful under the DMCA, while the Sixth Circuit has found that merely accessing a copy-protection scheme for the purposes of compatibility is not actionable under the DMCA. *Compare Universal City Studios, Inc. v. Reimerdes*, 82 F. Supp. 2d 211 (S.D.N.Y.,2000), *aff'd sub. nom. Universal City Studios, Inc. v. Corley*, 273 F.3d 429 (2d Cir. 2001) (affirming lower courts injunction barring individual software developers and users from posting "DeCSS" DVD copy-protection decryption software on web sites and from knowingly linking web sites to any other web site on which DeCSS is posted), *with Lexmark Int'l Inc. v. Static Control Components Inc.,* E.D. Ky., Civ. Action No. 02-571, 3/23/05; *Static Control Components Inc. v. Lexmark Int'l Inc.,* E.D. Ky., Civ. Action No. 04-84, 3/23/05, en banc hearing denied 387 F.3d 522, 72 USPQ2d 1839 (6th Cir. 2004) (ruling that the anti-circumvention provisions of the DMCA only protect copyrightable subject matter, and that Lexmark's on-cartridge security software functioned to protect subject matter that was not sufficiently original to meet copyrightable standards or was subject to fair use or merger under the scene affair or other doctrines.).

not prohibit the modification of the software outright but would require a modifying party to assume the regulatory burdens of certifying the modified SDR device. The Certifications rules function together with the definitions of a "responsible party" to track who is responsible for initial and subsequent technical compliance of the device.[43] However, the legally required submissions of the certification rules for SDR make both individual and group collaborations complicated for FOSS development.

A threshold question for a FOSS developer seeking authorization to modify SDR software from a grantee is do the rules allow a grantee to "authorize" modifications to SDR software and if so how. The rules provide that "[a]n equipment authorization issued by the Commission may not be assigned, exchanged or in any other way transferred to a second party, except as provided in" Section 2.929 of the rules.[44] The section provides in part that:

> The grantee of an equipment authorization may license or otherwise authorize a second party to manufacture the equipment covered by the grant of the equipment authorization provided:
>
> (1) The equipment manufactured by such second party bears the FCC Identifier as is set out in the grant of the equipment authorization.
>
> (2) The grantee of the equipment authorization shall continue to be responsible to the Commission for the equipment produced pursuant to such an agreement.[45]

Thus a manufacturer grantee as the responsible party under Section 2.909 could under Section 2.929 "license or otherwise authorize" an FOSS developer permission to modify the software of an approved SDR.[46] However, as Sections 2.909 and 2.929(b)(1) above indicate, the grantee would remain responsible for the technical compliance of the device in this case.[47] Certainly many manufacturers may wish to enlist the assistance of the FOSS community for collaborative work on a grantee's SDR software, and in cases where manufacturers share strong relationships with FOSS developers use of this rule is likely. However, under more independent working relationships, a grantee might be reluctant to maintain responsibility for the third-parties software modifications. Moreover, certification rules would require fillings and fees for many modifications that would require a grantee to assume regulatory burdens on behalf of the third-party.

43 Part 2 of the Commission's rules identifies "responsible parties," who are held accountable for ensuring that a device complies with our rules. *See* 47 C.F.R. § 2.909.

44 47 C.F.R. § 2.909(a).

45 47 C.F.R. § 2.909(b).

46 The rules would require notice of such a change be submitted to the Commission via the Internet at https:// gullfoss2.fcc.gov/prod/oet/cf/eas/index.cfm within 30 days. 47 C.F.R. § 2.909(c).

47 47 C.F.R. § 2.909(a) ("The following parties are responsible for the compliance of radio frequency equipment with the applicable standards: In the case of equipment which requires the issuance by the Commission of a grant of equipment authorization, the party to whom that grant of authorization is issued (the grantee).").

Absent the above collaborative relationship with the grantee authorizes and assumes the regulatory burdens for FOSS modifications, FOSS developers would be required to assume the role of "responsible party" and comply with the rules—assuming the above threshold issue of actually modifying the device is overcome. The rules regarding "responsible party" state that "[i]f the radio frequency equipment is modified by any party other than the grantee and that party is not working under the authorization of the grantee pursuant to § 2.929(b), the party performing the modification is responsible for compliance of the product with the applicable administrative and technical provisions in this chapter."[48] Moreover, the section continues that a new party who becomes responsible for compliance by virtue of a modification, and does not obtain a new equipment authorization must relabel the device indicating their name and contact info.[49]

The rules also require that certified equipment comply with the applicable technical rules,[50] that an applicant or grantee supply a sample of a device to the Commission upon request, which we can test to determine if the device is compliant,[51] and additionally grantees are required to maintain and make available for inspection records of equipment specifications and any changes that can affect compliance.[52]

Thus the rules may permit FOSS developers to independently modify SDR software, but the rules would again pose difficulties for the individual FOSS developer in particular. The first matter is one of economics. Application require fees, and the Class II changes discussed above for example would require a [$400] filling fee simply for modifications under that rule. Moreover, the typical developer is likely intending to develop and share his work. While FOSS licenses do not require modifications be resubmitted to the author or otherwise place a mandatory disclosure on modified code, the nature of the licenses are specifically designed to address problems of how to share code. As discussed above, the role of the "responsible party" in certifying and maintaining approval of a device is a burden that many FOSS developers may find too burdensome to get involved in wireless innovation.

E. Part 15 and "unlicensed" rules background and the "Static Rules" Dilemma for Real-Time Radio Processing

The current market in unlicensed devices provides an excellent illustration of the effectiveness of the above approach of balancing flexibility with reasonable protec-

48 47 C.F.R. § 2.909(a).

49 47 C.F.R. § 2.909(d). ("If, because of modifications performed subsequent to authorization, a new party becomes responsible for ensuring that a product complies with the technical standards and the new party does not obtain a new equipment authorization, the equipment shall be labeled, following the specifications in § 2.925(d), with the following: "This product has been modified by [insert name, address and telephone number of the party performing the modifications]."").

50 *See* 47 C.F.R. § 2.931.

51 *See* 47 C.F.R. §§ 2.943 and 2.946.

52 *See* 47 C.F.R. §§ 2.936(a) and 2.938(a).

tions against harmful interference. WiFi, Bluetooth and other technologies operate under technical rules in Part 15 of the Commission rules.[53] The devices are ubiquitous, and widely used in every demographic of the U.S. public.[54] Briefly, these rules allow use of the radio spectrum without an individual license subject to various conditions. Specifically, use of spectrum under Part 15 rules are subject to the general conditions of operation in Section 15.5.[55] Section 15.5 first denies any use constituents any vested or recognizable right to continued use of any give frequency.[56] The Section states that operations do not enjoy protection from harmful interference from authorized radio station, by another intentional or unintentional radiator, by industrial, scientific and medical (ISM) equipment, or by an incidental radiator.[57] The Section states that operation under the part is subject to the condition that it not cause harmful interference and must cease operation when notified it may.[58]

In the Commission's recent review of the history of the development of the Part 15 regime, it stated that in establishing the Part 15 regime, the Commission realized that any attempt to license all transmitters of radio frequency energy would be infeasible and contrary to Congress's intent in establishing a "rapid, efficient, Nationwide, and world-wide wire and radio communication service."[59] The Commission clarified that despite the fact that certain devices are unlicensed, the Commission's technical and other regulations ensure that they do not cause harmful interference to authorized users of the spectrum. Moreover, the Commission called particular attention to

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53 47 C.F.R. Part 15 et seq.

54 The Consumer Electronics Association estimates that there is an installed base of more than 348.23 million Part 15 consumer electronic devices. That is more than one for every US citizen. *See* OSP Working Paper Series Number 39, *Unlicensed and Unshackled: A Joint OSP-OET White Paper on Unlicensed Devices and Their Regulatory Issues*, May 2003, at pg. 22 (this report includes additional data on the increase in the use of various unlicensed devices, such as cordless telephones, wireless local area networks, spread spectrum devices, and WiFi) [OSP Unlicensed Working Paper].

55 47 C.F.R. § 15.5 General conditions of operation.

(a) Persons operating intentional or unintentional radiators shall not be deemed to have any vested or recognizable right to continued use of any given frequency by virtue of prior registration or certification of equipment, or, for power line carrier systems, on the basis of prior notification of use pursuant to § 90.63(g) of this chapter.

(b) Operation of an intentional, unintentional, or incidental radiator is subject to the conditions that no harmful interference is caused and that interference must be accepted that may be caused by the operation of an authorized radio station, by another intentional or unintentional radiator, by industrial, scientific and medical (ISM) equipment, or by an incidental radiator.

(c) The operator of a radio frequency device shall be required to cease operating the device upon notification by a Commission representative that the device is causing harmful interference. Operation shall not resume until the condition causing the harmful interference has been corrected.

(d) Intentional radiators that produce Class B emissions (damped wave) are prohibited.

56 47 C.F.R § 15.5(a).

57 47 C.F.R § 15.5(b).

58 47 C.F.R §§ 15.5(b)(c).

59 47 U.S.C. § 151; *see also* UWB R&O.

the fact that part 15 sets out the regulations under which one may operate without an individual license, and that any operation that is not in accordance with the Part 15 regulations must be licensed under Section 301 unless exempted elsewhere in the rules.

Thus the balance of the Part 15 rules provides significant regulatory flexibility promoting real-time spectrum access, at the cost of technical flexibility and real-time spectrum efficiency. For example, the rule that WiFi, Bluetooth and many other unlicensed applications operate under allows two flavors of spectrum protocols that balance allowable power and bandwidth.[60] The rule states in part that "[o]peration under the provisions of this Section is limited to frequency hopping and digitally modulated intentional radiators that comply with" a series of engineering provisions. These provision are intended to prevent harmful interference and other problems such as spectrum hogging (bandwidth and timing) and congestion (timing and channelization). For example, frequency hopping systems, depending on the band of operation the system must use transmissions of a certain breadth, with a certain separation, and certain degree of randomness in selecting operating frequencies.[61] Digitally modulated intentional radiators are subject to a minimum 6 dB bandwidth of at least 500 kHz with regard to the output and are also subject to a power spectral density requirement the further defines the acceptable bandwidth power relationship.[62]

The success of the technical balance of these and the other rules in Part 15 is evident in the plethora of devices that today operate under these rules. Clearly, for the bulk of consumers the balance has been an appropriate one that has yielded tremendous benefits and satisfied the Commission's obligations under the act to "maintain the control of the United States over all the channels of radio transmission; and to provide for the use of such channels…by persons for limited period of time, under licenses granted by Federal authority…" while at the same time "encourag[ing] the provision of new technologies and services to the public."

However, for FOSS software developers there are significant drawbacks to using the Part 15 framework for wireless software development. The first concern is

60 Wi-Fi is a trade name covering a variety of IEEE wireless protocols. Some of these operate under other rules in Part 15, but the popular IEEE 802.11b protocol operates under 47 C.F.R. § 15.247. The certifying body for Wi-Fi devices, the Wi-Fi alliance, explains "Wi-Fi is short for "Wireless Fidelity," and it is the popular name for 802.11-based technologies that have passed Wi-FI certification testing. This includes IEEE 802.11a, 802.11b, 802.11g and upcoming 802.11 technologies." Wi-Fi Alliance, FAQ, available at http://www.wi-fi.org/OpenSection/FAQ.asp?TID=2#what_is.

61 The rule describes two acceptable techniques for selecting hopping channel bandwidth based on a maximum 25 Mhz channel or alternatively 20 dB of the hopping channel, though all techniques most randomly hop through a list of channels with equal time for each channel. 47 C.F.R. § 15.247(a)(1). Specific rules specify number of required hopping channels, allowable time of occupancy of a given channel, etc. based on the bands of operation. 47 C.F.R. § 15.247(a)(1)(i)-(iii).

62 47 C.F.R. §§ 15.247(a)(2),(d).

that of certification and the issues discussed above. Making modifications to existing Part 15 approved RF software requires certification to operate lawfully. However even assuming the certification issues could be overcome the framework of the Part 15 rules are not well-suited to open-ended real-time engineering experimentations. The rules are drafted conservatively with a mass consumer market in mind in achieving the balance of policy issues discussed above.

Naturally, spectrum users with specialized expertise can avoid most problems even in the field without intervention by the Commission. The rules in fact rely heavily on this assumption and are rift with provisions advising or admonishing spectrum users on the resolution of harmful interference should it occur.[63] Moreover, the statute and certification rules also reflect this difference in assumptions about the nature of the spectrum user in the balancing of flexibility. For example, the statute exempts certain users from various aspects of the certification process.[64]

Thus the development environment of the certification and part 15 rules are not tuned for the independent FOSS entrepreneur. It must be pointed out that this is not a fault of the rules or the Commission but simply a function of the assumptions and balance achieved by the rules. Moreover, modifying the existing balance of SDR certification or other rules to better accommodate FOSS development could pose serious risks to the overall balance achieved by the rules. There exists an alternative to altering the balance achieved by the existing SDR regulatory framework. The paper now turns to the system of Amateur licensing and the benefits of adopting this approach as an alternative for SDR FOSS development

F. Amateur Radio Certifications

These SDR rules make perfect sense in the context of a market of millions of devices marketed in mass-retailers markets with consumers purchasing SDR wireless devices together with a VCR many may have trouble even programming the clock for. Unfortunately for FOSS developers, the assumptions about technical knowledge and diligence are not necessarily congruent with many in the FOSS development community.

FOSS developers, as discussed above, typically share a strong sense of community civics and technical expertise. They are not the typical consumer unable to program a VCR but instead the one who takes it apart to see how the clock functions and whether they can replace it with a fancy new blinking light. As indicated above

63 In many licensed bands, there are a mix of primary, co-primary, and secondary users that must share spectrum. Under current policies, the Commission adopts specific mechanisms to specify the respective rights of users, such as "prior coordination" and "first-in, first-protected" regimes. *See, e.g.,* 47 CFR Pts 25.203 & 101.103.

64 *See* 47 U.S.C. § 302c (Statutory exceptions); *see also fn*. 36 and accompanying text.

these same "cultural values" evident in the FOSS community are at the core of the Amateur licensing regime as well, and merit the attention of the FOSS community.

The amateur radio service, governed by Part 97 of the Commission's Rules, provides spectrum for amateur radio service licensees to participate in a voluntary non-commercial communication service which provides emergency communications and allows experimentation with various radio techniques and technologies to further the understanding of radio use and the development of new technologies.[65] Important distinctions in how amateur licensees and their devices are regulated make the Amateur licensing system extremely attractive for many FOSS developers. Twenty-seven small frequency bands throughout the spectrum are allocated to this service internationally. Some 1,300 digital, analog, pulse, and spread-spectrum emission types may be transmitted. The design, construction, modification, and repair of amateur's personal stations is encouraged, reflected by the fact that the FCC equipment authorization program does not generally apply to amateur station transmitters.[66] Thus in contrast to the above, amateur licensees have access to a liberal certification system and real-time spectrum experimentation environment.

As regards real-time spectrum use and technical modifications, in contrast to the nature of the acceptable modulation and emission technical rules of Part 15 describing acceptable bandwidth of emissions, Sections 97.305 and 97.305 provide broad directives for authorized emission types and standards, providing for example that "[a] data emission using an unspecified digital code . . . also may be transmitted" with an authorized bandwidth 100 kHz subject to the caveat that "[n]o amateur station transmission shall occupy more bandwidth than necessary for the information rate and emission type being transmitted, in accordance with good amateur practice."[67]

Thus subject to four general prohibitions, any amateur-operator-to-amateur-operator communication is generally permitted.[68] Firstly some transmissions are specifically prohibited. Transmissions for personal compensation or for the pecuniary benefit of the station control operator his employer are also prohibited.[69] In addition certain other transmissions are prohibited such as: "Music using a phone emission except as specifically [permitted]; communications intended to facilitate a criminal act; messages in codes or ciphers intended to obscure the meaning thereof, except as otherwise [permitted]; obscene or indecent words or language; or false or deceptive messages, signals or identification."[70] "Communications, on a regular basis, which could reasonably be furnished alternatively through other radio services" are also prohibited.[71] While cipher restrictions, in particular, could constrain some development, the

65 See 47 C.F.R. § 97.1.
66 See generally, http://wireless.fcc.gov/services/amateur/about/.
67 47 C.F.R. § 97.307(a),(f)(13). Codes defined in Section 97.309(b) and elsewhere have different, in many cases more liberal, technical characteristics.
68 47 C.F.R. § 97.113.
69 47 C.F.R. § 97.113(a)(2)-(3).
70 47 C.F.R. § 97.113(a)(4).
71 47 C.F.R. § 97.113(a)(5).

system remains an attractive regulatory environment and a good match for the general motivations of FOSS development.

Gaining access to this development environment comes at the cost of obtaining a license and observing the rules of the Amateur Service in Part 97. Obtaining a license grant requires passing an examination administered by a team of volunteer examiners (VEs) for the desired class of license. There are three classes of license, each authorizing privileges corresponding to the qualifications required from most liberal to restrictive: Amateur Extra Class, General Class, and Technician Class.

G. Current Activity and Promise of Amateur Radio and FOSS Collaborations

Amateur licensing can provide the FOSS developer access to a variety of development opportunities unavailable under the SDR and Part 15 rules. There is already a vibrant development community emerging under the amateur rules that offers newcomers to wireless software development a valuable center for technical software and hardware assistance. These projects demonstrate that synergies between the Amateur and FOSS communities already exist and are yielding important technical contributions.

Most significant in the area of hardware is the FlexRadio System SDR manufactured by Gerald Youngblood.[72] The device functions in many popular amateur spectrum bands and comes with PowerSDR, the device's freely distributable software meeting the GNU General Public License FOSS definition.[73] DttSP, signal processing software used in the PowerSDR, is made available under a FOSS license by the DttS Microwave Society.[74] AMSAT, the Radio Amateur Satellite Corporation now develops and deploys all of its satellites using SDR based transponders.[75] The ARRL's High-Speed Digital Networks and Multimedia (HSMM) and SDR working groups are developing an Orthogonal Frequency Division Multiplexing (OFDM) based SDR modem that will leverage turbo trellis coding and other techniques for a system that promises to be largely "fading immune."[76] On the FOSS development side, the GNU-

72 Steve Ford, QST editor wrote recently in the April 2005 issue, "The debut of the FlexRadio SDR-1000 opens a new chapter in the history of Amateur Radio. I'm not indulging in hyperbole by making such a statement – it is a fact. For the first time in ham history, you can purchase 'off the shelf' an HF and 6 meter transceiver that uses software to define its functionality – a software defined radio." quoted at http://www.flex-radio.com/products_files/index.htm.

73 *See* http://www.flex-radio.com/home_files/GPLPolicy.pdf.

74 The DttS Microwave society explains: DttSP is an open source project started by Dr.Frank Brickle and Dr. Robert McGwier of the DTTS Microwave Society to provide code to be used in various DSP projects with an emphasis on Software Defined and Cognitive Radio. *See* DttSP Project Home Page, *available at* http://dttsp.sourceforge.net/.

75 AMSAT will soon launch Phase 3E, its 52nd satellite, using all software based telecommand links and SDR based transponders. *See* email conversations with Dr. Robert McGwier.

76 *See id*. OFDM is an advanced technique that emits messages at different frequencies at mathematically defined intervals, and is a focus of spectrum engineering because of its high

Radio project under the auspice of the Free Software foundation, releases a variety of transmit and receiver-side software and is heading the development of a modular SDR hardware platform called the Universal Software Radio Peripheral.[77]

The American Radio Relay League, Inc., provides a useful portal of information on SDR development and active amateur work in the area via their Technical Information Service.[78] The website provides links to many of the important articles on SDR and the amateur service, many of which are accessible to the non-technical policy community. Dr. Michael Marcus in his article "Linux, Software Radio and the Radio Amateur" first discussed the possible synergies of Amateur Radio and the Linux kernel FOSS development experience.[79] Other serial articles by Leif Åsbrink and Gerald Youngblood, focus on technical development of both hardware and software aspects of SDR under the Amateur regime.[80]

IV. Conclusion

FOSS SDR development can contribute much to the development and innovation poised to revolutionize how spectrum is used. FOSS development under an amateur licensing model can flourish under the liberal regulatory framework for technical experimentation. The broad influx of new engineering insights and talent will also benefit amateur radio by providing invigorating it with renewed focus on engineering innovation relevant for the modern communications world. Individual FOSS developers will acquire valuable new skills likewise providing a new pool of talent for the commercial, academic and government spectrum engineering communities.

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efficiency and resilience to interference. *See generally*, Wikipedia, Orthogonal frequency-division multiplexing, available at http://en.wikipedia.org/wiki/OFDM.

77 GNU Radio, the gnu software radio, http://www.gnu.org/software/gnuradio/; see also http://comsec.com/wiki?UniversalSoftwareRadioPeripheral.

78 *See* American Radio Relay League, Inc., Technical Information Service, available at http://www.arrl.org/tis/info/sdr.html. The TIS provides the following contact info for contact. 225 Main St., Newington, CT 06111 (860) 594-0214. Email: tis@arrl.org (Internet).

79 *See* Dr. Michael Marcus (N3JMM/7JIAKO), *Linux, Software Radio and the Radio Amateur*, QST, Oct 2002, available at http://www.arrl.org/tis/info/pdf/0210033.pdf.

80 Gerald Youngblood's four part series titled, A Software-Defined Radio for the Masses, were published in the*QEX* from July 2002 through April 2003. *QEX*, Mar/Apr 2003, pp. 20-31; *QEX*, Nov/Dec 2002, pp. 27-36; *QEX* Sep/Oct 2002, pp. 10-18; *QEX* Jul/Aug 2002, pp. 13-21. Leif Åsbrink's five part article titled, Linrad: New Possibilities for the Communications Experimenter, first appeared in QEX in the Nov/Dec 2002 issue and part five most recently in the Jan/Feb 2004.

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The author plans to offer a more extended and formal treatment of this subject and related Cognitive Radio topics in upcoming articles, and welcomes comments and critiques at the contact info above.

VI.Brief bio/CV:

James Miller is a 2004-2006 Mansfield Fellow, on detail from the Policy and Rules Division of the Office of Engineering and Technology at the FCC, where he was employed as an attorney advisor. As a Mansfield Fellow, Mr. Miller develops expertise in Japanese information-technology regulatory policies while working directly in the Japanese Ministry of Internal Affairs and Communications (MIC), Ministry of Economy, Trade and Industry (METI), and Tokyo High Court's recently formed High Technology and Intellectual Property Section. Mr. Miller leverages his past responsibilities at the FCC in the regulation of spectrum, Internet policy, and emerging technologies. He has rulemaking experience in internet technology and spectrum matters related to non-geostationary orbit fixed satellite service, terrestrial fixed and mobile services, software-defined and cognitive radio, and part 15 device certification, and intentional and unintentional radiators. He was a member of the FCC's Spectrum Policy Task Force, and has a strong interest in copyright law and continues research in the area. Prior to entering the practice of law, he worked in Japan and the U.S. in the public sector and private technology sector performing a variety of business development and software engineering functions. He has technical experience in network programming, localization and internationalization, embedded systems, and Unix administration. He is a cum laude graduate of the Washington College of Law, American University, and holds a bachelors degree in economics and East-Asian studies from the University of Kansas. He is a Japanese-English bilingual and during his fellowship resides in Tokyo, Japan with his wife, and two children.