Before the
Federal Communications Commission
Washington DC 20554

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

PETITION FOR CLARIFICATION OR PARTIAL RECONSIDERATION OF VANU, INC.

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Appendix A: Vanu, Inc.

Appendix B: Independent-Transmitter Radios

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Pursuant to Section 1.429(a) of the Commission's Rules, Vanu, Inc. hereby files this Petition for Clarification or Partial Reconsideration of the First Report and Order in the above-captioned proceeding.[1]

A. SUMMARY

The Commission proposed -- and ultimately adopted -- a rule for software-defined radios (SDRs) requiring that every combination of hardware and software be tested for compliance.[2] At appropriate points in the proceeding, Vanu noted that the number of combinations required to be tested will become intractable if, as we expect, the SDR concept is successful. Vanu proposed an alternative, showing it is possible to design "layered" radios, such that only one layer need be certified for compliant operation. Once that layer is approved, then even defective or malicious code in the other, unregulated layer cannot take the radio out of compliance. The flexibility offered by this arrangement will encourage innovation and competition.

Reliability and compliance. The regulated software -- the only code where errors can cause noncompliance -- will be substantially smaller and simpler than conventional SDR

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[1] *Authorization and Use of Software Defined Radios*, ET Docket No. 00-47, First Report and Order, FCC 01-264 (released Sept. 14, 2001) ("First R&O").

[2] 47 C.F.R. Sec. 2.932(e) (2001).

software, and so can be made less vulnerable to errors. Moreover, because the regulated software will be shared by many different services and modulations, manufacturers can subject it to rigorous testing. This will make the radio far more likely to maintain compliant operation despite unanticipated combinations of input or malicious attempts at misuse.

Relief via clarification. The Commission adopted a rule exempting from regulatory approval software changes that do not affect the transmitter's radio frequency emissions.[3] The Commission can, and should, clarify that software changes not affecting the transmitter's compliance as to radio frequency emissions are likewise exempt.

Relief via reconsideration. In the alternative, the Commission should, by reconsideration, permit a certification applicant to identify software that does not affect compliance, and changes to which do not require regulatory approval. Reconsideration (or clarification) is required in this case because the Commission has not yet responded to issues Vanu properly raised during the proceeding. A Further Notice, on the other hand, is unnecessary because the original Notice expressly invited these issues.

Relief via Further Notice. As a last resort, the Commission should expeditiously issue a Further Notice of Proposed Rule Making to amend the rules as described here.

* * * *

About Vanu, Inc. Vanu was formed in 1998 to explore the feasibility of building software radios using object oriented computer languages running on general purpose processors. The extent to which Vanu uses software to implement signal processing distinguishes us from other radio developers. In the nomenclature of the SDR Forum, Vanu develops "software radios"

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[3] 47 C.F.R. Sec. 2.1043(a) (2001).

as opposed to "software defined radios." Pushing the digitization of signals closer to the antenna permits our products much greater flexibility to adapt the nature of the signal processing performed by the radio.

For more information on Vanu, see Appendix A and www.vanu.com.

B. VANU PROPERLY RAISED THE ISSUE OF WHETHER THE COMMISSION SHOULD REQUIRE TESTING OF ALL HARDWARE/SOFTWARE COMBINATIONS.

The Notice in this proceeding tentatively concluded that to test each hardware/software combination in an SDR would be no more burdensome than the current process, which requires testing each mode in which a radio operates.[4] Vanu filed Comments that respectfully disagreed.[5]

Vanu explained that *N* current radio platforms, each operating in two or three modes, require only 2*N* or 3*N* separate tests. A successful SDR industry, however, will develop large numbers of software packages for multiple hardware platforms. *N* different hardware platforms, each running *P* possible software packages, will require a total of *N* x *P* distinct tests. If the SDR concept is successful, as we expect, the number of combinations requiring separate testing will become intractable.

We also showed in our filings that testing the complete software package with every type of hardware is not necessary to assure compliance. Manufacturers can address all of the Commission's concerns about radio performance by testing the hardware together with the software that controls the transmit hardware. Other parts of the software -- referred to below as signal-processing software -- need not be evaluated for Commission approval at all, because that

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[4] *Authorization and Use of Software Defined Radios*, 16 FCC Rcd 596 at para. 18 (2000) (Notice of Proposed Rule Making) ("Notice").

[5] Comments of Vanu, Inc. at 7 (filed March 19, 2001).

software does not control any transmission characteristics that the Commission regulates. Eliminating certification for the signal-processing software therefore adds no risk, yet both reduces costs and facilitates innovation. As we show below, moreover, this approach actually *increases* the likelihood of compliance by making radio performance more reliable, even when running defective or malicious code.

Vanu presented a technical plan for separating software into regulated and non-regulated layers.[6] Following a meeting with Commission staff on April 24, 2001, Vanu substantially revised its proposal to resolve concerns raised by OET, and made a timely submission of the new proposal.[7]

C. THE COMMISSION SHOULD PERMIT CERTIFICATION OF RADIOS CAPABLE OF ENSURING FULL COMPLIANCE WHILE RUNNING UNCERTIFIED SIGNAL PROCESSING SOFTWARE.

Vanu asks the Commission to provide for "layered" radios, designed so that only one layer need be certified to assure compliant operation.

Vanu proposes that manufacturers be *permitted* -- not required -- to design an SDR as two distinct components: a non-regulated "signal processing unit" (SPU), and a fully regulated "independent transmitter unit" (ITU). The SPU provides the baseband signal to the ITU, which generates and amplifies RF. The two units are independent, except for predefined control and data channels. See Appendix B for details.

Compliant operation is assured by a table in the certified ITU, which lists the bands and services for which the radio is approved, along with the technical limits applicable to each. The

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[6] Comments of Vanu, Inc. at 5-6.

[7] Reply Comments of Vanu, Inc. at 2-8 (filed May 18, 2001).

SPU requests a band and a channel (if applicable) from the table, and then begins delivering a modulated baseband signal. The ITU's behavior is limited to the parameters in the table. This prevents the ITU from responding to an SPU request that calls for operating characteristics or combinations (frequency, power, modulation, etc.) not expressly listed in the table. Even defective or malicious SPU code cannot take the radio out of compliance. At worst, the radio will simply turn off.

The hardware manufacturer is responsible for ensuring compliance of the ITU under all conditions. But this does not require testing all possible SPU data streams. As explained in Appendix B, certain features of the architecture can be exploited to exercise all possible limits in a manageable number of tests.

Improved reliability and compliance. A radio of this type will be significantly less vulnerable to software errors than a conventional SDR. The ITU software -- the only code where errors can cause noncompliance -- will be substantially smaller and simpler than conventional SDR software. Moreover, because the same ITU software will be shared by many different services and modulations, manufacturers will have both economic opportunity and incentive to subject it to rigorous testing. Conventional SDRs, in contrast, are potentially vulnerable to harmful or interfering transmissions from failure of any software in the device. ITU software is far more likely to maintain compliant operation despite either unanticipated combinations of input or malicious efforts to misuse the radio.

Regulatory details. To maximize manufacturer flexibility and expedite the prompt delivery of new services to the public, Vanu proposes that the Commission identify a sub-class of SDR devices in which the signal processing software can be changed without Commission

approval. We call this category "independent-transmitter radios" (ITRs). By definition, such a device contains an ITU unit that prevents the radio from transmitting out of compliance with Commission Rules.

SPU software implements the bidirectional transform between user data and a digital sample stream representing a baseband or low IF version of the RF signal. Changing this software enables changing the modulation, state machines, transmission timing, power control algorithms, etc. -- essentially, all of the features that distinguish one communications standard from another. As shown in Appendix B, however, SPU software need not be certified, because no changes to the SPU software can cause a properly designed ITR device to exceed its certification parameters. On the other hand, the ability to change SPU software freely will substantially accelerate the benefits of spectrum efficiency, interoperation, and potential for innovation that the Commission has correctly identified as benefits of SDRs.

Vanu does *not* ask the Commission to adopt the design in Appendix B by rule. Such a requirement would only hinder innovation and competition. Rather, Vanu submits this information as an "existence proof" that design of a compliant ITR is practicable using current technology. The Rules should accept any design that accomplishes the same result.

D. THE COMMISSION SHOULD ISSUE A CLARIFICATION THAT PERMITS INDEPENDENT-TRANSMITTER RADIOS UNDER THE PRESENT RULES.

Vanu believes the Commission can lawfully authorize ITRs as described above simply through a clarification of the existing rules.

The newly adopted language of Section 2.1043(a) provides:

> Changes to the software installed in a transmitter that do not affect the radio frequency emissions do not require a filing with the Commission and may be made by parties other than the holder of the grant of certification.[8]

The text of the adopting R&O explains:

> This rule is intended to clarify that any party may install software applications on a device that are separate from the software that controls the radio frequency operating parameters. For example, a wireless device may be designed to run software such as a web browser that does not affect the radio operating parameters.[9]

Vanu believes the ITRs described above fall within the scope of this rule. Although changes to SPU software "affect the radio frequency emissions" (in the words of the rule), they can only do so within the boundaries enforced by the certified ITU. Similarly, although SPU software is part of the software that "controls the radio frequency operating parameters" (in the words of the R&O), again the RF output is constrained in all respects by the ITU. As we explained above, no possible output of the SPU can make the ITU behave contrary to its certification parameters. Thus, changes to SPU software "do not affect the radio frequency emissions" beyond those parameters for which the radio is certified. The intent of the rule is fully satisfied.

Based on these facts, we ask the Commission to clarify that the revised Section 2.1043(a) exempts "[c]hanges to the software installed in a transmitter that do not affect <u>its compliance as to</u> the radio frequency emissions . . . . (Words added for clarification are underlined).

Vanu believes this clarification is fully within the original intent of the Rule, and will promote manufacturing flexibility without causing any threat to other users of the spectrum.

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[8] 47 C.F.R. Sec. 2.1043(a) (2001).

[9] First R&O at para. 20 n.42.

E. IN THE ALTERNATIVE, THE COMMISSION SHOULD PERMIT INDEPENDENT-TRANSMITTER RADIOS BY RECONSIDERATION.

1. The Commission Has Not Adequately Explained its Actions in Accordance with the Administrative Procedure Act.

The First R&O acknowledged Vanu's concern that requiring tests of each hardware/ software combination could be burdensome.[10] The R&O likewise acknowledged Vanu's proposal for separation of software into two layers, only of which would require certification.[11]

In the very next sentence, however, with no explanation, the Commission abruptly concluded: "As proposed, we will require that software defined radios be tested with each software application under which the radio will operate."[12] The remainder of the R&O goes on to discuss other issues, beginning with the testing of *combinations* of software. The R&O never responds to the point raised by Vanu: that testing every combination of hardware and software is both burdensome and unnecessary.

The Administrative Procedure Act requires the agency to provide a better explanation. The D.C. Circuit has plainly stated,

> [T]he opportunity to comment [in a rulemaking] is meaningless unless the agency responds to significant points raised by the public.[13]

Similarly,

> An agency need not respond to every comment, but it must respond in a reasoned manner to the comments received, to explain how the agency

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[10] First R&O at para. 41.

[11] First R&O at para. 41.

[12] First &O at para. 42.

[13] *Home Box Office, Inc. v. FCC*, 567 F.2d 9, 35-36 (D.C. Cir. 1977).

> resolved any significant problems raised by the comments, and to show how that resolution led the agency to the ultimate rule.[14]

By the standard of the relevant case law, the Commission's disposal of Vanu's concerns has "crossed the line from the tolerably terse to the intolerably mute."[15]

2. The Commission Can Grant Reconsideration Without a Further Notice of Proposed Rule Making.

A Further Notice of Proposed Rule Making is not required for grant of the relief requested. A Further Notice is required only where the rules to be adopted are not a "logical outgrowth" of those proposed[16] -- *i.e.*, where the original Notice did not give adequate opportunity to comment on the final rule.[17] The courts have never required that the final rule be identical to that proposed. To the contrary, notice-and-comment rulemaking expects the agency to modify its proposals in

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[14] *Action on Smoking and Health v. CAB*, 699 F.2d 1209 (D.C. Cir. 1983) (internal quotation marks omitted). *See also Navistar Internat'l Transportation Corp. v. EPA*, 941 F.2d 1339, 1359 (6th Cir. 1991) (same).

[15] *WAIT Radio v. FCC*, 418 F.2d 1153, 1157 (D.C. Cir. 1969).

[16] *Texas Office of Public Utility Counsel v. FCC*, No. 00-60434 slip op. at 30 (5th Cir. Sept. 10, 2001) ("[I]f, after notice and comment, the agency alters the proposed rule, a new comment period will not be required so long as the modified rule is a 'logical outgrowth of the published proceedings.'"); *Omnipoint Corp. v. FCC*, 78 F.3d 620, 631 (D.C. Cir. 1996) (second round of comment not required where final rule is "logical outgrowth" of proposed rule).

[17] *National Exchange Carrier Association, Inc. v. FCC*, 253 F.3d 1, 8 (2001), *citing Arizona Public Service Co. v. EPA*, 211 F.3d 1280, 1299 (2000) (other citations omitted). *See also The Fertilizer Institute v. EPA*, 935 F.2d 1303, 1311 (D.C. Cir. 1991).

response to reasonable comment.[18] Without that flexibility, the agency could only ignore incoming comment, or use it to restart the rulemaking from the beginning.[19]

Here, the original Notice expressly raised the questions of the burden that will result from a requirement to test all hardware/software combinations.[20] The public was fairly apprised of the issue. A grant of reconsideration is well within the scope of the original Notice, and does not require another round of notice and comment.

3. The Commission Should Grant Reconsideration on the Issue of Independent-Transmitter Radios.

Vanu has shown that (1) testing every hardware/software combination will become burdensome if, as expected, the SDR concept succeeds in the marketplace; (2) present-day technology allows for an ITR radio in which SPU certification is unnecessary to assure compliance; (3) ITR radios will be more reliable -- and hence more compliant -- than SDRs generally; and (4) the ITR concept will promote faster innovation and more competition in SDR software.

For these reasons, and because the issue has been properly before the Commission since the original Notice, the Commission should grant reconsideration.

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[18] 5 U.S.C. Sec. 553.

[19] *National Cable Television Ass'n v. FCC*, 747 F.2d 1503, 1507 (D.C. Cir. 1984) ("An agency, after all, must be free to adopt a final rule not described exactly in the [notice of proposed rulemaking] where the difference is sufficiently minor, or agencies could not change a rule in response to valid comments without beginning the rulemaking anew.")

[20] Notice at para. 18.

Proposed rule. The Commission can easily and unambiguously grant the relief requested with the change to Section 2.1043(b)(1) that follows. Added language is shown in double underscore.

> (1) A Class I permissive change includes those modifications in the equipment which do not degrade the characteristics reported by the manufacturer and accepted by the Commission when certification is granted. No filing with the Commission is required for a Class I permissive change. An application for certification of a software defined radio may optionally identify software that does not affect the characteristics relied upon by the Commission, any changes to which will qualify as a Class I permissive change.

To invoke the added language, of course, the applicant must satisfy the Commission that changes to the indicated software cannot take the radio out of compliance.

F. AS A LAST RESORT, THE COMMISSION SHOULD GRANT THE REQUESTED RELIEF BY FURTHER RULEMAKING.

If the Commission determines that it cannot grant the requested relief either by clarification or by reconsideration, then Vanu requests that it expeditiously issue a Further Notice of Proposed Rule Making to amend the rules as described above.

CONCLUSION

Vanu expects the new rules authorizing SDRs to launch a large and successful industry. Without appropriate precautions, however, the technology is likely to stumble on its own success. As hardware platforms and software versions proliferate, the requirement for testing all hardware and software combinations will soon become onerous.

Vanu has shown it is possible to design a radio that is certain to remain in compliance even though only part of the device is certified. The unregulated section can be changed and updated as needed. This will encourage innovation and competition. Moreover, the small code

size and widespread applicability of the regulated portion of the software offers both opportunity and incentive to bullet-proof the code. The resulting radio will be more reliable than a conventional SDR, whose compliance is vulnerable to any software failure in the device.

The Commission should grant the requested relied by clarification or reconsideration. If no other course is available, the Commission should promptly issue a Further Notice of Proposed Rule Making.

Respectfully submitted,

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November 5, 2001

Appendix A: Vanu, Inc.

Vanu was formed in 1998 to explore the feasibility of building software radios using object oriented computer languages running on general purpose processors. This approach to software radio was initially investigated by the founders of Vanu in the SpectrumWare Project at Massachusetts Institute of Technology, which began in 1995. Project participants recognized that the rapid rate of improvement in microprocessor speed would soon bring the implementation of complex signal processing systems into the realm of software. We believe this paradigm shift in the implementation of wireless communications systems will enable more efficient spectrum use, interoperation between historically incompatible radio systems, and much faster acceptance and adoption of advances in digital communications.

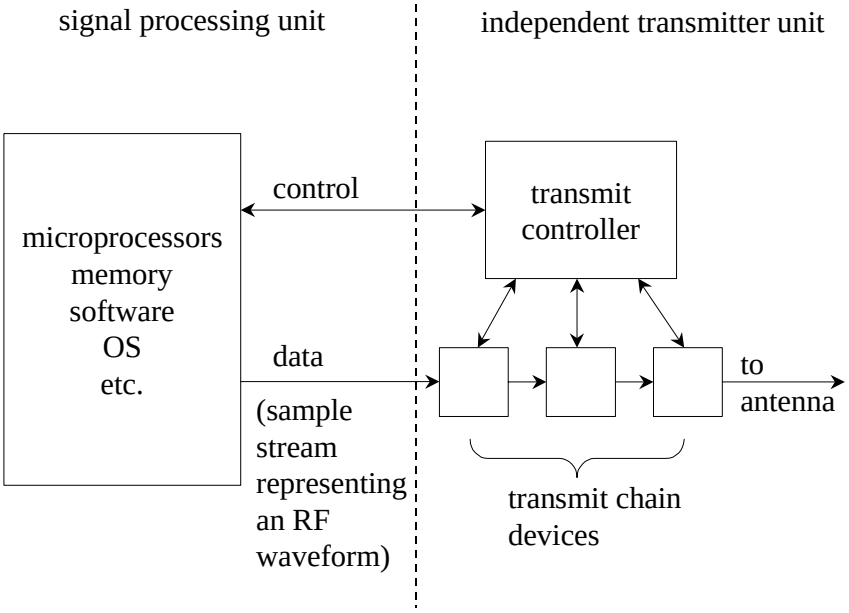
Vanu continues to focus on object oriented software that is portable across multiple platforms, and that supports independent specification and download of software radio applications. But the extent to which Vanu uses software to implement signal processing distinguishes us from other radio developers. In the nomenclature of the SDR Forum, Vanu develops "software radios" as opposed to "software defined radios." Pushing the digitization of signals closer to the antenna permits our products much greater flexibility to adapt the nature of the signal processing performed by the radio. Vanu is currently involved in commercial partnerships to develop software radio products and is participating in Step 2B of the armed services' JTRS program. We are also engaged in a cooperative agreement with the National Institute of Justice to develop a prototype software radio interoperability device targeted at law enforcement needs.

Appendix B: Independent-Transmitter Radios

The following is an "existence proof" showing that a compliant independent-transmitter radio (ITR) is practical using current technology, and describing how tests can be performed on a radio built this way to demonstrate compliance.

A. Hardware design criteria

An ITR has a hardware separation between its *signal processing unit* (SPU) and *independent transmitter unit* (ITU):



All of the hardware, and the ITU software, will be fully certified by the Commission under criteria discussed below. Software running on the SPU, however, need not be regulated.

One feature that characterizes an independent-transmitter radio is the information that flows across the data connection between the SPU and the ITU. This data stream comprises samples that describe the waveform to be transmitted, perhaps at baseband or at a low intermediate frequency. This is different from a traditional digital radio transmitter, in which the values that flow into the transmitter represent raw user data (for example, samples that describe a voice waveform).

The SPU can ask the ITU to shift to any of two or more preset “modes.” Each mode embodies a set of characteristics corresponding to the Commission’s technical rules governing a

particular radio service, typically including frequency range, maximum power, operating bandwidth, TDD duty cycle, out-of-band emissions, and so forth.[1]

The requirement that the SPU and ITU be *separate* hardware units supports a higher level requirement that no software running on the SPU can compromise the integrity of the ITU. In particular, the hardware must meet two design critera relating to the separation of the units in order to be certified as an ITR:

First, the hardware must be designed so that SPU software can affect the state of the ITU only via the control and data connections shown in the diagram. For example, each unit must contain its own processor, and the processors must not share memory. (The two units can be constructed on the same board without violating this requirement, or even on the same silicon die, and can share a power supply and other components.)

Second, the control and data connections must keep the two units independent, so the SPU can use the connections only to present values for the ITU to read. Many well-established mechanisms can enforce this kind of separation. These are widely used to keep two computers on a computer network independent of each other's behavior, or to keep separate parts of a fault-tolerant device independent of each others' failure.

B. Transmit controller design criteria

The transmit controller is a component of the ITU (see earlier diagram). It configures the devices in the transmit chain according to requests from the SPU. It also monitors those devices, and sends any required backchannel information to the SPU. Most important from a regulatory standpoint, it is the component responsible for ensuring that the radio remains in compliance.

The transmit controller must provide two mechanisms to ensure compliance:

- Configuration control: The transmit controller must refuse requests from the SPU to modify transmit chain device configuration, if the resulting configuration could allow the radio to transmit out of compliance.

- Transmission monitoring: The ITU must shut off the transmitter if the data values sent by the SPU would cause the radio to transmit out of compliance, for example by exceeding the permitted average power limit.

In support of both functions, the transmit controller will ordinarily contain a table listing the modes for which the radio has been certified. Associated with each will be settings or limits for each device in the transmit chain, as well as average power, duty cycle, and any other applicable limits. To set up a transmission, the SPU requests a mode, which implies a particular operating band, and (if applicable) requests a channel within that band. That causes the transmit

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[1] Some radios may, at different times, operate in different services in the same band. For example, a device might be switchable between an unlicensed 2.4 GHz spread spectrum or digital modulation radio, and a Part 90 radio that overlaps the same frequency range. Therefore we use the term "mode" instead of the term "band."

controller to configure all the devices appropriately for that mode and channel, including monitoring devices such as those that measure average power and duty cycle. Such a design makes it impossible for the SPU to cause the transmit chain devices to be configured in a way other than that listed in the table. The manufacturer can thus prevent noncompliant configurations by reserving to itself the right to install entries in the table.

Normally, this table will be stored in a memory device whose contents can be changed in the field through a Class III software modification, thus allowing the manufacturer to extend the functionality of fielded devices. The mechanisms envisioned in the Notice to maintain security over software downloads apply equally to authorizing updates to the transmit controller tables.

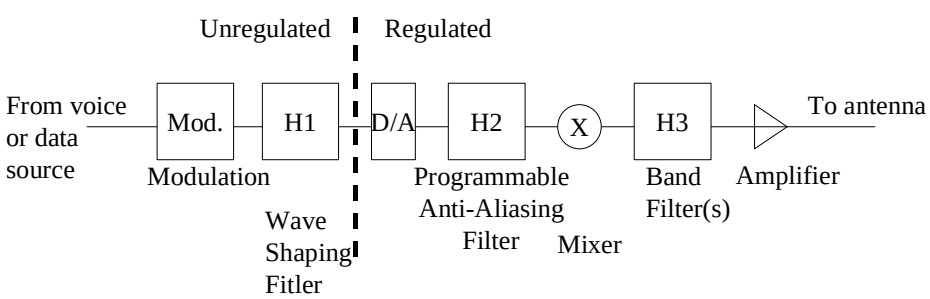
C. Demonstrating compliance for a given channel

Certification for transmission in a given mode and channel requires the manufacturer to demonstrate that no values sent over the data connection from the SPU to the ITU can cause the device to transmit out of compliance. **Nevertheless, exhaustive testing of all possible data streams produced by the SPU is not needed to demonstrate compliance.**

The key observation needed to eliminate exhaustive testing is that the sample rate of the D/A converter in the transmit chain and the setting of the anti-aliasing filter are controlled by the transmit controller as part of the mode and channel setting. This imposes theoretical limits on what can happen in the transmit chain, as described next.

C.1 Background

The figure illustrates a typical sequence of processing steps in the transmission system for an independent-transmitter radio. Note that a traditional software-defined radio has the same sequence of processing steps, but the boundary between unregulated and regulated steps is off to the left of the diagram.



Processing steps in ITR Transmission

In the figure, the boundary indicated by the vertical dotted line is the point at which the data stream from the SPU is passed to the ITU. In the ITU, this data stream is then converted to an analog signal in the D/A converter, using a sampling rate (F_s) specified by a value in the transmit controller mode table. This analog signal is then low-pass filtered by the anti-aliasing filter, which is also controlled by the transmit controller. For any data stream supplied by the

SPU, even if the signal processing software is malicious, the maximum bandwidth of the signal output from the antialiasing filter is $F_s/2$. This greatly simplifies the compliance testing process, since the test process need not consider arbitrary inputs, but only a restricted set of band-limited inputs.

C.2 Specific System Tests

Each ITU mode is described by a set of parameters which fall into two groups, those which describe the band and those which describe a channel within the band. The band parameters are:

a. Frequency range (e.g. 824-835 MHz)

b. Out-of-band emissions envelope

c. Peak radiated power of any transmission

d. Limit on average transmitted power

e. Maximum duty cycle (fraction of time in which antenna is transmitting)

Within a band, each channel is described by:

a. Center frequency

b. Bandwidth

c. Out-of-channel emissions envelope.[2]

A number of tests are required to demonstrate that the system, when switched into a given mode and channel, necessarily remains in compliance with the specified band and channel parameters irrespective of the behavior of the software in the SPU. These tests must be repeated for each channel in the band, since different settings on the transmit chain devices can alter their frequency response.

Many of the tests require a “white noise” input to the ITU. This is a sample stream representing maximum power white noise covering the widest frequency range that can be expressed at the sample rate (F_s).

***Center Frequency*:** Send white noise to the ITU. The measured energy of the transmitted signal (in the frequency domain) must be centered on the specified channel center frequency.

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[2] Bandwidth and sample rate may vary from channel to channel within a band. For example, in the 700 MHz band allocated to public safety, the basic channel plan of 6.25 kHz channels allows particular groups of channels to be aggregated into 12.5 kHz or 25 kHz channels under control of the state or regional planning authority. Therefore, bandwidth of a given transmission and out-of-channel emissions are a property of the channel rather than the mode.

***Bandwidth / Sample Rate*:** Send white noise to the ITU. The measured channel bandwidth of the transmitted signal (in the frequency domain) must not exceed that specified.

Since the signal input to the ITU is bandlimited, and white noise spreads the energy out over the widest possible band, there is no other ITU input that can cause a transmission whose bandwidth exceeds the bandwidth of the white noise input.

Note that this test also serves to verify the sample rate setting of the D/A converter, since the transmitted bandwidth is directly related to the sampling frequency as discussed previously.

***Peak Radiated Power*:** In a traditional device, it is usually sufficient to test the peak emission at the carrier frequency, since this is where the modulation algorithms center the energy in the sample stream sent to the D/A converter. However, in a ITR device, malicious software in the SPU could concentrate the energy anywhere in the frequency range of the sample stream. Therefore, the tests must verify that the peak power limit is not exceeded even if the energy is concentrated away from the carrier frequency.

To verify the peak power limit, set the transmit power to the maximum allowed by the transmit controller, then execute a frequency sweep test in the SPU and measure the transmitted power. The frequency sweep test sends a sample data stream to the ITU consisting of a maximum-power sinusoid that sweeps smoothly in frequency from the lower edge of the frequency range to the upper edge. The output power must not exceed the specified maximum peak radiated power at any time during the test.

***Out of Band Emissions*:** Two tests are required. The first is a frequency sweep test as described above. The specified out-of-band emissions limit must not be exceeded at any point during the test.

The second test is a two-tone intermodulation distortion test. In traditional radios this test typically involves a high-power tone at the carrier frequency plus a tone at a lower level off the carrier. ITR devices require a more sophisticated test, since unregulated SPU software may center the energy of the sample stream anywhere in the channel. The required test is a *two-tone IMD sweep test*, which involves testing a pair of tones at different power levels. The primary tone is at a higher power and the secondary at a lower power.

To execute the two-tone IMD sweep test, send a sample stream to the ITU in which the primary tone sweeps across the entire frequency range of the channel, and at each value of the primary tone, the secondary tone sweeps across the entire range. The specified out-of-band emissions limit must not be exceeded at any point during the test.

This test provides a high level of confidence that there are no significant non-linearities in the transmit chain devices, within the frequency range associated with the selected channel, that could lead to spurious out of band emissions above acceptable levels.

Average Transmitted Power: Limits on average transmitted power can be verified by performing two tests, the first to check correct behavior on narrowband inputs, the second to check behavior on wideband inputs.

The narrowband test consists of several subtests. For each subtest, choose a random in-channel frequency X, and an average power level Y, then send input to the ITU representing a sinusoid at frequency X with an average power level of Y. Verify that the transmitter is cut off for the tests where Y exceeds the specified average power constraint. Repeating this test with a variety of frequencies and power levels eliminates the possibility that the ITU detection system only functions properly for one specific frequency or for a sinusoid of a specific average power level.

The wideband test also consists of several subtests. For each subtest, choose a random average power level Y, then send white noise to the ITU with an average power level of Y. Verify that the transmitter is cut off for the tests where Y exceeds the specified average power constraint.

***Duty Cycle*:** Limits on duty cycle are verified in one of two ways depending on how the device is constructed.

In some ITR devices, SPU software controls the duty cycle by sending transmitter-on and -off commands over the control connection to the transmit controller. In such a device, the required test is to perform several subtests, in each of which a randomly chosen duty cycle X is generated by commanding a sequence of varying individual transmission periods. Verify that the transmitter is cut off when X exceeds the duty cycle limit. The data input given to the ITR is unimportant.

In other devices, SPU software turns off the transmitter by sending the ITU a sample stream of all zeros, or some other specified pattern. The same test just described is performed, but the duty cycle is generated by modifying the data input sent to the ITU rather than by sending commands over the control connection.

***Out of Channel Emissions*:** The ITR device depicted in the figure above cannot prevent malicious software from violating limits on out-of-channel emissions, and cannot guarantee that a particular modulation type is used in the band. It would be possible add a digital filter to the ITU (under the control of the transmit controller) that would perform the wave-shaping function. This mechanism could ensure that malicious software cannot interfere with neighboring channels. However, mandating this mechanism would significantly increase the cost and reduce the flexibility of software radio systems, and so is not desirable.

Channel-to-channel interference within the band is not a regulatory issue where one provider controls the band, as in most geographically-licensed services. The Commission's primary role, in that context, is ensure that the radio does not interfere with users of other bands. The mechanisms described above fully accomplish that purpose. Any other risk of malfunction is properly borne by the licensee, who will have control over what signal processing software is used on devices operating in its licensed band and geographic area.

D. Certification

An ITR certification will cover the device hardware (including both SPU and ITU) and all software in the ITU, including specifically the software in the transmit controller and the data tables it uses. **Changing any software or data in the ITU will require filing for a Class III**

permissive change. The device must include security mechanisms to ensure that only authorized software and data can be installed or executed in the ITU.[3]

A certification application will include:

- Presentation of test results and/or information relating to the hardware design sufficient to convince the examiner that the guidelines of section B (on hardware design criteria) have been satisfied.

- Presentation of test results and/or information relating to the transmit controller design sufficient to convince the examiner that the guidelines of section C (on transmit controller design criteria) have been satisfied.

- Demonstration of compliance as described in section D (test procedures) for all modes and channels for which certification is sought.

The software running on the SPU is unregulated. It can be changed by the manufacturer at will, or downloaded by the user from a third party provider if the manufacturer permits, without recertification.

Uncertified SPU software is safe because the ITU hardware and software—which must be certified together—assure that no stream of data produced by the SPU can take the radio out of compliance. The radio will either operate in accordance with Commission rules or, if the SPU puts out faulty data, will shut itself off. The risk of interference to other users of the spectrum is no higher than the risk from a conventional radio running firmware-based programming on a DSP, or even an old-fashioned hardware radio. The risk of RF safety exposure is similarly controlled.

E. Additional benefits of ITR architecture

An ITR device will be significantly less vulnerable to software errors than a software-defined radio as envisioned in the Notice. The ITU software—the only code where errors can cause noncompliance—will be substantially smaller and simpler than conventional SDR software; and the ITU insulates the radio against defective SPU software. (Moreover, because the same ITU software will shared by many different services and modulations, there will be both economic opportunity and incentive to subject it to rigorous testing.) The conventional SDR of the Notice, in contrast, is vulnerable to harmful or interfering transmissions from failure of *any* software in the device.

Moreover, the ITR architecture permits the device manufacturer to test and certify a device for bands and channels whose signal processing software is not yet complete. This allows the signal processing software development effort and the certification testing effort to proceed in parallel, reducing overall time to market.

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[3] *See* Notice at para. 30.

F. Enforcement

The hardware manufacturer bears full responsibility for compliance of the device. The hardware manufacturer will have developed and certified both the hardware and the software in the ITU to prevent noncompliant transmissions. The hardware manufacturer is thus responsible for any faulty transmissions, even those from defective SPU software, and regardless of whether the problems arise from badly written or malicious code.

We note, however, that an ITU capable of passing the certification tests outlined above is very unlikely to raise enforcement issues.

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