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2022-04-22 regulating radiation

One^wTwo days late for 4/20, I return to discuss equipment authorization. This is a direct followup to my last post about unlicensed radio. I apologize for my uncharacteristic decision to actually provide a promised follow-up in a prompt manner, and give you my assurances that it's unlikely to happen again. I will return to my usual pattern of saying "this is the beginning of a series" and then forgetting about the topic for two years.

But equipment authorization is sort of an interesting topic, and moreover I think I really shortchanged the last post by not going into it. Because ISM bands and other so-called "Part 15" bands are unlicensed, the limitations that exist on usage of those bands stem pretty much entirely from the equipment authorization process. I also think I shortchanged the last post a bit by not providing some background on the regulatory structure, so here that goes first:

when I refer to the "FCC regulations," I of course mean 47 CFR, or the 47th title of the Code of Federal Regulations. The CFRs are a compiled version of all of the regulations promulgated by various federal agencies and are not laws (those are found in the USC) but are sort of like them. The difference is basically in the way they are developed and changed: laws are set by legislators, while regulations are set by the staffs of agencies, but typically with some sort of formalized process that incorporates public comment. This whole concept of codified regulations is referred to as "administrative law." In practice, the way it works at the federal level (and simplified somewhat) is that agencies develop regulations using their normal process, they publish the new regulations in the Federal Register, and some staff pull the changes out of the Federal Register and compile them into the CFR which provides a handy reference to find all the federal regulations.

Because the stuff in the CFR comes from various agencies, it's broadly organized by those agencies. So 47 CFR is stuff that comes from the FCC, while the FAA produces what are often called the "Federal Aviation Regulations" but are more properly known as 14 CFR. This is useful knowledge because the federal government maintains eCFR.gov, a convenient website where you can browse and search the current version of the CFRs. This is a lot more convenient than the old system of going to a federal depository library to look at the big printed volumes that are already out of date.

When discussing FCC regulations, it is very common to talk about them in terms of Parts and identify services by the Part that describes them (this is broadly a common way to refer to federal regulations) [1]. So when we say "Part 15 device" we are describing a device which emits RF radiation under the rules in 47 CFR 15. In 47 CFR 15.1(a) we read:

This part sets out the regulations under which an intentional, unintentional, or incidental radiator may be operated without an individual license. It also contains the technical specifications, administrative requirements and other conditions relating to the marketing of part 15 devices.

So that pretty much lays it out. As a result, "Part 15 device" and "unlicensed device" are somewhat synonymous. Devices that are used under a license are discussed under other parts. Many types of license must be applied for, but there are licensed services that are "licensed by rule." This means that they are a licensed service covered in another part, but that license is granted automatically subject to certain conditions. An example of a licensed by rule service is the family radio service or FRS, which is one of the services used by the ubiquitous consumer walkie-talkies made by companies like Motorola and Midland. This is *not* a Part 15 or unlicensed service, but you also don't need to apply for a license, as 47 CFR 95 says that you automatically have one.

Now, all of this so far is talking about radio *services*. This distinction can be confusing because, particularly in Part 15, there is some crossing of the lines. Broadly, though, a radio service is a means of using the RF spectrum and the rules and regulations that apply to it. Point-to-point microwave is a radio service. Broadcast FM is a radio service. Amateur radio is a radio service.

There is a separate issue of *equipment authorization*. I tend to refer to this as device certification because that term just makes more sense to me, but I should break the habit because the FCC consistently uses the term equipment authorization. Equipment authorization is broadly described in 47 CFR 2, and particularly 2.801 and up (Part 2 is sort of a general or definitions section, and contains the high-level rules for a lot of things). In 2.901, we read:

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 and parts or components thereof. 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 provided, the rules governing the service may require that such equipment be authorized under Supplier's Declaration of Conformity or receive a grant of certification from a Telecommunication Certification Body.

I'll spare quoting all the different sections that really put this together, but here is the general idea: you cannot market, sell, distribute, or use a radio frequency device unless it has an equipment authorization (EA). Part 2 lays out the process for getting that EA, which are either a declaration of conformity (manufacturer pinky promises it meets the rules) or an independent test depending on the device and service.

But what are the actual restrictions a device must meet? They're contained in the sections that describe services. For devices not associated with any service, Part 15 serves as a "catch-all." Part 15 thus covers unintentional and incidental radiators, and intentional radiators not associated with a licensed service. Sort of a "miscellaneous" basically.

I'm not going to spend much time on Part 2 because it's mostly procedural and not all that interesting. However, the prohibition on marketing laid out very explicitly in 2.801 has important implications that you have probably seen in the marketing of cellphones. You generally cannot *advertise* a device until it has an EA. If you do, you must clearly state that the device cannot yet be sold. Early marketing for cellphones often includes such a disclaimer:

This device has not been authorized as required by the rules of the Federal Communications Commission. This device is not, and may not be, offered for sale or lease, or sold or leased, until authorization is obtained.

Part 2 also provides some general exceptions. The basic idea is that it is permissible to operate a device that doesn't yet have an EA *on an experimental basis* with some protections and restrictions in place. It's even acceptable to distribute a device prior to EA, as long as distribution is only to people who will be using the device for testing/engineering/integration purposes and they are aware of and comply with the restrictions. In other words, the FCC is fine with prototypes, but requires that the prototypes be restricted to limited uses.

Finally, when the FCC approves an EA it issues a number usually called an FCC ID. Devices are required to be labeled with their FCC ID in a fairly conspicuous way, although because designers hate labels the FCC now allows the FCC ID to be presented in software and on packaging rather than physically on the device in some cases. Most smartphones are now like this.

That's probably enough of Part 2. Since the actual certification requirements are laid out in other parts, let's take a look at some, starting with our favorite Part 15.

Remember how right up there I quoted 15.1(a) saying that Part 15 applies to unlicensed devices? Let's just reinforce that real quick with 15.1(b) to remind us what's up.

The operation of an intentional or unintentional radiator that is not in accordance with the regulations in this part must be licensed pursuant to the provisions of section 301 of the Communications Act of 1934, as amended, unless otherwise exempted from the licensing requirements elsewhere in this chapter.

So this is basically the converse. If it's unlicensed, it's Part 15. If it's not Part 15, it needs to be licensed.

First, there's an interesting question of what devices are considered radio devices and thus subject to EA. It's fairly clear that any device that radiates RF radiation is either a license device or a Part 15 device and is thus subject to EA requirements. But what's RF radiation?

(u) Radio frequency (RF) energy. Electromagnetic energy at any frequency in the radio spectrum between 9 kHz and 3,000,000 MHz.

Okay so I set that up as a bit of a joke because this definition is kind of funny, but it's funny in an important way. For the purposes of FCC regulation, the radio

spectrum ranges from 9kHz to 3THz. Below and above that range, it's not considered RF. Above tends not to be an issue because if you go much past 3THz you start being able to see it. Below 9kHz is a different issue: lots of devices emanate EM fields below 9kHz, but the FCC does not consider them to be RF devices.

Important implication: with few exceptions, any device that contains a clock or pulse of 9kHz or greater is a device that emits RF. In fact, the FCC is quite explicit elsewhere in the Part 15 definition that any digital device with a clock speed higher than 9kHz is an RF device, because it can be expected to emit some RF noise within the range considered the RF spectrum. This is the reason that virtually all electronic devices are subject to Part 15 regulation. If you don't want to deal with the FCC, 9kHz is effectively the speed limit for any kind of pulsing or modulation.

Also very important to understanding my previous post is 15.5(a):

- (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...
- (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.

In other words, the FCC doesn't give a shit about your WiFi network. There is some nuance to the term "accepted" here. They're not saying that Part 15 devices aren't allowed to shield themselves from interference. They're saying, in casual parlance, that Part 15 devices must put up and shut up. They don't have any regulatory protection from interference.

15.15 provides some very general engineering guidelines for Part 15 devices. I will not quote them, because they can be well summarized as "do a good job." The gist is that Part 15 devices must employ good engineering practices to minimize their RF emissions, and under no circumstances can exceed the specified limits.

15.23 is the home use exception. This should be of interest to all hobbyists and "makers." It essentially says that it is permissible to build and operate an RF device without an EA as long as it's for personal use, you don't market it, and you build fewer than 5. You *are* required to use good engineering practices to limit RF emissions, but you aren't required to perform testing. "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" (15.23(b)). Thanks, FCC.

The majority of the remainder of Part 15 involves detailed technical standards. It lays out the emission limits and the ways that those limits should be measured. It's fairly long and boring, but also pretty easy to read, so you can feel free to take a look through it on your own time.

It is useful to understand that the limits and means of measurement vary by band and sometimes types of device, but for the most part "transmit power" is not a factor. This makes sense in light of the fact that Part 15 applies to unintentional or

incidental radiators where there is no “transmit power.” Part 15 limits are primarily specified in terms of field strength, in volts per meter, at various distances from the device. Rules about power and antenna characteristics are mostly reserved for licensed services, although there are some found in Part 15. For example, WiFi devices are mostly subject to a 1w transmit power limit, in addition to the limits on field strength, and there are more restrictive special limits if a high-gain antenna is used. This is some of the confusion of Part 15: WiFi is not a licensed radio service, but rules have been added to Part 15 to regulate it sort of like one, as far as having restrictions on power and antenna characteristics. It also implies that you can make a WiFi device non-compliant by fitting a high-gain external antenna. You can!

Notable as well is 15.103 which provides some “soft” exceptions. 15.103 is a list of types of devices which are subject to the general high level Part 15 rules, but not to the specific testing requirements. They include some major categories like things used exclusively in vehicles, medical devices used under supervision of a physician, and some digital devices with clock speed under 1.705MHz which are strictly battery powered (tends to apply to remote controls). These exceptions combine two different motivations: first, some of the excepted devices are excepted because they pose a very low risk of emitting problematic interference (simple battery powered electronics). Second, some of the excepted devices are subject to other engineering, regulatory, and application controls that limit the risk of interference (vehicle components and medical devices).

Finally, remember U-NII from the last post? the spectrum that allows for 5GHz and 6GHz WiFi? it’s not a service, it’s still Part 15, and it’s discussed specifically in 15.401 and up. This includes the special characteristics of U-NII that I mentioned like DFS (radar avoidance) and AFC (automatic coordination).

Let’s compare and contrast Part 15 to parts that cover licensed services. An obvious one is Part 73, Radio Broadcast Services. This includes your AM and FM radio stations. Much like Part 15, Part 73 is heavily concerned with limits on these broadcasters, but unlike part 15 they are generally expressed in terms of transmit power (which can actually be measured a few different ways, the regulations clarify how for each service) and antenna characteristics. More interesting is the type of emission regulation that really distinguishes a licensed service from Part 15: Part 73 describes the rules to protect broadcast stations from interference. Methods and calculations are described to determine, for example, whether or not an AM station is sufficiently far away from another AM station on the same or nearby frequency to avoid the two overlapping. Unlicensed devices must accept interference, licensed devices are generally protected from interference by the regulations.

The exact details of these limits can get fairly technical. Part 15 includes a number of formulae, Part 73 has even more as it gets even into the modulation used by transmitters. This is one of the reasons administrative law is differentiated from legislation: the details of regulation are often very technical, and so they are developed and evaluated by technical professionals. These things can be tricky, and so in places Part 73 reads almost like a textbook. In a number of spots it specifies the formula to be used, and then provides an example calculation just to make sure you really get it.

There are things like this (47 CFR 73.151(c)(2)(i)):

The computer model, once verified by comparison with the measured base

impedance matrix data, shall be used to determine the appropriate antenna monitor parameters. The moment method modeled parameters shall be established by using the verified moment method model to produce tower current distributions that, when numerically integrated and normalized to the reference tower, are identical to the specified field parameters of the theoretical directional antenna pattern. The samples used to drive the antenna monitor may be current transformers or voltage sampling devices at the outputs of the antenna matching networks or sampling loops located on the towers...

Who knew regulations could be so fun! This is basically getting into the details of how the specifications of a directional antenna array for an AM radio station can be established. Antenna engineering is complex and I barely understand the most basic parts of it. When you get into arrays operating at low frequencies it can get very complex indeed and so the FCC specifies that computer modeling alone is not enough, the actual performance needs to be verified against the model.

How about another? Part 90 covers Private Land Mobile Radio Services. Land mobile radio (LMR) is a broad category of portable radios used on land... mostly handheld or in vehicles. LMR is a pretty big category because it encompasses everything from public safety dispatch to some cellular bands (most cellular bands in use today are part of other services, though). Land is specified because aviation and marine radio are both their own services.

Part 95C describes the Industrial and Business Pool, a widely-used service for everything from non-government vehicle fleets to some retail store handheld radios. A few different types of users are eligible to use the pool but under 47 CFR 90.35(a) it basically comes down to "anyone who is in business, and most organizations that aren't in business as well."

47 CFR 90.35(b)(3) is a lengthy table that lists the frequencies available for industrial and business use, which span many bands but are most dense in the popular VHF mid area (140MHz or so) and UHF low area (460MHz or so). These are very popular parts of the spectrum in general as they have good propagation and penetration characteristics and RF electronics for these wavelengths are relatively easy to construct. Amateur radio operators might recognize these as being more or less the 2m band and the 70 cm band [2], which are also perhaps the most popular bands in amateur radio. Most mobile radio services have some frequencies allocated in these areas and so they are fairly densely packed with different users. This approach highlights one of the many variations between different radio services: some radio services are allocated a band, some radio services are allocated a list of bands or even a list of specific frequencies scattered across many bands.

As with most things in radio regulation, this table comes with caveats and exceptions. For example, a number of I/B pool frequencies in the UHF band overlap UHF aviation radio used by the military. Note 61 on the table states that these frequencies cannot be licensed near any of a long list of airports and bases, and are subject to a lower power limit elsewhere.

Let's dwell for a moment on this topic of UHF military aviation radio, as it is an example of an important complexity of US spectrum regulation. Military aviation radio is *not* an FCC radio service. The FCC is an independent agency created by Congress. This means that while its leadership is appointed by the President and confirmed by Congress, it is not a part of any branch of government. For both historic and present

reasons, the executive branch of the federal government maintains its own, separate authority to authorize radio use in the form of the National Telecommunications and Information Administration, which derives its authority directly from the President. Because the military is also part of the executive branch, its authority to use radio is granted by the NTIA and not the FCC. Obviously the NTIA and FCC must coordinate their activities to avoid conflicting allocations.

There can be some nuance to the line dividing NTIA and FCC authority. Aviation is once again a good example. Because VHF aviation radio is used by a wide set of individuals in the aviation field, and not only by the executive branch, it is regulated by the FCC (Part 87). The FAA, though, uses radio for its own internal purposes, such as for communication between control centers and remote equipment like radars and radio transceivers. Since this use is entirely within the executive branch, it is regulated by NTIA. Air traffic control thus simultaneously involves FCC and NTIA services, although the NTIA services are not exposed to pilots, since they are not part of the executive (except for military pilots, who are!). Further illustrating this complexity, the FAA has chosen to fully contract the operation of most of its radio facilities to a private company (L3Harris), on an M&O basis. Because Harris is not part of the executive, they must gain authorization from the FCC... leading to a process of the FAA "turning in" its NTIA licenses so that Harris can apply for an FCC license for the same equipment.

It is a somewhat common misconception that NTIA authorizations are somehow secret. This is not the case; while the NTIA has failed to provide the online records access that the FCC does, you can submit a FOIA request to the NTIA and receive in response a PDF of over 3,000 pages listing all NTIA frequency allocations. I have several times started on writing a parser to convert this report into a more usable database but I fear my lack of a computer science degree proper shows here and I have not succeeded. Maybe that automata class everyone else in the department took was good for something.

We will return to the topic of Part 90 to examine one last interesting aspect: frequency coordination. The role of the FCC is often mis-described as being coordination of frequencies. While there are exceptions, for the most part the FCC restricts itself to coordination of services and leaves the more detailed work to other organizations. In aviation, for example, the FAA does the actual frequency allocation. In the industrial/business pool, frequency coordination is entrusted to private corporations that have obtained a certification from the FCC. So, the first step in applying for an I/B license is typically to contact one of these organizations and receive their "suggested" frequency. You then include a letter from the coordinator as an attachment to your application, to show the FCC that you are requesting that particular frequency for a good reason. Many variations on these models exist, but the rule of thumb is that the FCC allocates bands or frequencies to a service, and what goes on within the scope of that service is coordinated by someone else. Broadcast radio is a very notable exception, since the FCC itself is also the agency responsible for non-spectrum regulation of broadcast radio.

Let's wrap up by discussing one last service, and I'll make this a fun one: Part 97, the amateur radio service. One of the interesting things about Part 97 is that it makes frequent reference to radio-telecommunications as an art, e.g. listing one of the purposes of the amateur radio service as "continuation and extension of the amateur's proven ability to contribute to the advancement of the radio art" (47 CFR 97.1(b)). This is a more aspirational view of communications technology which I attempt, but mostly fail, to capture in my writing: since the time of Marconi, Fessenden, etc., radio has been the type of human achievement that is appealing on both practical and aesthetic grounds.

Unfortunately, just as the consolidation of airlines and decay of entry-level general aviation has largely robbed flight of its romance, the consumerization of radio technology has removed much of the fun. Still, though, if you want to twiddle knobs and strain to hear through static, amateur radio is here for you. It's a lot of fun! And besides, the promise of advancement to the art seems to continue to pan out. The new generation of amateur radio operators has developed a number of innovative digital techniques and built infrastructure that is useful for theoretical and industrial research on atmospheric physics, propagation, astronomy, etc. Improvements in technology seem to now be driving a return to commercial use of HF radio, long of limited use due to a degree of complexity that tends to require an experienced operator. Many of the methods being used to automate HF operations are derived at least partially from dweebs tinkering around with GNU Radio for fun.

Anyway, enough of that. Let's look at the rules. 97.5 lays out the basics, namely that amateur radio stations must be "under the physical control of" a person who holds a license. There are various nuances to this rule but for the most part a very literal reading works. The main caveat is that the licensed operator need not be physically present; subject to some limitations amateur radio stations may operate unattended or by remote control as long as reasonable measures are in place to prevent tampering.

Much of Part 97 is fairly obvious and uninteresting, although there are some regulatory oddities like the fact that the National Environmental Policy Act applies to amateur radio and so amateur radio operators may need to complete environmental impact statements when siting stations or equipment in areas of environmental, historic, or cultural significance. NEPA is sort of a hobby interest of mine and I'll probably write about it in more length eventually.

On the flip side, Part 97 provides some positive protection to amateur radio stations. 97.15(a):

Except as otherwise provided herein, a station antenna structure may be erected at heights and dimensions sufficient to accommodate amateur service communications. (State and local regulation of a station antenna structure must not preclude amateur service communications. Rather, it must reasonably accommodate such communications and must constitute the minimum practicable regulation to accomplish the state or local authority's legitimate purpose. See PRB-1, 101 FCC 2d 952 (1985) for details.)

This was added in response to a series of municipal governments enacting zoning regulations that prohibited antenna structures. Radio, though, is regulated by the federal government, which claims supremacy on the topic. State and local laws generally cannot prevent activities which the FCC permits. A similar situation exists in aviation, where the FAA has supremacy, and leads to a confusing paradox related to bans on UAS or "drones" enacted by state and local governments. They lack the authority to do so, and so these bans are actually bans on *ground operations*, not flight. This whole federation thing can be complicated.

What about frequency coordination? 97.101 tells us that "Each station licensee and each control operator must cooperate in selecting transmitting channels and in making the most effective use of the amateur service frequencies. No frequency will be assigned for the exclusive use of any station." In other words, in keeping with the nature of amateur radio as a loosely regulated, hobbyist service, frequency coordination is light. Various organizations, typically the ARRL or organizations

under its auspices, perform various types of frequency coordination in the amateur service. For the most part, this is purely voluntary and does not have the force of regulation, although one could argue (and the FCC has) that willfully ignoring organized frequency coordination constitutes a failure to operate in accordance with “good amateur practice” as is required at the beginning of 97.101.

97.111–97.117 regulate the use of amateur radio. The general idea is that amateur radio cannot be used for commercial purposes and is intended only for two-way (that is, not broadcast) use with limited exceptions. 97.119–97.221 provide regulations related to the operations of different types of stations and functions. 97.301 lists the authorized bands, with many caveats depending on the particular band. A notable thing about amateur radio is that it often shares its bands with other services. This is pretty common overall: a lot of radio services are allocated bands or frequencies on a secondary or shared basis, which makes more efficient use of the spectrum but does require radio users to take precautions to avoid interfering with other band users.

The rest of Part 97 deals with administrative details; things like exams, licensing, reporting, etc. It’s the kind of thing that isn’t much fun to read, but is useful to be familiar with a an amateur radio operator.

This concludes our general tour of 47 CFR. This has gone on for quite a while, and the great thing is that I still didn’t get to the thing I meant to explain... the sort of odd rules regarding equipment authorization and amateur radio. But still, there’s a lot here that gets towards that point: equipment is almost always required to be authorized by the FCC, and the specific requirements for authorization come either from Part 15 or from the Part that covers the service for which the equipment is to be used. As a result, equipment authorization is *specific to a service*. Generally speaking, a Part 15 device cannot be used in any licensed service. A device authorized under another Part can be used only with the specific service for which its authorized. The FCC itself sometimes refers to this as “type certification” or “type acceptance,” and it is the dominant area where device manufacturers, marketers, and users are currently getting in trouble. So let’s get into that topic properly... later.

[1] The CFRs are actually organized into chapters and subchapters for reading convenience, but the parts are numbered straight through. So no one ever writes “47 CFR I.A.15,” just “47 CFR 15” or “Part 15” will do.

[2] For historic reasons amateur radio has a habit of referring to bands by wavelength rather than frequency, which I have always found frustrating. This is no longer common in most forms of commercial radio, where the IEEE radar band designations are more common (VHF low/mid/high, L band, C band, etc). Not that these are really any more convenient.