computers are bad

https://computer.rip - me@computer.rip - fax: +1 (505) 926-5492

2022-04-14 unlicensed radio

I had a strong feeling that I had written a post at some point in the past that touched on license-free radio services and bands. I can't find it now, so maybe it was all a dream. I wanted to expand on the topic, so here we are either way.

As a general principle, radio licensing in the United States started out being based on the operator. As an individual or organization, you could obtain a license that entitled you to transmit within certain specifications. You could use whatever equipment you wanted, something that was particularly important since early on most radio equipment was at least semi-custom.

In some cases licenses rested with individuals, and in others they rested with organizations. It tended to depend on the type of service; in the maritime world in particular radio operators needed to hold licenses regardless of the separate station licensing of the ship.

In other services like most land-mobile radio, a license held by an organization may entitle its staff to use radios (within license parameters) with no training or qualifications at all. These types of radio services impose limitations intended to prevent unqualified users from causing undue interference. A common example is the prohibition on face programming of most land-mobile radios in business or government use: restricting users to choosing from pre-programmed channels prevents use of unlicensed frequencies, based on the assumption that the pre-programming was done by a competent radio technician. This doesn't always hold true in real organizations [1] but the idea, at least, is a good one.

Today, though, we most commonly interact with radio in a different form: services that are fully unlicensed. We use WiFi constantly, but neither ourselves nor our organizations have a radio license authorizing it. You might think that the manufacturer of the equipment, perhaps, holds a license, but that's not really the case. The reality is strange and a result of happenstance.

Early in the history of radio, it was discovered that radio frequency had applications other than communications. As a form of electromagnetic radiation, RF can be a useful way to deliver energy. In 1933, Westinghouse demonstrated the use of a powerful shortwave transmitter as an oven. This idea was not especially practical due to the physics of heating with low-frequency RF, but the basic concept became quite practical around a decade later when a Raytheon engineer famously noticed that a specialized type of transmitter tube used for radar systems melted a chocolate bar in his pocket. One wonders if the localized heating to his body this would have involved as well was noticeable, but presumably RF safety was less of a workplace priority at the time.

This specialized transmitter tube was, of course, the magnetron, which has largely fallen out of use in radar systems but is still used today as the RF transmitter in microwave ovens. A magnetron is a vacuum tube that exploits some convenient physics to emit RF at a fairly high level of efficiency, and with a fairly compact device considering the power levels involved. As a downside, the output of magnetrons is not particularly precise in terms of frequency control, and is also not very easy to modulate. This makes them unattractive for modern communications purposes, but quit suitable for non-communications use of strong RF emissions such as Totino's pizza rolls.

This whole tangent about the history of the microwave is a way to introduce a field of RF engineering different from what those of us in the information and communications industry usually think of. We could broadly refer to these applications as "RF heating," and while the microwave oven is the most ubiquitous form there are quit a few others. The use of RF for localized heating, for example, is useful in a number of situations outside of the kitchen. Synthetic textiles, particularly for more technical applications like tents and life jackets, are sometimes "seamed" using RF welding. RF welders clamp the fabric and then put a strong HF signal through the join to cause heating. The result is similar to direct thermal welding but can produce a more reliable join for some materials, since the heating process is more even through the thickness of the material. Similarly, a variety of instruments are used in medicine to cause RF heating of specific parts of the body. While normally RF heating of the body is a Bad Thing caused by poor safety practices, surgeons can apply it to destroy tumors, cauterize wounds, etc.

RF is also useful for non-heating purposes due to the way it penetrates materials, and there are various measurement instruments that pass RF through materials or emit RF and observe reflections. I am of course basically describing bistatic and monostatic radar, but many of these devices are far smaller and lower power than radar as we typically think of it and so it's useful for them to be available without complex licensing or coordination requirements. A somewhat extreme example of such devices are the millimeter wave imagers used in airport security, which take advantage of the minimal water penetration of very high frequencies in the range of 60GHz and above.

This whole category of RF devices is an interesting one because they are not "radios" in the typical sense, but they still use the same spectrum and so impact radio use. This is a particularly important issue since many RF heating devices operate at very high power levels... few people possess a radio transmitter in the range of a kilowatt, but most people have a microwave oven. As a result, radio spectrum regulators like the FCC need to coordinate these devices to prevent them causing severe interference with communications applications. It was the microwave oven which first revealed this need, and so it's no surprise that shortly after the Raytheon chocolate accident the FCC proposed a set of bands which it called Industrial, Scientific, and Medical, or ISM--this term intended to encompass the set of non-communications RF applications known at the time (microwave ovens had not yet become practical for home use).

The microwave oven continues to serve as an excellent case study for the evolution of unlicensed radio, because for several reasons microwave ovens operate at around 2.4GHz, and so one of the original ISM bands is the 2.4GHz band. That number will be familiar because most WiFi standards except very old ones and very new ones operate in that same band. What gives? Why does a sensitive, high-rate digital radio system operate in a band that was explicitly reserved for being hopelessly splattered by a thousand microwave ovens?

The answer is licensing. Because the ISM bands were basically reserved to be a no-man's land that non-communications devices could freely emit into, there are no licensing requirements for ISM emissions. ISM devices must pass only a device certification process which exists mostly only to ensure that they do not produce external emissions outside of safety limits or emit in other bands. In other words, WiFi uses the 2.4GHz band because it's the easiest one to use.

Other ISM bands show the same problem. 900MHz is reserved for ISM applications, also mostly for heating, but was widely used by cordless phones and baby monitors. The lower ISM bands, in the HF range, are typically not used by consumer devices due to the higher cost of HF power electronics, but there are exceptions.

These unlicensed communications applications of the ISM bands have been formalized over time, but remain from their origin a workaround on licensing requirements. This original sin of many consumer radio devices is the reason that, early on, microwave ovens were a major source of problematic interference with radio devices. The thing is, everyone blamed the microwave ovens even though it was actually WiFi that was intruding in spectrum that rightfully belonged to hot pockets.

One might wonder why these unlicensed systems use bands that are allocated to ISM applications, instead of bands that are actually intended for unlicensed, low-power communications. The short answer is politics, and the longer answer is that no such bands existed at the time (in usable parts of spectrum) and the process to create them was a long one. Remember that for most of the history of spectrum regulation radios were big, expensive devices that required expertise to operate. It was the expectation that everyone using a radio either had a license or had been issued it by a licensed organization. It was cordless phones and baby monitors that really started to chip away at that expectation, and WiFi caused it to completely collapse.

We talked about 2.4GHz WiFi, and so you might be wondering about 5GHz WiFi... the band used by 802.11a, and at least optionally in 802.11n, 802.11ac, and 802.11 "WiFi 6" ax. There's good news: 5GHz is not an ISM band. Instead, it's allocated for "Unlicensed National Information Infrastructure," or U-NII. The term is both weirdly vague (Information Infrastructure) an weirdly specific (National), but U-NII's history is revealing. The 5GHz band was first widely applied by the HIPERLAN standard, an ultimately unsuccessful competitor to WiFi in Europe. The model of HIPERLAN, though, caused none other than Apple Computer to start the regulatory process to allocate a similar band in the US for computer networking. Originally, in 1995, Apple largely envisioned the band being used for wide-area networking, or what we might now call WISPS, but the rules were made sufficiently general to allow for local area applications as well. Apple never succeeded in this product concept but the band was selected for 802.11a. 801.11a had limited success due to higher cost and poorer range, and subsequent WiFi standards returned to 2.4GHz... but as interference became a major problem for WiFi that lower range became more attractive, along with the many advantages of a more dedicated band allocation.

The U-NII band was allocated relatively late, though, and so it comes with some complexities. By the time it was allocated for U-NII it had already been in use for some time for radar, and indeed the issue of 5GHz WiFi interfering with radar proved severe. To resolve these issues, many 5GHz U-NII devices are now required to implement a feature called Dynamic Frequency Selection or DFS. This might be better referred to as "radar dodging," because that's what it does.

5GHz WiFi APs actively monitor the channel they're using for anything that looks like a radar emission. If they detect one, they switch to a different channel to avoid it.

Because radar is relatively sparsely deployed, this usually works quit well. If you live near an airport, for example, there may be a terminal weather radar at 5GHz that will quickly scare your WiFi network off of a particular channel. But it's almost always the only such radar anywhere nearby, so there are still other channels available. The issue becomes a bit trickier for higher-performance WiFi standards like WiFi "802.11ax" 6 that use wider channels, and so some people might see more issues caused by DFS (probably the 5GHz AP shutting off entirely), but this should remain uncommon.

WiFi continues to grow as a radio application, and so too does its allocated spectrum. Just a couple of years ago, the FCC allocated a huge swath--5.925 to 7.125GHz--to unlicensed communications systems, as secondary users to existing mostly point-to-point microwave links. This range has effectively been glued on to the top of the existing U-NII, and so it is referred to as U-NII 5 through U-NII 8 (U-NII 1-4 being the original 1997 allocation). Once again, WiFi must take actions to play nice with existing spectrum users. Indoor WiFi APs don't have to do anything too special but are limited to very low power levels to ensure that their emissions do not substantially leak outside of the building. Outdoor APs are allowed a higher power level since potential interference is inevitable in an outdoor environment... but there's a cost.

Outdoor 6GHz WiFi APs must use "automatic frequency coordination." AFC is not yet completely nailed down, but the general idea is that someone (I put my money on L3Harris) will operate an online database of 6GHz spectrum users. AFC WiFi APs will have to automatically register with this database and obtain a coordinated frequency allocation, which will be selected by the database to prevent interference with existing fixed users and, to the greatest extent practical, other 6GHz WiFi APs. This system doesn't actually exist yet, but we can expect it to add a layer of management complexity to outdoor use of the 6GHz band that might limit it to campus operators and other enterprise WiFi systems, at least in the short term.

But then the issue is kind of moot for the moment, because there are very few actual 6GHz WiFi devices. In keeping with the decision to brand 802.11ax as "WiFi 6," 6GHz application is called "WiFi 6E." We can all ponder the direct parallels to the confusing, but the other way, marketing term DECT 6.0. At the moment only indoor WiFi 6E APs are available (due to AFC not yet being standardized), and only the very cutting edge of client devices support it. This includes the Pixel 6, but not yet any iPhone, although it's a pretty safe bet that the iPhone 14 announcement will change that. A few mini-PCI-e form factor WiFi 6E adapters are available, often called "tri-band," and are starting to pop up in high-end laptops. As usual with new bands, it will be some years before WiFi 6E finds common use.

Of course I am upgrading my home APs to 6E models, so that whenever I use my Pixel 6 Pro I can feel just a little but smug. That's the important thing about new WiFi standards, of course: spending nearly a grand on an upgrade that only even theoretically helps for your phone, where real-world performance is actually limited by JavaScript execution. Twitter.com still takes 10 seconds to render 140 characters of text, but it's getting that text at the better part of a gigabit per second!

There's some more complexity to this situation related to FCC certification of devices, which has become more complex and important over time, but that's a story for another time...

[1] Everyone grumbles about Baofeng people, but I've had some contact with rural police and fire departments and you would be amazed at the things their "radio

technician” (chief’s nephew) thinks are a good idea.