What Your Frequency Display Really Tells You

How close to a band edge can you operate? What your radio’s frequency display doesn’t tell you may be more important than what it does!

By David Newkirk, WJ1Z
Senior Assistant Technical Editor

Judging by the size of our radios’ tuning knobs and frequency displays relative to other front-panel features, frequency must be pretty important. And it is. If you operate at the wrong frequency, other stations may not hear you, you may cause harmful interference, or you may violate the frequency privileges of your license class.

Assuming that your transceiver is functioning normally, operating at the wrong frequency can be as easy as operating on the right frequency. This is so because:

1. You may misread, or otherwise be unsure of, what your transceiver’s various indicators mean.

2. Your transceiver may be capable of transmission on frequencies other than those authorized by your license—frequencies just a flick of the tuning knob away.

3. You may mistakenly operate using a mode or power not authorized for a frequency otherwise allowed by your license.

4. Your signal, or part of your signal, may fall on an unauthorized frequency even though your license allows you access to the frequency shown on your radio’s display.

As a licensed ham, you’re responsible for seeing that these things—all of these things—don’t happen. That’s not news to you, I hope! We all occasionally make mistakes connected with Reasons 1 through 4; these can usually attribute to honest error or confusion. We avoid such mistakes through learning, experience and attention. But this may be news: Off-frequency operation attributable to Reason 4 occurs because many hams do not understand that the radio feature most important in keeping you on frequency—your radio’s frequency display—doesn’t tell you everything you need to know about choosing an acceptable frequency! And your radio’s operating manual probably doesn’t fill in the gaps, either. So, QST to the rescue! This article shows you how to be frequency-conscious whenever you go on the air.

As you read, please keep in mind that FCC-rule brevity, and variations in equipment performance and how you use your equipment, may make it impossible for me to give you specific numbers about how wide your signal can be or how close you can or can’t go to a given frequency or band edge. Whenever I can’t give you hard numbers, I’ll tell you—and I’ll tell you why.

You Are Here

Becoming frequency-conscious is as easy as locating a particular store at an unfamiliar shopping mall. You stride into the mall and make a beeline for the store directory. The directory kiosk displays a mall map and lists stores by type. Each store listing includes a number. Having found a listing for your store—say, 599 Shops—you scan the mall map for that number. Got it! Okay, but before you sneaker-squeak off to the store, you do two more things: You scan the map to find your position in the mall—You Are Here—and mentally chart your course from Here to There. And then off you go.

You go through a similar process when changing frequency with your Amateur Radio transceiver. Seeking to contact a friend at 14205.48 kilohertz—just one of many possible places to go in the cosmic shopping mall called The Electromagnetic Spectrum—you check your radio’s frequency display to find your current position in that spectrum (say, 7201.25 kilohertz), mentally chart your course from Here to There, and take off.

Nowadays, of course, you’re as likely to jump to your target frequency via keypad as you are to spin your radio’s tuning knob from 7201.25 to 14205.48, but the process is the same. The radio spectrum is like a large space that encompasses many possible places to be (particular frequencies). Your radio’s frequency display serves as a constant, real-time You Are Here marker to show you your position in that spectrum (Fig 1). Your radio’s tuning knob (or UP and DOWN buttons, or keypad), like your feet, gets you from one frequency place to another.

But hold on. Your radio’s frequency display and a store-directory kiosk. You Are Here marker share an important similarity: They indicate your position but not your width. And width is important! If you don’t account for your body width as you walk through a mall, you’ll make a lot of people (including you) sore. You’ll run into walls, railings and people. If you don’t account for your radio’s signal’s width when you operate at the frequency shown on your radio’s display, you may unknowingly interfere with other amateurs or even transmit outside an amateur band!

You Stretch From Here to There

Whenever you use a radio signal to do something useful—that is, whenever you use radio to send information (code, voice, data, control signals, a picture—whatever), you modulate it (electronically add information to it) by changing its characteristics over
play probably indicates only your carrier frequency—even in suppressed-carrier modes like SSB. Because of this, you absolutely must know something of your sidebands' width and their position relative to your carrier. You need to know this to be sure your sideband or sidebands don’t fall out-of-band when you operate close to a band edge. You also need to know this to keep from interfering with other amateurs.

Once you’ve gotten an idea of how wide your signal is, you need to know one more hardware-dependent thing before using your frequency display to set an operating frequency. You need to know your radio’s frequency-display accuracy. See the sidebar, “Finding Your Radio’s Frequency-Display Accuracy.”

Before we explore how wide your signal gets and where its sidebands fall relative to its carrier when you operate CW, AM, SSB, FM, data (including packet), RTTY and AMTOR, you need to understand why I can’t give you solid numbers for a lot of this stuff. See the sidebar “FCC and Necessary Signal Bandwidth.”

**CW**

**CW signal width.** As shown in Fig 2B, keying your carrier on and off produces identical keying sidebands on both sides of the carrier. How far those sidebands extend depends on the transmitter’s keying rise and fall times, not on how many words per minute you send. (Overdriving your rig’s final or an external amplifier can make your signal even wider.) If your transmitter’s CW rise and fall times are 5 milliseconds, your signal is about 150 hertz wide. (This and other numbers in this article that refer to CW-signal bandwidth convey necessary bandwidth as calculated per §2.202 of the FCC Rules. Equation 11 on page 9-8 of the 1991 ARRL Handbook for Radio Amateurs shows the formula used, which also provided the CW-bandwidth numbers shown on page 9-2 of ARRL’s FCC Rule Book, 8th edition, 4th printing.) If its rise and fall times are 2 milliseconds (fairly typical of commercial transceivers), your signal’s bandwidth is about 375 hertz. (If QST Product Reviewed your transceiver, you may be able to get a closer approximation of your transceiver model’s keying rise and fall times from the keying oscillogram contained in the review.)

How close you may be able to go to a band edge: Half of your signal’s bandwidth, plus your transceiver’s maximum display error. In this example, if your transceiver has a maximum display error of 300 hertz and emits a CW signal 375 hertz wide, you might conclude that you can go no closer to a band edge than 487.5 hertz (300 + ½ of 375 [187.5]).

But your radio may display frequencies less precisely than it can tune them. In other words, you may be able to tune your radio a few hertz or tens of hertz before its display actually indicates that change. Because of this, I recommend that you take this into

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### Read the Manual

Some current transceivers offer you the option of selecting whether your frequency display indicates mark or the suppressed-carrier frequency. Some current transceivers include more than one frequency display for sub-receivers or multiple VFOs, and this may confuse you if you operate split or jump between memories or VFOs. How can you figure all this out? What does your radio’s manufacturer have to say about how to use its frequency display, anyway? Read the operating manual and practice setting your rig’s controls according to its instructions. Don’t let your rig operate you.—WJ7Z

time. Doing so widens the signal (Fig 2) compared to its unmodulated state because sidebands containing that information appear on both sides of the carrier.

**What Your Frequency Display Doesn’t Tell You**

Your radio’s frequency display tells you nothing about how wide your signal gets with modulation. This can lead you to operate illegally even though your transceiver is working right, and even though your license allows you access to the frequency shown on your radio’s display.

**What Your Frequency Display Does Tell You**

Unless your radio’s instruction manual states otherwise, your radio’s frequency dis-
account when you choose your operating frequency. To do this, tune your transceiver no closer to the band edge than its maximum display error + half of your bandwidth + the next display increment farther from the edge. In this example, that’s 500 hertz for a transceiver that displays frequencies to the nearest 100 hertz (0.1 kilohertz) or 490 hertz for a transceiver that displays frequencies to the nearest 10 hertz (0.01 kilohertz).

AM
AM signal width. As with CW, amplitude-modulating your carrier produces identical sidebands on both sides of the carrier. How far these sidebands extend depends on the highest modulating frequency the transmitter signals can handle (300-3000 hertz is a long time convention). Overmodulating your carrier or overdriving an external amplifier can make your signal even wider. If your transceiver can reproduce audio up to 3000 hertz (3 kilohertz), your signal is about 6000 hertz (3000 + 3000) wide because it has two sidebands.

How close to a band edge you can operate AM: Your transceiver’s maximum display error (example: 300 Hz) + half of your bandwidth + the next display increment farther from the edge. In this example, that’s 3400 hertz for a transceiver that displays frequencies to the nearest 100 hertz (0.1 kilohertz) or 3310 hertz for a transceiver that displays frequencies to the nearest 10 hertz (0.01 kilohertz).

FCC and Necessary Signal Bandwidth
I wish this article could consist of nothing other than a list of rock-solid statements like “In CW, don’t operate any closer to band edge X than Y hertz” — but it can’t. I can’t give you hard numbers about exactly how wide your signal is, or exactly how close to a band edge you can play, because (1) I don’t know exactly how your equipment performs and (2) Part 97 of the FCC Rules — FCC’s rules regulating Amateur Radio — only goes so far in specifying signal characteristics.

Currently, any Part 97 search for this information always ends in hazy, hedges phrases like “good engineering practice,” “to the greatest extent practicable” or “communications-quality ASE emission.” FCC hedges on signal width and purity because it must: Even internationally agreed-upon formulas for necessary bandwidth include fudge factors! (The FCC rules include those formulas in §2.202, Bandwidths; Chapter 9 of The ARRL Handbook for Radio Amateurs, Modulation and Demodulation, takes you through a number of such calculations step by step.) The fudge factors are necessary because radio physics doesn’t always return hard, clean numbers for signal bandwidth — and even when it does, strict adherence to those numbers doesn’t always ensure safe, practical and efficient radio communication at a price and complexity affordable by real people.

That’s why FCC’s Amateur Radio rules — and therefore, this article — only go so far in defining signal bandwidth and purity: Safe, practical and efficient radio communication at a price and complexity affordable by real people is what Amateur Radio is all about. — WJ1Z

Finding Your Radio’s Frequency-Display Accuracy
Finding out where you’re really operating requires that you know your radio’s frequency-display accuracy. Your transceiver’s operating manual may specify it. If it can’t locate this information (or if your radio’s age makes you wonder if its published display-accuracy specification still holds), you can estimate the accuracy yourself.

Published accuracy specs usually speak in relative or absolute terms. Relative accuracy means that the display’s accuracy relates to something else (you’re usually told what); absolute accuracy means that the display’s accuracy is specified directly in frequency units.

6 ppm means 6 parts per million. Translated, this particular specification means “plus or minus 6 parts per million.” The “plus or minus” means that the display may read a bit high or a bit low, or anywhere in between. One megahertz is a million hertz, so “10 parts per million” means “10 hertz per megahertz.”

You can find how many hertz this is at your operating frequency by multiplying 10 hertz by the number of megahertz displayed. At 26.623 megahertz, then, this display’s accuracy is ± 286 hertz (10 x 28.623). At 1.803 kilohertz, this same display is accurate to within ± 18 hertz (1803 kilohertz = 1.803 megahertz; 10 x 1003 = 18).

(Some manufacturers use scientific notation when specifying accuracy; “1 ppm,” for instance, becomes “1 x 10^-6” or “1 x 10^-6” in scientific notation.)

Specifying a radio’s display accuracy in absolute frequency units is a bit simpler: “± 200 hertz.” This means that no matter where you tune in that radio’s range, its frequency display will display a frequency within ±200 and ±200 hertz of your true carrier frequency.

You can find or confirm your display’s accuracy yourself by selecting the AM mode and tuning in the highest standard-frequency-and-time signal you can receive. (That means WWV or WWVA at exactly 20, 15 or 10 megahertz; CHU at exactly 14670, 7335 or 3330 kilohertz — the higher the better.) Note the pitch of the test tones (WWV/WWVA) or time beeps (CHU). Switch to USB and carefully tune the radio until the tones you hear in USB match those you hear in AM. If they’re closely pitched, you can measure switching back and forth between AM and USB a few times to match the tones closely. If your rig can’t receive AM, use WWV or WWVH, not CHU (CHU does not transmit a lower sideband), and tune your radio so that the test-tone pitches match as closely as possible when you flip between USB and LSB. The difference in hertz between the station’s exact frequency and the frequency displayed on your radio is your radio’s display error at that frequency. Even though the number you get is absolute (in frequency units), you’re safer if you treat your results as conveying relative accuracy. In other words, if you measure an error of 150 hertz at 10 megahertz, assume that the display will be off by 150 hertz at 10 megahertz (3 x 10), and use this number when calculating how close to band edges you can go.

Even if you own a brand-new radio with well-specified frequency display error, I recommend that you use this “find it yourself” procedure at least every month or so to keep tabs on the radio’s display accuracy. Record the results in your radio’s operating manual for future reference.

Finding your true operating frequency. Okay, but where are you really operating? Once you’ve determined your radio’s display accuracy in absolute (frequency) terms, you need to apply the ± concept and do a bit of arithmetic. Saying that your radio’s display is accurate to within ±266 hertz at 28.623 megahertz means that your operating frequency is somewhere between 28.623 megahertz — 266 hertz and 28.623 megahertz + 266 hertz — in other words, somewhere between 28.62271 and 28.62328 megahertz. In a radio specified to display frequencies to within ±200 hertz, your carrier frequency is actually somewhere between 10143.55 and 10143.95 kilohertz when the displayed frequency is 10143.75 kilohertz. — WJ1Z
edge. Your frequency display shows your suppressed-carrier frequency. If you’re operating LSB below a band edge or USB above a band edge, position your suppressed carrier as you would your transceiver’s CW signal. (I recommend doing this because your radio’s carrier suppression is not perfect, and because your radio may emit a carrier—in effect, a CW signal—in a TUNE mode even though you’ve otherwise set it for SSB emission.) Tune your transceiver no closer to the band edge than its maximum display error + half of your radio’s CW bandwidth + the next display increment farther from the edge. See “CW” for details.

If you’re operating LSB above a band edge or USB below a band edge, space your suppressed carrier from the band edge by the highest audio signal your transmitter can handle + your transceiver’s maximum display error + the next display increment farther from the edge. Example: with a transceiver that handles audio from 300 to 3000 hertz and displays frequencies with a maximum error of 300 hertz, go no closer than 3400 hertz (0.1-kilohertz display resolution) or 3310 hertz (0.01-kHz display resolution).

Modes Generated By Feeding Non-Voice Audio into an SSB Transmitter

Many hams operate RTTY, AMTOR, fax, slow-scan TV and 300-band HF packet by feeding these modes’ baseband audio into their SSB transmitters. As with SSB voice, your transceiver’s frequency display indicates your suppressed-carrier frequency when you operate in this way.

Because these modes’ baseband audio is frequency-modulated (FMed), the resulting RF emissions have multiple upper and lower sidebands. You might think, for instance, that the frequency-shift keying (FSK) used by AMTOR, 300-band packet and RTTY creates a signal that looks like two CW signals side by side. Not so! Fig 5 shows a generic example of practical direct FSK.

Never Transmit On the Edge

Because your signal has width, and because band and subband frequency limits are limits to stay inside of, never operate at a band-edge frequency—even if you operate an SSB, suppressed-carrier mode that should fail safely in the band. How do you know that your transmitter isn’t going to leak enough carrier to get you in trouble? You don’t—so never operate at the edge. — W/1Z

I don’t recommend that you try to operate as close as possible to a band edge with such emissions unless you know enough about them to calculate your bandwidth. (If you know that, you don’t need this article!) Instead, I recommend that you keep your signal away from band edges by positioning your suppressed carrier as you would for SSB voice operation. Because the maximum tone frequencies used by these image and digital modes are all lower than the highest frequency used in voice transmission and because your radio includes filtering that limits the bandwidth of the signal you transmit, you should stay safely within the band. Comparing frequencies with other key-board/image-mode operators is a more important practical problem. The sidebar, “Where the Heck Am 1?,” sheds light on this issue.

Moving to a desired RTTY or AMTOR operating (mark) frequency is easy once you know how to do the arithmetic. For example, say you want to operate AMTOR at 18.105 megahertz, and you’re going to get there by feeding audio from your multimode communications processor into your SSB transceiver. Your know that your AMTOR signal consists of two signals, mark and space, 170 hertz (0.00017 megahertz) apart, and that, by convention, mark should be the higher of the two. So you know that “operating AMTOR at 18.105 megahertz” actually means “operating AMTOR with my mark at 18.105 megahertz and my space at 18.10483 megahertz” (18.105 - 0.00017).
Further Reading

Fig 5—Feeding an audio-frequency-shift-keyed (AFSK) data signal into an SSB transmitter results in FSK on-air. Because the actual spectrum generated may vary from modem to modem even for the same operating mode, and because FM (of which FSK is one case) generates multiple upper and lower sidebands as shown here, I recommend treating AFSK via an SSB-transmitter modes like SSB when setting your operating frequency—unless you know enough to calculate or measure your signal bandwidth directly.

Putting It All Together
Now that you know that our official band limits—round, easy-to-remember phrases like "7.0 to 7.3 megahertz"—are actually narrower in practice because of our signals' width, here's how to put that knowledge to use. Calculate your radio's practical band limits for each of your operating modes and subband segments, and record this information in a Personal Band Limits chart. (For instance, if you find that you can safely operate 40-meter LSB only at carrier frequencies between 7153.1 and 7299.5 kilohertz, record these frequencies as your real band limits for 40 phone, not 7150 and 7300.) Keep it right beside your radio, and use it when you operate.

What Your Frequency Display Doesn't Tell You—Reprise
Your frequency display doesn't tell you your signal's width relative to the displayed frequency—undisplayed information that's pretty darned important. You need to know something of your signal's width when choosing an operating frequency so you won't bump into other signals or slip out of the band. Signal width is only part of the story, though. You should also be aware that your frequency also doesn't indicate whether:
• your license allows you to operate at your chosen frequency
• the mode you've selected is allowed at that frequency
• your operating power is appropriate or legal at that frequency
• another station is already operating at that frequency
• an ARRL Band Plan exists for that frequency, and you're operating in accordance with that band plan
• that frequency is shared with other radio services on a noninterference basis
• an FCC-declared communications emergency exists that takes priority over normal Amateur Radio communication at that frequency

Frequency consciousness may seem complex and scary. It may seem like you have to know almost everything about everything before you do much as call a CQ. But you don't. Many parts of the frequency-consciousness picture—stuff like your operating privileges, power and whether or not your operating frequency is shared—don't change very often. So you review them in your mind, check your Personal Band Limits, and go on the air. Once you're on the air, you can rightfully devote most of your frequency attention to your transceiver's two largest features—its tuning knob and its frequency display.
Feedback

Bud Thompson, NØIA, points out an error in David Newkirk, “What Your Frequency Display Really Tells You,” QST, Aug 1991, pp 28-32. The sample calculation in paragraph 2, column 1, page 32, mistakenly uses an audio MARK frequency of 2195 rather than 2125 Hz. Beginning with sentence 3 of that paragraph, the example should read:

Figure out what your display should read by adding your MARK audio frequency (2125 hertz [0.002125 megahertz] in this example) to the operating frequency you want. Okay: 0.002125 + 18.105 = 18.107125 megahertz or 18107.125 kilohertz. (Your radio probably only tunes in 10-hertz steps, so you’ll have to set it to either 18.10712 or 18.10713 megahertz; the ±5-Hz error doesn’t matter.) Your display probably shows these frequencies as 18.107.12 or 18.107.13. So, to recap: To operate 170-hertz AFSK AMTOR at 18.105 megahertz using 2125-hertz MARK and 2295-hertz SPACE tones, set your radio to LSB and tune it to display 18.107.12 or 18.107.13 megahertz.

More on finding your frequency in keyboard modes appears in this month’s Hints and Kinks, beginning on the previous page.

—WJ1Z