Analog FM Repeaters — an Overview

Why your local voice repeater acts the way it does, and how to get along with it.

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Repeaters have become the essential tool of modern FM communications. Individual repeaters allow V/UHF mobile and handheld transceivers to communicate with each other over much larger areas and more difficult terrain than would be possible with direct simplex contacts. Repeater linking has enhanced this ability even more. Linked repeater systems connect repeaters with each other through direct radio or Voice over Internet Protocol (VoIP) connections. Here in Connecticut, one club has built a system of linked repeaters that covers the entire 100-mile length of the state. You can access this repeater network near Connecticut's New York border and chat with another station in Rhode Island, using just a handheld transceiver.

Two in One

Many thousands of hams use repeaters every day without really understanding them. There's lots of chatter about frequency pairs, shifts, tone codes, courtesy beeps, transmit timers, and link delays. What does all this stuff actually mean to you as you operate, and why are they necessary for using the local repeater?

Hardware-wise, a repeater is one receiver and one transmitter, which are operated by a controller and connected to the same antenna. "Okay," you say, "I've got a transceiver, which is a transmitter and a receiver, connected to one antenna at my shack, but it doesn't act like a repeater. So what's the difference?"

When you use your rig at home, whether it's a base station, mobile, or handheld transceiver, you switch between the receiver and transmitter, using each *alternately* to communicate with another ham. In a repeater system, both the receiver and transmitter must be operating *simultaneously*. A repeater functions by hearing your signal with its receiver, demodulating your signal to extract your voice, transferring your voice audio to its transmitter, which then retransmits your signal *through the same antenna where it is being received.*

Those of you who see a problem here get a gold star; for those who don't, let me give an example. Let's say that instead of a receiver and transmitter doing all that modulating and demodulating, we just have a microphone, amplifier, and speaker. If you place the microphone directly in front of the speaker and turn on the amplifier, two things will happen. First, you get a really ugly squeal that keeps getting louder and louder, commonly known as feedback. Second, at some point, either the microphone, amplifier, or speaker will fail, putting an end to the squeal — and a dent in your wallet when you buy its replacement.

Unless we take certain hardware precautions, feedback will occur with a repeater, but in a repeater the feedback loop would occur in the RF circuit instead of the AF circuit. The retransmitted signal, if coupled directly to the common antenna, would quickly overload the receiver's front end. Obviously, a system that fries the receiver's front end every time the power is turned on cannot be considered a reliable means of communication. Steps need to be taken to prevent this eventuality. Enter the *duplexer* (see Figure 1).

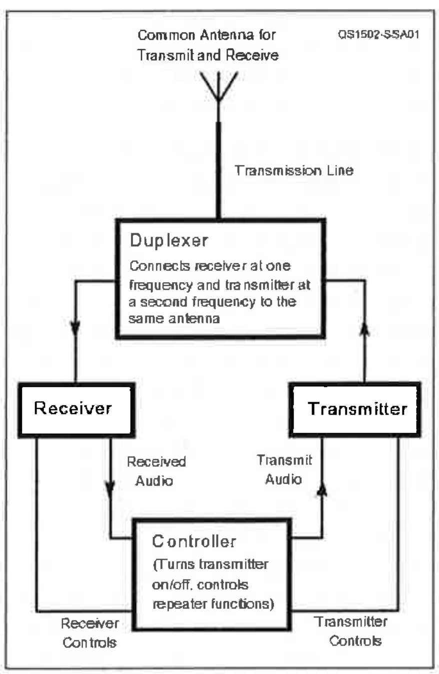

Figure 1 — This is a block diagram of the essential components of a repeater. Most practical repeaters are more complicated than this, but all will have these basic components.

A Divided Highway

The duplexer uses a series of tuned circuits to allow the 100 W output of the transmitter to flow to the common antenna while keeping that same powerful signal from doubling-back into the microwatt sensitive receiver front-end. Of course, the duplexer's tuned circuits aren't the whole story. By separating the transmitter and receiver frequencies by some nominal amount, the design requirements — and cost — of the duplexer are greatly reduced. Enter the *offset* or *shift.*

Small Change

The receiver and transmitter in a repeater are fixed-frequency devices. Unlike your rig at home, which can tune to thousands of individual frequencies, a repeater's transmitter and receiver must be locked to a particular frequency — or more accurately, a *frequency pair.* A frequency pair refers to two frequencies separated by a fixed amount — the *offset* or *shift.* Each V/UHF band has a standard shift. On 2 meters, the offset is 600 kHz; so for any 2 meter repeater, the transmit frequency is shifted from the receive frequency by 600 kHz. It's customary to refer to a repeater by its transmit frequency — *your* receive frequency. For example, the W1AW 2 meter repeater transmits on 145.450 MHz. The repeater's receive frequency — *your* transmit frequency — will be 600 kHz away.

"Hold on," you say, "doesn't that leave us with two different repeater transmit frequencies, 144.850 and 146.050 MHz?"

Yes, it would, which brings us to shift's little brothers, "+" and "–," which define the direction the offset has for a particular repeater. Remember, the shift is often the same amount on a given band, but the direction of that shift, up or down, is specific to a particular repeater. For the W1AW repeater, it is designed for a "–" offset, so the repeater's receiver frequency — your transmit frequency — will be at 144.850 MHz. If it had a "+" offset, the receiver frequency would be at 146.050 MHz.

If you go through a list of the 2 meter repeaters in your area, you'll see + and – symbols scattered all over. These shift directions aren't random. They usually follow the pattern shown in Figure 2. For each band where repeaters are used, certain segments are defined for repeater outputs (transmit frequency, T) and inputs (receive frequency, R). Where the repeater's transmit frequency is and what other repeaters are on adjacent frequencies determines a particular repeater's offset.

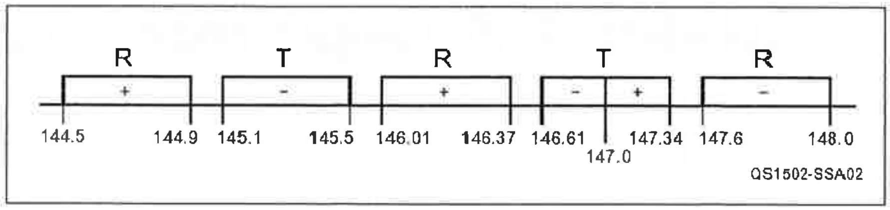

Figure 2 — This diagram shows a typical arrangement of offsets for the 2 meter band. These frequency segments and offsets vary regionally, so check the local repeater listings for your area before programming your radio.

Keeping Things Organized

So you see, each repeater needs a frequency pair in order to operate. To keep things organized, frequency coordinating committees have been formed throughout the country to assign frequency pairs to new repeaters. These local committees operate under the umbrella organization the National Frequency Coordinators Council (**nfcc.us**).

These frequency coordinating groups aren't legal bodies, but operate under the "self-regulation" aspect of ham radio. Note that there are uncoordinated repeaters in operation, but the vast majority of repeaters are coordinated, especially in urban areas where there can be dozens of repeaters competing for band space.

Even with this coordination, there can be unintentional interference between repeaters in neighboring areas. Propagation conditions can create an "opening" that will carry a signal far beyond the local area. It's possible to have two repeaters, operating on the same frequency pair in two different but nearby cities. Under normal conditions they are outside each other's range and both operate without interfering with the other. Then a really hot opening comes along and the two are stepping all over each other. To solve this problem, *tone encoding* (sometimes referred to as *PL*, a Motorola trademark) was introduced.

A Sonic Separator

Tone encoding is a system that was borrowed from the commercial sector. The most common system is the Continuous Tone Coded Squelch System (CTCSS). CTCSS consists of 49 discrete tones ranging from 67 – 254.1 Hz. When a repeater is placed on the air, the owner sets the repeater's controller to scan any signal received for its assigned tone. If the controller detects the correct tone, it activates the repeater's transmitter and retransmits the received signal. If the controller receives a signal, but without the correct tone, the transmitter is not activated and the received signal is not retransmitted.

The tones used are referred to as "subaudible" tones, even though they are in the audible frequency range. They are called subaudible because the repeater's receiver filters them out before passing the audio to the transmitter. The tones are not heard by the hams using the repeater.

A more recent development is the use of Digital-Coded Squelch (DCS). This is a system that modulates a subaudible tone with a 23-bit digital code. Just as with the CTCSS system, the digital code of the transmitter must match the code of the repeater for the repeater to "open."

Communications Courtesy

Most repeaters are "open" repeaters, that is, they can be used by any ham within their operating area (there are some "closed" repeaters that can only be used by a limited group, but closed repeaters are not common). A consequence of this is that you can get a group of hams having a conversation on a repeater. This is called a *roundtable*. In a roundtable, each participant speaks, then passes the discussion to the next ham in the group. Such discussions can make it difficult for new stations to access the repeater. To allow a space for a new ham to join the group, most repeaters will transmit a short courtesy tone or beep a few seconds after the last station stopped transmitting. The time between the end of the last ham's transmission and the beep is a courtesy period when a new station can jump into the discussion.

The courtesy tone system does have a drawback. If a large group is having a discussion or a net is using the repeater then, even with each station waiting for the beep, it's possible for the repeater's transmitter to be active for an extended period. To prevent this, repeaters have a transmit timer. This timer is required by FCC regulations to be a 3-minute timer. It starts when the *repeater's transmitter* is first triggered. For this reason, whenever you participate in a roundtable or net on a repeater, it's a good idea to let the repeater's transmitter drop periodically to reset the transmit timer.

One final bit of courtesy that you will run into involves linked repeater systems. A linked system connects many different repeaters together to form a continuous system. When you "key up" one repeater in the system, an activation signal is passed to all the other repeaters, causing all the transmitters to be activated. The linked system I mentioned at the beginning of the article has a total of 15 repeaters on four bands connected into the system.

When using a linked system, remember that it takes a short time for all these links to be activated. When first keying your transmitter, wait a second or two before speaking to allow all the links to be activated. If you speak too quickly, all the links may not be established and the first word or two of your transmission (or your call) can be cut off.

I hope this discussion clarifies some of the finer points of analog FM repeaters for you. (Digital repeaters are quite a bit different and that's fodder for a future article.) So turn on that rig and check out your local repeaters. Join in a discussion or check into a net and enjoy another of the many aspects of ham radio.

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