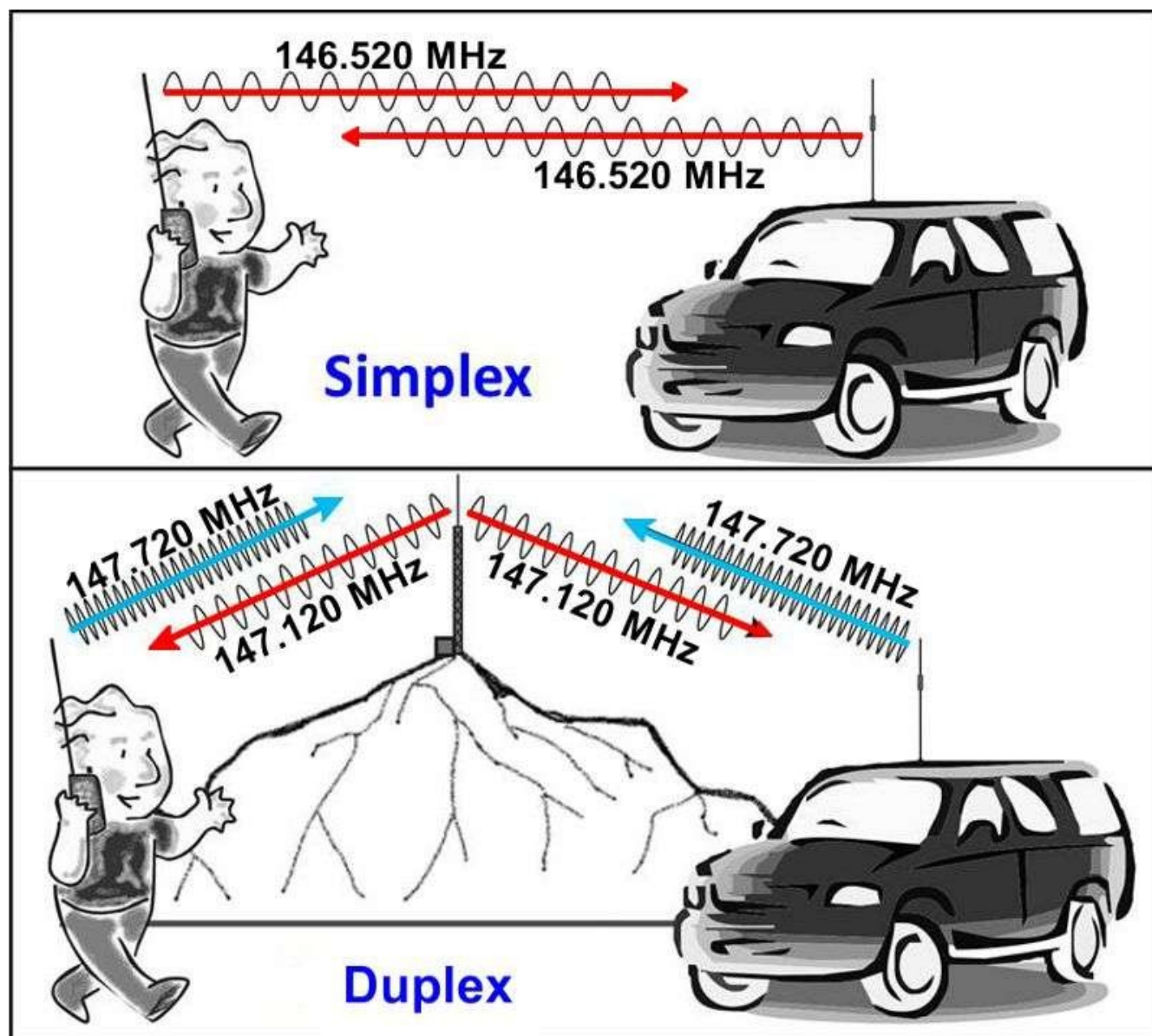


FM Repeaters -- An Introduction

Operating on VHF/UHF FM repeaters is one of the most popular activities in amateur radio. For the new ham, FM repeater ops are often the first and most common on-air experiences, but accessing repeaters also represents a significant initial vexation for the new ham to overcome. Mastering the integrated concepts of frequency pairs, tones or other squelch methods, transceiver channel programming, and repeater on-air protocols is the first significant operational challenge that many hams will encounter in their new hobby.



This article introduces fundamental concepts of FM repeater operations for the new ham and depicts a high level view of typical FM phone repeater anatomy and functioning. The goal is to demystify repeaters and help the newly licensed Technician overcome any initial bewilderment about repeaters. Let's get off to a great start in ham radio with solid footing in repeaters.

Repeater Basics: As the name implies, an FM repeater repeats your radio signal. It is just an amateur radio station that has been designed for the special purpose of retransmitting your signal instantaneously as it is received. Typically, an FM repeater station will be located in a high position, perhaps on a hill or mountain, or on a sizable tower or building. A repeater station may also retransmit with higher power than an operator uses with a handheld transceiver or other station transmitting to the repeater. As a result, the FM repeater's relay of your signal is transmitted over a much broader area than you can achieve with your station alone. The fundamental benefit is that operators who are geographically separated significant distances can use the repeater to achieve radio contact when simplex operations are not feasible or practical due to the separation or terrain.

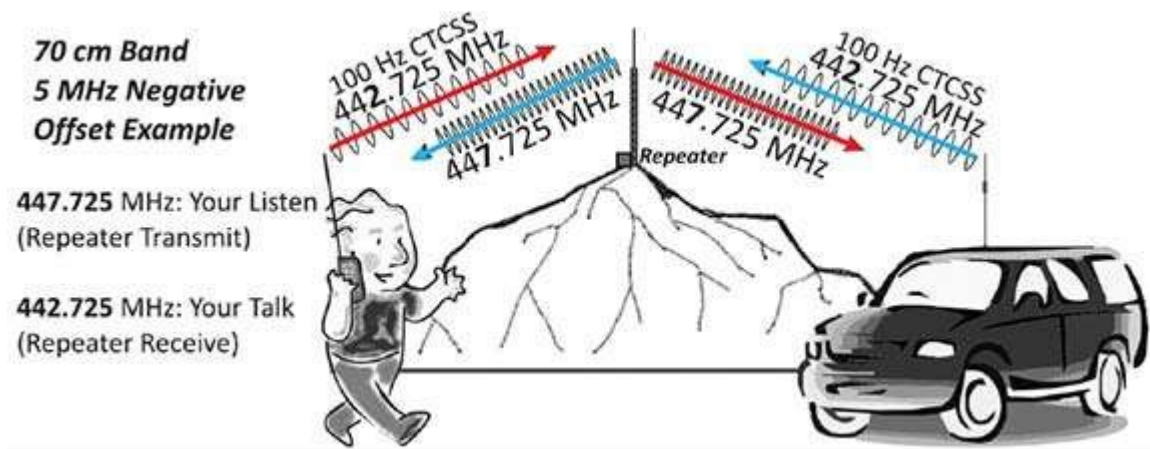
Further, because an FM repeater uses published, unchanging frequencies, it is a convenient way for amateurs within its reach to convene on the air. Groups of amateur operators will use a repeater to operate *nets*, on-air meetings at prearranged times, usually for a specific purpose or topic of interest. Nets on repeaters may also be convened by amateur radio emergency response agencies to coordinate emergency aid efforts across a broad area within the repeater's range.

While multiple types of repeaters are operated by amateurs around the world, the most common type is the FM voice repeater using VHF or UHF frequencies. But repeaters may be operated using single sideband mode, digital modes, and HF frequencies, as well. In this article we will refer almost exclusively to those most common VHF/UHF FM repeaters for voice or phone mode.

FM Repeater Operation: What do you need to do to use an FM repeater with your transceiver? Let's consider the practical aspects of repeater operation using an example. Then we can build on these basics for a more thorough understanding of repeater functions.

As an FM repeater receives your signal it must retransmit it on a different frequency. It cannot retransmit on the same frequency that you are using to reach the repeater – that would cause a feedback loop in which the repeater's receiver would “hear itself” transmitting and then try to retransmit its own output signal. Trouble lies there.

Frequency Pairs: Instead, repeaters use *frequency pairs*: One frequency is used to receive signals from ham station operators and another frequency is used to retransmit those received signals. Consider the UHF 70-centimeter band example in the graphic below. Each calling station transmits to the repeater using 442.725 MHz. Each station monitors the repeater using a frequency of 447.725 MHz. When the pedestrian HT radio operator transmits his signal (red arrows), the 442.725 MHz transmission is received by the repeater and it retransmits the signal on 447.725 MHz to be received by any other stations monitoring that repeater frequency. Any other station, such as the SUV mobile station (blue arrows) operates exactly the same way, transmitting on the lower frequency 442.725 MHz and listening on the higher 447.725 MHz frequency.



These paired frequencies are often referred to as the “listen frequency” and the “talk frequency,” as considered from the calling operators’ perspective. Of course, different FM repeaters will use different frequency pairs and entirely different amateur bands, and this is just one frequency pair example from the 70-centimeter band.

Offsets: Notice in our example that the difference between the listen frequency (447.725 MHz) and the talk frequency (442.725 MHz) is exactly 5 MHz. This difference between the repeater’s paired frequencies is called the *offset* or *shift*. Standard values for repeater offsets are established for each band, but these are only recommendations. Most repeaters follow the standard offsets as follows, but not all:

Amateur Band	Standard Offset	Example Pair, Listen/Talk (MHz)
2-meter band	0.6 MHz (600 kHz)	147.345 / 147.945 (+)
70-centimeter band	5 MHz	449.125 / 444.125 (-)
1.25-meter band	1.6 MHz	224.940 / 223.340 (-)

A frequency pair offset may be positive (+) or negative (-). That is, the talk frequency may be higher (+) or lower (-) than the listen frequency. The shift, positive or negative, is always determined as:

$$\text{Talk Frequency} - \text{Listen Frequency} = \text{Offset}$$

So, in our picture example above the repeater has a negative offset since the talk frequency is lower than the listen frequency. In the 2-meter band example in the table above the offset is positive since the talk frequency (147.945 MHz) is higher than the listen frequency (147.345 MHz).

Transceiver Channels: At this point you may be wondering how you can readily operate your radio this way, shifting between listen and talk frequencies during an on-air conversation. It is simple, really. You will program a memory channel into your radio for a specific repeater through which you wish to communicate. Just like the FM repeater, your programmed memory channel will use two different frequencies, the repeater’s listen and talk pair. When you tune to your programmed memory channel for the repeater your radio will automatically shift to the transmit frequency any time you push-to-talk, and it will automatically shift back to the listen frequency when you release the PTT key. So, radio

communications through a repeater become just as easy as simplex contacts directly between two stations.

Squelch Tones: Many repeaters utilize one additional wrinkle that you will need to include in your channel programming or the repeater will ignore your transmissions. A repeater often will use a special method of squelch in its receiver, and you must include the correct squelch information in your transmission to open the squelch of the repeater. One of the most common methods of repeater squelch employed in the US is a low frequency audio tone that is transmitted continuously along with your voice signal. If this continuous tone is not transmitted in your signal, the repeater's squelch will not be opened and the repeater will not receive your transmission.

This squelch method is known as the Continuous Tone Coded Squelch System, or CTCSS. (Sometimes this is also referred to as PL tones by hams, a Motorola trademark referring to "private line," but it is not at all private.) A repeater will use a single established tone from a set of standard frequencies. When you program a channel into your radio for a specific repeater you must select the appropriate CTCSS tone used by the repeater and ensure your CTCSS transmit function is activated for the channel. When properly accomplished, your transmission will automatically include the selected continuous tone and the repeater will happily receive your signal. Repeaters filter out the CTCSS tone from retransmissions so that it is not heard as audio by receiving stations.

Standard set of CTCSS tones (Hz)

67.0	82.5	100.0	123.0	151.4	186.2	225.7
69.3	85.4	103.5	127.3	156.7	192.8	229.1
71.9	88.5	107.2	131.8	162.2	203.5	233.6
74.4	91.5	110.9	136.5	167.9	206.5	241.8
77.0	94.8	114.8	141.3	173.8	210.7	241.8
79.7	97.4	118.8	146.2	179.9	218.1	254.1

Other methods of repeater squelch are sometimes implemented, although in the US CTCSS is the most common. Digital-Coded Squelch (DCS) uses a stream of digital data or codes to open the repeater squelch, while simple carrier squelch opens the squelch any time an RF carrier signal is detected (i.e., no special squelch tones or codes).

Repeater Coordination: You can probably imagine that if two FM repeaters implementing the same frequency pair have transmission ranges that overlap, a significant interference issue arises. For example, a single operator in range of both repeaters could cause both repeaters to activate when only one activation is intended, possibly interfering with ongoing communications on the repeater of accidental activation. Since repeaters tend to have significant range it is important to ensure they are coordinated to avoid mutual interference. Consideration of repeater geographic separation, transmission power, as well as the use of different frequency pairs and careful selection of CTCSS or other squelch methods helps to avoid repeater conflicts.

Regional frequency coordinators are selected by operators and organizations whose stations are eligible to be repeaters. The coordinator recommends repeater pair frequencies and other station parameters to help avoid interference. The frequency coordinator may itself be a group or organization comprised of repeater operators or club representatives.

On-Air Protocols: Be aware that every FM repeater will have a community of regular operators who use it, and these communities tend to develop something of a personality for the repeater. Some repeaters may have policies or rules established for its use. For example, many wide area repeaters (repeaters that reach over a very wide range) may have a policy of priority-only traffic, or a “no rag chewing” policy. That is, the repeater operators wish to keep the repeater available for long-range communications of a more important nature than checking up on the health of your friend’s cat in the midst of an hour-long, idle chit-chat QSO. Still, other repeaters may be designated specifically for extended rag chewing, yucking it up, and generally having fun on the air within the regulations of FCC Part 97. It is a good idea to monitor a repeater for a while, contact the repeater operator, look for information about the repeater online or inquire with other hams before using a repeater extensively. Get to know the repeater’s personality.

Many FM repeaters will host regular nets at designated times. Become familiar with the repeater’s schedule of events and plan to avoid use during scheduled nets or other on-air events. If you are engaged in a QSO and another operator breaks in to notify you that a net will soon be starting on the repeater, graciously yield your privilege to the frequency and perhaps take part in the net if it is of interest to you.

If you wish to make known your presence on an FM repeater, perhaps to pick up a casual contact, simply state your call sign on the air – no other elaborations required. Many operators using mobile stations will tack on “mobile” to their call sign to clarify that they are not at their home station. Hams operating from a stationary location other than their registered home station will often add the term “portable” to their call sign. But “CQ” (calling any station) is rarely used on FM repeaters, and most operators will skip the use of phonetics as well due to the clear, low noise character typical of most FM repeaters.

You may hear courtesy tones on a repeater that indicate the end of a repeated transmission, and these tones substitute for the use of terms like “over” at the end of a transmission. You will also typically hear the repeater identify itself with either Morse Code tone patterns or by recorded or electronic voice ID at least every 10 minutes. A good rule of thumb during an extended QSO is to identify your station whenever the repeater identifies itself, helping you to keep with the 10 minute identification rule of the FCC Part 97.

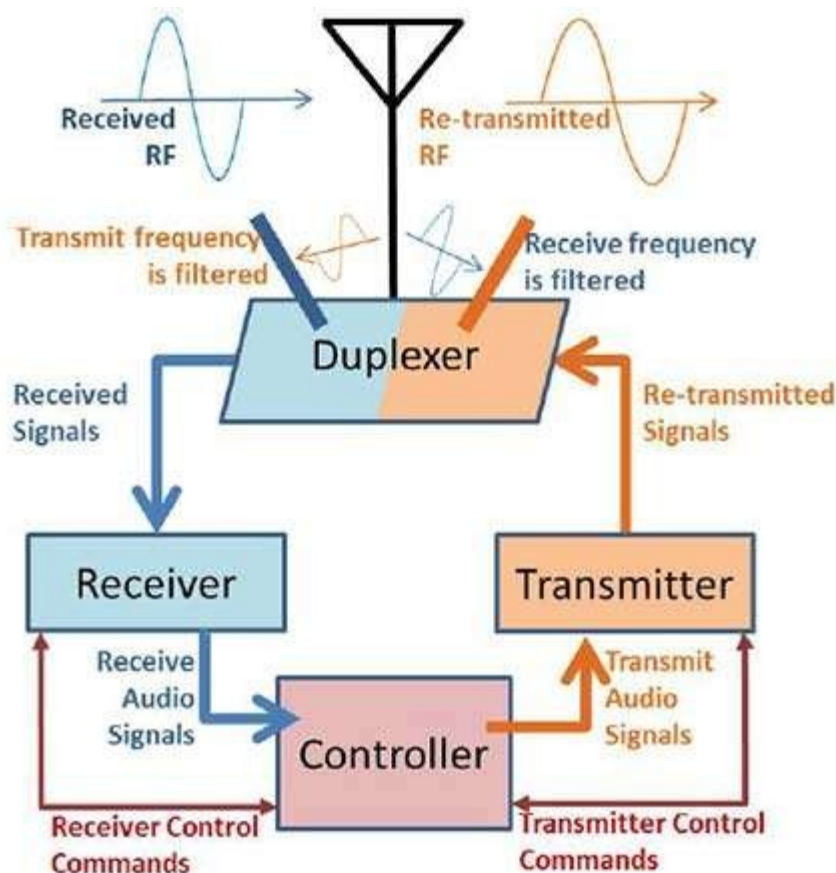
For most casual conversation via repeater, common language and common courtesy is the norm. You will hear a few [Q signals](#) thrown in by operators on repeaters, so it pays to be familiar with the most commonly used Q signals such as QSO, QSY, QRM, QSL, and others. But the beginner will have little trouble fitting in immediately on most repeaters.

However, when a *tactical net* is convened on an FM repeater, perhaps for public event communications operations or an emergency communications tactical net, the casual nature of on-air communication is significantly reduced, especially if the net is busy with traffic. During a tactical net the transmissions will be succinct and to the point, with specific protocols implemented by a net control station.

So, find the FM repeaters in your area, monitor each for a while, and do your research. Get your radio channels programmed and get on the air with one or more repeaters that suit your needs and your preferences.

How Repeaters Work: Understanding a bit about how FM repeaters are designed and how they work will improve your understanding of their on-air operations. Repeaters are not very different from other

transceivers, but a few specialized components have been added to affect the repeat function via frequency pairs and to automate the repeater control. Let's take a surface glance under the hood of a typical FM repeater. Follow along in the simplified block diagram below of the most basic repeater architecture.



Duplexer: Inbound RF signals from a transmitting station are received by the repeater antenna and directed to a component called the *duplexer*. A duplexer is a device that allows a single antenna to be used simultaneously for transmitting and receiving two different frequencies. Why is this needed, you ask?

Necessarily, a repeater must receive and transmit at the same time, albeit on two different frequencies. When a high power transmitter and a receiver of great sensitivity operate in the same band near one another in frequency, the transmitter's signal will overwhelm the receiver even though the tuned frequencies for transmit and receive are not identical. A typical receiver system cannot adequately *reject*, or filter out, the powerful blast of the transmitter. As a result, the repeater's strong re-transmitted signal will mask the weaker inbound signal from a distant station, making the repeater useless... unless a duplexer is introduced.

A duplexer is a set of resonant circuits that serve as a very sharp and effective RF filter. This filtering circuit applied to the receiver side of the repeater keeps the frequency of the transmitter out of the receiver – the transmit frequency is rejected and not allowed to proceed to the receiver, but the normal receive frequency of the repeater is allowed to pass. Further, the duplexer rejects the normal receive frequency on the transmit side, requiring that all received signal strength is directed to the receive side path, while allowing the transmit signal to pass on to the antenna unimpeded.



Duplexer cavities for a 2-meter repeater. Courtesy N1BUG: <http://www.repeater.n1bug.com/>

An alternative to using a duplexer in a repeater is to arrange separate antennas for transmit and receive that are physically separated by a substantial distance so that the strong transmitted signal does not overload the receiver. Because of the physical challenge and long feedlines this arrangement presents, the more common scenario is use of a duplexer with a single antenna.

Duplexers are typically constructed as cylindrical cavities of highly conductive material, such as silver, and usually at least $\frac{1}{4}$ wavelength long for the repeater frequencies used. The cavity and associated components are designed to be resonant circuits of very high Q, meaning that only a very narrow range of frequencies will be resonant and passed through the circuit with good efficiency. In this way, the duplexer cavities serve as very sharp filters that may be tuned to pass only a narrow band of frequencies in the receive band or the transmit band of the repeater.

Controller: A repeater utilizes automatic control since no control operator is in constant attendance of it functions. A repeater *controller* is an electronic device that is functionally interposed between the receiver and transmitter of the repeater to orchestrate repeater functions.

The controller accepts the audio signals output by the receiver and routes them to the input of the transmitter. The controller automatically activates the transmitter when signals are received for re-transmission, it initiates the repeater station identification transmissions with proper regularity, and it stores data or audio for transmission of the station call sign, courtesy tones, and other information.

The controller may also detect special tones or other signals transmitted to the receiver remotely by the station operator for the purpose of implementing or changing control functions. For instance, a repeater operator may transmit sequences of DTMF tones to the receiver to initiate a phone patch, a radio connection to a conventional telephone land line. Other control functions may change the repeater's power output, the courtesy tones, the duration of the *hang time* over which the repeater continues to transmit following the termination of a received signal, or other functions.

That's a Wrap: The duplexer and the controller are the two most significant components of a modern FM repeater station that augment the normal transceiver's functions of transmitting and receiving, but

they are not the only ones. Keep in mind that our block diagram above is the simplest depiction and many FM repeaters include other specialized components for specific functions, including those of power management across the various parts of the repeater.

I hope this introduction to FM repeaters will help a few new hams to overcome the challenge of initial repeater operations. There's a lot to learn about repeaters, much more than is represented in this brief introduction, but the information here should be sufficient to start the beginner down the path to tons of FM repeater fun.

-- Stu WØSTU