frequency translation in ssb transmitters

After an ssb is generated, it has to be put on at least one of the amateur bands; here's how it is done

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Single-sideband signals for ham communications are almost never generated at the operating frequency of the ssb transmitter. For example, a transmitter output consisting of either the upper or lower sideband of 14.25 MHz is not actually generated at that frequency. No matter what the output frequency of the transmitter, sidebands are developed in the balanced modulator with a constant "carrier" frequency.

The fixed-frequency sideband is changed to the several operating frequencies through what is basically a heterodyne process. The sideband is mixed with a pure rf signal; they beat together and form a new sideband signal near the desired frequency. The process has several names. The most common is **frequency conversion.** But, in transmitters, to distinguish from the similar process in receivers, the term **frequency translation** is more accurate.

the simplest system

You can understand the basics of the process easily if you refer to **fig. 1.** The block diagram illustrates the simplest form of frequency translation.

A crystal oscillator generates the carrier for modulation. Its signal is mixed with voice signals in the balanced modulator, producing a double-sideband signal with the carrier eliminated. A sideband filter, either mechanical or crystal-lattice, trims off the unneeded sideband. All that is left is the one sideband of the initial carrier frequency.

To translate the desired sideband upward to an operating frequency, a heterodyne mixer is used. A variable-frequency oscillator (VFO) furnishes a signal that beats with the sideband from the filter and produces a sideband at the desired frequency. In the process, the simple mixer can't avoid also producing a carrier at the VFO frequency and an image sideband (as far from the VFO carrier as the desired sideband, but on the opposite side).

Ordinary tank circuits, tuned to the desired sideband, eliminate the carrier and the unwanted sideband—neither of which is very close to the frequency of the wanted sideband. The sideband, which is now the sideband of the operating frequency, is fed to the linear power amplifier.

The reasons for going through this process may not be obvious. First of all, the isolated sideband can't be raised in frequency by simple frequency multipliers, as in non-ssb transmitters, because they would lose their identity completely. In the second place, a constant carrier frequency in the balanced modulator means that the resulting sidebands can always be fed to the same filter. If there were a lot of different frequencies, a different filter would be needed for each one. It's much easier to heterodyne or **translate** the fixed frequency up to the various desired ones.

double heterodyning

Not many ham transmitters use the simplest single-translation version just described—only a couple of kit-type models, that I know of. Such systems are not very effective at producing high output frequencies. Therefore, in multiband ssb transmitters and in those for vhf use, something more elaborate is preferable. A double heterodyne arrangement can produce the higher output frequencies needed. It's the most popular frequency-translating system found in ham transmitters.

A typical double-heterodyne system is diagramed in **fig. 2.** The diagram includes more detail of an actual transmitter than did **fig. 1,** yet it is still simplified. Also included are frequencies as they occur in one model of transmitter; they will help you understand exactly what's happening in a transmitter like this.

The carrier oscillator in this one is in the 455-kHz range. (Others include 1.65 MHz, 2.2 MHz, 3.3 MHz, 5.5 MHz, and 9 MHz.) To pick which sideband will be generated, the carrier frequency is shifted above and below the nominal 455 kHz; the two frequencies are listed on the diagram. I'll base my explanation of the system on generating a lower sideband (lsb) in the transmitter output; the carrier oscillator runs at 453.65 kHz.

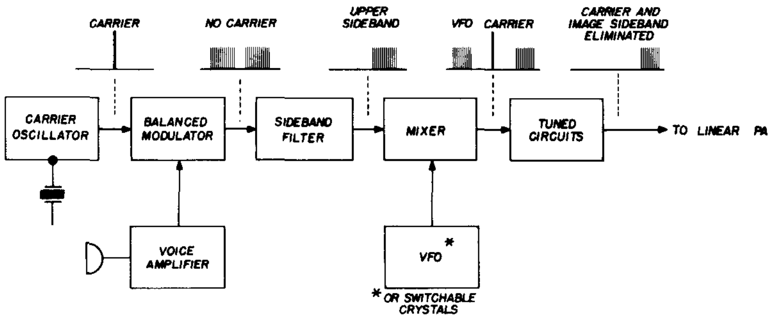


fig. 1. Simplest means of translating a sideband from a carrier-generated frequency to an operating frequency.

Mixed in the balanced modulator with the .1–3 kHz voice signals, the carrier produces a pair of sidebands. The lower sideband contains frequencies from 450.65 to 454.55 kHz (the differences between the lsb carrier frequency and the voice frequencies). The upper sideband contains frequencies from 453.75 to 456.65 kHz (the sums). The mechanical filter sharply chops off the upper sideband, leaving only a single sideband encompassing 450.65 to 453.55 kHz. For simplicity, this can be called the lower sideband of 455 kHz, even though there is some separation from that frequency. The carrier itself is eliminated in the balanced modulator.

The first frequency translation takes place in the first mixer. The VFO is tunable from 2.5 to 2.7 MHz; a frequency of 2.6 MHz (2600 kHz) is chosen for the example. Again, because of the heterodyne process, two sidebands are produced, but they are far apart. The desired one encompasses the sideband frequencies from 3050.65 to 3053.55 kHz; the other is an "image," with frequencies from 2146.45 to 2149.35 kHz. The desired sideband is still a lower sideband even though it has an "upper" position with respect to the image. The desired sideband is the lower sideband of 3055 kHz (2600 + 455 kHz).

The tuned circuits that follow the first mixer get rid of the 2.1-MHz sideband, being tuned to the vicinity of 3 MHz. The VFO carrier doesn't appear in the output of this mixer, as it did in **fig. 1,** because the mixer is a **balanced mixer.** It's a close relative of a balanced modulator and cancels whatever rf carrier is applied to it. Translation therefore affects only the sideband that is applied to the balanced mixer.

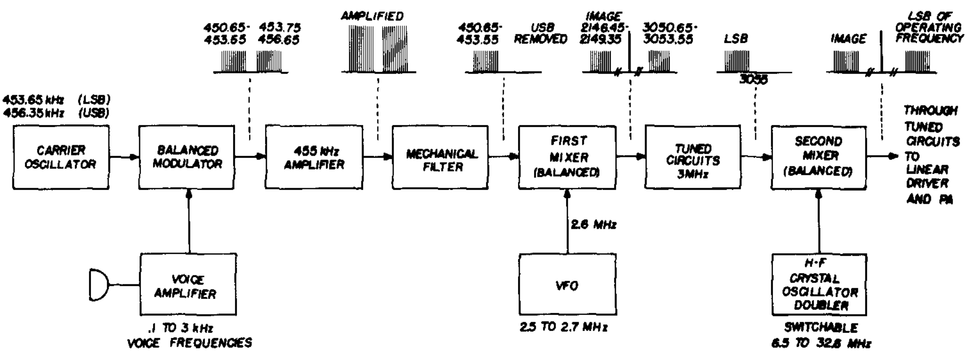
The 3055-kHz sideband must still be raised to the operating frequency. The second translation is handled much like the first. A switchable crystal oscillator supplies an rf signal for the second balanced mixer. Beating with the sideband signals that were produced in the first mixer, the rf signal develops a single-sideband signal in one of the ham bands. The band depends on the crystal selected in the hf oscillator, and the exact frequency depends on the setting of the VFO. An example will show you how this works.

Suppose you want to produce the lower sideband of 14.25 MHz. You set the switch of the hf oscillator to the crystal that places the output frequency in that vicinity. The crystal for this happens to have a frequency of 8.6775; but its oscillator is a doubler, so its operating frequency is 17.3550 MHz. The lower sideband of 14.25 MHz lies from 14.2470 to 14.2499 MHz. The sideband signal fed to the second mixer must therefore be the difference between those frequencies and the hf crystal frequency; that sideband covers from 3.1051 to 3.1080 MHz.

For the first mixer to produce that sideband for the second mixer, the VFO must be set at the difference between it and the input sideband from the filter. Calculating the differences, you can find that the VFO must produce an rf signal at 2654.45 kHz. (You can subtract 450.65 from 3105.1 kHz or you can subtract 453.55 from 3108.0 kHz; those are the limits of the lower sideband coming from the mechanical filter and the limits of the sidebands to be developed by the first mixer.)

On the front of the transmitter, the hf-crystal switch would point to the 14.2-MHz sector of the 20-meter band, and the VFO dial would indicate 50 kHz. The combined readings would signify an operating frequency of 14.25 MHz. The transmitter output would be the lower sideband of that frequency.

fig. 2. Double heterodyning gives the operator a wide choice of frequencies, grouped into the several bands.

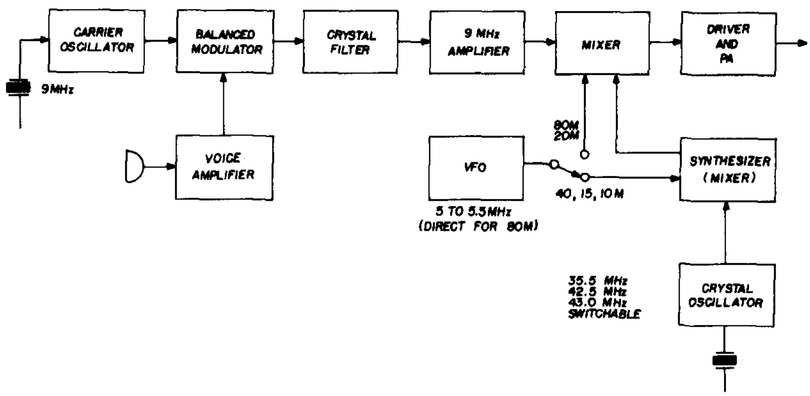


frequency synthesis

Developing bands of frequencies by one translation and developing the frequencies within that band by another are excellent reasons for using double and triple heterodyne systems. Frequencies can be spread out wider than with any other system. Bands can even be sectored, and the VFO range used to cover only a portion of each ham band—thus spreading the frequencies even wider and making it that much easier to tune a particular operating frequency.

There's another way this can be done—by a method called **frequency synthesis.** The chief principle behind synthesis is illustrated in the transmitter diagramed in **fig. 3.** For simplicity, the frequencies are marked without reference to the sidebands; you know that what comes through the 9-MHz amplifier is actually one sideband or the other of 9 MHz. The same is true of the frequencies following the mixer.

fig. 3. The basic setup for frequency synthesis. The translating signal itself is heterodyned up before it is mixed with the sideband for the translation process.



The switching from band to band, and the tuning within bands, is all accomplished before the rf signal is mixed with the sideband signal. Developing all the various rf mixing signals artificially is where the term **synthesis** comes from. In commercial multifrequency transmitters, it is done entirely with crystals; a few crystals can synthesize hundreds of individual frequencies by the heterodyne translation method.

How the transmitter in **fig. 3** works is not hard to figure out. The 9-MHz carrier oscillator is common in modern ham transmitters. After the balanced modulator, the sideband filter, and some amplification, the single sideband is applied to the mixer. There, the translation process is simple—just a single heterodyne. The synthesizer (sometimes called **heterodyne mixer** or **premixer**) must supply a signal that will heterodyne with the 9-MHz sideband to form the sideband of the desired operating frequency.

If the desired operating frequency is to be, say, 28.9 MHz, the synthesizer must supply an rf signal at 37.9 MHz to beat with the 9-MHz sideband signal coming from the filter and amplifier.

How does the synthesizer create such a signal? It mixes the signal from the 43-MHz crystal with a signal from the VFO. To synthesize a 37.9-MHz signal, the VFO must be set to generate a 5.1-MHz signal.

From the panel of the transmitter, with the viewpoint of the operator, it looks like this: the bandswitch knob is tuned to cover the segment of ham band from 28.5 to 29 MHz; this selects the 43-MHz crystal. The VFO dial is twisted until it reads .9; this represents 900 kHz (.9 MHz) on the dial and sets the VFO frequency at 5.1 MHz. The synthesizer mixes the 43-MHz and the 5.1 MHz signals. A tuned circuit that was selected by the bandswitch control picks off the difference between the two, or 37.9 MHz, which is fed to the main mixer. There, the 37.9-MHz signal beats with a sideband of 9 MHz; another tuned circuit picks off the difference, which is the sideband of 28.9 MHz—the desired operating frequency.

Other crystals and mixing schemes in this transmitter produce the other frequencies in the ham bands that are used for ssb. In some bands, the VFO is fed to the mixer directly to produce the desired operating-frequency translation.

triple heterodyning

From the words, you can figure out that

a transmitter with triple translation is one with three mixers. And, of course, it also needs three oscillators in addition to the carrier generator.

You can probably picture the arrangement in your mind. After the balanced modulator and sideband filter, the sideband signal goes to a first mixer where a crystal-generated signal is beat against it to produce a sort of intermediate-frequency sideband signal. At the second mixer, a VFO puts in a signal to tune the sideband signal **within** each band. A third mixer, usually with crystal switching, translates the sideband signal to bands or segments of bands. In other words, a triple-heterodyne system works like a double system with an extra stage of mixing in front of it.

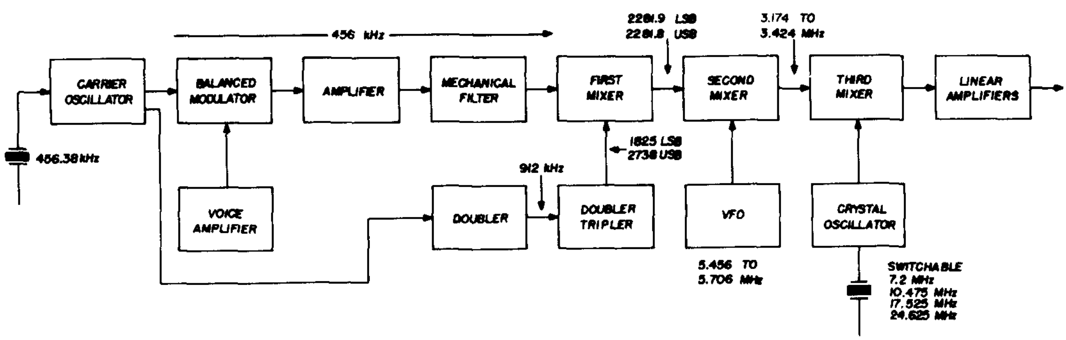
An interesting example of triple translation in a ham ssb transmitter is in the Sideband Engineers SB-34 transceiver. **Fig. 4** is a block diagram of it. An interesting thing about this one is the use of the carrier oscillator to also furnish the rf signal at the first mixer. By careful choice of the carrier frequency, the designer has also come up with a novel way to shift sidebands.

band near 2281.9 kHz. If the stage is operating as a tripler, the signal going to the first mixer is 2738.2 kHz. That translates the 456.38-kHz sideband signal to a sideband near 2281.8 kHz.

The VFO generates a signal that is tunable from 5456 to 5706 kHz. This translates the sideband to some frequency between 3.174 and 3.424 MHz—the exact frequency depending on the dial setting of the VFO. Whatever the VFO setting, the sideband developed is on the upper or lower side of the new frequency, whichever is selected at the doubler/tripler stage.

You've probably already figured out the third mixer, if you've been studying **fig. 4.** With the crystal selector set for the 7.2-MHz crystal, the range of difference frequencies tuned in the second mixer by the VFO is from 3.775 to 4.025 MHz. For the 10.475 crystal, it is from 7.05 to 7.3 MHz; for the 17.525 crystal, from 14.1 to 14.35 MHz; for the 24.625 crystal, from 21.0 to 21.45 MHz. Thus, the 80-, 40-, 20-, and 15-meter ham ssb bands are all covered. Naturally, the VFO dial is calibrated to show each of these band sectors.

fig. 4. Special case of triple translation. The first mixer gets multiplied signal from the carrier oscillator.



The 456.38-kHz carrier is modulated as usual, amplified, and filtered to produce the sideband signal. A sample of the carrier is also fed to a doubler to produce a 912.75-kHz signal. The stage following that is either a doubler or a tripler, depending on the setting of the sideband switch. With the signal frequency doubled, a signal at 1825.5 kHz is fed to the first mixer. There it beats with the sideband of 456.38 kHz, translating to a side-

mixers that translate ssb

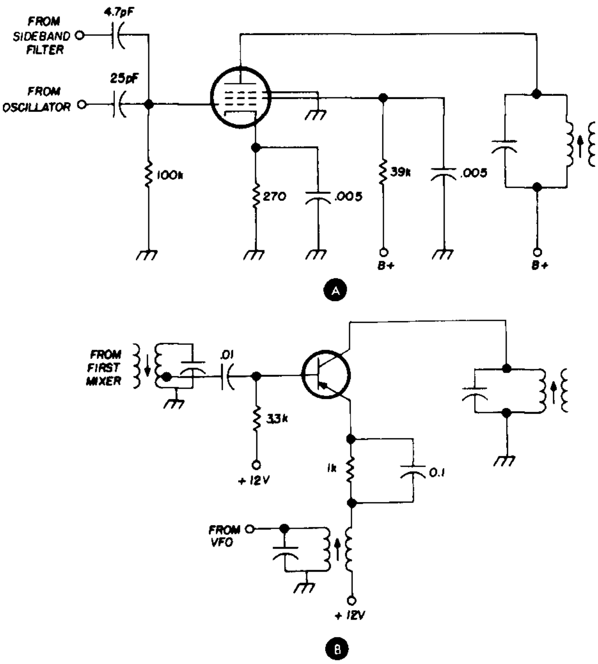
In most single-sideband ham transmitters, the mixer circuits are ordinary tube or transistor mixers. In one transmitter I know of, a semiconductor diode mixer is used for translating the carrier frequency to an intermediate frequency. Typical tube and transistor transmitter mixers are shown in **fig. 5.**

These are not the only configurations used, by any means, but they are typical. Tube mixers are usually pentodes in modern ssb transmitters; seldom do you find a triode used for this purpose. The two signals are merely coupled to the grid, mixed inside the tube, and fed along to the next stage.

In transistor mixers, common practice is to couple one signal to the base and the other to the emitter. In the transistor stage shown, the sideband is fed to the base, and the VFO signal to the emitter. The output frequencies are developed in the collector circuit.

Simple frequency conversion like this is okay for ssb transmitters, although it does create a problem. When two signals are beat together in a nonlinear mixer, the output consists of the two original frequencies, their sum, and their differences. As an example, suppose the VFO in the transmitter of **fig. 4** is set at 5500 kHz, and the lower sideband has been chosen. The frequencies applied to the mixer (the transistor in **fig. 5**) are 2281.9 and 5500.0 kHz. The output consists of four frequencies: 5500.0 kHz, a sideband of 2281.0 kHz, a sideband of 7781.9 kHz (sum), and a sideband of 3218.1 kHz (difference). Picking out the right one is the job of the tuned circuits following the mixer. In this example, a broadband tuned circuit centered around 3.3 MHz can do the job. Only the sideband of 3218.1 kHz gets through. The tuned circuit thus eliminates the new carrier that was generated as part of the translating process, as well as the original sideband and the new image sideband.

fig. 5. Two versions of frequency mixers used in amateur ssb transmitters.



In first mixers, getting rid of the new carrier can be a problem because it is so near the sideband frequencies. It may even be troublesome to get rid of the image sideband unless the translation is a long step upward. Also, some of the original carrier may be lingering with the sideband, having slipped through the balanced modulator and the sideband filter.

The solution to all these possibilities is a balanced mixer, which was already mentioned briefly. An example of a tube-type balanced mixer is shown in **fig. 6.** A balanced mixer looks and operates just like a balanced modulator; the difference is that two rf signals are fed in rather than rf and af signals.

As in the usual balanced modulator stage, the signal to be canceled out is fed into the stage in parallel, and the output is taken in push-pull. Mixing is accomplished by feeding in the other signal—in this instance the sidebands—in the same mode as the signal is taken out of the stage. Thus, the VFO signal is fed simultaneously to the grids of both tubes (in parallel), and the sidebands from the mechanical filter are fed to the mixer grids in push-pull. The two 220-pF capacitors couple the VFO signal equally to the grids.

Balance is important in the two tubes, so a balancing-type cathode bias circuit is common to both tubes. During alignment of a transmitter using this system of translation, the balancing potentiometer is adjusted for a null of VFO signal in the mixer output.*

Bringing the sideband up to the operating frequency in a single-sideband transmitter is obviously not as simple as mere frequency multiplication. That approach would be im-

* The subject of ssb transmitter alignment, including how to adjust balanced modulators, is covered by Larry Allen in *repair bench* on page 58.

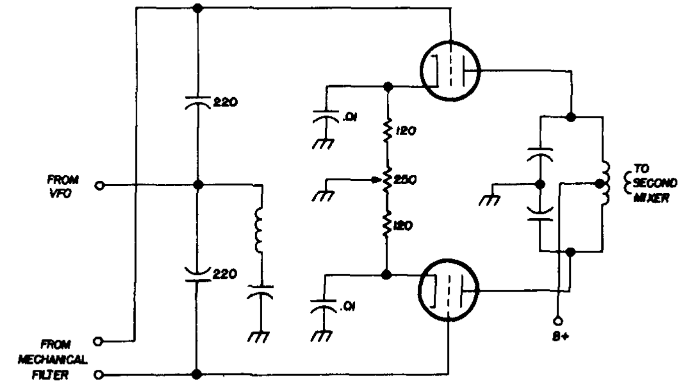


fig. 6. Balanced mixer used in some ssb transmitters to eliminate the carrier that is generated by frequency translation.

possible with sideband. An alternative, in hf ssb transmitters, is phase-shift generation of the sideband signal; the sideband can be produced right at the operating frequency. This method was discussed in the July issue of **ham radio.** Modern designs shy away from the phase-shift method because multiband characteristics are desirable in ham transmitters. Frequency translation seems to be the most practical way to raise the sideband frequency.

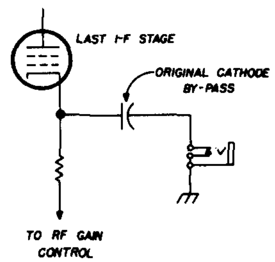
Next month I'll delve into another little-understood facet of the modern ham ssb transmitter: voice-operated transmission, better known as **VOX.** I'll explain various methods of accomplishing this type of hands-off operation. Also, we'll take a quick look at **MOX**—the manual version, usually called **PTT** or **push-to-talk.** VOX and MOX go together, in a way, and the up-to-date ham should understand both.

ham radio

the i-f cathode jack

Here is a very simple modification that will greatly increase the versatility of your communications receiver. Only one part is required: an ordinary closed-circuit phone jack. The diagram shows where the jack goes: in the lead between the i-f stage cathode bypass capacitor and ground. The jack may be mounted on the rear apron of the receiver chassis near the last i-f stage.

As long as nothing is plugged into the jack, it is a short circuit and the receiver works exactly as before the modification. When a phone plug is inserted, the i-f stage becomes a cathode follower, and provides a low-impedance i-f output for driving a Q-5'er, fm adapter, monitor scope, etc. An ac vtvm can be plugged into the jack for precise indication of signal level. With a vtvm plugged in, it is possible to make comparisons of antenna gain, measurement of front-to-back ratio, transmission line attenuation, preamp gain, TR switch loss, image rejection, signal fading, skirt steepness ratio—practically any measurement requiring dB comparisons or rf signal levels. Be sure to turn the agc off.



Sometimes a cathode follower becomes regenerative if terminated in a capacitive reactance. If there is any sign of instability, the phone plug should be shunted with a suitable loading resistor.

Fred Brown, W6HPH