Online Radio & Electronics Course

Reading 31

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AM TRANSMITTERS & RECEIVERS PART 2

SINGLE SIDEBAND (SSB)

Some Repetition:

Amplitude modulation occurs when the modulating audio is combined with a radio frequency carrier in such a way that the <u>total wave power</u> is made to vary in accordance with the modulating audio.

I would really like you to be very firm in your understanding of ordinary AM before we move to Single Sideband (which is another type of AM).

The basic principle of radio transmission is to convert the voice frequencies coming into the microphone to radio frequencies, so that they can be radiated as an electromagnetic wave. At the receiver, the electromagnetic wave can be intercepted and the original voice frequencies recovered.

The audio frequencies from a human voice range up to about 3000 Hz. Of course, the human voice can make sounds above this range, but for voice radio communications we do not need to use those higher voice frequencies. All of the intelligence (information) we need is contained in the voice frequencies below 3000 Hz.

Because this is such an important topic, we are going to go over the process of amplitude modulation again with a slightly different approach. If we were to look at what was going on in an AM transmitter using an actual voice, there would be too many frequencies. Therefore, we are going to pretend that a sound is being made by a human voice, which only contains two frequencies. Our <u>pretend human voice</u> is making two audio sounds, one on <u>1000 Hz</u> and the other on <u>2000 Hz.</u>

The diagram in figure 1 shows the sound containing these two frequencies going into a microphone. The audio sounds are amplified by the microphone amplifier and fed to the modulator (a non-linear device). Also going into the modulator is a radio frequency signal of 1000 kHz (1 MHz) from an oscillator, called the carrier oscillator.

The modulator is going to mix the audio and radio frequency signals together to produce new signals. At the output of the modulator, there will appear the original carrier and the sum and difference of all the voice frequencies (which we have simplified to just two). The output of the modulator is all radio frequencies and is called double sideband full carrier, as shown.

Look long and carefully at figure 1. The voice frequencies have been converted to two frequencies above the carrier, and two below the carrier.

Nothing else has happened. Do not try and read anything complicated into this diagram. It is a frequency converter. We call it a carrier oscillator and modulator only because of what we are doing with this frequency converter; that is, moving audio to radio frequencies in a DSB system. The two voice frequency tones remain the same distance apart in the radio spectrum as they were at audio. Their amplitude is the same. All we have done is move the two audio frequencies to two sets of radio frequencies.

Figure 1.
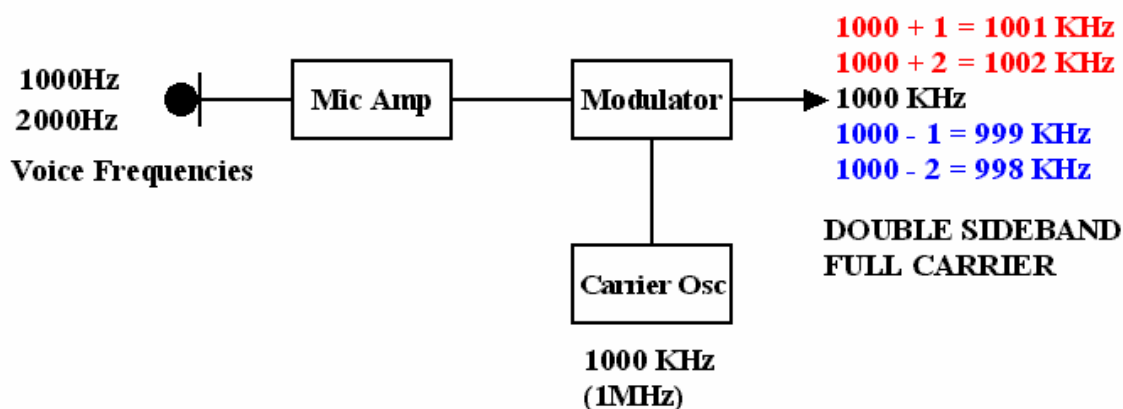
SIDEBANDS

The frequencies above the carrier are the upper side frequencies. Those below the carrier are the lower side frequencies. Collectively, all of the upper side frequencies are called the upper sideband (of frequencies). Collectively, all of the frequencies below the carrier are called the lower sideband.

There is no information in the carrier (1000 kHz or 1 MHz).

All of the information is in the upper sideband **AND** all of the information is in the lower sideband.

If we choose to amplify and transmit the lot, fine, we have what most people just refer to as AM. The highest voice frequency being 3000 Hz means that the total bandwidth of the signal is 6 kHz - twice the highest modulating audio signal.

We do not have to transmit the entire signal (above). We could just transmit *either* sideband and then convert those sideband frequencies back to the original audio in the receiver. This has obvious advantages, the main one being the bandwidth of one sideband would never be greater that 3KHz. Spectrum space is not an infinite resource and this would mean we could get twice as many channels into the same spectrum space.

MORE REINFORCEMENT

A Spectrum Analyser is a very expensive piece of test equipment. You do not to need to know anything about it for exam purposes. However, discussing what this device displays will help our understanding. A spectrum analyser when fed a radio signal, displays on its screen frequency on the horizontal axis, and amplitude on the vertical axis.

Figure 2 shows what a spectrum analyser would display for our special two frequency only
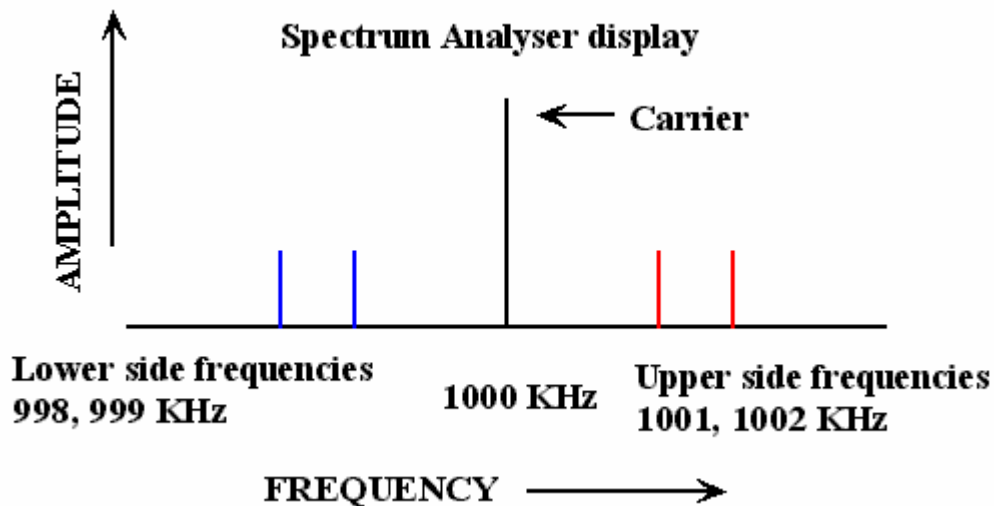
voice. The diagram shows the output of the modulator in the first diagram of this reading.

I have not shown the length of the lines (amplitude) in exact scale.

You can clearly see the carrier in the centre, and the individual upper and lower side frequencies. Alternatively, we could call them the upper and lower sidebands, which is the collective name used for all of the upper and lower side frequencies. I hope your are beginning to catch on.

The lower sideband contains our two audio sounds moved to radio frequencies, as does the upper sideband. Radio transmission and reception is about moving the audio frequencies to radio frequencies (maintaining the relative positions of individual frequency components), and transmitting the signal. Then, receiving the signal and moving the radio frequencies back down into the audio range so that we can hear them.

Figure 2.

Spectrum Analyser display

← Carrier

Lower side frequencies
998, 999 KHz

1000 KHz

Upper side frequencies
1001, 1002 KHz

FREQUENCY ⟶

You should be beginning to see that it appears silly to transmit an AM signal when we could just transmit a single sideband (SSB).

We still use AM as it is just so downright easy to produce, transmit, and receive.

SSB

To transmit and receive single sideband has many advantages, but is technically more difficult. The principle of SSB transmission is to simply remove one of the sidebands (either one) completely, and also get rid of the carrier. In practice, it is easy to get rid of one of the sidebands, a sharp bandpass filter will do this for us. We can *reduce* the carrier by using a special modulator. Yes reduce, but not eliminate. The full correct name for SSB is Single Sideband Suppressed Carrier. Which means we have done our best to suppress or reduce the carrier.

Now, if we were going to get rid of a sideband and suppress the carrier, it would make a lot of sense to do this down in the milliwatt range. Getting rid of a carrier of say 100 watts (and a sideband) would be silly when it can be done more efficiently at low power levels.

The advantage of SSB is not just more efficient use of spectrum space. The radio

spectrum contains noise from many sources. If you turn on any receiver and <u>do not tune to a signal</u>, you will hear <u>noise</u>. This noise is from hundreds of sources, both man made (QRM) and natural (QRN). Some noise is also generated inside the receiver by active devices and even resistors. The narrower the bandwidth of a receiver the lower this noise. Think of the bandwidth of a receiver like an open window. Think of the noise as rain. The more you close (narrow) the window the less rain (noise) gets in. So yes, SSB is technically harder, but well worth the benefits in power efficiency at the transmitter and noise reduction in the receiver.

SSB TRANSMISSION
THE BALANCED RING MODULATOR

A Balanced Ring Modulator produces at its output a double sideband signal with the carrier suppressed by 40-60 dB.

You will not be asked to describe the operation of a balanced modulator. You will have to know what a balanced modulator is and what it does.

There several types of balanced modulators. The balanced ring modulator is the most common, and the one, if any, you will find in the exam. You may need to identify the circuit. You may be asked to identify what the circuit does.

Figure 3 shows the schematic diagram of a balanced ring modulator scanned from an article I once wrote. This actual diagram has appeared in AOCP exams.
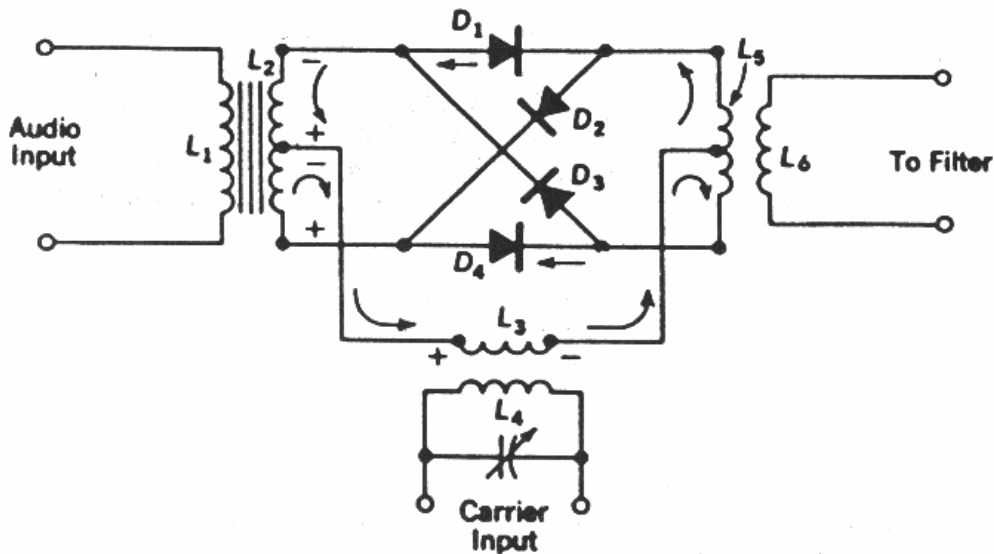
Balanced ring modulator
Figure 3.

You should learn to identify the circuit. I am going to provide a description of its operation. However, this is for *interest sake* only. I will not be asking any assignment questions on the specific operation. Though you will need to know the operation as a block - that is, inputs and outputs and what it does.

OPERATION OF THE BALANCED RING MODULATOR

With carrier input alone applied, RF currents will flow during one half-cycle through diodes D1 and D4 as shown. During the next half-cycle of RF, current will flow through D2 and D3. Notice that no matter which pair of diodes conduct, the current flows equally and in

opposite directions through the upper and lower parts of the primary winding of L5. Because of these equal and opposite primary currents through L5, the voltage induced into the secondary L6 by the carrier will be **zero**.

This means that, provided the carrier controls the diode switching (conducting), no carrier will appear in the output.

With audio input only applied, current will flow through D3 and D4 or D1 and D2, depending on the polarity of the audio voltage, but no current will flow through L5 - so, for audio alone, the output voltage at L6 is again zero.

Suppose that both audio frequencies AF and carrier are applied with the instantaneous values as shown in the diagram. The carrier input level is 6 to 8 times higher than the AF and, as such, determines which diodes will conduct. The arrows show the current produced by the carrier. With the polarities as shown, the audio voltage is assisting current flow through the top half of L5 and opposing current flow through the bottom half. The current through L5 is now upset (unbalanced), and an output at the sideband frequencies will appear in L6.

In practice, some type of balancing of the circuit is required. This is usually a simple resistive voltage divider network, the resistance of which is adjusted to balance the modulator with carrier only. In an SSB transmitter this control is inside the transmitter on the circuit board, and labelled carrier balance on the schematic diagram.

SUMMARY

When modulating audio and carrier are applied to the balanced ring modulator, unequal currents flow through L5 producing a double sideband suppressed carrier output.

A COMPLETE BLOCK DIAGRAM OF AN SSB TRANSMITTER

It's time we took a walk through the complete block diagram of an SSB transmitter and discuss the operation of each stage.
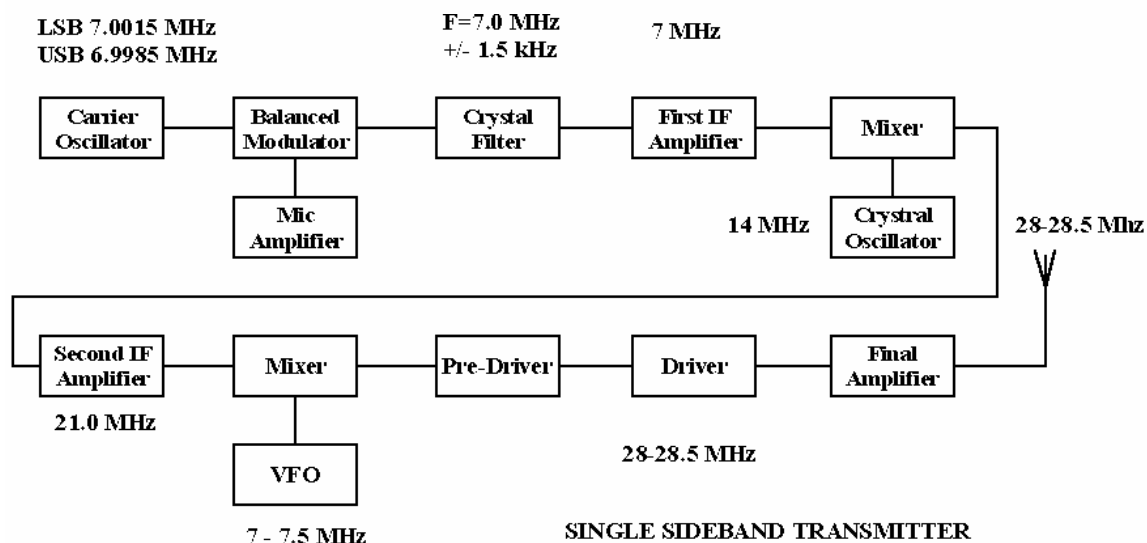

SINGLE SIDEBAND TRANSMITTER

Figure 4.

The block diagram of figure 4 is that of an SSB Transmitter (TX) which will operate between 28 to 28.5 MHz. The carrier oscillator produces the radio frequency voltage necessary to heterodyne with the modulating audio voltage in order to convert the audio signals to radio frequencies.

The carrier oscillator must be able to operate at two frequencies to enable switching between upper and lower sidebands, if this is required. The carrier oscillator frequency will determine which sideband will pass through the crystal filter (to be discussed). The crystal filter is a high selectivity bandpass filter. The carrier oscillator frequency will place one sideband inside the crystal filters passband. It is the crystal filter then that passes one sideband and rejects the other.

Bandpass filter – definition: A filter that passes a band of frequencies with minimum attenuation and rejects (attenuates) all others.

I have not shown a microphone connected to the microphone amplifier, of course there would be one.

Following the carrier oscillator and all other oscillators in the block diagram there would be buffer amplifiers (not shown) to prevent the carrier oscillator from being too heavily loaded - such loading could pull the oscillator off frequency.

The microphone amplifier increases the signal power from the microphone to the level required to obtain a satisfactory modulation percentage with the signal from the carrier oscillator.

Adjusting the power output of the microphone amplifier controls the percentage of modulation. This is a control on the front of the transmitter usually called 'mic gain'.

The RF and modulating AF signal voltages are fed to the balanced modulator. The fundamental requirement of the balanced modulator is to provide non-linearity to enable the process of modulation to take place. Balanced modulators have a second important characteristic that enables the original carrier frequency to be suppressed. The output of the balanced modulator then, will consist of two sidebands and a suppressed carrier. The carrier suppression should be typically at least 40 dB down from the sideband power.

The bandwidth of the crystal filter (bandpass filter) will only permit the passage of one sideband. Which sideband will pass through the filter is determined by which sideband is positioned on the centre frequency of the crystal filter. A typical crystal filter for this use will have a bandpass of about 2.8 kHz, which allows most of the sideband to pass through.

The purpose of both IF amplifiers is to simply amplify the required sideband as much as possible while maintaining the high selectivity in a narrow band system (SSB is narrow band).

In any communications system the greatest amplification is provided by the IF amplifiers. Amplification gains of 40-60 dB are typical, whereas power amplifiers usually have a gain of around 10dB. The IF amplifier can provide such high amplification gains because it is a fixed and sharply tuned amplifier.

A combination of a mixer and an oscillator provide the function of a frequency converter. Both mixers and their oscillators serve to position the required sideband on the output

frequency. Notice how the first mixer has an oscillator which is crystal controlled. This is possible since the conversion from the first IF frequency to the second IF frequency is always the same, requiring no adjustment of the first oscillator. The crystal oscillator also provides high frequency stability.

The variable frequency oscillator (VFO) connected to the second mixer enables adjustments to be made to the final transmit frequency. The VFO frequency should be low to obtain stability and is typically no more than 8 MHz. At higher frequencies, the LC components of the VFO would become so small as to make the frequency of oscillation very susceptible to external effects such as temperature variations.

In modern transmitters the VFO can be made to operate at higher frequencies while still maintaining stability - these designs employ the phased locked loop (PLL) system. With the PLL type VFO, the output of the transmitter is adjusted in discrete increments, typically as low as 10 Hz per step.

The chain consisting of the pre-driver, driver, and final amplifier uses only linear amplification. Their sole purpose is to raise the power level of the selected sideband with minimum distortion.

As the carrier and modulating audio were combined at an early low power stage, the SSB transmitter is by definition a low-level modulation system - so all amplification after the balanced modulator must be done with linear amplifiers. A feedback path between the final amplifier and the pre-driver marked could be drawn in as a line and marked 'ALC'. ALC stands for Automatic Level Control. Part of the RF signal arriving at the final amplifier is rectified and turned into a DC voltage, which is used to control the gain of an earlier stage - in this case, the pre-driver.

The purpose of ALC is to prevent the operator from over-modulating the transmitter. The higher the transmitter output, the higher the ALC voltage - this ensures lower gain in the preceding stage that the ALC voltage is applied to. ALC is a type of negative feedback that prevents the transmitter from being over-modulated.

If the transmitter were to be over modulated the linear amplifiers would become non-linear and further unwanted modulation and new frequencies would be created, causing out of channel interference. This out of channel interference is referred to as "splatter" (exam question).

MORE ON THE CARRIER OSCILLATOR OF AN SSB TX

As mentioned earlier, it is the carrier oscillator which determines on what range of frequencies each sideband ends up. If we want to transmit on the upper sideband, the carrier oscillator must place the upper sideband on the band of frequencies that will pass through the crystal filter. Likewise for lower sideband. So the carrier oscillator must be switchable between two frequencies and of course, crystal controlled for frequency stability.

The circuit of figure 5 is one of the best ways of switching the carrier oscillator and hence selecting the sideband to be used.

We have discussed oscillators earlier. Can you recognise what type of oscillator it is? The two capacitors C1 and C2 should give you the clue to the identification of this circuit. It's a

Colpitts crystal oscillator.

Forward biasing the appropriate diode achieves sideband switching. A positive potential connected to the anode of D1 will cause D1 to be forward biased, connecting the sideband crystal (X1) to the rest of the circuit.

In this circuit, D1 and D2 are acting as electronic switches. When a diode is forward biased, the switch is closed. Without bias, the switch is open. R1 limits the forward current drawn by the diodes to a safe value. The bias applied to the diodes would upset the operation of the N-channel FET if it were not for the DC blocking capacitor C3. R3 provides source bias for the FET.
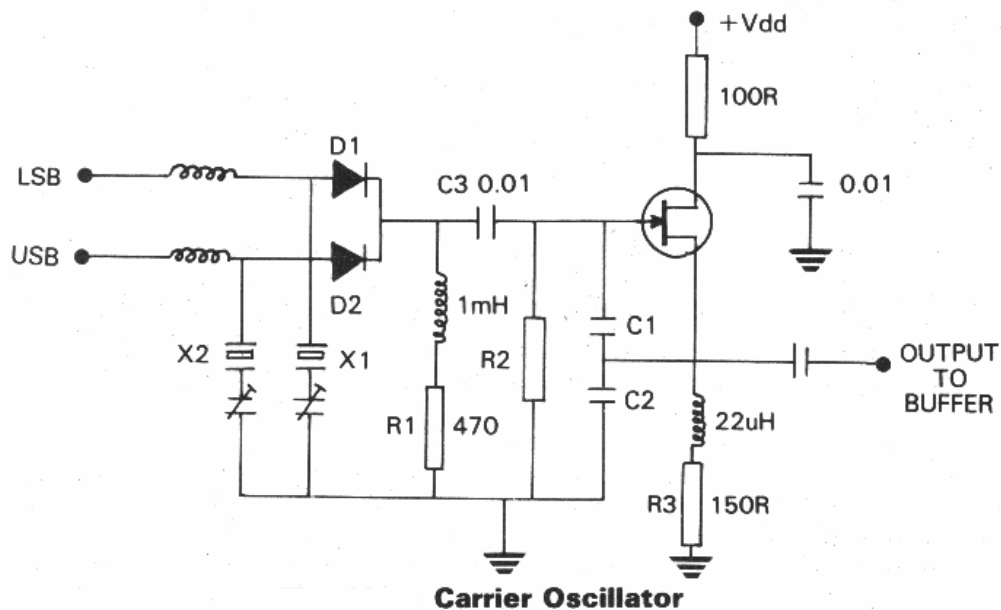

Carrier Oscillator

Figure 5.

You do *not* need to know this circuit for exam purposes, however you do need to be able to identify a Colpitts oscillator.

SSB RECEPTION

To finish off the topic of AM transmitters and receivers we need to look at two final things.

An SSB receiver is no more than a Superheterodyne receiver. The difference is that the demodulator is called a product detector, along with another oscillator (called a beat frequency oscillator –BFO)

Imagine receiving a single sideband signal like the one we created at the beginning of this reading. If the carrier were present as in a DSB full carrier signal, we would just have to feed the signal into a non-linear device. The carrier would mix with the sideband and one of the mixing products would be the demodulated audio.

When we just have a sideband in the receiver, we need to make the carrier in the receiver. We need to create the carrier in the receiver, on the frequency it would be on had it *not* been removed.

As you have seen, the sideband started as an audio frequency band of frequencies. It has been frequency converted. Moved through different IF stages, which involves changing

frequencies. There may be many frequency conversions between transmission and reception. The important thing to realise is that all of the individual audio frequency components are still in the same place relative to each other – and if the carrier had been transmitted, it would be there for us to use. The carrier is at the bottom of the upper sideband and the top of the lower sideband.

In an SSB receiver, we don't have a carrier so we need to make one. The oscillator that makes the carrier in an SSB receiver is called a BFO (Beat Frequency Oscillator) It's just an RF oscillator which reproduces the carrier. We feed the carrier and the sideband into a demodulator - and just to make life hard they call the demodulator in an SSB receiver a product detector. The output of the product detector is the demodulated audio.

An SSB receiver would also contain a crystal filter (sharp bandpass filter) on one of its IF frequencies, to obtain high selectivity.

So, look at your Superheterodyne diagram in an earlier reading. Add a crystal filter in the IF stage. Call the demodulator a product detector, and feed the carrier into the product detector from a BFO, and you have an SSB receiver.

The product detector and BFO are really just another mixer and oscillator forming a frequency conversion of the sideband from RF back to audio. This audio is the original transmitted audio.
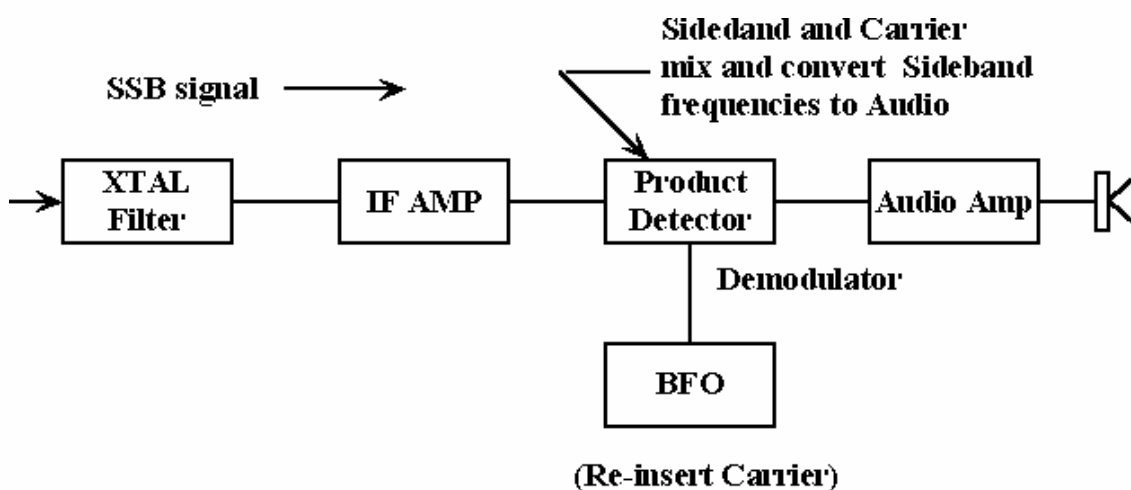

Figure 6.

THE DUAL ROLE OF BFO AND CARRIER OSCILLATOR IN SSB TRANSCEIVERS

In SSB transceivers (transmitter and receiver) it makes sense not to duplicate circuitry. In many transceivers the same oscillator is used for the BFO and carrier oscillator. So on transmit the oscillator is the carrier oscillator, and on receive it functions as a BFO.

AUTOMATIC GAIN CONTROL - IN ALL RECEIVERS

Automatic Gain Control (AGC) applies to all receivers, and not just for SSB. You are required to know what AGC is.

What ALC is to a transmitter, AGC is to a receiver.

Almost without exception all radio receivers whether AM, SSB or FM (FM - Frequency

Modulation - to be discussed), are superheterodyne. Review the block diagram of the superhet if you have forgotten it. The problem with receivers is that the signals they are receiving can vary enormously in strength. For example, one signal from one transmitting station could arrive at the receiver at a level of minus 120dBm (about 0.2 microvolts) and the operator may be in communication with another station whose signal arrives at minus 20 dBm. There is 100 dB difference between these two signals. Without AGC the stronger signal would either be too loud or completely overload the receiver causing distorted output. To receive the weaker signal the operator would probably have to adjust the receivers gain control. AGC does all of this for you.

A small amount of received signal from an early receiver stage is rectified and converted to DC. This DC voltage is then use to determine the gain of an IF stage in the receiver. Recall that most of the gain (amplification) in any receiver system occurs in the IF stages. Pretty simple eh! The AGC voltage determined by the strength of the received signal automatically adjusts the gain of the receiver.

That's about all you need to know about AGC for the exam. AGC can be a pain though. For example, suppose an amateur station is in contact with two stations, one of which is very strong and the other which is very weak. After the strong one has finished transmitting the AGC has made the gain of the receiver low, and if the weak station was to begin transmitting immediately, then he or she may not be heard for a while because the AGC has not acted fast enough to return the receiver to full gain.

For this reason, many transceivers (or receivers) have a switch for the AGC. This switch is usually marked slow, fast and off.

In the 'off' position the AGC is disabled. The 'fast' and 'slow' positions determine how fast the AGC returns the receiver to full gain. This gives the operator more control over the receiver. Slow, is handy when talking to a single station on SSB who pauses a lot during transmission. If the operator of an SSB transmitter pauses (to think perhaps), there is no sideband output. The receivers AGC could interpret this brief pause as an end of transmission, when it is not, and raise the gain of your receiver. When the transmitter station transmits (speaks) again, your receiver may be overloaded. Therefore, the 'slow' AGC position is useful here. The 'fast' AGC position is great for controlling a signal which is fading up and down.

That is AM transmission and reception completed. We will be discussing the operation of the crystal filter when we do filters. This is an important reading, though it does have a lot more in it than you will be examined on. I have tried to emphasise the important points, and more will be emphasised in the assignment for this reading. In addition, the conclusion on this course will be exam preparation covering all topics.