

# RF VISION. WHAT YOU ALWAYS WANTED TO KNOW, BUT DIDN'T KNOW WHO TO ASK! A TUTORIAL.

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The "Poor Man's Spectrum Analyzer" is designed to give you RF VISION. With RF VISION you will have a new monitoring mode, with rapid signal detection, modulation analysis, and band condition and activity information constantly available at your finger tips! This instrument will provide information and operating techniques that will add to your appreciation of the RF spectrum in ways you never thought possible before. As an educational tool, it will allow you to actually *SEE* the *Electronic Spectrum* in "real time". It will help you understand the real significance of sidebands, and help debunk the myth that "the amplitude of the carrier varies in AM, but not in FM". You will see that the exact *OPPOSITE* is true! More on that later.

What we are describing is an instrument that converts any 'scope from a *TIME DOMAIN* display into a *FREQUENCY DOMAIN* display. Spectrum Analyzers have been around as laboratory instruments for many years, ranging in price from \$4000 to \$50,000. What makes this one so special is it's simplicity and ultra low cost. The Spectrum Analyzer we will build consists of six individual modules. The addition of a seventh module (Tracking Generator) converts the Spectrum Analyzer into a powerful receiver system for stimulus-response measurements. More on that later.

## WHAT'S IT ALL ABOUT?

First, lets talk a bit about the "*Spectrum*". Radio, television, and radar transmitters are constantly radiating energy into our environment. This energy is called "electromagnetic radiation". Broadcast radio transmitters radiate energy in a band of frequencies ranging from approximately 500 to 1500 Kilohertz. Commercial FM transmitters operate in the 88 to 108 Megahertz band. Television and radar signals are located in the VHF, UHF and microwave bands. The basic difference between these transmitters is their frequency. If we continue to even higher frequencies, we get into the realm of infrared radiation. This band of frequencies are so high that we perceive them in the form of heat, even though they are a form of electromagnetic energy. Going even higher in frequency, we get into the area of light, starting with red light at lower end of the band, green at the center and violet at the upper end. Going a bit higher takes us into the ultraviolet range of frequencies. Energy in this range of frequencies becomes invisible again, but causes certain materials to fluoresce. Above ultraviolet frequencies are the X-Rays, Gamma Rays, etc. All are forms of electromagnetic radiation, with the basic difference being their frequency! Incidentally, all electromagnetic radiation travels at the speed of light.

Draw a horizontal line on a sheet of paper. Label it "*Frequency*". Mark the location of all the different signals we have discussed along it's length, with the

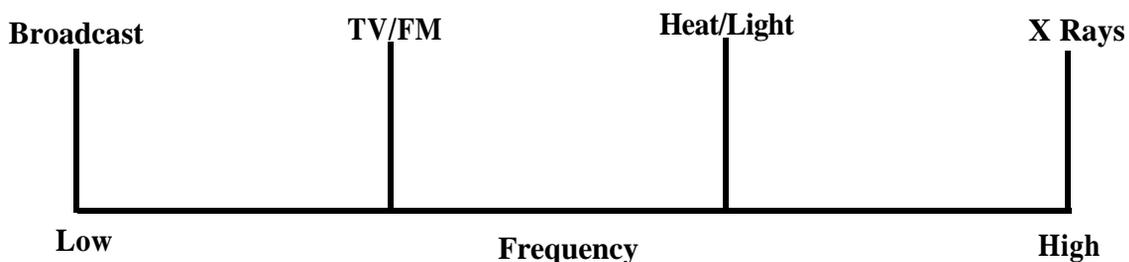


Fig.1

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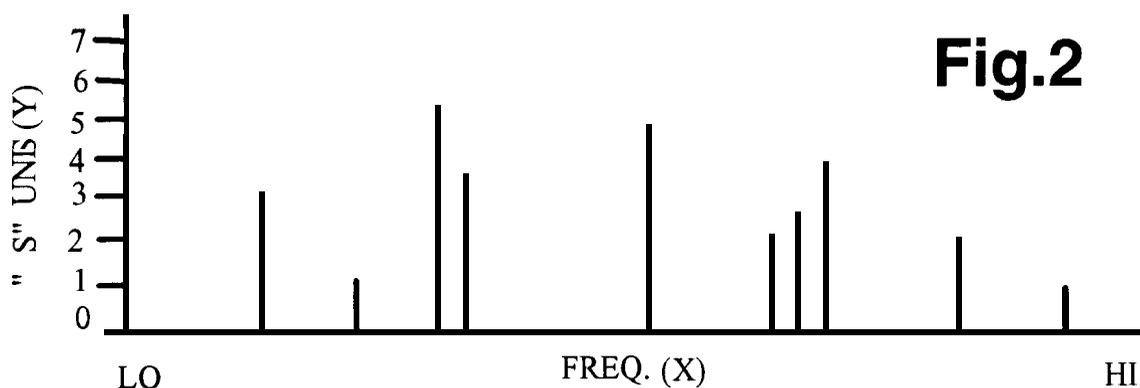
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Broadcast Band at the left (LO-Frequency) end and the X-Rays at the right (HI-Frequency) end. What we have drawn (Fig.1) is a simple representation of a major portion of the *ELECTROMAGNETIC SPECTRUM*.

There is another piece of the Frequency Spectrum, from 0 Hertz up to the Broadcast Band which we haven't mentioned. ("Zero" Hertz actually could be considered DC, if we assumed some energy present at 0 Hertz.) Most of these lower frequencies are not considered part of the Electromagnetic Spectrum, since they do not have the characteristics of Electromagnetic Radiation. For example, the 20 to 20,000 Hertz portion of this lower part of the spectrum is the audio band of frequencies. Since our analyzer is an *RF Spectrum Analyzer*, it operates in that part of the spectrum above the broadcast band and extending up through the UHF band. The transmitters in this range are pumping RF energy into their antennas. Electromagnetic waves radiate out from these antennas at the speed of light, 186,000 miles per second. As they pass a receiving antenna, they induce RF currents which are fed into a receiver. A resonant circuit in the receiver selects the signal from one of the transmitters, rejecting (hopefully) all the others.

We can't SEE any of the radio signals that are always around us, but we could use a radio receiver to HEAR them, one at a time. Or, we could use a TV receiver to see the images carried by the RF signals in the TV part of the spectrum. Imagine what we might see if we had a device that could look at all those signals at once, and display them lined up in a row, with the lowest frequency signals at the left! Each signal could be represented by a vertical line whose height would be directly proportional to its strength at our receiving location.

How could we develop such a display? Lets start with a receiver which covers the band we are interested in observing. We start by first tuning to the lowest frequency on the band and slowly tuning up in frequency. As we do this we monitor the signal strength readings on the "S" meter, recording the frequency and strength of every signal we receive as we go. Rather than list all the numbers, we'll use a sheet of



graph paper on which we have drawn a horizontal line across the bottom. This line (the X axis) should be marked "**frequency**", with the lowest frequency we will be tuning on the left, and the highest on the right. Each square above the line would be marked in "**S**" units, starting with 0 on the base line and increasing as we go up. These readings

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on the Y axis will represent received signal strength. Now, as we tune across the band, draw a vertical line, starting from the horizontal base line at the location corresponding to the frequency at which the signal was found, and rising vertically as many units as the "S" meter indicates. When we have completed this task, we will have drawn a display of a section of the RF spectrum showing all of the signals received and their relative strengths (Fig.2). Now, if we could replace this tedious, manual procedure with an all electronic, continuous display on a CRT, we would have a basic Spectrum Analyzer.

Most commercial spectrum analyzers have a built-in 'scope to display the spectrum. The Spectrum Analyzer we will build will work with ANY 'scope, since it's

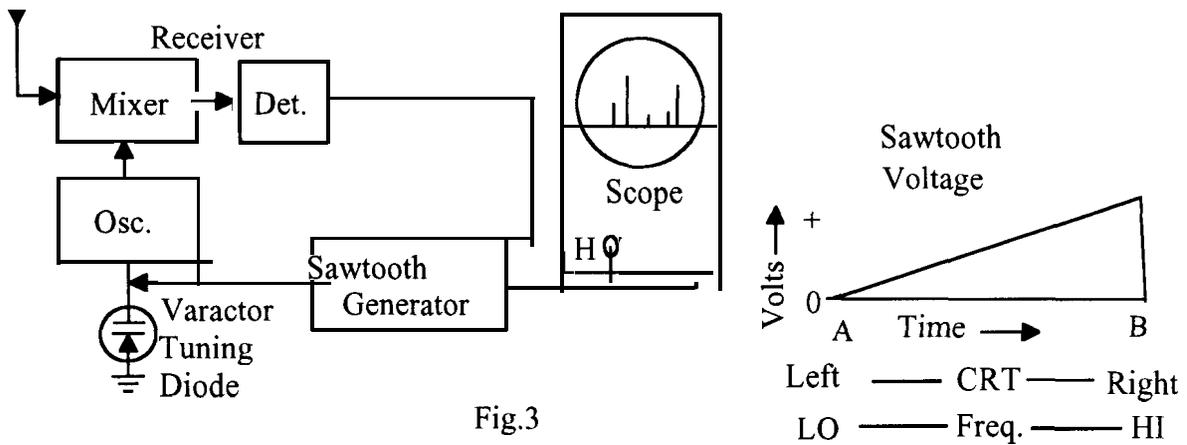


Fig.3

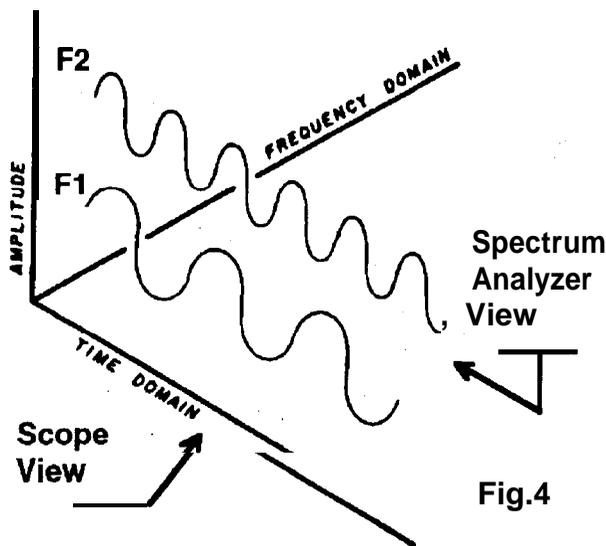
output signals are in the audio range of frequencies. The analyzer itself is an electronically tuned superhetrodyne radio receiver, similar to a scanner, except that the tuning is continuous, rather than in steps. An electronically tuned receiver uses varactor diodes (voltage variable capacitors) in place of mechanically variable capacitors to tune across the band. A sawtooth voltage is applied to the varactor tuning diodes. As this tuning voltage increases in amplitude (Fig.3), it causes the receiver to tune across the band. This same sawtooth voltage is also applied to the horizontal input of the 'scope. This causes the electron beam in the CRT to trace a horizontal line across the screen, from left to right. Let's assume that we are tuning from 50 to 100 MHz. When the sawtooth tuning voltage is at it's lowest level (point A), the receiver will be tuned to 50 MHz. At the same time, the horizontal sweep on the 'scope will be at the extreme left side of the CRT. As the sawtooth voltage increases in amplitude, the receiver tunes to a higher frequency and the beam in the CRT moves across the screen from left to right. When the sawtooth voltage reaches it's maximum amplitude (point B), the receiver will be tuned to 100 MHz and the 'scope beam will be at the extreme right hand side of the CRT. Therefore, the instantaneous horizontal position of the electron beam is always directly related to the frequency being tuned by the receiver. The horizontal axis now represents FREQUENCY, rather than TIME, as in the conventional 'scope application.

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At the same time, the "S" meter output of the receiver is applied to the vertical input of the 'scope. As the receiver tunes up across the band, the beam of the CRT moves from left to right in synchronism. When a signal is received, the beam is also deflected vertically, tracing a vertical line whose height is proportional to the received signal strength. When the sawtooth voltage reaches it's maximum value, the receiver is tuned to it's highest frequency and the CRT beam is at the extreme right. The sawtooth voltage then drops rapidly to it's lowest value, tuning the receiver back to it's lowest frequency and snapping the CRT beam back to the left hand side. This process is repeated continuously, updating the display so that any changes appear instantly. Since the vertical deflection corresponds to received signal strength, and the horizontal deflection corresponds to frequency, the resulting display is instantaneous signal strength versus frequency. The conventional scope is said to be operating in the "The Domain" while the Spectrum analyzer operates in the "Frequency Domain".

## COMPARING THE FREQUENCY AND TIME DOMAINS.

Now that we have seen how the basic spectrum analyzer uses the 'scope, lets delve a bit deeper into the difference between the conventional 'scope display and the spectrum analyzer 'scope display. If we visualize the spectrum as being 3-dimensional,



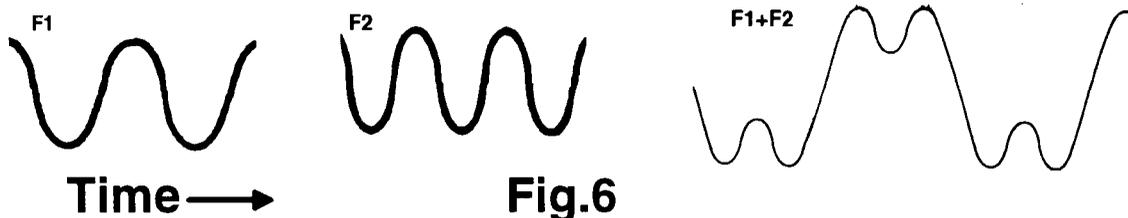
(Fig.4) the difference becomes immediately apparent. This 3-dimensional drawing combines the 3 axis we have been discussing, into one illustration. In the conventional 'scope display, the horizontal (X) axis represents "Time" and the vertical (Y) axis represents "Amplitude". The third axis, "Frequency" would not be visible since it is positioned 90 degrees relative to the other two, which would have it running from the front of the CRT back into the 'scope.

All electrical waveforms or signals are composed of a combination of sinusoidal signals of varying amplitudes and frequencies. We can look at these signals in the *TIME* domain with a

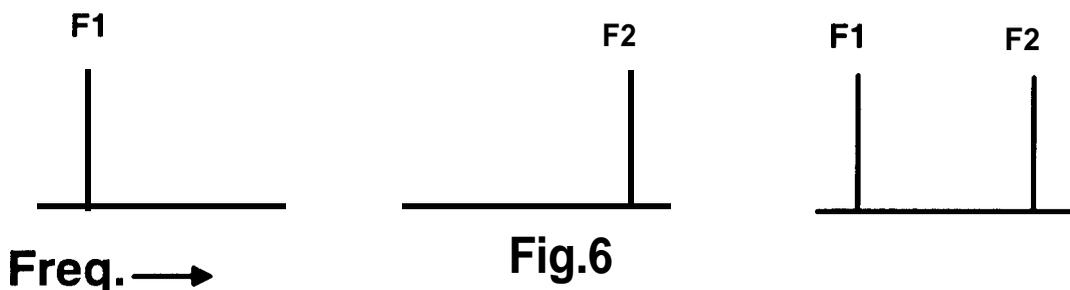
conventional 'scope, or in the *FREQUENCY* domain with a Spectrum Analyzer. The conventional scope lets us see the amplitude and shape of the signal with respect to time. The Spectrum Analyzer on the other hand, lets us see the amplitudes and frequencies of the various discrete sine wave signals that make up the more or less complex waveform displayed by the conventional 'scope.

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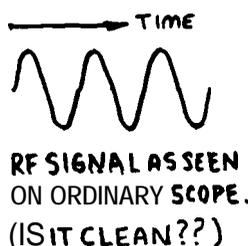
Lets look at a simple example. F1 represents a sine wave signal. If it were the only signal applied to the vertical input of the 'scope, all we would see would be the sinewave F1 on the CRT display. If F1 were replaced by F2 (a higher frequency sine wave), we would see more cycles of the sine wave, since more of them would occur in



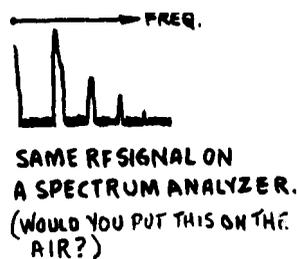
the same period of time that it would take the CRT beam to move from left to right. The conventional 'scope has no difficulty displaying single signals. However, it does have a problem when more than one signal is applied to the vertical input at a time. Instead of displaying each individual signal, the 'scope adds them all together and displays the instantaneous algebraic sum of all of the signals present. Fig.5 illustrates the three different displays we have just discussed.



Now, lets see how the spectrum analyzer would display these same three signals. Since the spectrum analyzer's horizontal axis represents "Frequency", rather than "Time", we would see the three displays illustrated in Fig.6. Both the "Frequency" and



**Fig.7A**



**Fig.7B**

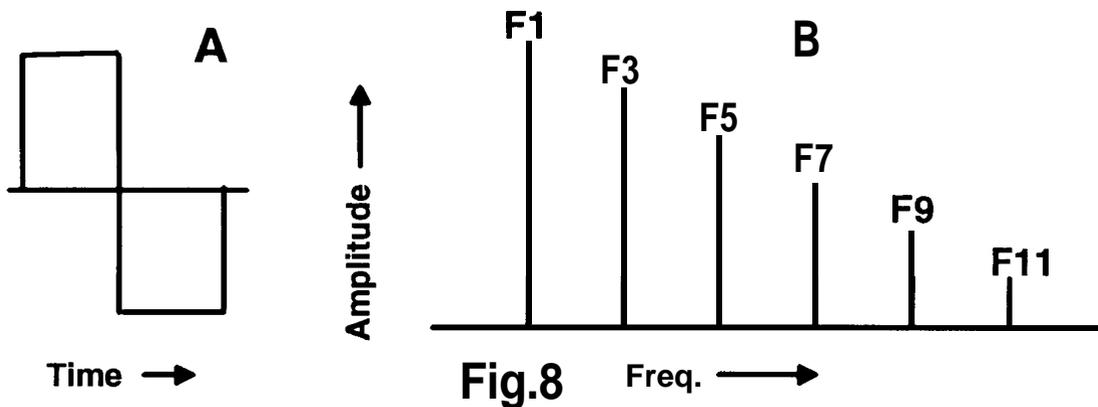
"Amplitude" relationships are very clearly visible. If the horizontal ("Frequency") axis were calibrated, not only could we tell that there are two distinct sine wave signals present, but also their relative signal strengths and absolute frequencies!

Another comparison illustrates the power of the spectrum analyzer display. Fig.7A shows us a typical signal that we might see on a conventional 'scope display.

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It looks like a “perfect” sine wave. However, looking at the same signal on the spectrum analyzer display Fig.7B tells us a lot more about this “perfect” sine wave. It reveals the fact that this almost “perfect” sine wave is slightly distorted! Something that was completely invisible in the conventional ‘scope display. The large vertical component off to the left is the fundamental component of the sine wave. The two smaller vertical lines show that there is a measurable amount of harmonic distortion present in the almost “perfect” sine wave. Those two components represent the amount of second and third harmonics of the fundamental sine wave. A measurement of the harmonic amplitudes relative to the amplitude of the fundamental is a measure of the percentage of harmonic distortion.



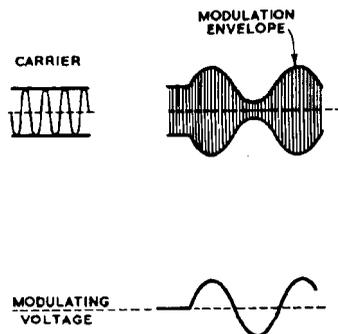
The second example (Fig.8A) shows a square wave displayed on the conventional ‘scope. Look at the dramatically different display (Fig.8B) of the same signal when viewed by the Spectrum Analyzer! Now we can see the “fundamental” sine wave at the same frequency as the square wave, plus the other decreasing amplitude signals that make up a square wave. These other frequencies are the 3rd, 5th, 7th, etc. (odd) harmonics of the fundamental frequency.

## SIDEBANDS, ETC.

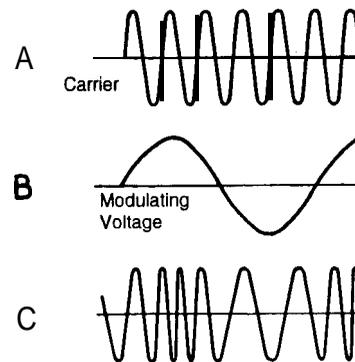
Now that we can appreciate the significance of the 3 dimensional characteristics of electrical signals and know how to look at them in both the TIME and FREQUENCY domains, lets explode a few common myths!

We were always taught that the “carrier” frequency in AM radio carries the “intelligence” (audio, video, etc.) when it is modulated. Right? **WRONG!** It was also explained to us that the “carrier varies in amplitude when it is modulated” in AM radio. Right? **WRONG!** We were also told that in FM radio, the “carrier varies in frequency when it is modulated, and not in amplitude, as in AM radio”. Right? **WRONG!**

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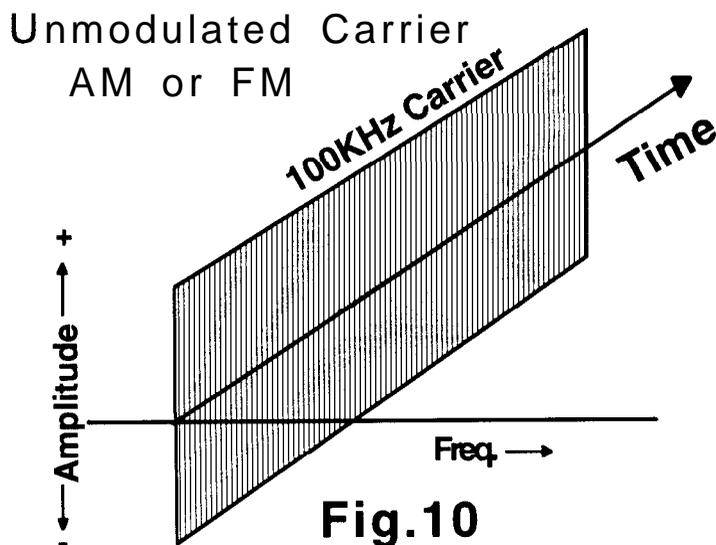


**Fig.9A**



**Fig.9B**

Fig.9A (amplitude modulated carrier) and 9B (frequency modulated carrier) illustrate the typical textbook drawings that help to perpetuate these popular myths. Both carriers are being modulated by a single, continuous audio tone. Technically, these illustrations are correct, but they neglect to point out that this is what a conventional TIME DOMAIN 'scope would display if either of these 2 signals were applied to it's vertical input. Remember what happens if more than one signal is applied to the vertical input of a conventional 'scope? It shows us the instantaneous SUM of all of the signals being applied! Unfortunately, we can't see the 3rd (FREQUENCY) axis. We can only see the X and Y (AMPLITUDE & TIME) axis, so we can't see the different frequencies that are present.

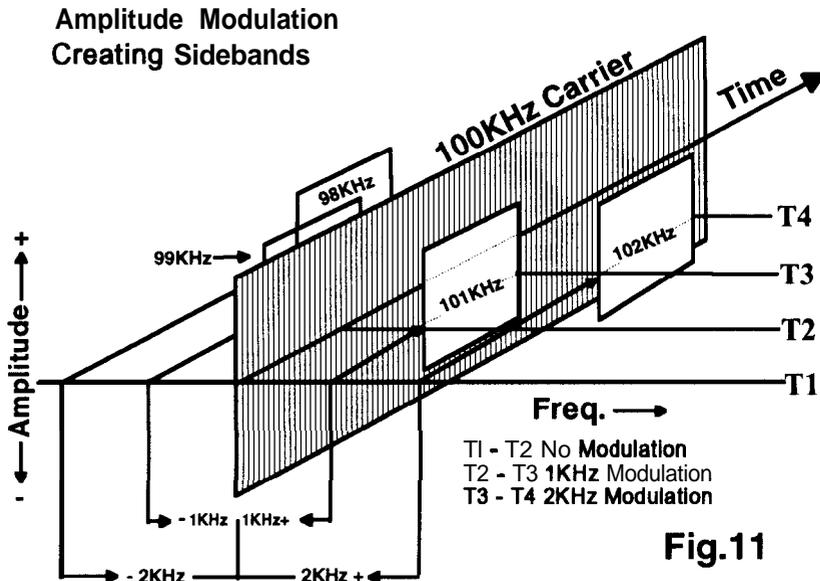


## BACK TO THE DRAWING BOARD.

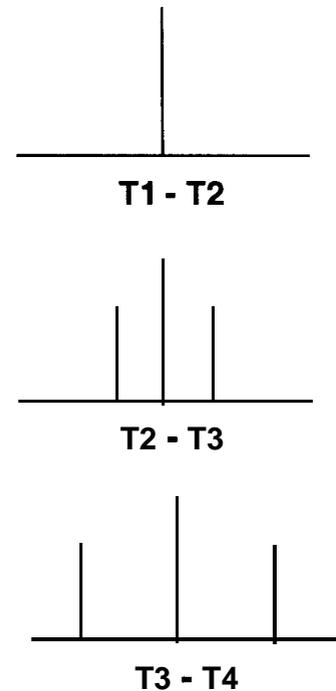
Since we don't have access to a 3-dimensional display, we will revert back to our 3-dimensional drawings which will show us what is actually happening. Fig. 10 shows us an unmodulated carrier. It is a single frequency, crystal controlled, continuous amplitude sine wave. We will assume our transmitter is operating on a carrier frequency of 100 KHz. Before it is

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modulated, we can't tell whether it is an AM or an FM transmitter. They would both look alike.



## Spectrum Analyzer Displays



Now lets see what happens when we *AMPLITUDE* modulate this carrier. In Fig.1 1 we have divided the *TIME* axis into four equal *TIME* intervals, T1 thru T4. The carrier is left unmodulated for a period of time equal to the interval from T1 to T2, as indicated on the *TIME* axis. For this period there is no change in the *AMPLITUDE* or *FREQUENCY* of the 1 00KHz carrier. Now we will modulate the carrier with a continuous.1 ,000 Hz audio tone for the time period from T2 to T3. This 3-dimensional illustration now shows us what *ACTUALLY* takes place when an AM transmitter is modulated! The 1,000 Hz audio creates a pair of *SIDEBANDS*, one 1,000 Hz above the carrier, and another 1,000 Hz below the carrier. Notice that the "carrier" signal at 100 KHz hasn't changed a bit, either in frequency or amplitude! The only change that has occurred has been the addition of the 2 sidebands. Let's change the frequency of the audio tone that is modulating the carrier from 1,000 Hz to 2,000 Hz. The time interval from T3 to T4 shows us the result. Again, we see that the carrier hasn't changed in amplitude or frequency. The only thing that has changed is the distance between the 2 sidebands and the carrier. They are now 2,000 Hz above and below the carrier.

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From this we can see that modulating a carrier in AM radio *DOES NOT VARY THE AMPLITUDE OF THE CARRIER!* Instead, the effect of modulation is to *CREATE SIDEBANDS! NO MODULATION, NO SIDEBANDS.*

So far, so good. But, how often do we transmit a single tone? Other than during tests of the Emergency Broadcast System, not too often. Then, what happens when we transmit voice or music, or even TV pictures? These are relatively complex modulating

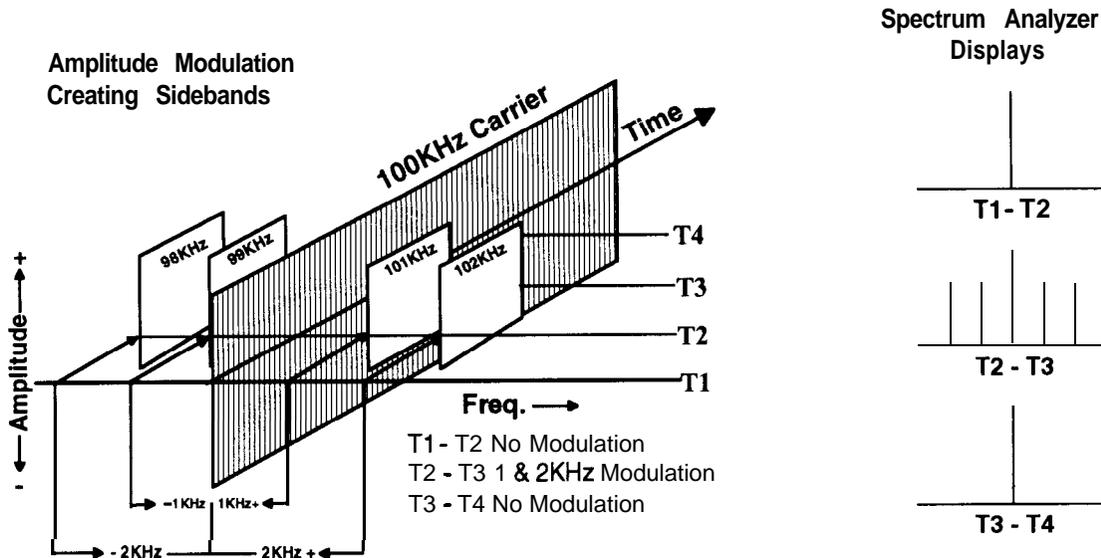


Fig.1 2

signals. However, as we have previously said, all complex waveforms are actually made up of many individual pure sine waves. For every one of the many individual sine waves that make up the most complex waveform, the AM modulation process will create a unique pair of sidebands, one above and one below the carrier, spaced away from the carrier on the frequency axis by a distance equal to it's individual sine wave frequency. Fig.12 above illustrates what happens when two (or more) tones modulate the carrier at the same time.

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## ANOTHER LOOK AT THE TEXTBOOK MYTHS.

Further in our study of AM radio we are taught that detection (demodulation) simply consists of rectifying the “varying amplitude carrier” and filtering out the “half wave” pulses, as in Fig.13. Sounds so simple and plausible. However, if our new

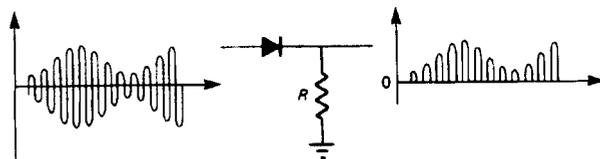


Fig.1 3

understanding of what is actually happening is true, and if the carrier *NEVER* really varies in amplitude, then how DOES the diode detector work? As a matter of fact, if we were to reduce the receiver's bandwidth to a point where only the carrier frequency would reach the diode detector, we would find that the output of the detector would be a steady DC voltage whose amplitude would only be a measure of the strength of the received signal. Since the sidebands were eliminated by the reduced bandwidth, none of the audio that originally modulated the carrier would be recovered! More on this later.

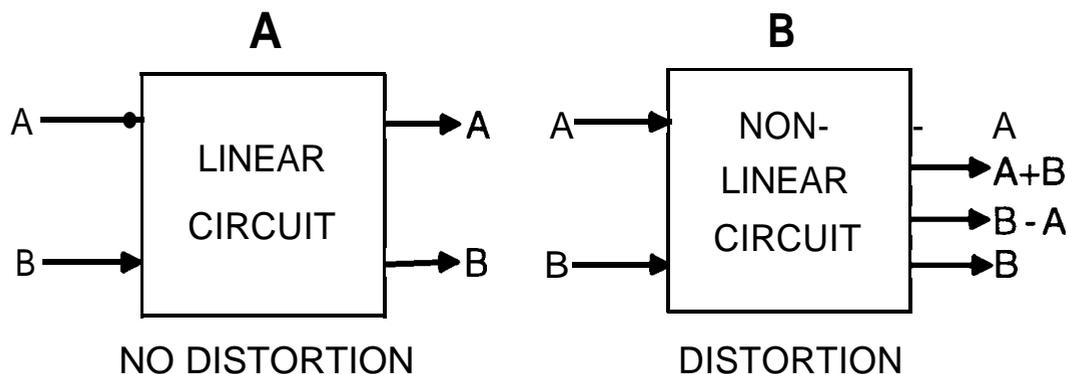
## DISTORTION, IS IT GOOD OR BAD?

Let's step back a bit and see if we can gain a better understanding of what is happening, and while we are at it, explode another myth. DISTORTION is always BAD. Right? **WRONG!** You mean there are times when DISTORTION is GOOD? Yup! As a matter of fact, without distortion, neither our transmitters, nor our receivers would work. Remember the “almost perfect” sine wave we talked about earlier? It looked perfect on the conventional 'scope, but when we looked at it with the Spectrum Analyzer we found that it was slightly distorted, and that the distortion showed up as additional sine waves, harmonics of the fundamental frequency. If we could clean up the distortion, the harmonics would disappear. It's this ability to create new frequencies when signals distort that makes it possible to modulate and demodulate, as well as do many other useful chores in electronic circuits.

When we are shopping for HI-FI audio equipment, we look for amplifiers with the lowest distortion figures we can find. We don't want the equipment to add new frequencies that were not intended by the performers. We want the circuits to operate in the most LINEAR fashion. Any non-linearity produces distortion products, which are new frequencies. If we apply two frequencies (A and B) to the input of a linear circuit (Fig.14A), we would only see those same two frequencies in it's output. However, if we were to apply those same two frequencies to the input of a non-linear circuit (Fig.14B), we would find that in addition to the two input signals A and B, two new frequencies...

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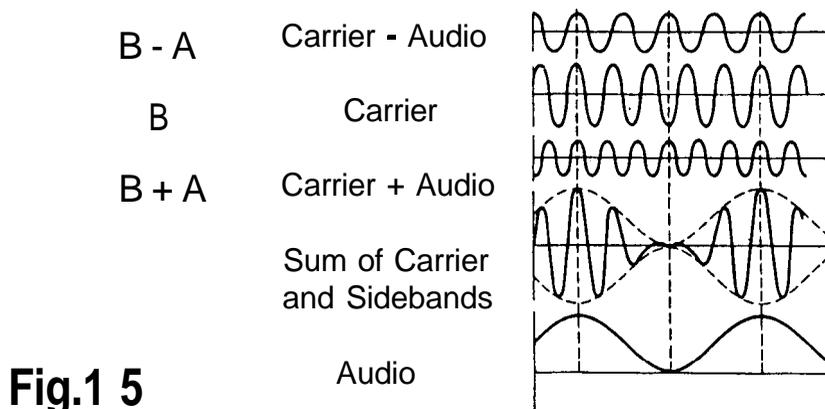
**Fig.1 4**

their sum ( $A+B$ ) and their difference ( $A-B$ ). This is what Modulators, Demodulators, Mixers, Detectors, Frequency Multipliers, Converters, etc. all have in common. They all create DISTORTION. If they didn't, they wouldn't work!

Let's substitute some numbers for A and B in Fig.14. If A is an audio frequency (1 KHz) and B is an RF frequency (100 KHz), then their sum ( $A+B$ ) would be 101 KHz, and their difference ( $B-A$ ) 99 KHz. If B was an AM carrier and A was the audio frequency modulating that carrier, then  $A+B$  would be the upper sideband (101 KHz) and  $B-A$  (99 KHz) would be the lower sideband, and the non-linear circuit that accomplished this miracle, would be called a "Modulator". One element is missing to make the circuit operate properly. Notice that we have 4 output signals. All but one are RF signals. "A" is the original audio signal that produced the sidebands, but is unwanted in the output of the transmitter's modulator. Let's add an LC circuit tuned to 100 KHz at the output of the modulator. This tuned RF circuit has enough bandwidth to pass the 3 RF signals, but looks like a short circuit to ground for the audio signal. All we have left is the carrier, plus it's two sidebands. Remove the audio signal (A) from the input to the circuit, and audio signal (A), the sum signal ( $A+B$ ) and difference signal ( $B-A$ ) disappear. All that remains is signal (B), the carrier. Without audio to modulate the carrier, no sidebands would be created. All that is left is a "dumb" carrier without any "intelligence".

If the output of Fig.14B was viewed on a 'scope, we would see the traditional textbook illustration of what appears to be the carrier varying in amplitude. Fig.15 illustrates the three components,  $B - A$  (Carrier minus Audio), B (Carrier) and  $B + A$  (Carrier + Audio) whose instantaneous amplitudes are added together and displayed on the 'scope. The three vertical dotted lines illustrate clearly how the instantaneous amplitude and phase of the three components, when added together affect the instantaneous TOTAL POWER of the overall signal. The first (leftmost) vertical line occurs at a time when all three components are at maximum amplitude and in phase. The resulting sum of the carrier and sidebands is then at maximum. The next vertical line occurs at a time when all three components are also at maximum, BUT the carrier is 180 degrees out of phase! At this point, the sum of the power in the sidebands

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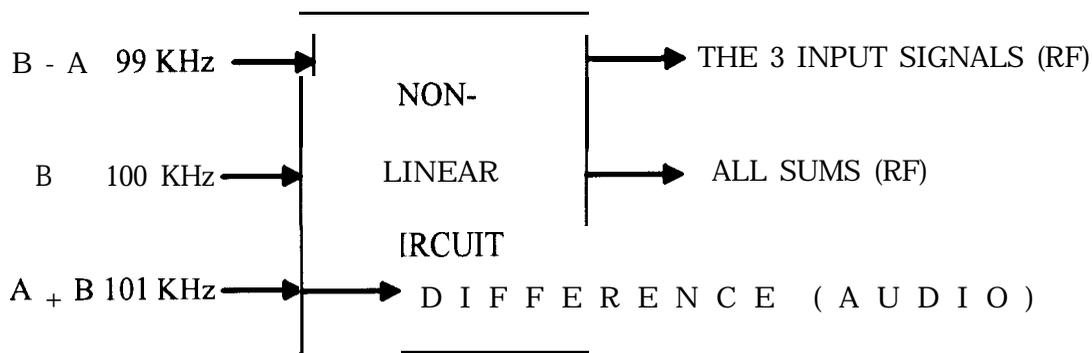


**Fig.1 5**

equals the power of the carrier, resulting in almost 100% power cancellation. This is typical of the condition of 100% modulation. The third vertical line again occurs at a time when all three components are at maximum and in phase, producing maximum total power.

## DEMODULATORS

Demodulators reverse the process of the Modulators. Referring back to Fig.1 4B, we saw how two signals into a non-linear device (the Modulator) produced SUM and DIFFERENCE signals in the output. If we were to now take those same three signals and put them into another, similar non-linear device, we would find this process repeated, except that we would be starting with three input signals instead of two. The distortion now produces a new set of SUM and DIFFERENCE signals (Fig.1 6 above).



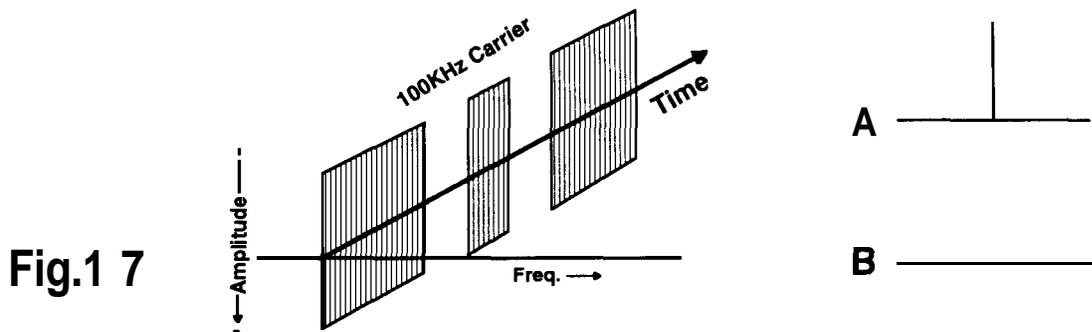
**Fig.1 6**

Since all of the input signals (Carrier and Sidebands) are RF signals, their sums would also be RF signals. However, their differences would be audio, equal to the spacing in

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frequency between the carrier and it's sidebands. In a receiver's detector (demodulator), it's this "difference" signal that we are interested in, since it represents the original audio signal that was input into the non-linear (modulator) stage at the transmitter. Diodes are commonly used as detectors in AM receivers. It can function as a detector (demodulator) because it is a non-linear device. Referring back to our diode detector circuit in Fig.13, the simple addition of a capacitor across the resistor **R** shorts out all of the RF signals (the 3 input signals plus the sums) but appears as an open circuit to the recovered audio (difference) frequency.

**A QUESTION AND AN OBSERVATION:** Since the AM carrier NEVER varies in AMPLITUDE, how can it "carry" intelligence? It's the frequency relationship between the carrier and it's sidebands that "carries" the intelligence. That's what makes DSB (Double Sideband) and SSB (Single Sideband), etc. possible.



The simplest method of transmitting intelligence by radio uses ICW (Interrupted Continuous Wave) transmission. A carrier signal is keyed on and off (Fig.17) in a pre-arranged manner (Morse code or Digital, etc.). In this system, the intelligence is actually "carried" by the carrier. There are no sidebands carrying the intelligence, as illustrated by the Spectrum Analyzer displays in A and B. (Strictly speaking, for the "purists", some sideband energy may be generated by the abrupt on-off transitions). This type of transmitter doesn't even have a modulator stage. All of the transmitter's output energy is concentrated in the carrier, instead of being spread out over a much wider segment of the spectrum. This increase in system efficiency accounts for the widespread use of this mode in amateur radio DX (long distance) communication. Since the signal occupies such a narrow part of the spectrum, the receiver's bandwidth can be reduced to substantially improve the signal-to-noise ratio as well as it's sensitivity. This improved selectivity also makes the receiver more immune to interference from adjacent signals and noise.

Since this type of transmitter does not send sidebands, a receiver with a simple diode detector could not recover any audio tones to help us listen to it's signal. All we would hear would be "thumps" as each burst of RF was received. However, if we were to add a signal (in the receiver) 1 KHz above or below the received signal, it would act

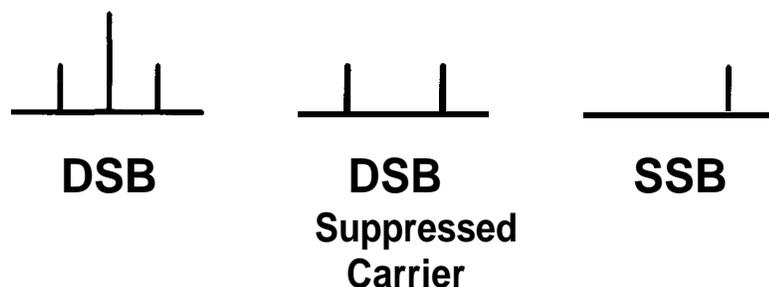
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as a sideband. The diode (or any other non-linear circuit) would produce a 1 KHz difference signal which we would hear every time the carrier was being received! This locally generated RF signal is produced by the BFO (Beat Frequency Oscillator) in a communications receiver. As we adjust the frequency of the BFO, we are moving it closer to, or further away from the received carrier, resulting in a varying tone that is exactly equal to the difference between it (the BFO) and the received carrier. This gives us a very efficient system, in terms of spectrum utilization. All the transmitted energy is used to get the signal from point A to point B. No energy is wasted in signals that will only be used as a REFERENCE in the receiver to recover the transmitted intelligence, as in the previously discussed DSB (Double Sideband) signal.

Looking back at the conventional AM DSB system, think about how wasteful it really is. We have learned that the carrier doesn't carry any intelligence, and it uses up most of the transmitter's power. The intelligence is in the sidebands by virtue of it's frequency relationship to the carrier. If all we need the carrier for at the receiver is to be able to determine it's frequency relationship to it's sidebands, why can't we use a locally generated signal (as with the ICW signal) to replace the carrier in the receiver? Turns out that we can. If we suppress the carrier at the transmitter and only transmit the sidebands, a locally generated signal inserted ahead of the non-linear circuit (detector/demodulator) provides us with the reference needed to recover the audio (difference) signal.

Since each of the sideband pairs (upper and lower sidebands for each modulating frequency) carry the same intelligence, why transmit both? Good question. Suppressing one set of sidebands (SSB), either upper or lower, further reduces the transmitter power, as well as reducing the amount of spectrum needed to half of the original bandwidth.



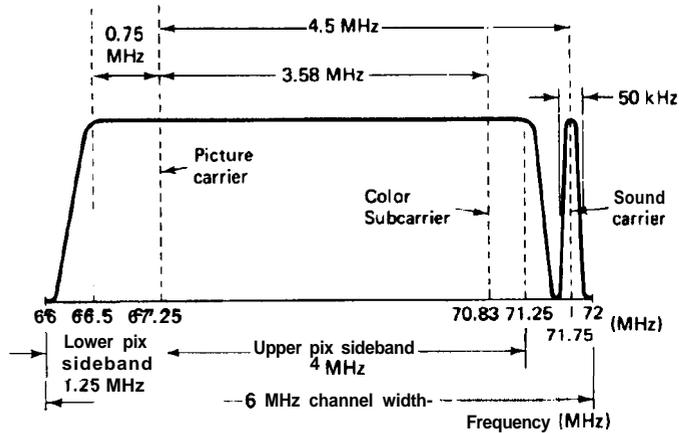
**Fig.1 8**

Fig.1 8 above illustrates the Spectrum Analyzer view of the three systems, full DSB (Double Sideband), DSB (Suppressed Carrier), and SSB (Single Sideband).

A further variation of AM Single Sideband is the Vestigial Sideband system used to transmit commercial TV. The video (picture) signal is transmitted using amplitude

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modulation and contains frequency components up to approximately four megahertz. Conventional AM modulation would produce sidebands extending up to four megahertz above and four megahertz below the carrier, occupying a total of EIGHT megahertz of spectrum! Then there is the audio signal, using frequency modulation, which requires some additional spectrum space. Realizing that the upper and lower sets of sidebands were mirror images of each other, the developers of the system elected to eliminate



**Fig. 19**

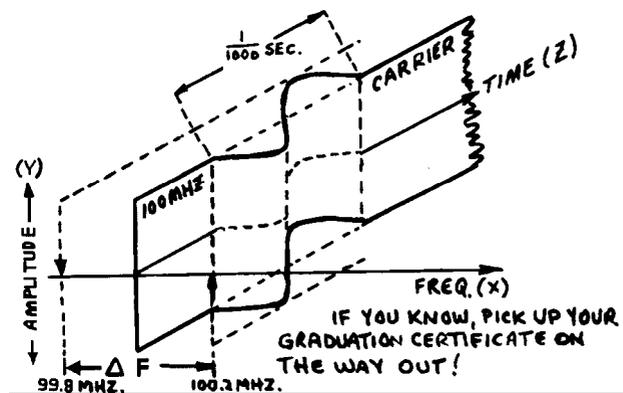
one set of sidebands to conserve transmitter power and spectrum. Designing a filter to produce a sharp cutoff (square corners) without introducing phase shifts was an impossible task, so a compromise solution was adopted. The filter was designed so that it was flat from 0.75 MHz below the picture carrier (lower sideband) to 4.0 MHz above it (upper sideband). It then allows 0.5 MHz more of the lower sideband, plus 0.2 MHz

more of the upper sideband to pass before it drops to zero. Allowing a "vestige" (part of) the lower sideband to pass, creates a *Vestigial Sideband* system. Instead of occupying almost 10 megahertz of spectrum (including the FM sound signals), all of the intelligence of the TV signal fits into a 6 megahertz slot..

Now that we know all about sidebands in 3-D, can you tell me what Fig.20 illustrates?

And, if you liked this tutorial, drop me a line and I will continue it in Volume 2.

Murray, WA2PZO



**Fig.20**