Radio FUNdamentals

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THINGS TO LEARN, PROJECTS TO BUILD, AND GEAR TO USE

Intermodulation Distortion (Or Why Does Big Mouth Take Up Half The Band?)

You have all heard Big Mouth, I'm sure. He's got a loud signal with plenty of speech processing. You can hear kids yelling in the background, the sound of passing cars, and other miscellaneous loud noises. When he stops speaking (if he ever does), your S-meter hangs at about half signal strength, buoyed up by the background racket, which sounds like a wind tunnel. Big Mouth is happy. He has lots of processing and he knows his signal is LOUD.

Well . . . perhaps. The "all-knobs-to-the-right" syndrome will probably never be eliminated from the amateur bands. More audio, more processing, that's the way to a big signal! Let the listener beware!

This may be an ego trip for Big Mouth, but he is a headache to the other unfortunate occupants of the band. His signal is unpleasant to listen to. In addition to the raspy, noisy audio, Big Mouth has splatter ("buckshot") on his signal that spreads out on both sides, making life miserable for amateurs operating near his frequency.

Big Mouth doesn't know (or doesn't care) that all SSB transmitters have an overload point. Operating beyond this point won't make the signal louder or more readable. It just takes up more space on the dial and actually wastes useful power in the splatter!

Observing The Transmitter With A Spectrum Analyzer

Transmitter overload by Big Mouth produces intermodulation distortion (IMD). This noxious form of distortion is created whenever a complex signal (such as the voice, which is composed of many audio tones) overloads an amplifier or mixer stage of a transmitter. A CW signal, on the other hand, is a single-frequency entity and does not create IMD (fig. 1). This is a representation of an unkeyed CW signal viewed in the frequency domain. The X-axis represents frequency; the Y-axis represents signal amplitude. The signal is constant at 14.2 MHz.

To display the frequency domain requires a device that can discriminate between frequencies while measuring the power level at each one. The spectrum analyzer is one instrument that will accomplish this. Simply, it is a receiver coupled to an oscilloscope. A block diagram of a basic analyzer is shown in fig. 2. It consists of a highly selective (narrow passband) receiver which is electronically tuned in frequency by means of a sawtooth voltage applied to the horizontal deflection plates of the cathode ray tube. A plot of frequency versus amplitude is displayed. The screen of the analyzer is calibrated to provide meaningful information. In this case, the vertical plot (Y-axis) represents watts output of the transmitter and the horizontal plot (X-axis) represents frequency in kHz. The picture is of a 100 watt CW signal viewed over a span of 10 kHz.

In real life the analyzer picture of a CW carrier is a bit more complex than the idealized representation of fig. 1. Photo A shows the CW signal of a popular 100 watt transceiver, as seen on a spectrum analyzer. Each horizontal division represents 1 kHz, so the picture displays 10 kHz (left to right) centered on 14.2 MHz. The vertical divisions represent amplitude.

The picture tells us a lot about this signal. Note that close in to the carrier, at the base of the plot, the trace widens out before it drops into the background noise.

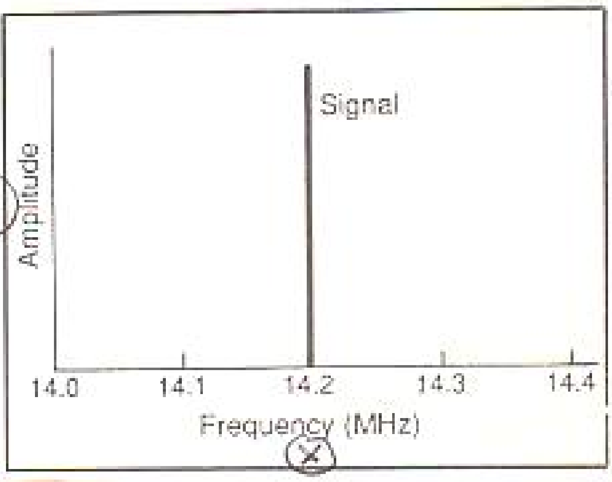

Fig. 1– An unkeyed CW signal viewed in the frequency domain. The X-axis represents frequency; the Y-axis is amplitude (signal strength). The signal is constant at 14.2 MHz.

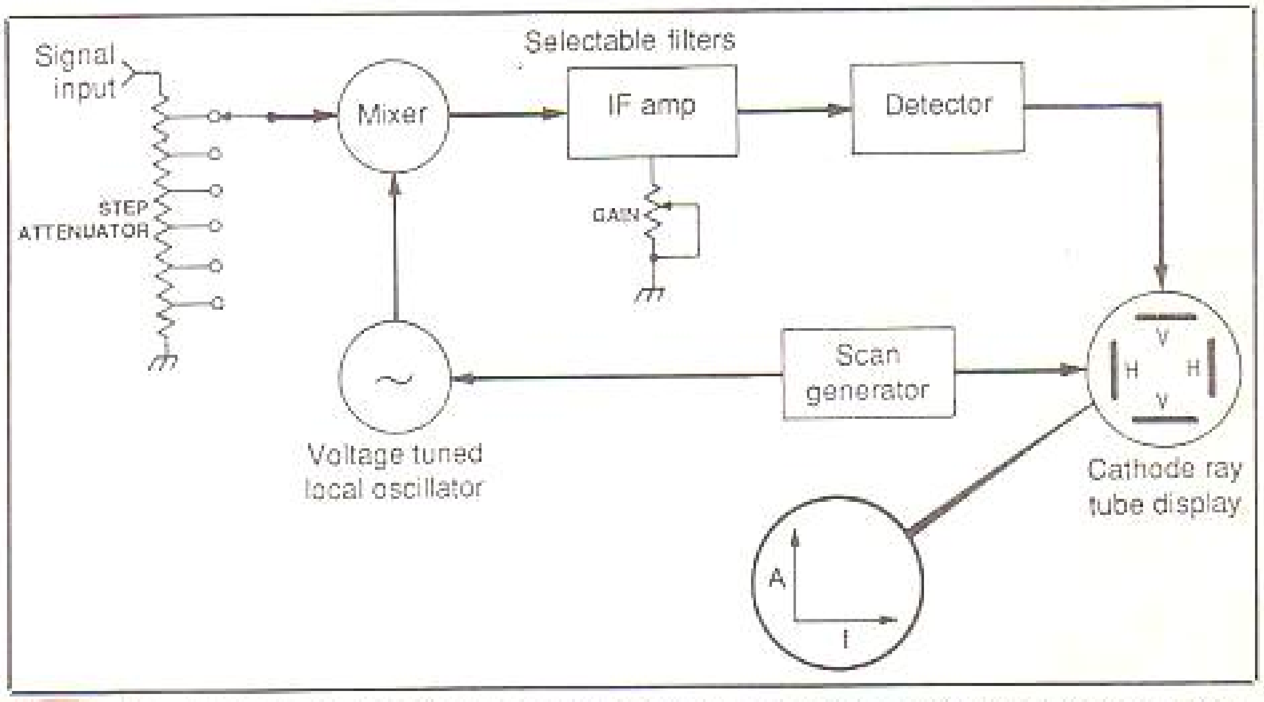

Fig. 2– Block diagram of a simple spectrum analyzer. It is a highly selective receiver coupled to an oscilloscope. The input signal is attenuated to the proper level and mixed to an intermediate frequency. The IF amplifier has adjustable gain and a selection of narrow-band filters. The receiver's local oscillator is electronically swept in frequency by a sawtooth control wave created in the scan generator. Output of the detector is applied to the vertical deflection plates of a cathode-ray tube while the sweep signal is applied to the horizontal plates. A frequency vs. amplitude plot is displayed.

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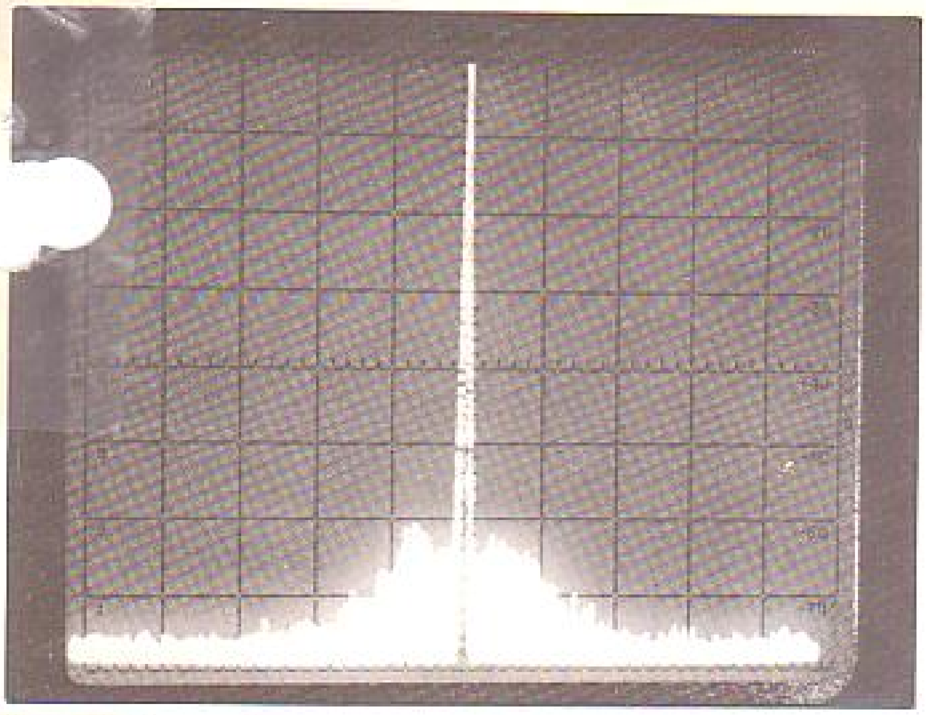


Photo A– An analyzer picture of the signal represented in fig. 1. Each horizontal division represents one kiloHertz; the vertical divisions represent signal amplitude. Notice the broadening of the signal at the base. This represents "white noise" generated by the transmitter. It can be heard as a hiss on each side of the signal, dropping into the background noise about 2 kHz each side of the signal.

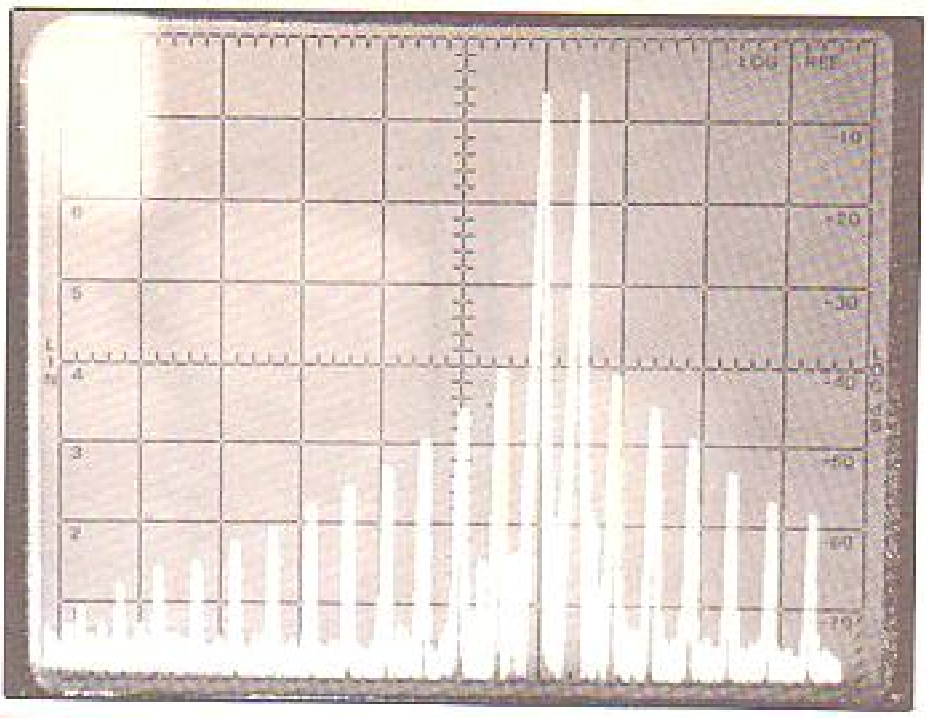


Photo B– A representation of a modern transceiver incorporating RF feedback. The third-order products are down 34 dB below the two tones, and the higher order products are reduced accordingly. Nearby amateurs would still notice close-in hash from intermodulation distortion. Commercial exciters (costing ten times as much) can better this condition by 20 to 40 dB across the passband.

This broadening represents "white noise" on the signal. The noise is generated in the mixing and amplifying circuits of the transceiver. It is the job of the designer of the equipment to reduce this noxious product to a minimum. In this case the noise drops into the background about 2 kHz from the carrier. This is a rather "clean" signal. Nearby operators can hear the white noise as a rushing sound close to the carrier that follows the transmitter keying. Older transceivers often have white-noise sidebands that spread out over the whole band, driving nearby amateurs crazy.

To make matters worse, some receivers generate white noise when overloaded. This makes it risky to accuse a nearby amateur of clogging you up with white noise, when it may be your receiver that is generating the problem!

Viewing an SSB Signal

The spectrum analyzer is a valuable tool for examining an SSB signal. The amount of intermodulation distortion can clearly be seen on the screen of the analyzer as spurious signals. A perfect SSB signal does not exist; all transmitters have some degree of IMD. The goal is to hold IMD to the lowest possible level.

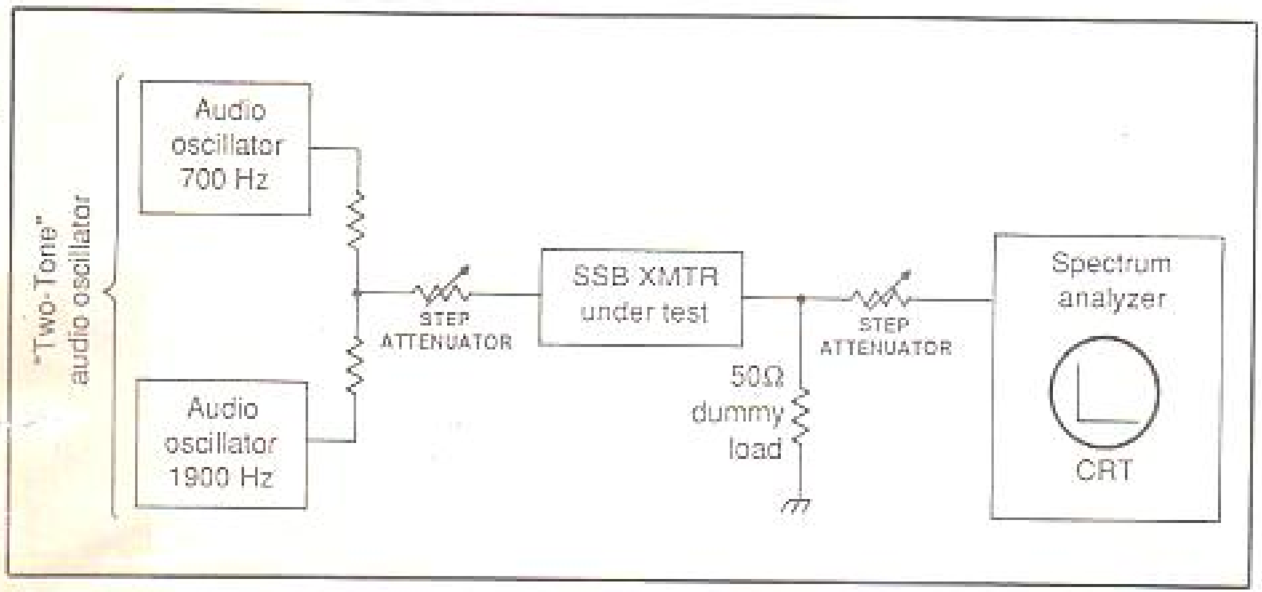
In a nutshell, this is how a transmitter is tested for IMD. Let's look at some of the details. Fig. 3 shows a simplified block diagram of a test setup for analyzing an SSB signal. The industry-standard audio test signal is composed of two equal amplitude tones. (One tone is insufficient to produce IMD. More than two tones result in so many intermodulation products that analysis is confusing. I'll spare you the ugly mathematics that relate the intermodulation products to the audio tones.)

Any two audio tones that pass through the filter system of the transmitter are satisfactory; many experimenters use 700 Hz and 1900 Hz. In any event, the tones should not be harmonically related.

Two-tone audio generators are not complicated, and several small transistorized models have been shown in various publications and handbooks. The requirements of the generator are that the tones are isolated from each other (the generators do not "see" each other) and that they have very low distortion products.

Analyzer Presentation

The easiest test signal is to say "hello, test" into the microphone. But since individual voices vary and it is not easy to maintain a constant audio level and view the voice in a meaningful way on the analyzer, the standard two-tone test signal is employed. If there is no IMD in the transmitter, the output signal is a replica of the two tones, raised to the carrier frequency of the transmitter (fig. 4). This is a representation of a commercial SSB transmitter, driven by a two-tone RF signal; the tones are separated by 2 kHz. The test signal is created by using a combination of 3000 Hz and 5000 Hz audio tones introduced into the microphone jack of the transmitter. The transmitter suppressed carrier frequency is 14,200 kHz. Upper



Fi[illegible]· Diagram of the test setup for analyzing an SSB signal. Two standard audio signals are injected into the transmitter via the mic jack. Level of the tones is set to provide the desired transmitter power output. The transmitter is operated into a dummy load and a small sample is injected into the analyzer. If the transmitter is perfect, the analyzer will show a true representation of the two tones in the frequency domain.

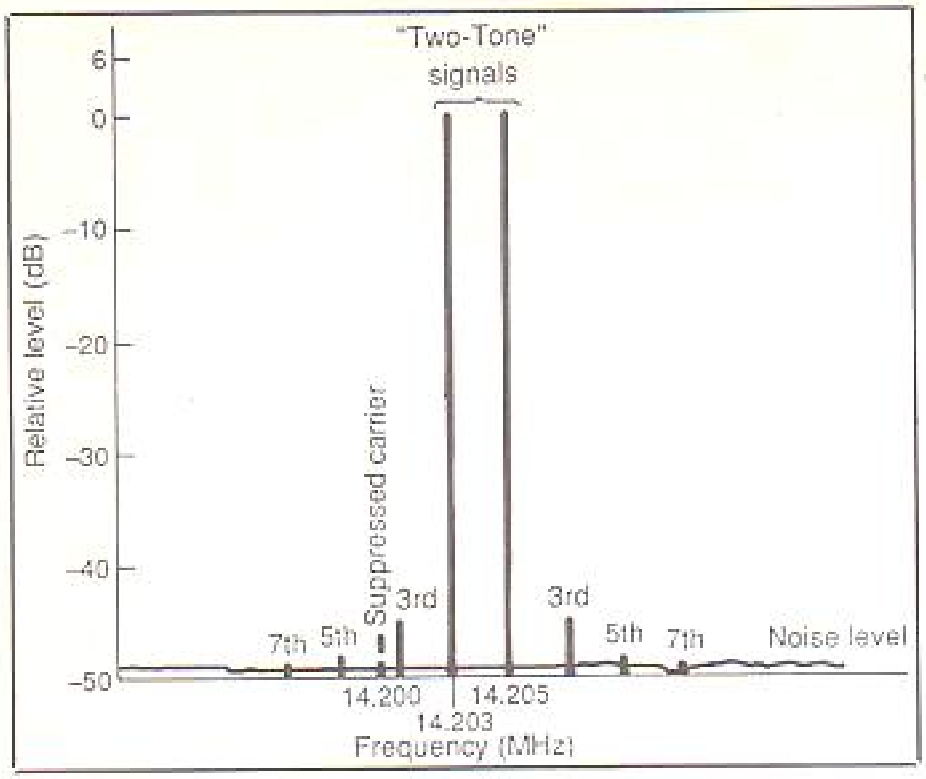


Fig. 4– *An analyzer presentation of a transmitter driven by a two-tone signal. The two tones are shown as separate RF signals (upper sideband). The suppressed carrier (down 45 dB from the level of the tones) is shown, plus the intermodulation products (spurious signals) of the tones. The unwanted products are caused by transmitter nonlinearity and fall symmetrically each side of the test signals. The third-order products are suppressed 45 dB below the test tones, and the fifth-order products are "down" 48 dB. The seventh-order products are so weak they are almost in the background noise. Higher order products (ninth, eleventh, etc.) cannot be observed in this test.*

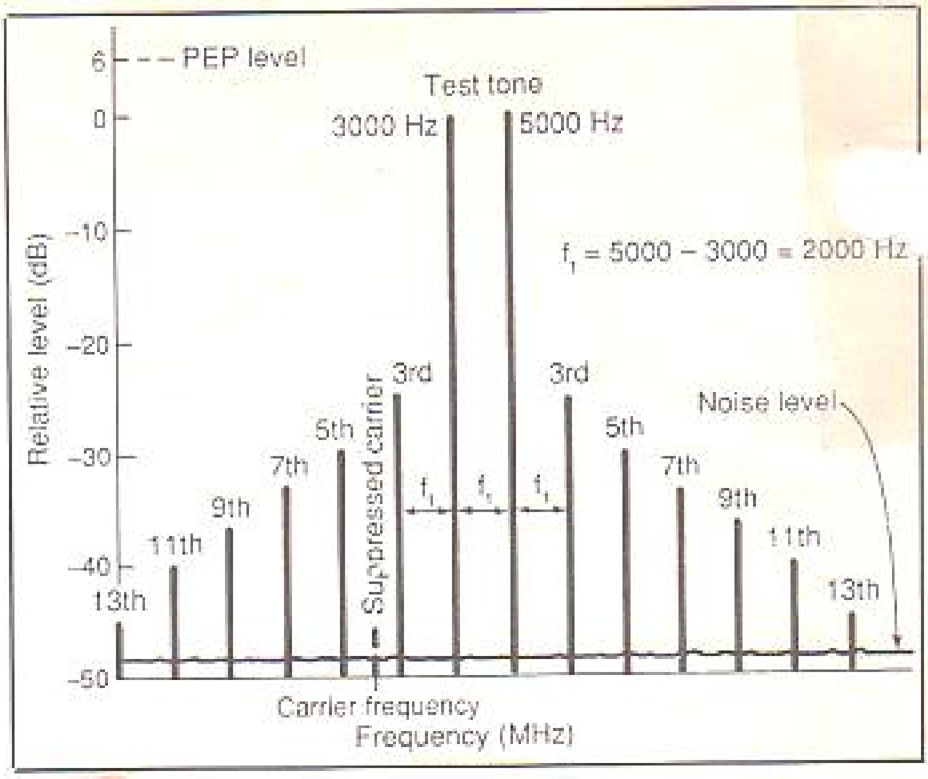


Fig. 5– *A representation of a typical 100 watt SSB signal (USB). The two test tones are 2000 Hz apart, so the spurious odd-order products are also 2000 Hz (2 kHz) apart. The thirteenth-order products are down only 45 dB from the two tones. They are about 12 kHz away from the tones. If the received signal of this transmitter is 20 dB over S-9, the thirteenth-order products could easily be heard by nearby amateurs, and the signal would have "splatter" over a 28 to 30 kHz range! This example is representative of many of the transmitters on the air today.*

sideband is used, and the resulting RF signals are at 14,203 kHz and 14,205 kHz. The separation between the RF signals is 2 kHz, just as in the case of the audio signals.

In real life the analyzer picture may be complicated. If the transmitter has IMD, is out of adjustment (too much drive or too little loading), undesired signals (spurious products) are generated which are within the transmitter passband or very near to the transmitted signal. A representation of a two-tone test signal showing transmitter IMD is shown in fig. 5. A number of spurious frequency pairs are visible. The pairs adjacent to the test signal are called third-order distortion products; the next outer pair are fifth-order products spaced equally outsic third-order pair; the next pair are sev order; and so on. They are so-named because of their mathematical relationship to each other. Many of the spurious products are so small in amplitude they may be ignored in amateur practice. A photo of a well-behaved, 100 watt transmitter is shown in photo B. The third-order prod-

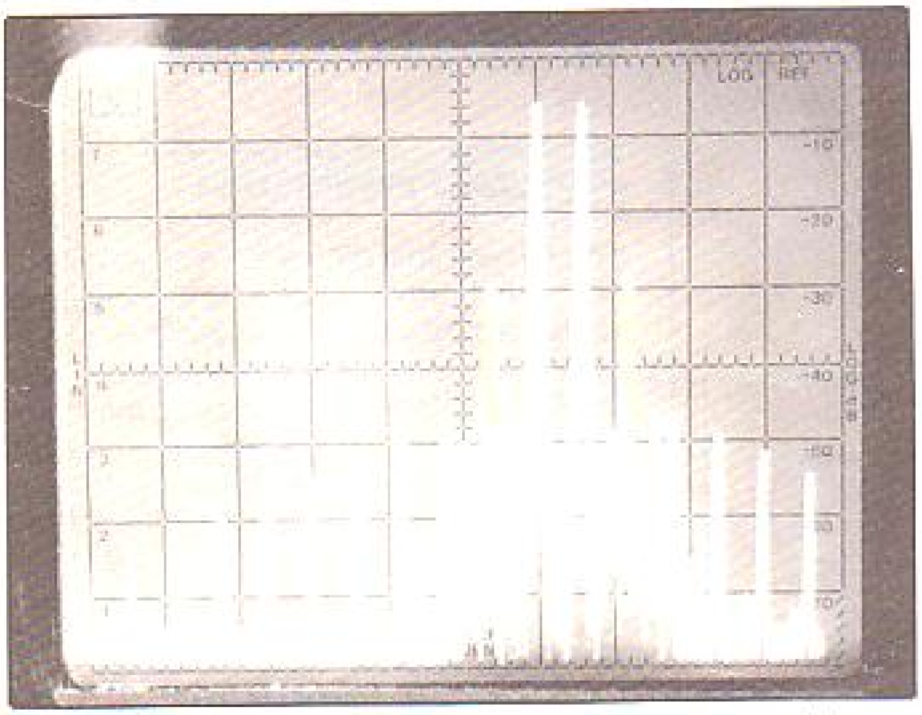


Photo C– *Spectrum analyzer photo of 100 watt transmitter operating with speech compression. Close-in intermodulation products rise. Other mixing products, close to the two-tone signal, can be seen. These are caused by the compression, and when voice is transmitted it tends to be harsh and raspy.*

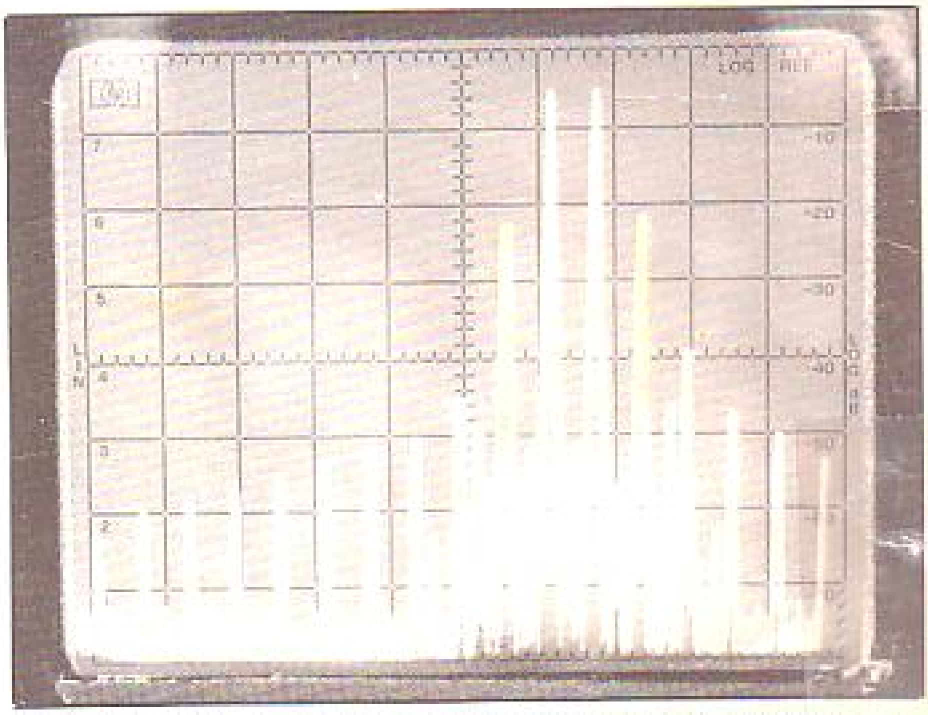


Photo D– *A high level of compression boosts close-in inter ulation products and increases spurious products. Too audio gain, too much compression combine to distort the v and broaden the signal. (All photos courtesy of W6GNX and taken on a Hewlett-Packard 141-T analyzer.)*

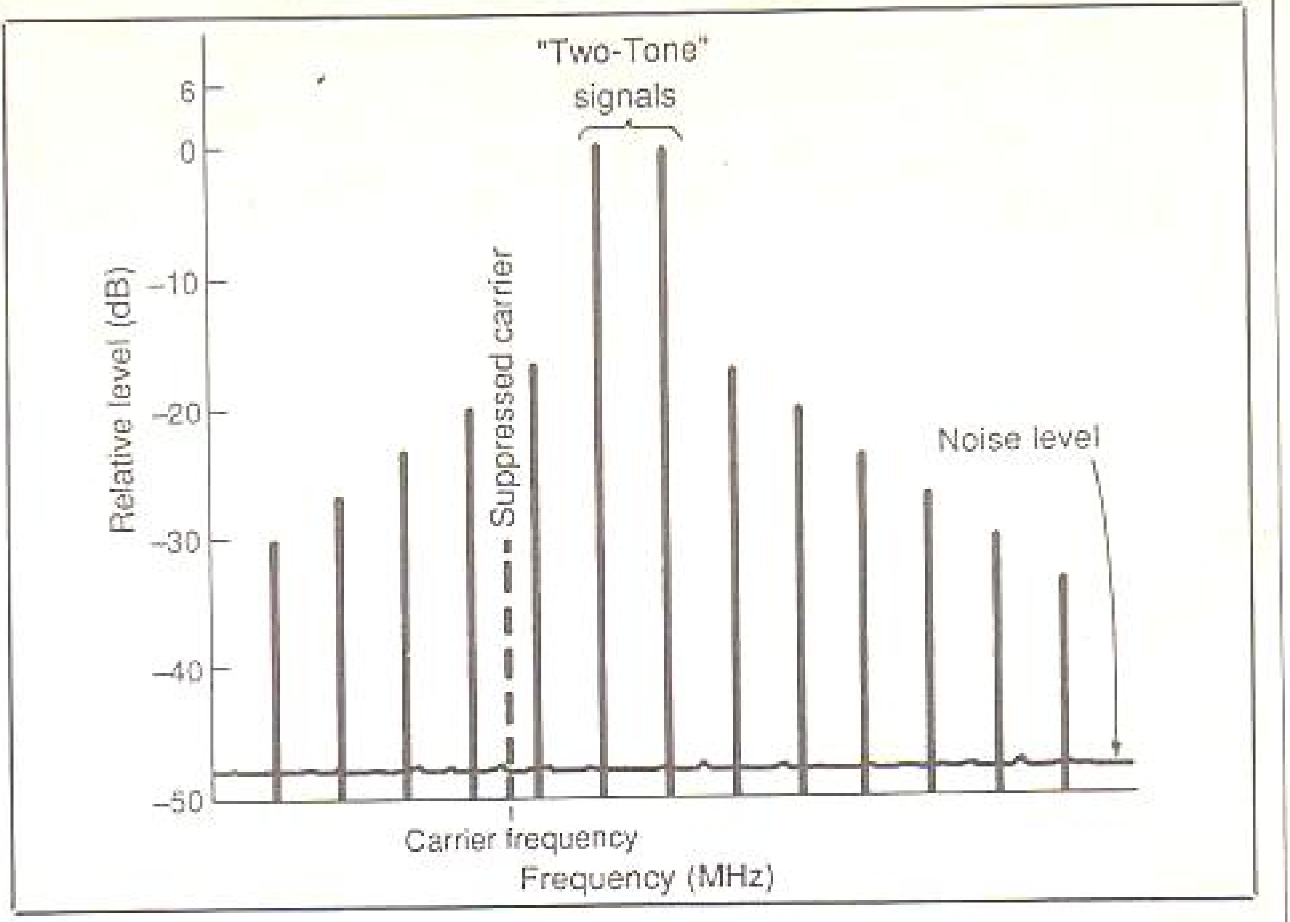


Fig. 6– An older transmitter using sweep tubes with no RF feedback. Intermodulation products are high and carrier suppression is poor. Improperly loaded, or over-driven, this transmitter can disrupt nearby frequencies for miles around.

ucts (those nearest to the two-tone test signal) are reduced 34 dB below the tones. The fifth-order products are down 40 dB. The higher order products drop off gradually until they drop into the noise at about 68 dB below the level of the two tones.

(In passing it should be noted that as the transmitter power is divided between the two tones, the PEP level is 6 dB above that of the tones. The top of the screen, therefore, represents the PEP level.) Older transceivers, especially those using sweep tubes and no RF feedback, present a bleak picture (fig. 6). This represents a transmitter with a pair of 6LQ6s in the amplifier. Note the high level of IMD products! A well-trained ear does not need a spectrum analyzer to pick out one of these transmitters, especially when it is being driven hard, with a lot of speech processing!

Regardless of the type of transceiver, by using a spectrum analyzer the operator can adjust the transmitter for best IMD performance, holding the two tones at constant amplitude and checking the amplitude of the odd-order products. (In some cases, the adjustment is merely turning down the audio gain or processing control!)

Photo C shows a transmitter operating with a small amount of speech compression. Power output is held at 100 watts PEP. Note that the third-order IMD products have risen 10 dB, as compared to those in photo B. Other mixing products close to the two tones have also risen, and the result is that the observer notices distortion in the transmitted signal. If a voice were used instead of the test signal, it would sound raspy.

Photo D shows a high level of compression. Third-order products are only about 16 dB below the two tones. A voice signal would sound "rough" with this amount of speech processing. Note that the higher order products have risen by about 6 dB, as compared to no compression. No doubt local amateurs will notice the difference in terms of close-in splatter. Even a modern transceiver, as good as it is, cannot withstand the effects of overdriving. Too much audio gain, combined with excessive processing, produces the results shown in fig. 6. This is a picture of why Big Mouth sounds so bad!

The cure is simple. If Big Mouth turns down his gain, his transceiver is not overloaded. If he turns down his processing, the higher-order intermodulation products quickly drop to tolerable levels. The problem is to convince him to do these simple cures!

Checking for IMD With Your Receiver

It is nice to have a spectrum analyzer, and this subject will be discussed later. However, if you have a modern transceiver, you can investigate the IMD of a received signal by just flipping sidebands, watching your S-meter, and simultaneously listening to the distortion products falling in the opposite sideband.

As an example, my good friend W6GNX has a Kenwood TS-950SD transceiver incorporating digital signal pro-