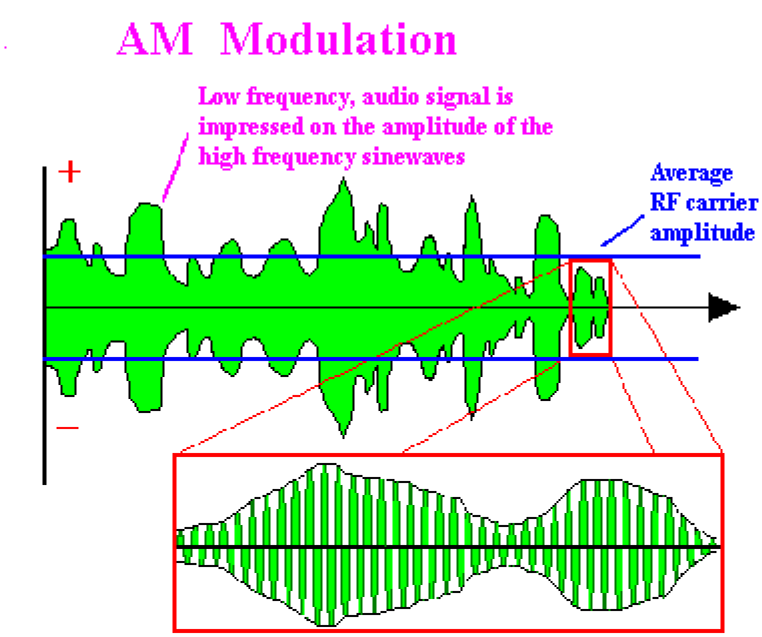
CRYSTAL SETS TO SIDEBAND

Chapter 16
ANCIENT MODULATION
And other topics

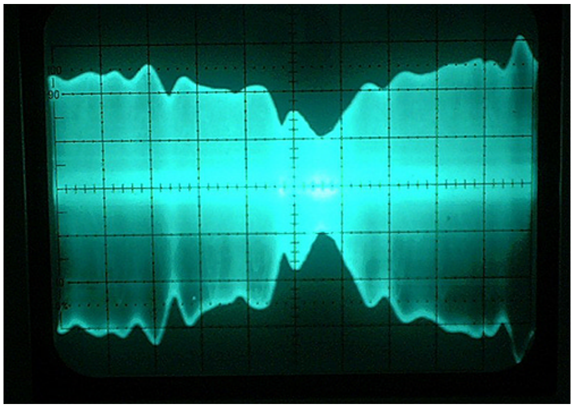
When I got back into ham radio 9 years ago, my ham friends told me that amplitude modulation (AM) was extinct. I was under the impression that SSB was the only mode of HF phone permitted. Later I learned that AM isn't actually illegal and there are a few diehards using AM on the 75 and 10 meter phone bands. I've also heard AM stations on 15 and 160 meters. In short, you might find a use for it. Besides, it's an interesting challenge to AM-modulate a transistorized transmitter.

Homebuilt AM

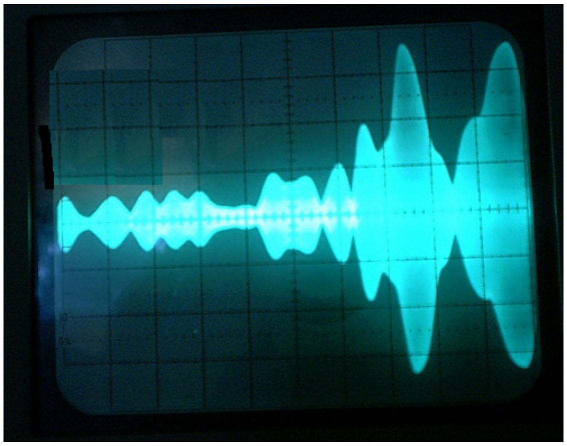
Back in the vacuum tube days many of us built our own transmitters and AM modulators. My first AM transmitter was a Heathkit DX-20. That was a 50 watt, CW, kit-built, vacuum tube transmitter to which I added a homebuilt AM modulator. Unlike SSB, AM could be added onto an existing CW transmitter. Rather than generate a low power AM signal and then amplify it with a linear amplifier, in the old days the usual method was to AM-modulate the final amplifier of the CW transmitter.



On an oscilloscope, the hallmark of AM is that, when you are **not** speaking, the RF carrier wave runs continuously at an average power. That is, in AM the highest peak power and zero power only occur at the very highest voice peaks. Although I could see these transient peaks on the scope, when I tried to catch one with a storage scope, they are statistically rare and I couldn't catch a zero power level. The waveform below was typical of what I saw.

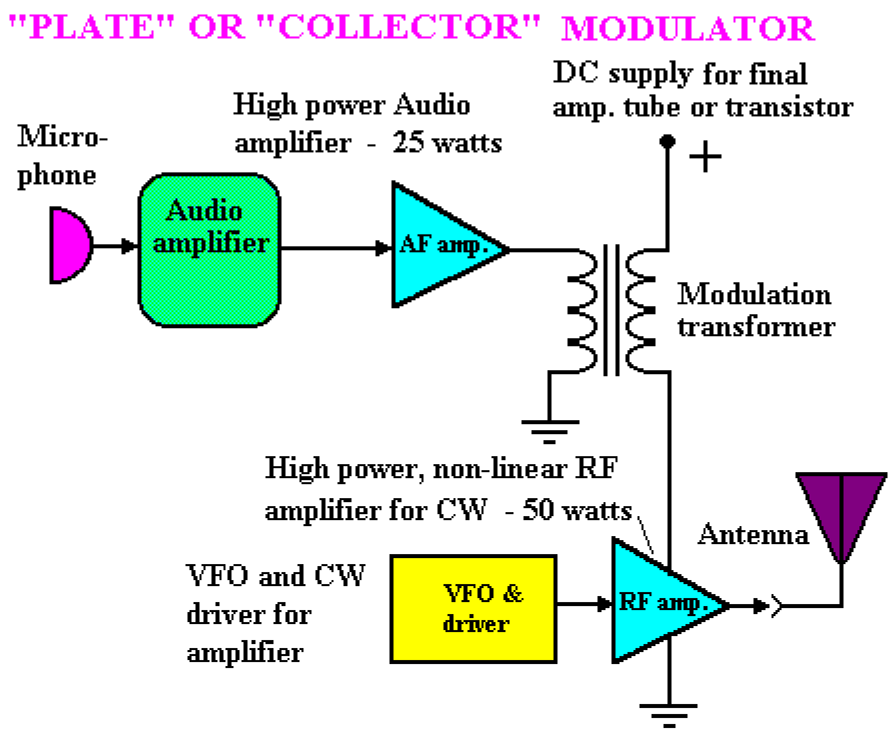


In contrast to AM, the RF output amplitude in SSB is always **zero** whenever you aren't talking. Notice in the SSB oscilloscope picture below that each RF blip representing the audio starts from zero. It doesn't start from a halfway, continuous carrier level.



Plate, screen, and cathode modulators

Formerly, there were three common methods of AM modulation. The "Cadillac" method was to use a ***plate modulator transformer***. These large iron transformers impressed the audio signal onto the DC supply current. That is, as you talked, the DC input current rose and fell around the level of what it would be for a CW sinewave. For a 100 watt transmitter, this transformer was about the size of a softball, weighed a ton, and cost like crazy. The transformer was driven with a big audio amplifier that put out at least 50% of the CW carrier power. In other words, the plate modulator circuitry was nearly as large and expensive as the rest of the transmitter.



The "Ford" and "Yugo" approaches to AM modulation were to modulate the gain of the final amplifier tube by impressing the audio on the screen or cathode, respectively. Screen modulators usually sounded pretty good. Cathode modulation, sometimes called Heizing modulation, tended to produce "down modulation" which meant that power decreased whenever you talked. It sounded just fine, but was inefficient use of RF power output. These methods required less audio power than plate modulation and were easy for a high school kid to afford and build.

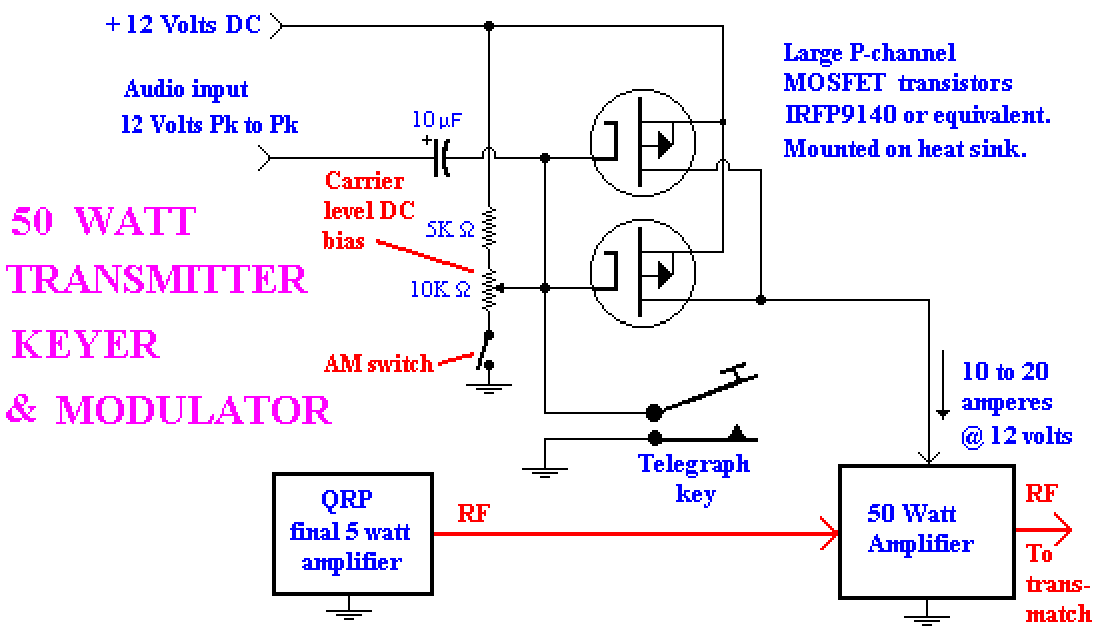
Modern AM construction

Now forward to 2003. Most modern SSB transceivers have the capability to generate AM modulation. To get into this mode, you read your manual for 20 minutes, bring up menu #26, push button numbers 14, 7, and 12 and you're done. That wasn't hard, I guess. But did you learn anything?

Let's suppose that you're a homebrew fanatic and wish to scratchbuild your own AM rig using transistors. Is that hard? Hmmmmm. Well, for one thing, transistors don't have cathodes and screen grids. Emitters are analogous to cathodes but, as explained above, cathode modulation wasn't all that great. Another difference between tubes and transistors is that, for the same power levels, ***the final amplifier transistor has DC currents about 50 times larger.*** So for DC supply modulation, you must impress 5 or 10 ampere audio signals onto the 12 volt DC power supply line. The modulation transformer will have to be just as large, but it will need a super low impedance output winding.

Modulating a transistorized 50-watt CW transmitter

I have a 25-watt, plate modulator transformer from the 1960s designed for use with a transistorized audio amplifier but a vacuum tube transmitter. In other words, it was designed to modulate a vacuum tube final amplifier, but the modulator itself was transistorized. In those days high frequency, high power transistors didn't exist, so transmitters were built with tubes, but audio circuits could be built with transistors. Since my transformer had low impedance primary windings, I thought I could "run it backward" and supply enough audio current drive to build an AM "collector modulator." I happen to have an old 10-watt vacuum tube hi-fi amplifier so I used that to drive the high impedance winding on my modulation transformer. Sure enough, even with music my AM modulation sounded great when I broadcast into a dummy load. However, it only modulated about 30% of the carrier amplitude. That is, I was wasting most of my RF power. I could have built a 25-watt vacuum tube output audio amplifier, but I had a more modern idea. Why not use my MOSFET CW keyer as an audio modulator?

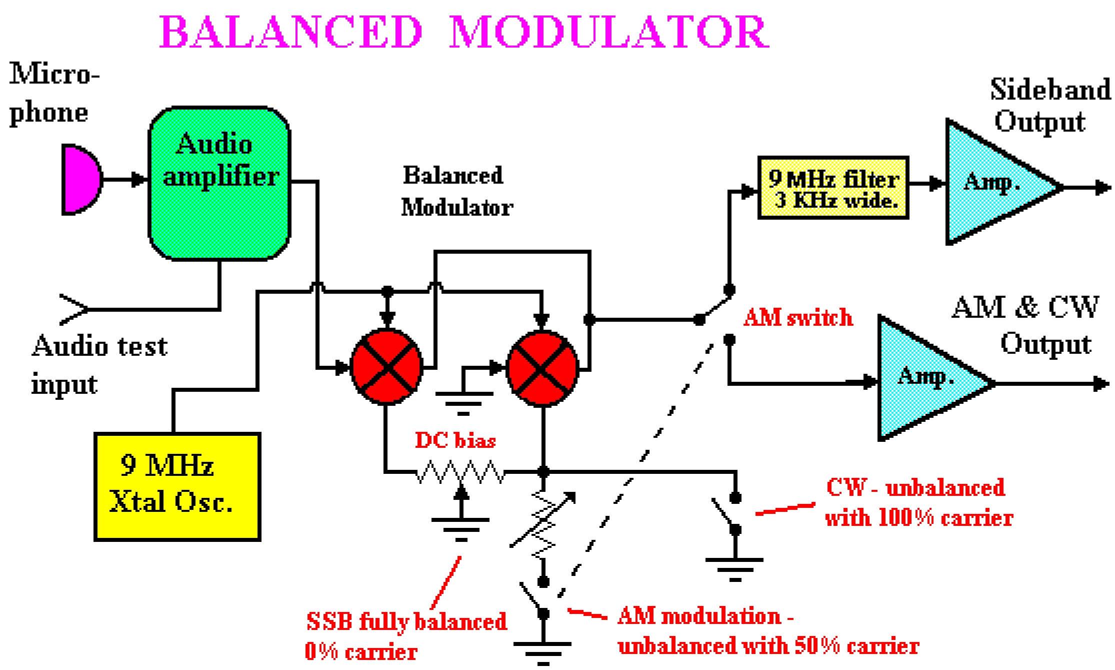


The above keyer was originally designed to turn the DC power to my final on and off with a telegraph key. My AM modulation scheme was to turn the MOSFETs half-on with a simple DC potentiometer, then modulate the gates with a 12 volt P-P audio signal. Because I was driving MOSFETs with a low (audio) frequency signal, hardly any power was needed. This simple scheme worked pretty well, but it was extremely finicky to adjust. It was easy to have too much bias or too little and too much modulation or too little. The difficulty was that the gate voltage versus drain current transfer characteristic is rather non-linear. With feedback and a more sophisticated drive circuit, I believe this method can be made to work well.

The SSB approach to AM

At this point in my R&D, I had not yet succeeded in building a practical SSB transmitter. So rather than invest more time on "obsolete modulation," I went back to work on SSB. I figured that, if I ever got the SSB working, it would be easy to downgrade my SSB generator to AM. This turned out to be true. I tried out several variations. ***The method that was simplest and worked the best was bypassing the SSB crystal filter with a switch and unbalancing the***

balanced modulator circuit using a circuit that resembles the CW switch.



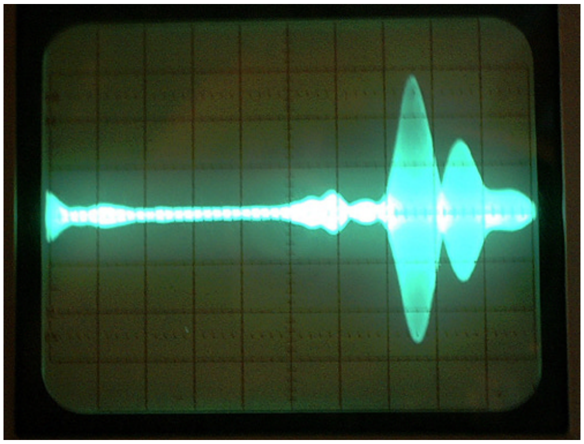
AM resembles CW in that a sinewave carrier is generated continuously. However, the same "unbalance" switch used as a SSB/ CW mode switch can't be used for AM. When modulation is applied, the instantaneous power must rise above and below the no-speech carrier level. Ideal AM modulation drives the carrier alternately between zero and 200% of the carrier level. Because there is a limit on the signal amplitude available, ***the carrier must be set to 50% of the level used for CW.*** This provides a modulation amplitude range of +/- 100%. A separate AM mode, double-pole switch bypasses the SSB filter and unbalances the modulator 50%. The AM switch is in series with an adjustable 5K ohm resistor that unbalances the modulator just enough to produce the 50% carrier.

The audio gain pot and your voice level should be adjusted to produce voice peaks twice the carrier level. Compared to SSB, you'll find that AM modulation is quite HI-FI. While testing the generator and transmitter on an 80 meter dummy load, music retransmitted from a Walkman was quite acceptable. In contrast, when using SSB, speech sounds OK, but music is really terrible. The principle difference is that the sideband filter greatly attenuates frequencies below 300 Hz whereas AM preserves the low frequencies. Speech transmitted on SSB can sound like the person's normal voice, but music on SSB is really bad. It's just as well. The last I heard, ham music is still illegal.

COMPRESSION BY ACCIDENT

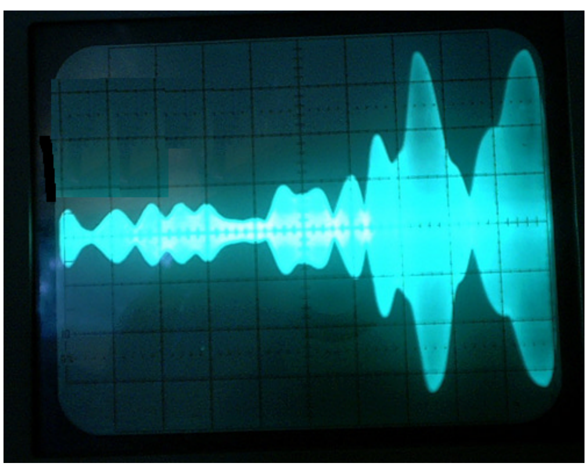
Or, sometimes we get lucky

A modern single sideband generator processes the amplified audio from the microphone before the audio is fed into the balanced modulator. This "***compression***" process attempts to equalize the voice peaks so that as many voice elements as possible are transmitted with full Peak-Envelope-Power. Without this process, most of what you have to say will be transmitted with far less than the nominal peak power. When most of your sentences are reduced to QRP muttering, your intelligibility suffers.



In other words, without compression, the single sideband RF envelope of a spoken word is close to zero most of the time. It would look something like the waveform shown above. A compressor circuit attempts to leave the peaks alone while proportionally amplifying the subtle, low voltage waveform wiggles near the horizontal axis. I guess the latest transceivers use digital processing to accomplish this feat. However, 15 years ago a compressor circuit usually performed the following tasks:

1. It amplified the whole audio waveform.
2. It clipped off the highest audio peaks.
3. And finally, it filtered the clipped audio with a 300 Hz to 3KHz bandpass filter.



After compression, the same RF sideband waveform might look something like the above picture. The idea is that all the tiny stuff near zero has been expanded. (These waveforms aren't actual before-and-after pix, but they illustrate the principle.) After transmission some modern receivers "re- expand" the waveform to try to restore the original waveform. This entire process is called ***companding.*** However, for me, building a homebrew SSB that worked at all seemed plenty difficult. Consequently I didn't worry about secondary issues like "companding."

A crystal filter does more than clip the unwanted sideband

In the beginning I was afraid my RF signal might be too wide. So, because it was relatively easy, I built a 3 KHz audio low pass filter. It turned out that I didn't need it. Once I had passed the 9.000 MHz RF double sideband signal through the crystal filter to cleave off the unwanted sideband, I found that the filter had also removed virtually everything above 3 KHz anyway. Also, when I adjusted the original sinewave frequency to get rid of every trace of the carrier, I found the filter had also clipped off the lower 300 Hz of the audio. It's remarkable how normal a voice can sound without the lower 300 Hz. Voices are quite lifelike. In any case the crystal filter accomplished the same frequency filtering that the ARRL Handbook specified for the audio compressor. Interesting!

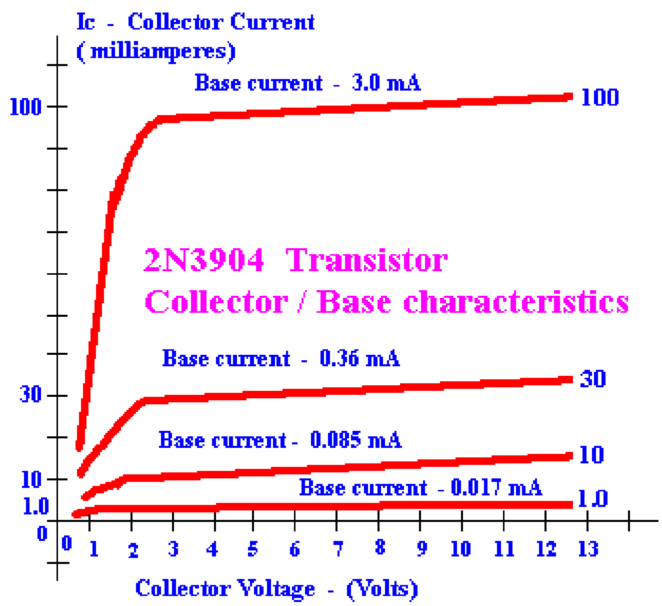
An SSB transmitter has several linear amps in series

After the SSB RF signal has been generated at a milliwatt level, the signal must be amplified and converted to the desired hamband. Including the mixer, this meant that my SSB signal had to pass through 5 stages of amplification to get to 100 watts peak. Each linear stage is forward biased so that even tiny signals will be amplified. Without this bias, all you hear are the voice peaks. In other words, an unbiased amplifier cuts off all the little audio signals a compressor tries to accentuate. I knew that the linearity of all these stages in series couldn't possibly be "perfectly linear." But since it sounded good, I stopped worrying about linearity.

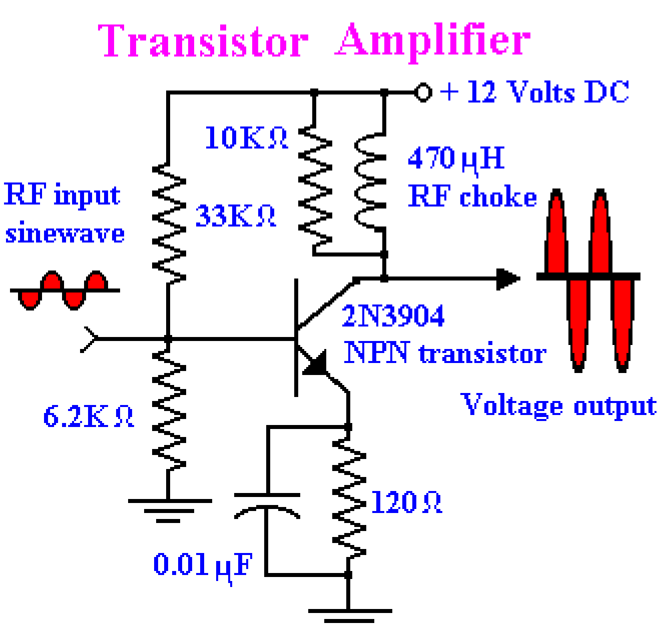
Where has all the AM modulation gone?

I didn't realize that my RF amplifiers were significantly non-linear until I added an Amplitude Modulator mode to my SSB generator. I listened to my little 9 MHz AM generator in my all band shortwave receiver. It sounded great and looked like 100% modulation on the scope. Next I fed the signal from the 9 MHz AM generator into my 80 meter "linear" QRP module which put out about 3 watts on 80 meters. Yes, it worked, but the signal was nearly all carrier. Instead of 100% modulation, on 80 meters I only had about 5% modulation. Where did that huge carrier signal come from? What happened to my modulation?

Transistors aren't linear



"Linear" implies that big signals will be amplified just as much as the small ones. However, if the raw output of the transistor covers most of the collector operating range, then it happens that small signals are amplified more than big ones. I have two 2N3904 transistors in my chain of amplifiers, so the Base/ Collector current characteristics for this transistor are shown above. Notice that one milliampere of collector current requires 0.017 milliamperes base current. But to get 10 milliamperes of collector current takes 0.085 milliamperes. That's 5 times more base current to get 10 times more collector current. But if you want 100 milliamperes of collector current, you need 3.0 milliamperes of base current. That's an additional 35 times more base current. Sure looks non-linear to me. ***BEHOLD, A NON-LINEAR COMPRESSOR!***



The "linear" amplifier above illustrates an accidental compressor circuit. The 33K resistor biases the transistor ON so that even tiny RF signals will be amplified. (By the way, the 10K resistor across the inductor keeps the amplifier from oscillating when there is no input signal.) The main reason for the 120 ohm resistor is to provide negative DC feedback to make the amplifier thermally stable. Without the emitter resistor, the amplifier works, but the transistor runs extremely hot. The emitter resistor also makes the amplifier more linear than the transistor characteristic would suggest because the feedback restricts the transistor to a narrower range of operation. However, 120 ohms feedback makes it a long way from linear. 470 ohms is much better, but still far from perfect.

Oh, well, why fight it? To fix my AM mode, I reduced the imbalance of the balanced modulator to just a few percent of voice peaks. This gives me roughly 50% carrier by the time it arrives at the final amplifier. And as for the SSB, it already works well. Apparently I had a pretty darn good compression system all along and I didn't even know it. Imagine! A happy accident! They sure don't happen often.

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HAM TELEVISION - The Old Way

First, a glimpse of modern amateur TV

I was inspired to write this article for my local newsletter by Jim Andrews, WAØNHD. At our August 2003 ham club meeting he gave a wonderful hour-long presentation on modern Amateur TV. He showed us oscilloscope and spectrum analyzer images of audio, RF, and video waveforms and block diagrams of all the required black boxes. At the end of his presentation he included a run-down on the available commercial ham TV equipment. It turns out that you can put together a first-rate ATV station for under $1000. Less than that if you already own a suitable camera, antenna, etc. If you plan to support your local emergency service and televise forest fires and riots, then a station like Jim's is what you need. On the other hand, if you just like to play around with circuits like I do, then building something from scratch may be more satisfying.

Homebuilt ham TV

Paradoxically, one of the best attributes of the old days was our relative poverty and the lower level of technology. Many services and gizmos that are routine today existed 50 years ago but were rare or unaffordable. Long distance telephony, walkie-talkies, RTTY, and TV cameras are obvious examples. Ham radio allowed us high school kids to play with these toys decades before they were cheap or even available to ordinary adults. Since our toys were the latest technology, we were extremely excited about them. If you show a TV camera to modern kids, they fall asleep.

Television fascinated me as much as short wave radio. So after I had a working HF station, I wanted to get on TV. In the 1950s, the hard part of ham TV was the camera. The cheapest way to get one was to buy a WWII Navy surplus flying bomb camera. The Navy built radio-controlled flying bombs that could crash into enemy ships, Kamikaze-style. After much searching I was finally was able to buy a camera with its huge iconoscope camera tube. Unfortunately, by the late 1950s finding an iconoscope that still worked was difficult and mine didn't. In contrast, TV monitors were easy to get. I toured the TV repair shops and bought old sets for a few dollars that their owners didn't want to pay to have repaired.

A flying spot camera

Since TV camera tubes were out of reach, I resorted to using a TV set as a scanner. Large paper or grease-pencil transparencies were taped to the TV tube. A 914 photo-multiplier tube was mounted on the tilted aluminum box on the left. The photo tube "looked" at the light from a blank TV picture raster passing behind the slide. The flying spot of light scanned the slide, one line at time. It took five stages of amplification to boost the signal to the required few volts. I usually used the retrace blanking pulses from the TV to make crude synchronization pulses. The pulses were combined with the varying light signal to make a complete TV signal. I wired a polarity switch on my combiner circuit so my slides could be either black on white or vice versa.

The TV signal was relatively high frequency and was easily separated from the constant background lighting signal. Consequently it wasn't necessary to operate in the dark or enclose the scanner in a box. The crude blanking pulse sync worked, but it pulled the image down and to the left. The easy way to get real sync pulses was to receive channel 4 from Denver, 30 miles away, then remove the picture. My light signal was recombined with the channel 4 pulses then sent on to the monitor.

Fun with flying spots

Obviously we couldn't televise forest fires with this scanner, but we played with it in other ways. When you're in high school, silliness can be great fun. Aside from televising test patterns, I liked to do silhouette hand puppets and rude finger gestures. My friends and I used to draw up transparencies of signs like, "Help! I'm trapped in your TV set" or we would draw single frame cartoons and slides showing supposedly humorous TV ads.

Synchronizing the picture to channel 4 had a more nefarious advantage. I could broadcast images and superimpose them on top of real channel 4 broadcasts. For example, I had a tiny cutout of a vulture that I could place on David Brinkley's shoulder during the NBC Huntley-Brinkley evening news. Alternatively, a giant black silhouette of a hand might slide into the picture and tickle him under the chin.

Normally I just broadcast this entertainment around the house. However, the kids across the street were interested so I thought, "It's only a few milliwatts. I'll just broadcast it over there on channel 3. It's 200 feet instead of the legal 50 feet maximum, but beyond that, how far can it go?" My little slide and puppet show for the kids worked great. Nothing more came of "The Frank Show" until several years later when Jim Synder, WØUR, was visiting my shack. I told him about my former flying spot project and he said, "So you were the culprit!" He described how his brother was watching TV in their living room across town from my house, about 5 miles away. Suddenly he began hollering for Jim to come look at the TV. Jim sprinted into the room just in time to see the word "HELP!" written on top of channel 4. A few moments later the mysterious signal disappeared. I dug out my old slides for Jim and he thought he recognized the perpetrator. This was interesting because I never deliberately broadcast on top of channel 4 using an outside antenna. Even in high school, I wasn't that reckless. On that other hand, if my lower sideband was on channel 3, the upper sideband would have been on ... channel 4.

Broadcasting properly on 420 MHz UHF

Unfortunately, being a poorly equipped kid, I was unable to generate and receive a signal on 70 CM over any distance. I scratch-built a little 420 MHz transmitter that appeared to work OK. That is, a 50 ohm ½ watt resistor on the output got hot and all the stages "dipped" when tuned. For all I could tell, it was working. At that time I had never even heard of filtering the output with a resonant cavity filter to get rid of the lower sideband, so the vestigial sideband issue was blissfully ignored. I also built an alleged 420 MHz converter that received my own signal, although I had no real knowledge of what frequency I was actually sending and receiving. Another barrier was that none of my ham friends were interested in putting up UHF antennas, building converters, and all that. They all were too busy with DX, building kilowatt finals, walkie-talkies, RTTY, and so on. We all had different interests and high school was a busy time.

As you can see, my ham TV project wasn't a complete success. It illustrates the difficulties with homebrew VHF and UHF. To be sure you're producing a quality signal on the right frequency, you need expensive UHF test equipment. Moreover, you need a high level of craftsmanship to control the unwanted oscillations. If 10 meters is tricky, imagine getting 0.70 meters to work right! The only advantages are that you can use low QRP power levels and compensate by building small, high gain antennas. Most of the difficulty with the high HF bands happens when you try to generate high powers over 1 watt. In contrast with a small rooftop antenna a few milliwatts of VHF or UHF can get you around town.

On the other hand, my TV project was loads of fun and I learned plenty. When you scratch-build, the rewards are usually quite different from store-bought ham radio and can be quite unexpected. For example, who would have thought QRP television could work so well?