Application Note
AN-46

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Amplifier Output Power for Various Modulations

Jim Andrews, KH6HTV

The question often arises, for a typical class A-B, linear, RF power amplifier, how much power can I get for various types of modulation ? A set of tests were performed on a KH6HTV Video model 70-9B, 70cm, amplifier to obtain some representative values. The tests were all performed on TV channel 60 (438-444MHz) with a center frequency of 441 MHz, or 439.25MHz for VUSB-TV. The table below summarizes the results. Details on the measurements are on the following pages.

Model 70-9B Amplifier Output Powers

MODULATION	P(out) dBm	P(out) Watts	Power type	notes
CW	49	80	rms	
FM	49	80	rms	
AM	41	12.5	rms	
AM	47	50	PEP	@99% mod.
SSB	47	50	PEP	@ -1dB
VUSB-TV	44.5	28	PEP	
QPSK - DTV	39	8	rms	
16QAM - DTV	38.5	7	rms	
64QAM - DTV	37.8	6	rms	

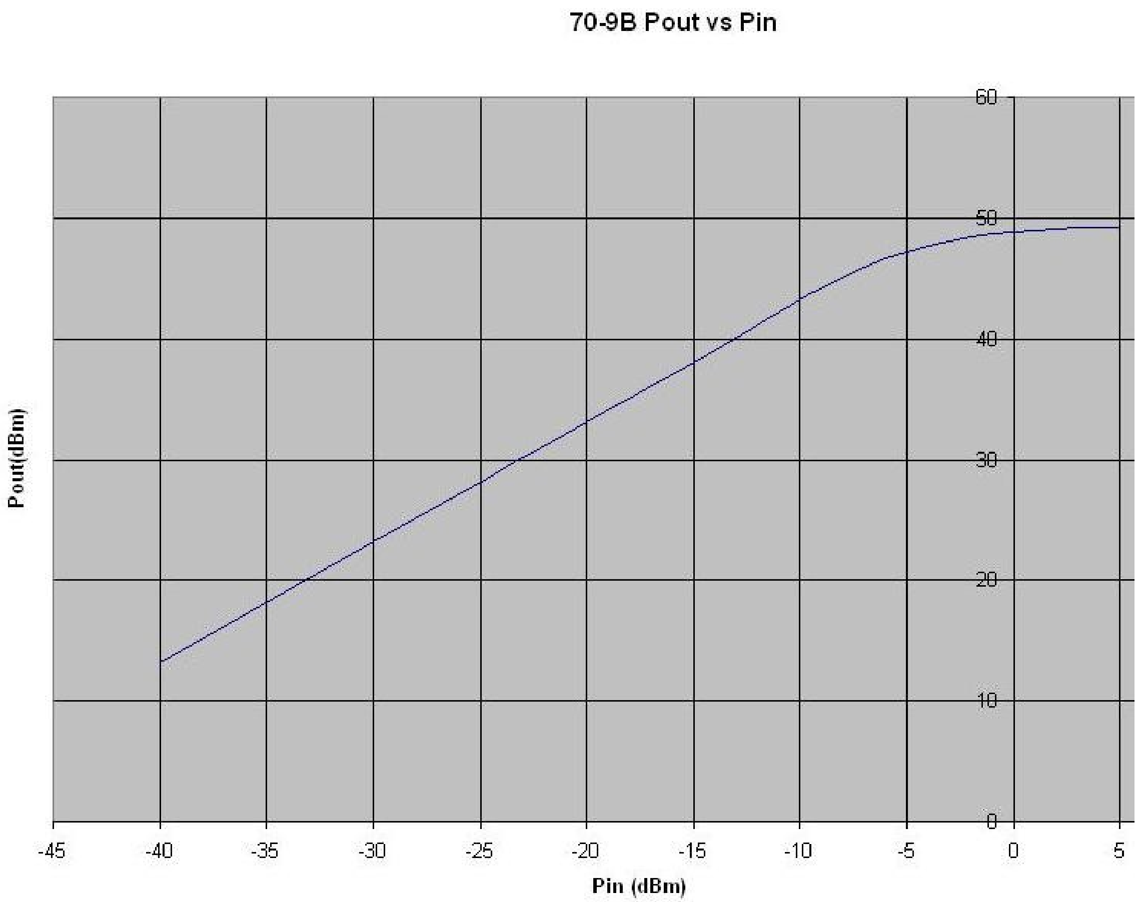

Fig. 1 Model 70-9B Amplifier Pout vs. Pin.

CW / FM: For FM/CW service a very non-linear, class C amplifier suffices and provides the best efficiency. For all other classes of service a linear amplifier is required [1]. All measurements for this report were made on a KH6HTV Video model 70-9B RF Linear Power Amplifier, S/N 123. Most all measurements were done at 441 MHz. Fig. 1 above shows a CW measurement of the output power vs. the input power. The signal source was a Fluke model 6060B/AK rf signal generator. The output was measured using a Rigol model DSA-815 spectrum analyzer. A 30dB, 150 Watt attenuator, plus a 10dB, 2 Watt attenuator were used on the output of the amplifier. The amplifier is seen to be very linear. Like all good linear amplifiers, it eventually saturates at it's max. output, but in a smooth, controlled fashion. The small signal gain was 53dB. The saturated output power was +49dBm = 80 watts. The -1dB gain compression occurred at +47.2dBm = 52.5 watts. Below 20 watts (+43dBm), the amplifier is extremely linear.

At low drive levels, the amplifier is in class A mode. It draws 7.9 Amps at a supply voltage of +13.8Vdc. Thus the quiescent dc input power is about 109 watts. At higher drive levels, it starts to draw more current and enters class A-B. When fully saturated, it draws 12.8 Amps. Thus, P(dc) = 177 watts. At max. saturated rf power output, the efficiency is 45%.

Fig. 2 shows the amplifier's spectrums with FM modulation at max. output of 80W and low power of 2 watts. They are identical, except for level.

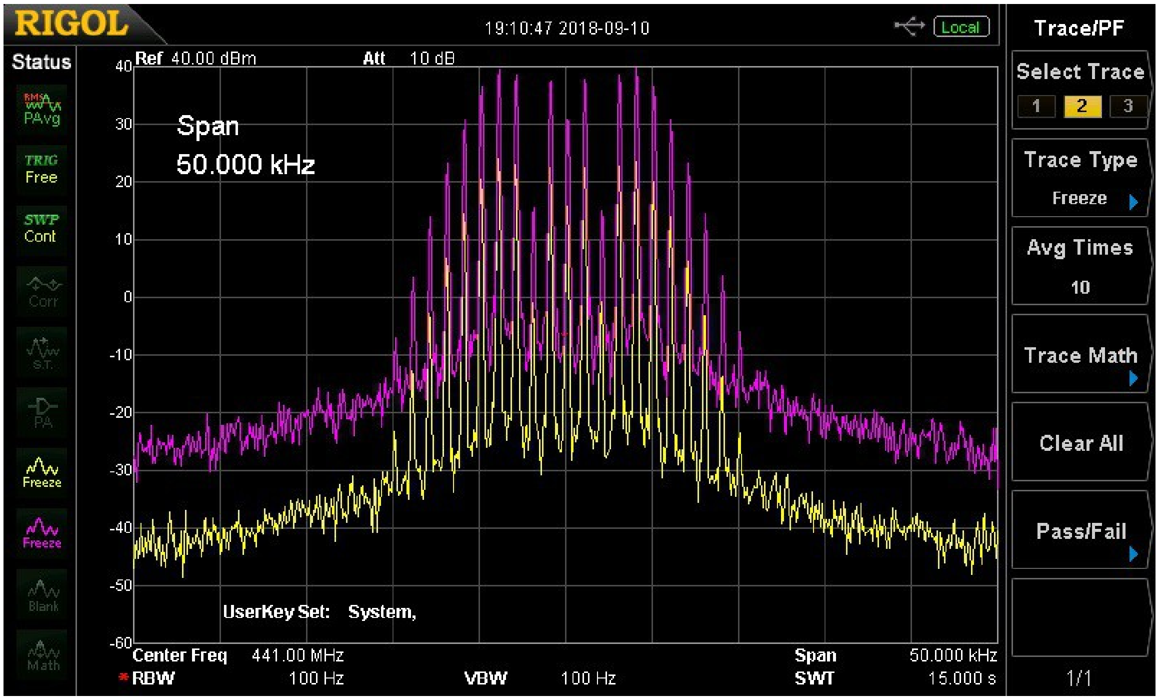

Fig. 2 70-9B Amplifier operating as an FM voice transmitter. FM spectrum with 1kHz tone and 5kHz deviation. Magenta = max. output of 80 watts. Yellow = low power of 2 watts. Spectrum analyzer settings: 10dB/div & 5kHz/div, 50kHz span, BW = 100Hz, VBW = 100Hz,

AM: For AM modulation, it is important to not overdrive the amplifier to maintain the fidelity of the waveform up to 100% modulation. With 100% modulation, the peaks of the modulated output waveform are 2 X in voltage and 4 X in power of the un-modulated carrier. To avoid compression of the peaks, they should not extend beyond the -1dB gain compression level. For this amplifier, it means the Peak Envelope Power (PEP) should be no more than 50 watts (47dBm). Figs. 3 & 4 show the resultant time domain waveform and frequency spectrums for a 1 kHz modulation tone when the amplifier is working at it's optimum setting of 12.5 watts power. The Fluke 6060B was the signal source for this test and the Rigol DSA-815 was used for the measurement.

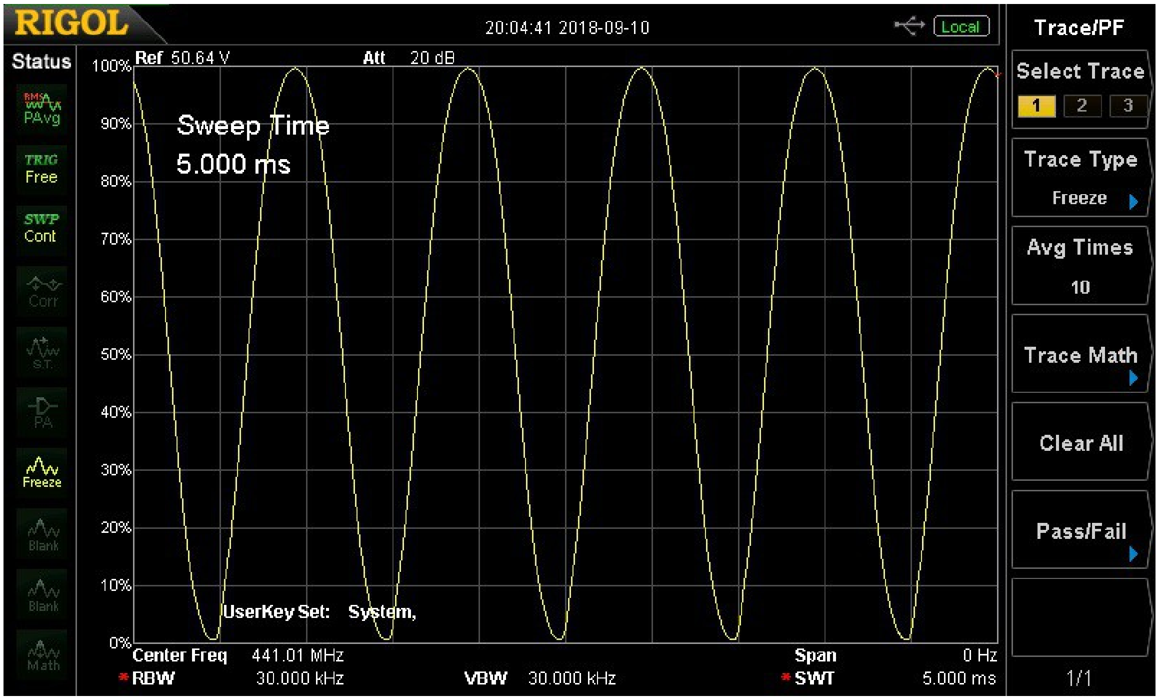

Fig. 3 70-9B Amplifier acting as an AM voice transmitter. This is the output RF voltage waveform for a 1KHz tone at 99% modulation. Spectrum Analyzer settings: Vert = linear detector, 100% = 50V = 50 watts (PEP). span = 0, horiz. sweep = 5ms, BW = 30kHz, VBW = 30kHz. Pavg = 12.5 watts = 41dBm

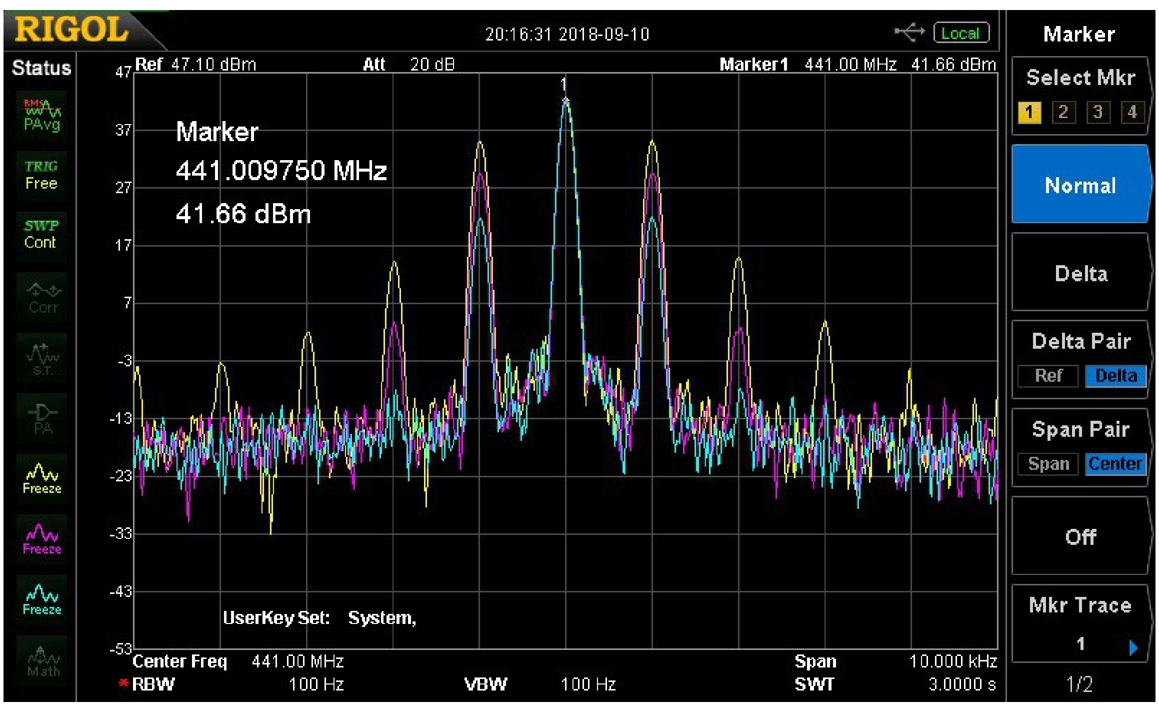

Fig. 4 70-9B Amplifier acting as an AM voice transmitter. These are the output spectrums for a 1kHz tone at 20% (cyan), 50% (magenta) and 99% (yellow) modulation. Carrier power = 12.5 watts = 41dBm Spectrum Analyzer settings: 10dB/div & 1kHz/div. BW = 100Hz, VBW = 100Hz

SSB: For Single Side Band (SSB) service, to maintain linearity, the max. peak output (PEP) should also be limited to the -1dB gain compression point. Thus, for the 70-9B, it should be rated at 50 watts (PEP) (47dBm). SSB tests were performed using a Yaesu FT-817 SSB transmitter. This transmitter is capable of 2.5 watts (PEP) when working on it's internal battery. The output was attenuated with a 30dB, 20 watt attenuator, plus an adjustable step attenuator and used as the test signal input to the 70-9B amplifier. The transmitter was set to 441.000 MHz, upper side-band, and modulated with a 1 kHz tone. Fig. 5 shows the spectrum of the FT-817 transmitter when putting out a 1 watt (PEP) (30dBm) signal. Fig. 6 shows the 50 watt (PEP) output from the 70-9B Amplifier.

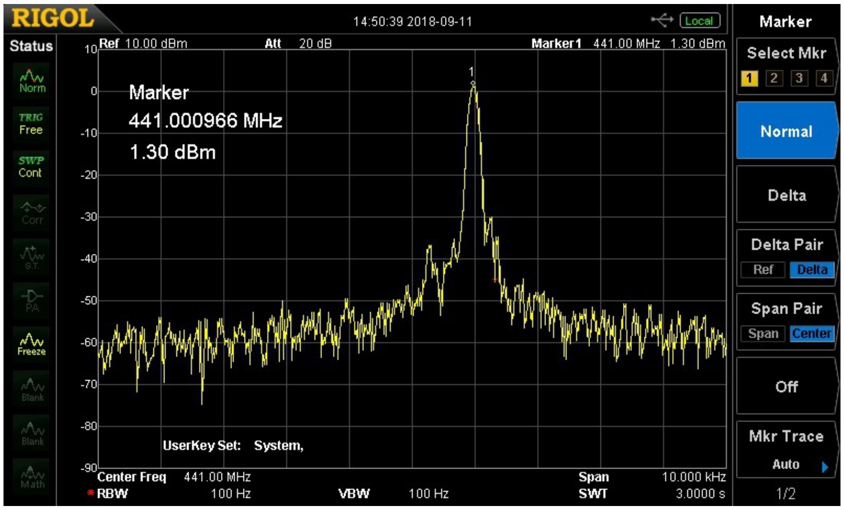

Fig. 5 Spectrum from the Yaesu FT-817, USB transmitter, putting out a 1 watt (PEP), 1 kHz tone. Attenuated by 30dB for measurement and use as the input to the 70-9B amplifier. Spectrum analyzer settings are: 10dB/div & 1kHz/div. 10kHz span, BW = 100Hz, VBW = 100Hz. Center Freq. = 441.000 MHz

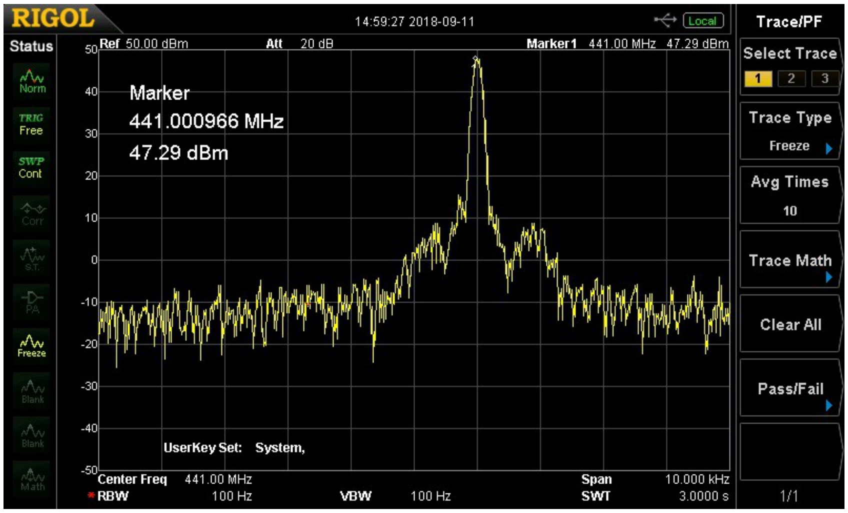

Fig. 6 SSB output from the 70-9B Amplifier when driven to 50 watts (PEP) (47dBm) output power by a 1 kHz, USB test signal. 10dB/div. & 1kHz/div.

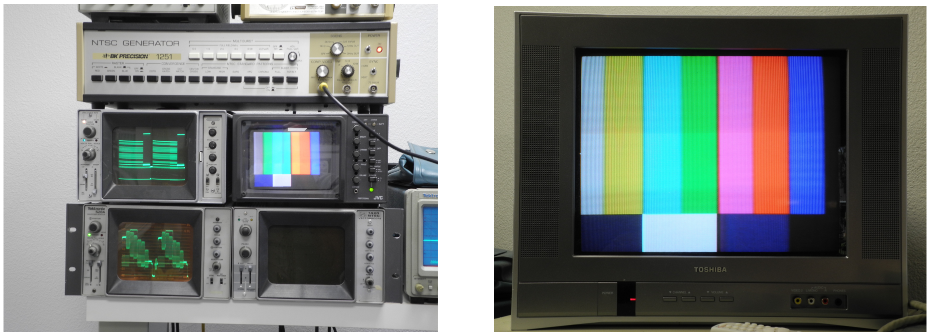

Fig. 7 NTSC signal generator and Tektronix waveform monitors (left) and Toshiba video monitor (right) showing color bar test signal.

VUSB-TV: For NTSC, analog TV, the linearity requirements are more severe than for AM or SSB voice. A 6 MHz wide, analog TV signal uses Vestigial Upper SideBand (VUSB). It is essentially an AM modulated signal with the video carrier present and all of the upper sideband, but only 3/4 MHz of the lower sideband present. To maintain the 6 MHz channel purity, the rest of the lower sideband must be suppressed. If a TV amplifier is driven too hard the sync pulse will be compressed and the non-linearities in the amplifier will then generate out of channel signals. On an analog TV signal, this is most evident by the re-appearance on the lower sideband of the mirror image of the 4.5 MHz Sound Sub-Carrier (SSC) and the 3.58 MHz Color Sub-Carrier (CSC). For amateur TV service, we have found an acceptable point is to limit the lower SSC non-linearity to be no greater than -20dB below the upper sideband SSC.

Analog TV transmitters are rated by the peak power of the highest feature of the video waveform, namely the sync pulse. They are thus rated in a similar fashion to SSB transmitters, with a PEP rating. Average (rms) power measurements on an analog TV transmitter are relatively meaningless. The average power varies depending upon the video content and thus will wander around considerably as the program material changes. Going from a totally white to totally black screen results in almost a 4dB variation.

For these VUSB-TV tests, a Blonder-Tongue model ACM-806 CATV modulator was used as the rf signal source. It was set to Ch 60 (439.25MHz), 0dBm (PEP) and -20dBc for the SSC. It was modulated using standard NTSC test signals from a B&K model 1251 TV signal generator. A Drake model DMM-806 CATV receiver was used to de-modulate the resultant rf TV signals from the 70-9B amplifier under test. The baseband video output from the Drake receiver was viewed and measured on a Tektronix model 528A, TV Waveform Monitor. It was also viewed on JVC and Toshiba video monitors. The standard test signal used was color bars, see Fig. 7.

Fig. 8 shows the rf spectrum from the CATV modulator, while Fig. 9 shows the rf spectrum of the 70-9B amplifier's output. The video test signal was standard color bars. The rf drive level was adjusted up to the point at which the spurious SSC on the lower sideband had risen to be -20dB below the SSC on the upper sideband. At this point, the sync pulse peak power is 28 watts (PEP) (44.5dBm). Note: that the spurious CSC on the lower sideband has come up to about -30dB below the CSC on the upper sideband.

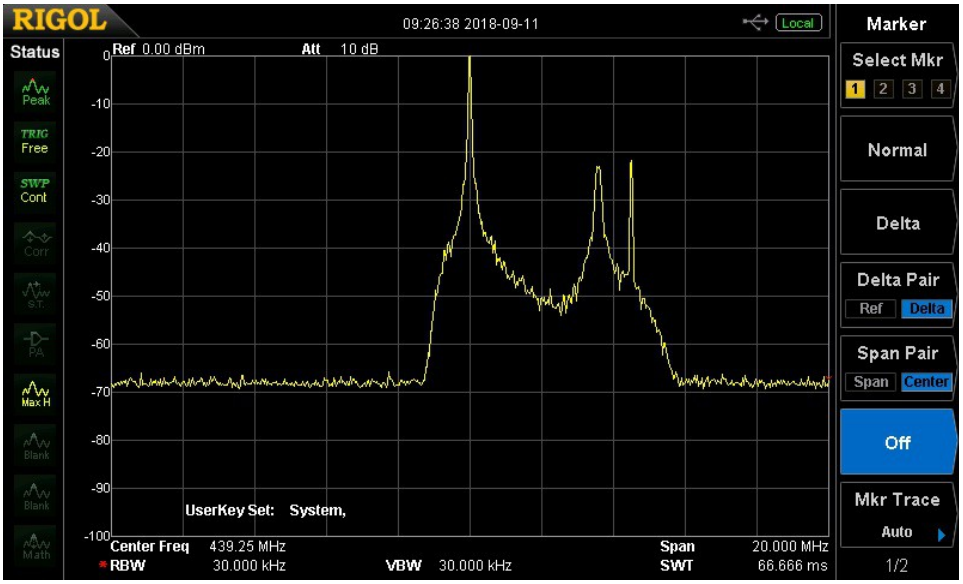

Fig. 8 RF spectrum of NTSC, VUSB-TV signal from CATV modulator. Test signal is color bars. Spectrum Analyzer settings are: 10dB/div, 2MHz/div. 20MHz span, IF BW = 30kHz, VBW = 30kHz. Detector = Pos Peak, Display = max. hold sweep = auto The video carrier is in the center at 439.25MHz. The color sub-carrier is the peak, 3.58MHz above the video carrier. The sound sub-carrier is the spike, 4.5MHz above the video carrier. Note that most of the lower sideband is severely attenuated.

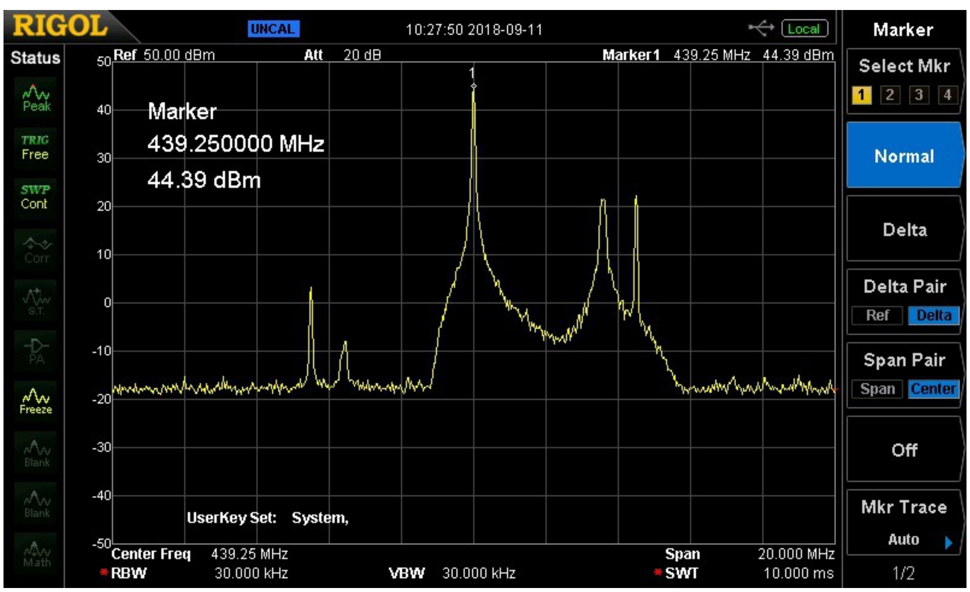

Fig. 9 RF spectrum of NTSC, VUSB-TV signal output from 70-9B Amplifier. Pout = 28 watts (PEP) (44.5dBm). Note presence of undesired SSC & CSC on lower sideband.

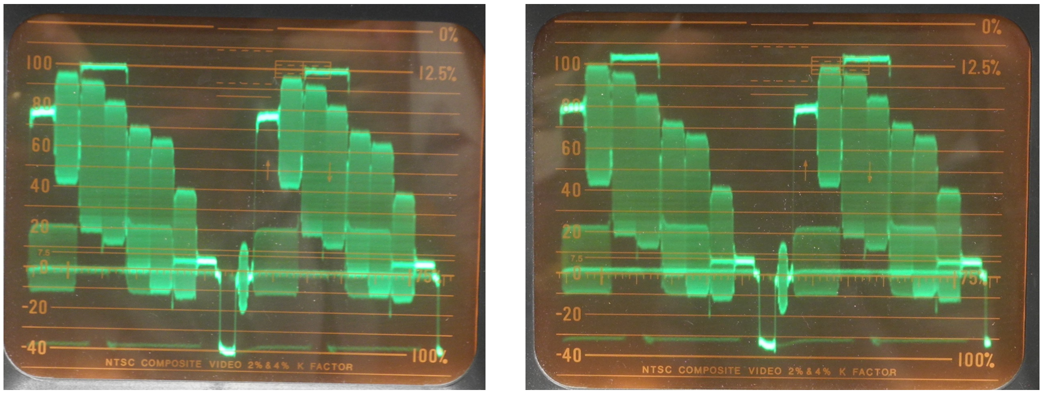

Fig. 10 Demodulated TV signal video, color bars, waveform as displayed on Tek 528A TV waveform monitor. Left photo is the test signal from the B-T ACM-806 CATV modulator. Right photo is the resultant output after the signal on the left was amplified by a model 70-9B rf linear power amplifier to 28 watts (PEP).

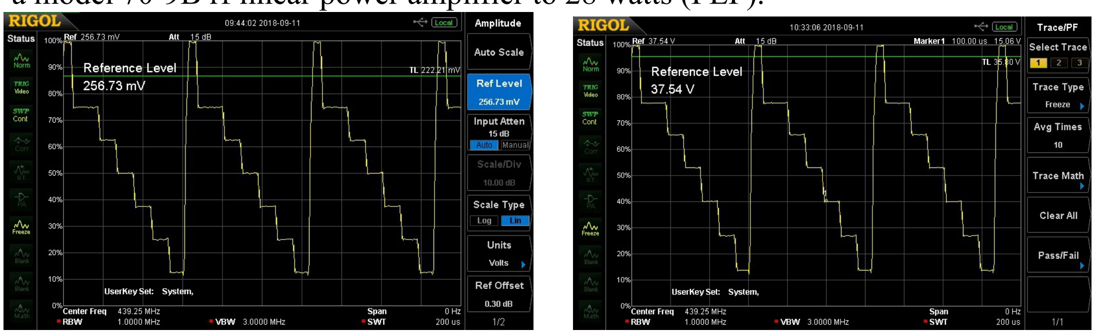

Fig. 11 B&W Staircase Video Test Signal. Detected RF waveforms from B-T CATV modulator (left) and after amplification by 70-9B rf linear power amplifier (right) to 28 watt (PEP). Measured by Rigol DSA-815 spectrum analyzer. Settings were: center freq. = 439.25MHz, 0 Hz span, BW = 1MHz, VBW = 3MHz, detector = normal, freeze display, vert = linear display, Ref. level (top) = 37.5 V = 44.5dBm = 28 watts, horiz = time display, 200us.

Fig. 10 shows the demodulated TV signals from both the CATV modulator and also after amplification by the 70-9B amplifier. The test signal displayed is the standard color bar test pattern. TV standards call for the video signal to be exactly 1.0 V ptp into 75 ohms, with the sync pulse being -40 IRE units in height and the white level being 100 IRE units above the black reference level. The CATV modulator's waveform meets this spec. After amplification, there is some distortion. The sync pulse is now compressed from 40 to 36 IRE units. The white to black is expanded from 100 to 103 IRE units.

Fig. 11 shows the actual RF envelope as measured by the spectrum analyzer. The video test signal was a standard B&W staircase. TV standards call for the tip of the sync pulse to be at the 100% (i.e. max.) level. The black, back-porch reference level is to be at the 75% level and the white level is to be at the 12% level. The rf output from the B-T CATV modulator meets these specs. (left photo). After amplification to the 28 watt (PEP) level, the rf envelope waveform has been distorted by a small amount. Due to compression of the sync pulse, the reference black level has shifted up from 75% to 78% and the white level has shifted up from 12% to 13%.

DIGITAL TV: Digital TV (DTV) utilizes extremely complex modulation waveforms consisting typically of many COFDM sub-carriers. Unlike an AM or VUSB-TV signal, there is no truly distinguishable major feature, such as a sync pulse, to lock onto for observation. The DTV signal instead resembles a random noise source. This can be confirmed by tuning in a DTV signal on an AM or SSB receiver. It sounds just like background, random noise, except that the signal strength, S meter reads the presence of extra rf power. Thus, for characterizing DTV transmitters, they are not rated in terms of peak power like an analog TV transmitter, but instead in terms of RMS, average power of the noise like signal. A DTV transmitter does need to provide considerable head room to accommodate peaks in the DTV signal many dB above the RMS average power.

Caution must be exercised in the selection of a power meter to accurately characterize a DTV transmitter. The power meter must measure true RMS power. Most inexpensive power meters use a simple semiconductor diode detector which actually measures the peak voltage. The meter readout is then calibrated in equivalent rms power assuming the signal was a true sine wave. This is obviously not the case for a DTV transmitter. A thermistor type power meter head will give a true rms reading.

Many TV amateurs in the USA that are experimenting with DTV are using the European terrestrial, digital broadcast TV standard of DVB-T. DVB-T supports three different types of modulation. They are: QPSK, 16QAM and 64QAM. Fig. 20.6 [2,3] below shows the constellation I-Q diagrams for these modulations. Each dot represents a particular amplitude/phase vector and a unique logic state. The more complex QAM modulations can support higher data rates within a fixed bandwidth channel, but at the expense of reduced receiver sensitivity.

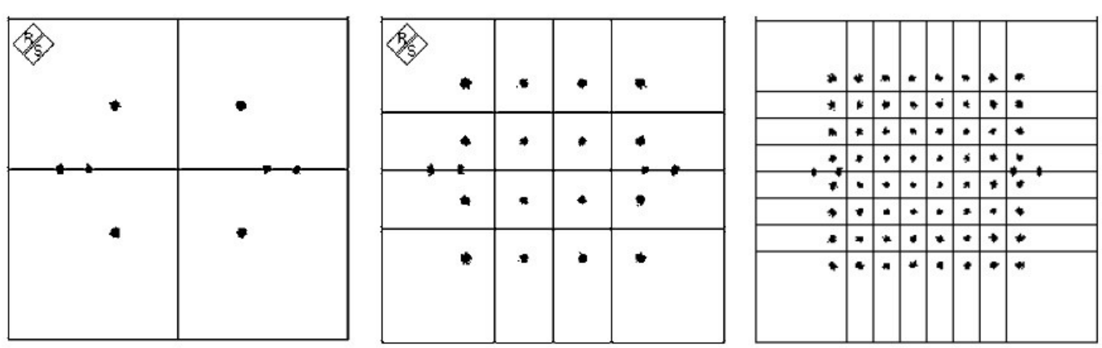

Fig. 20.6. DVB-T constellation diagrams for QPSK, 16QAM and 64QAM

Careful examination of the I-Q diagrams in Fig. 20.6 will reveal the presence of four additional dots on the horizontal, I line. These are identified in Fig. 20.3. [3] They are additional pilot carriers used to carry data for receiver initialization and synchronization, and for channel distortion measurement and correction.

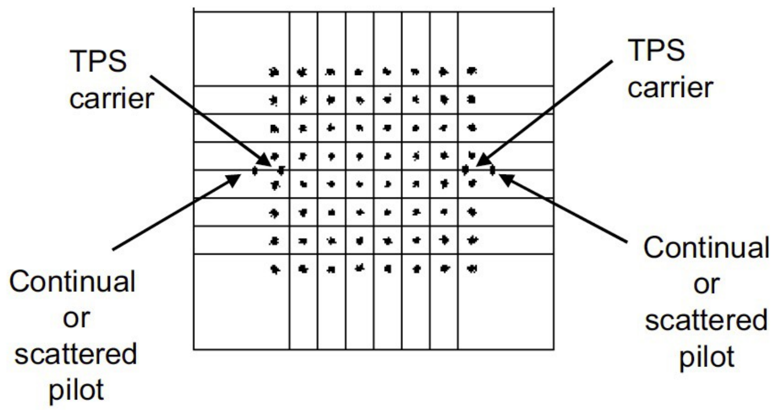

Fig. 20.3. DVB-T carriers: payload carriers, Continual and Scattered Pilots, TPS carriers

QPSK is the simplest of the three modulations. QPSK stands for Quadrature Phase Shift Keying. It is related to BPSK-31 which is commonly used by radio amateurs for digital text communications on the HF band. BPSK is simple binary phase modulation in which the phase of the transmitted signal is either 0^o or 180^o, which is the equivalent of simply turning a sine wave upside down.. For QPSK, the phase is rotated in 90^o increments from 45^o to 135^o to 225^o to 315^o. The signal amplitude always remains the same, much like a CW or FM signal. QPSK is the most robust form of DTV modulation as it does not require any amplitude changes, much like FM in this regard.

16QAM is the next higher level of modulation used in DVB-T. It stands for sixteen state Quadrature Amplitude Modulation. Each quadrant of the QPSK, I-Q diagram is now divided further into four more sectors, for a total of 16 sectors. There now are three distinct amplitude levels. Because different amplitudes represent different logic values, 16QAM is thus more susceptible to degradation than QPSK, more like AM vs. FM.

64QAM is the highest level of complexity allowed in DVB-T. As seen in Fig. 20.6, each of the 16QAM sectors is again divided by four, for a total of 64 sectors. It is even more susceptible to amplitude degradatin than 16QAM.

DTV Transmitter Measurements: A transmitter is obviously characterized by it's output power. See above discussion. For a DTV transmitter, another important parameter is the MER, or Modulation Error Ratio. However, MER is a very complex parameter and requires a sophisticated measurement instrument, not typically found in an amateur ham shack. Most DTV receivers, even the cheapest ones, give some indication of the signal strength and also quality. The quality rating is a relative measure of the decoded S/N ratio. On most cheap receivers, it is simply an uncalibrated bar graph, but this can still be a useful indicator. If you transmitter shows anything less than 100% quality, then it is distorting the rf signal and you need to back off on the drive level. On the Hi-Des receivers, they actually give an on screen display of the actual received signal strength in dBm and also the S/N in dB. For QPSK, the best S/N = 23dB. For 16QAM, the best S/N = 26dB. For 64QAM, the best S/N = 32dB.

Another measurement that can be easily performed, if one has access to a spectrum analyzer is the Shoulder Attenuation. It is a good indicator of the amount of non-linearity present in the transmitter's rf signal. The ideal DVB-T spectrum looks like white noise riding on top of a rectangular pedestal. The output from a good quality DVB-T modulator is a good example. See Fig. 14. Anything observed outside of the channel bandwidth other than the receiver noise floor is an undesired artifact created by non-linearites. Fig. 14 shows a minimal amount of shoulder energy well below -40dB outside of the 6 MHz channel. The DVB-T standards [4] specify that the shoulder attenuation is to be measured ± 200 kHz beyond the channel edges. For the example in Fig. 14, the shoulder attenuation was measured to be -45dB. The analyzer's noise floor in this example is at -77dBm.

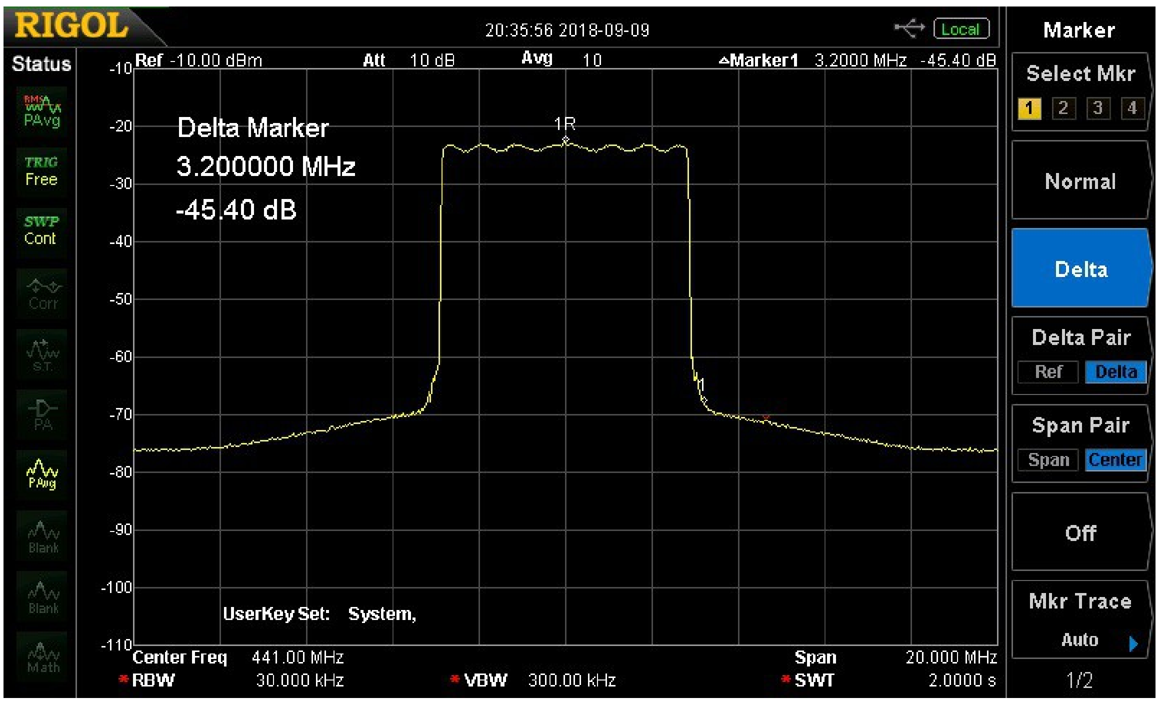

Fig. 14 QPSK spectrum from Hi-Des model HV-100EH, DVB-T Modulator. Measured by Rigol DSA-815 spectrum analyzer. Analyzer settings were: 10dB/div & 2MHz/div, 20MHz span, 2 second scan rate, BW = 30kHz, VBW = 300kHz, rms detector, plus signal averaging. Shoulder attenuation measured 200kHz beyond channel edge. Value of -45dB shown for a 6 MHz channel.

When a DTV signal is amplified by a power amplifier, as the drive level is increased, the undesired, out of channel, shoulders will be seen to rise more rapidly than the actual power of the input drive signal. These shoulders are undesirable for two reasons. The first is distortion and worse MER for the transmitted DTV signal. The second is spectrum contamination. To avoid interference with other services on frequencies outside of our assigned channel, our transmitters must be clean and not put signals into adjacent channels. Commercial, broadcast TV transmitters have extremely stringent out of channel requirements for the shoulders to be suppressed > 50dB. A typical broadcast DTV transmitter's shoulders will be at about -28dB. Then expensive, digital, pre-distortion is applied to the drive signal reducing the shoulders to -38dB. Finally a sharp cutoff, channel band-pass filter is used on the amplifier's output to further reduce the shoulders to -52dB [5].

For the amateur TV service, we do not have the big bucks $$$ to implement digital pre-distortion. We do however, often use, especially for our TV repeaters, sharp cut-off, band-pass, channel filters. For the typical, ham DTV station, a good compromise in terms of maximizing output power, minimizing adjacent channel RFI, and maintaining good MER is to set the drive level so that the amplifier's shoulder attenuation is about -30dB. Fig. 15 shows the resultant spectrum for a model 70-9B amplifier with -30dB shoulders.

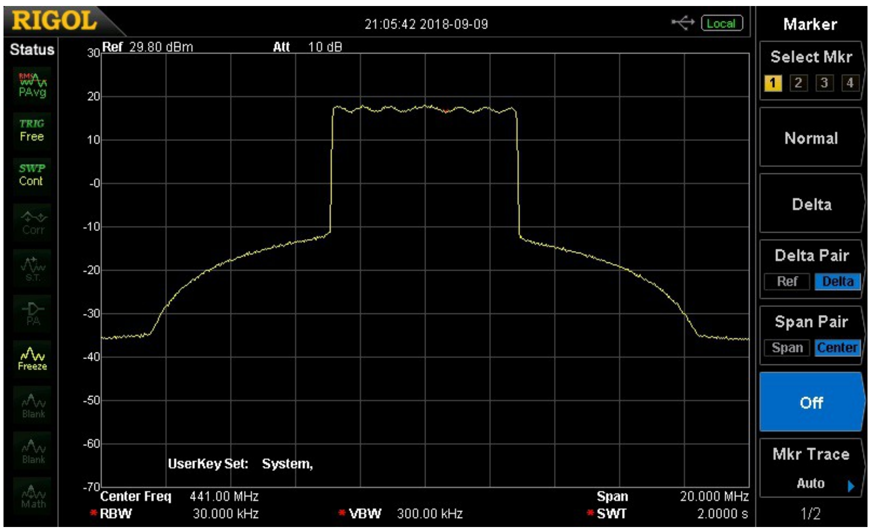

Fig. 15 Model 70-9B Amplifier output spectrum for optimum drive level resulting in -30dB shoulders. Pout = +39dBm = 8 watts rms

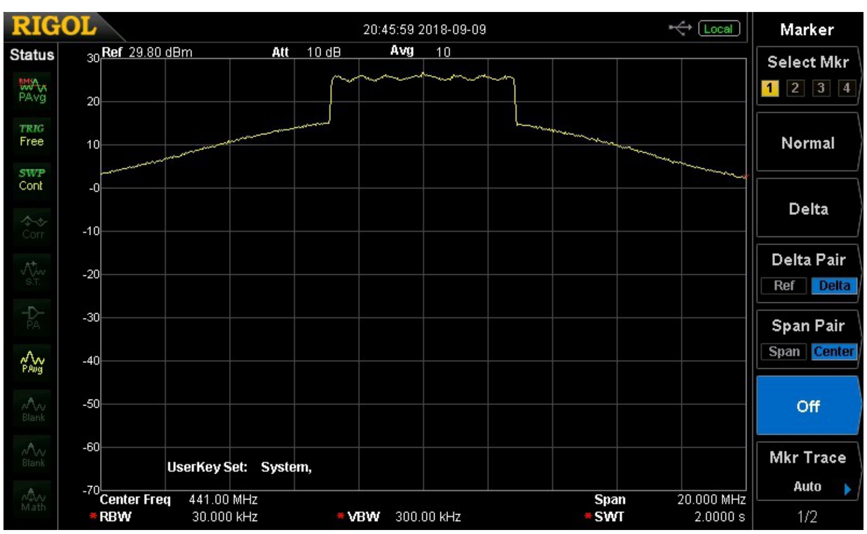

Fig. 16 Model 70-9B Ampler output spectrum for max. drive level resulting in -12dB shoulders. Pout = +47.5dBm = 56 watts rms Totally unacceptable spectrum contamination.

Tests were also run on increasing the rf drive power and observing the shoulder attenuation and also the S/N as measured on a Hi-Des model HV-110 receiver. For QPSK, when the output power was increased to +42dBm (16W), the S/N started to degrade and the shoulder dropped to -25dB. Driving the amplifier very hard to get maximum output power resulted in the totally unacceptable spectrum shown in Fig. 16. At this level of severe compression of the QPSK signal, the receiver's S/N dropped to 9dB, but the receiver was still able to decode the images. This demonstrated that QPSK is very resilient to amplitude compression, much like the results with FM.

The same tests were performed using 16QAM and 64QAM. For 16QAM, when the output power was increased to +41.1dBm (13W), the S/N started to degrade and the shoulder dropped to -25dB. Further increasing the drive power, the S/N dropped to 14dB and the receiver locked up. At this level, the output power was 45.3dBm (34W) and the shoulder was -16dB.

For 64QAM, when the output power was increased to +37.9dBm (6.2W), the S/N started to degrade and the shoulder dropped to -32dB. Further increasing the drive power, the S/N dropped to 20dB and the receiver locked up. At this level, the output power was 42.7dBm (19W) and the shoulder was -21dB. Thus for 64QAM, the shoulder requirement is even more stringent and should be set no higher than -33dB.

These above tests show the necessity of providing considerable "head room" in a DTV transmitter. The head-room is the difference between the acceptable rms output power and the amplifier's max. saturated output power. From the final results reported in the table on page 1, the minumum head rooms required are: QPSK = 10dB, 16QAM = 10.5dB and 64QAM = 11.2dB

REFERENCES:

1. "*Linear* Amplifiers - Buyer Beware", Jim Andrews, KH6HTV Video application note, AN-8, Sept. 2011, 2 pages
2. "Digital Video & Audio Broadcasting Technology", W. Fischer, Springer, Heidelberg, New York, 2010, 811 pages
3. Figs. 20.3 & 20.6 come from Ref. [2] pages 373 & 378
4. See Ref [2], section 21.2, pages 425-428
5. See Ref [2], section 21.7, pages 446-450