Sherwood Engineering HF Test Results

Model TS-990S Serial # B3300174 Test Dates: 05/03, 05/31, 06/08 & 06/25 of 2013

IF BW 2400 –6 / -60, Hz	2460 / 3660	Ultimate	90*	dB
IF BW 500 –6 /-60, Hz	503 / 722	Ultimate	90*	dB

* Phase noise limited

Front End Selectivity (A – F) Tracking preselector, if enabled		A
First IF rejection 8248 kHz	80	dB

All measurements made on 20 meters unless otherwise noted.

Dynamic Range of radio, no preamp, 500 Hz BW, 500 Hz roofing filter

Dynamic Range 20 kHz	111	dB	IP3	+39.5	dBm
Dynamic Range 10 kHz	107#	dB	IP3	+33.5	dBm
Dynamic Range 5 kHz	100*	dB	IP3		dBm
Dynamic Range 2 kHz	87*	dB	IP3		dBm

Combination of phase noise and 3rd order product
* Consisted of phase noise only

Dynamic Range of radio, no preamp, 250 Hz BW, 270 Hz roofing filter

Dynamic Range 20 kHz	112	dB	IP3	+39	dBm
Dynamic Range 10 kHz	110#	dB	IP3	+36	dBm
Dynamic Range 5 kHz	103*	dB	IP3		dBm
Dynamic Range 2 kHz	90*	dB	IP3		dBm

Combination of phase noise and 3rd order product
* Consisted of phase noise only

Dynamic Range of radio, Preamp ON, 500 Hz BW, 500 Hz roofing filter

Dynamic Range 20 kHz	108	dB	IP3	+24	dBm
Dynamic Range 10 kHz	102	dB	IP3	+15	dBm
Dynamic Range 5 kHz	97#	dB	IP3	+7.5	dBm
Dynamic Range 2 kHz	86*	dB	IP3		dBm

Combination of phase noise and 3rd order product
* Consisted of phase noise only

Dynamic Range of radio, sub receiver 14.2 MHz

Dynamic Range 20 kHz	105	dB	IP3	+27.5	dBm
Dynamic Range 10 kHz	105	dB	IP3	+27.5	dBm
Dynamic Range 5 kHz	104#	dB	IP3	+26	dBm
Dynamic Range 2 kHz	95*	dB	IP3		dBm

#Combination of phase noise and 3rd order products
* Consisted of phase noise only

Dynamic Range of radio, sub receiver, alternate conversion scheme 18.1 MHz

Dynamic Range 20 kHz	101#	dB	+21.5	IP3	dBm
Dynamic Range 10 kHz	93	dB	+9.5	IP3	dBm
Dynamic Range 5 kHz	83	dB	-5.5	IP3	dBm
Dynamic Range 2 kHz	81*	dB		IP3	dBm

#Consisted of phase noise and 3rd order products
*Consisted of phase noise only

Blocking above noise floor, 1uV signal @ 100 kHz, AGC On^	145	dB^

^ Signal plus phase noise went up 3 dB

Phase noise (normalized) at 2.5 kHz spacing:	-117	dBc
Phase noise (normalized) at 5 kHz spacing:	-129	dBc
Phase noise (normalized) at 10 kHz spacing:	-138	dBc
Phase noise (normalized) at 20 kHz spacing:	-143	dBc
Phase noise (normalized) at 30 kHz spacing:	-146	dBc
Phase noise (normalized) at 40 kHz spacing:	-148.5	dBc
Phase noise (normalized) at 50 kHz spacing:	-150	dBc
Phase noise (normalized) at 70 kHz spacing:	-151	dBc
Phase noise (normalized) at 100 kHz spacing:	-152	dBc

No significant change beyond 100 kHz

Noise floor, SSB bandwidth 14 MHz, no preamp	-119	dBm
Noise floor, SSB bandwidth 14 MHz, Preamp On	-132	dBm
Noise floor, SSB bandwidth 14 MHz, Preselector On	-113	dBm
Sensitivity SSB at 14 MHz, no preamp	0.75	uV
Sensitivity SSB at 14 MHz, Preamp On	0.17	uV
Sensitivity SSB at 14 MHz, Preselector On	1.4	uV
Noise floor, 250 Hz, 14.2 MHz, no preamp	-129	dBm
Noise floor, 500 Hz, 14.2 MHz, no preamp	-127	dBm
Noise floor, 500 Hz, 14.2 MHz, Preamp On	-138	dBm
Noise floor, 500 Hz, 14.2 MHz, Preselector On	-119	dBm
Noise floor, SSB, 50.125 MHz, no preamp	-120	dBm
Noise floor, SSB, 50.125 MHz, Preamp	-133	dBm
Sensitivity, SSB, 50.125 MHz, no preamp	0.6	uV
Sensitivity, SSB, 50.125 MHz, Preamp	0.13	uV
Noise floor, 500 Hz, 50.125 MHz, no preamp	-127	dBm
Noise floor, 500 Hz, 50.125 MHz, Preamp On	-138	dBm

SUB RECEIVER:

Noise floor by band, 500 Hz filter, preamp OFF & preamp ON:

160 meters	-128 / -137	dBm
80 meters	-128 / -137	dBm
40 meters	-129 / -137	dBm
30 meters	-128 / -137	dBm
20 meters	-129 / -137	dBm
17 meters	-130 / -139	dBm
15 meters	-128 / -138	dBm
12 meters	-130 / -142	dBm
10 meters	-130 / -142	dBm
6 meters	-129 / -142	dBm

Signal for S9, no preamp	-70 dBm	71	uV
Signal for S9, Preamp	-82 dBm	18	uV
Signal for S9, Preselector On	-67 dBm	100	uV

Gain of preamp(s)

Preamp	12	dB

AGC threshold at 3 dB, no preamp	2.0	uV
AGC threshold at 3 dB, Preamp On	0.46	uV
AGC threshold at 3 dB, Preselector On	2.5	uV

Audio roll-off, S9 reference, filter BW wide

-3 dB	220 Hz & 2000	Hz
-6 dB	175 Hz & 2900	Hz

Notes:

The gain of the receiver increases 1.5 dB after 4 hours warm-up compared a cold start. (A change of this amount is not unusual.) Measurements were on 20 meters unless otherwise noted.

The band scope has an on-scale dynamic range of 80 dB. Due to random noise on the display, the useful range is a bit more than 70 dB. With a span of 50 kHz (+ & - 25 kHz), it is not possible to see a 1 uV signal, which is copyable on any HF band on any radio where band noise isn't the limit (typically 20 – 6 meters in a quiet environment). With an Icom IC-781, Icom 756 Pro II or Pro III, a 1 uV signal is clearly 1 division above the baseline with the same span.

The S meter linearity from S9 to S9 +60 dB is spot on. Below S9 an S unit is only 3 dB, instead of the normal 5 or 6 dB. The S meter is affected by the preamp and attenuator, unlike SDR radios which correct for this, all newer Ten-Tec rigs, or the K3 when in absolute S meter mode. The real signal does not change just because the preamp or attenuator is enabled.

The AGC decay, even when set for slowest possible, is too fast for my liking on SSB. A greater adjustment range could easily be changed in a firmware update. (Version 1.04 may have addressed this issue.)

The AGC does exaggerate impulse noise (clicks, tick and pops), as do rigs from Icom and Yaesu. Elecraft, Flex and now Ten-Tec have solved this AGC problem.

The preselector cannot be enabled on 6 meters.

Comments on passive intermodulation (IMD):

Intermodulation occurs not only in mixers and amplifier, but in passive components to some extent. Coils with ferrite or powdered iron cores can cause IMD, and IMD definitely occurs in crystal filters. In filters, intermod usually occurs in the crystals themselves, though it can also happen in coils in a lattice filter, or impedance matching inductors.

While testing the TS-990S, I noticed that IMD could jump up dramatically (more than 10 dB) for a 1 dB change in test signal level. Hysteresis was also noted where the IMD would change depending on whether the two test signals were increased from a lower level or decreased from a higher level. Hysteresis is not unusual when testing radios with narrow roofing filters or radios that are single conversion.

Interestingly, the 500 Hz roofing filter in this sample of the TS-990S exhibited passive IMD, unlike the 270 Hz or the 2.7 kHz roofing filters. When the 500 Hz roofing filter was used, the 5^{th} order IMD dynamic range at 5 kHz spacing was only 107 dB vs. 100 dB for the third-order dynamic range. A 1 dB change in test signal level for both the third-order and the fifth-order IMD caused a 12 dB or greater change in the distortion product. Neither the 270-Hz roofing filter, nor the 2.7-kHz roofing filter exhibited this anomaly.

Thus I measured the radio with not only the standard 500-Hz bandwidth, but also with a 250 Hz DSP bandwidth and the 270-Hz roofing filter.

When measuring the dynamic range on 17 meters at 2-kHz spacing, if the receiver was driven a little higher than necessary to measure the RMDR value, the third-order distortion product was not just one tone, but two or more beatnotes. Moving the frequencies of the two-tone pairs did not affect this observation.

All dynamic-range measurements were made using a broadband HP 3400A or 3400B RMS meter connected to the output of an external Icom SP-20 speaker, my normal test setup. I do not agree with the League's decision to measure third-order dynamic range with an audio spectrum analyzer in a 3, 1 or sub 1-Hz bandwidth to eliminate phase noise from the evaluation. This is not how radios are used on the air. My numbers should be compared to the League's Reciprocal Mixing Dynamic Range (RMDR). As clearly stated by Bob Allison in his April 2012 review of the IC-9100 in his side bar, RMDR is often the limiting factor in receiver performance. In the case of the TS-990S, close-in phase noise of the synthesizer limits performance at 2 and 5 kHz, be it a single signal or a two-tone dynamic-range test. Note: phase noise improves dramatically beyond 5 kHz.

When measuring third-order dynamic range (DR3) as per the League, the third-order distortion product is far below what I can measure with the minimum 3-Hz resolution of an HP 3585A swept spectrum analyzer. The challenge of measuring the dynamic range (DR3) in this manner can be accomplished with a Fast Fourier Transform (FFT) spectrum analyzer. Using an HP 3561A FFT analyzer, it was possible to measure a signal buried in more than 20 dB of phase noise on 20 meters.

Note: The ITU does endorse measuring DR3 with the League's method. (Recommendation SM.1837) The measurement is technically correct, and may be of use to the design engineer who wants to know where to spend time and money in improving the product. During normal amateur operation, a ham will not be copying a desired signal with a filter of 1-Hz bandwidth.

Since the phase noise as measured by Peter Hart on 40 meters was significantly lower (6 dB) than my measurement on 20 meters, it was desirable to look at the synthesizer on all bands at a 2.5 kHz offset. The filter bandwidth was set to 500 Hz, and a 27 dB correction made for phase noise in dBc.

The worst band was 17 meters at -115 dBc / Hz, with 20, 15 and 12 meters -117 dBc / Hz. The phase noise on 10 meters was better than 20 – 12 meters. Due to the division of the LO on lower bands, 40 – 160 meters measured better than 20 – 12 meters by 5 to 8 dB. The lowest phase noise is on 30 meters.

Noise floor and phase noise at 2.5 kHz offset by band

6 meters	-128 dBm	-121 dBc / Hz
10 meters	-125 dBm	-122 dBc / Hz
12 meters	-126 dBm	-117 dBc / Hz
15 meters	-126 dBm	-117 dBc / Hz
17 meters	-125 dBm	-115 dBc / Hz
20 meters	-127 dBm	-117 dBc / Hz
30 meters	-125 dBm	-128 dBc / Hz
40 meters	-124 dBm	-122 dBc / Hz
80 meters	-128 dBm	-124 dBc / Hz
160 meters	-128 dBm	-125 dBc / Hz

The LO architecture has a PLL and a divide by N for the main amateur bands. N = 4 for 14, 18, 21 and 24 MHz. N = 8 for 7 MHz, and divide by 10 for 1.8, 3.5 and the 5 MHz band. For 10 MHz, 28 MHz and 50 MHz, and frequencies outside the amateur bands, the LO is direct from a DDS. This explains the 6 dB difference between my 20 meter measurements and Peter Hart's (RadCom) 40 meter measurements differing by 6 dB.

In general a DDS will have more spurs, while the advantage of a divide by N is greater reduction of phase noise the higher the divide ratio. I checked for spurs on all amateur bands except 5 MHz, and could see no significant difference in spurs between the DDS and the PLL / divide by N. Six meters had slightly more spurs, but not significant in number or level. Generally to produce a spur at or above the noise floor the test signal within an amateur band had to be -23 dBm (S9 +50 dB). On some bands it was necessary to drive the radio at -13 dBm (S9 +60 dB) in order to notice spurs above the noise floor.

For instance I could only locate one spur in the 30 meter band on 10.137 MHz with a test signal at 10.1 MHz. Thus the DDS used on 30 meters had no practical spur problem, and that band showed the best phase noise of all.

The phase noise (reciprocal mixing dynamic range) is worst on 20 – 12 meters, with 20 and 15 meters being major contest bands. Since 20 and 15 meters are relatively quiet in respect to band noise, strong local signals in a contest, for example, could cause the RMDR of the radio to be exceeded.

RMDR by band at 2 kHz spacing:

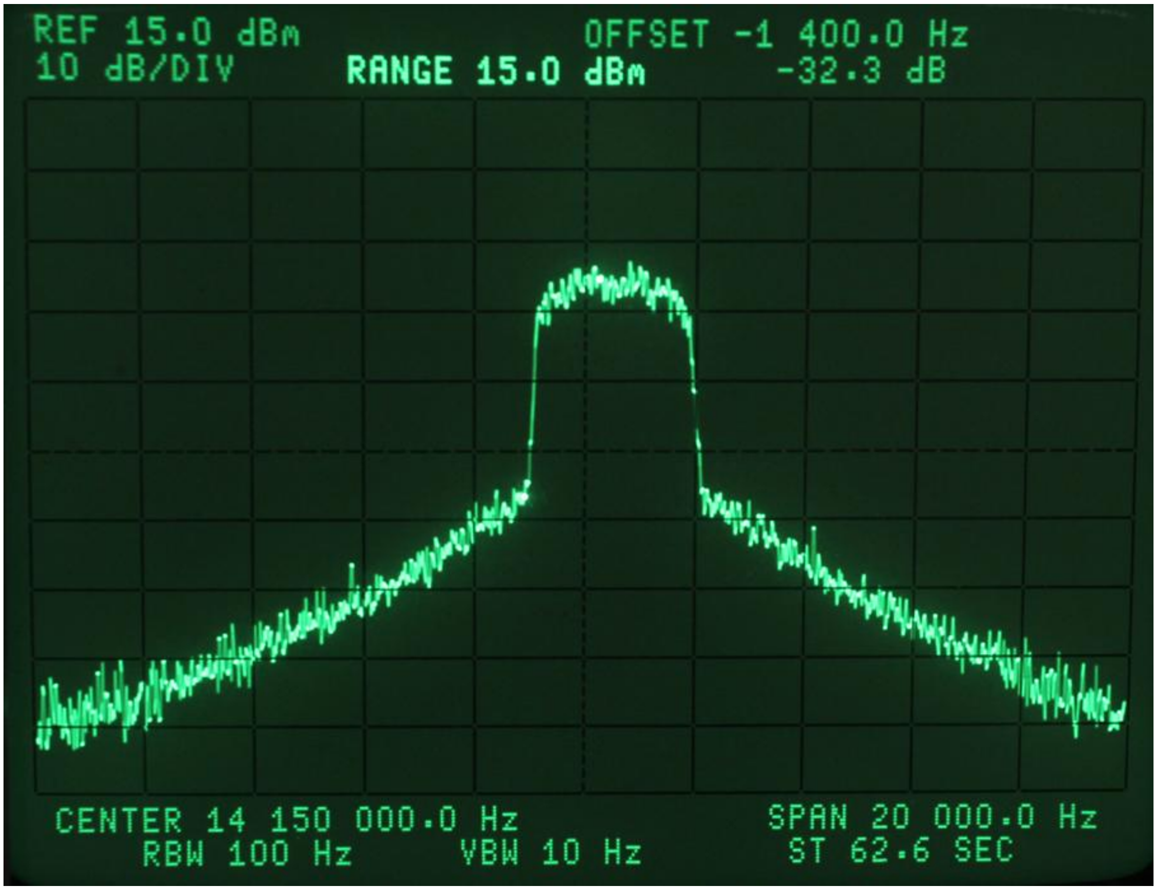
160 meters:	95 dB
80 meters:	94 dB
40 meters:	92 dB
30 meters:	98 dB
20 meters:	87 dB
17 meters:	85 dB
15 meters:	87 dB
12 meters:	87 dB
10 meters:	92 dB
6 meters:	91 dB

Transmit intermodulation measured with white noise fed into the microphone jack. The intermod is down 60 dB approximately 6 kHz from the edge of the transmit passband. This spectrum analyzer screen shot was taken at 200 watts PEP output, and with the ALC reading midscale on the LCD analog meter.

When the power level was reduced to around 90 watts PEP and with no ALC reading at all, the intermod at -60 dB improved to about 5 kHz from the edge of the transmit passband.

For comparison, the best measurement of this type has been with Yaesu rigs running in class A where the intermod was down 60 dB about 2 kHz from the edge of the transmit passband. The Yaesu class A rigs degrade significantly in class A when the ALC is driven to mid scale (about 3 dB). They degrade to a level similar to normal class B operation.

The point where the intermod starts to show up on the transition band of the filter is down about 32 dB for the TS-990S. This compares to the IC-7410 where the intermod was visible 22 dB down.



End Gaussian noise IMD test.

Two-tone tests added July 28, 2013

CW key-down at 200 watts was set to be down 1 division from the top graticule of HP 3585A.

The LCD analog meter read 200 watts.
Two-tone test #1 was with the LCD analog meter reading 100 watts, and the peak level on the HP 3585A was down about 2 dB.
Two-tone test #2 was with the LCD analog meter reading 50 watts, and the peak level on the HP 3585A was down about 5 dB.
ALC was one-half scale at all times.
Looking at the two-tone tests in the time domain, here is how the LCD meter reads in proportion to the scope.

Key down, CW at 200 watts was set to 6 divisions.
The LCD meter reads 165 watts when the two-tone PEP is 6 divisions = 200 watts PEP

The LCD reads 150 watts at 5.8 divisions = 187 watts PEP
The LCD reads 100 watts at 4.8 divisions = 128 watts PEP
The LCD reads 50 watts at 3.5 divisions = 68 watts PEP

The third-order IMD does not change at all between the two power levels.
The mid-level IMD products are virtually identical, while the higher level products do improve modestly at the lower-power level.

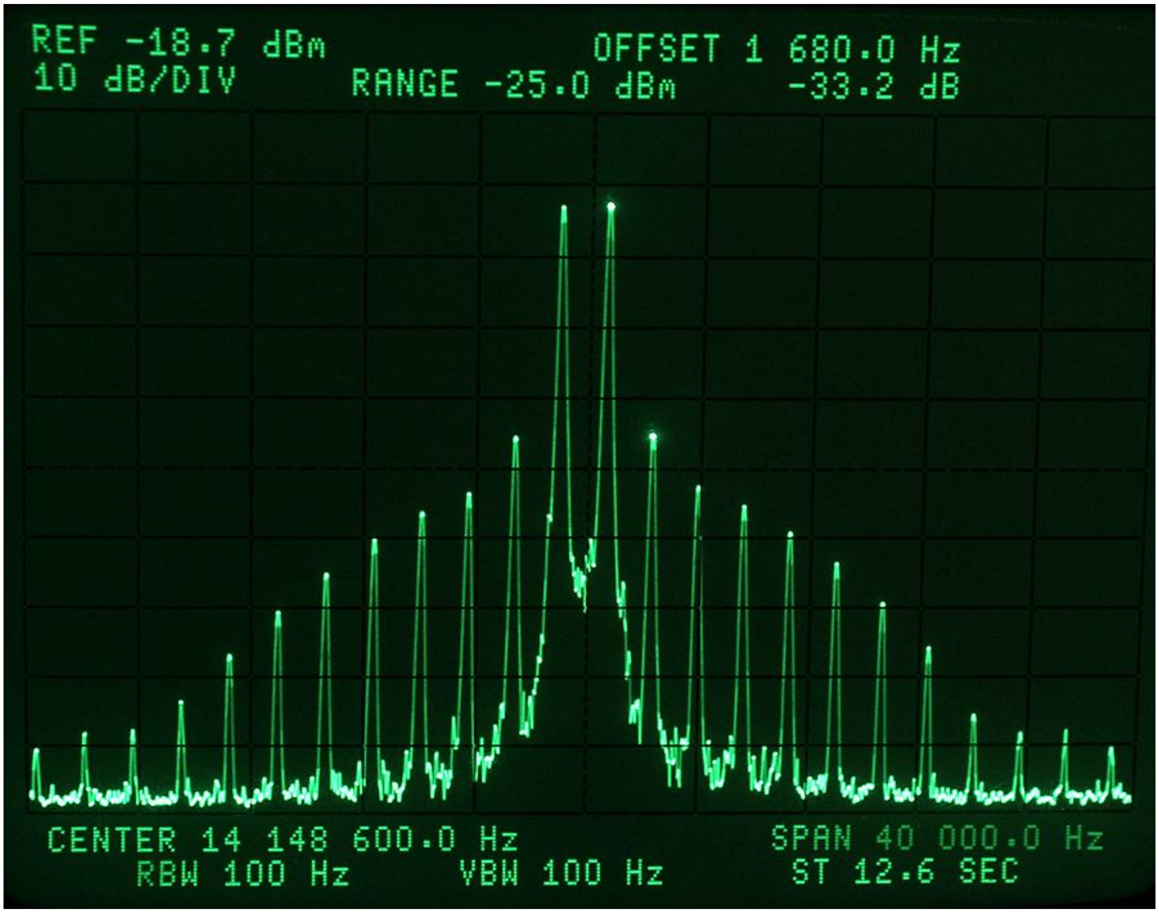
Raw data 3rd order through 15th order reference 100 watts and 50 watts on the LCD meter:

Two tones were 500 Hz and 2200 Hz

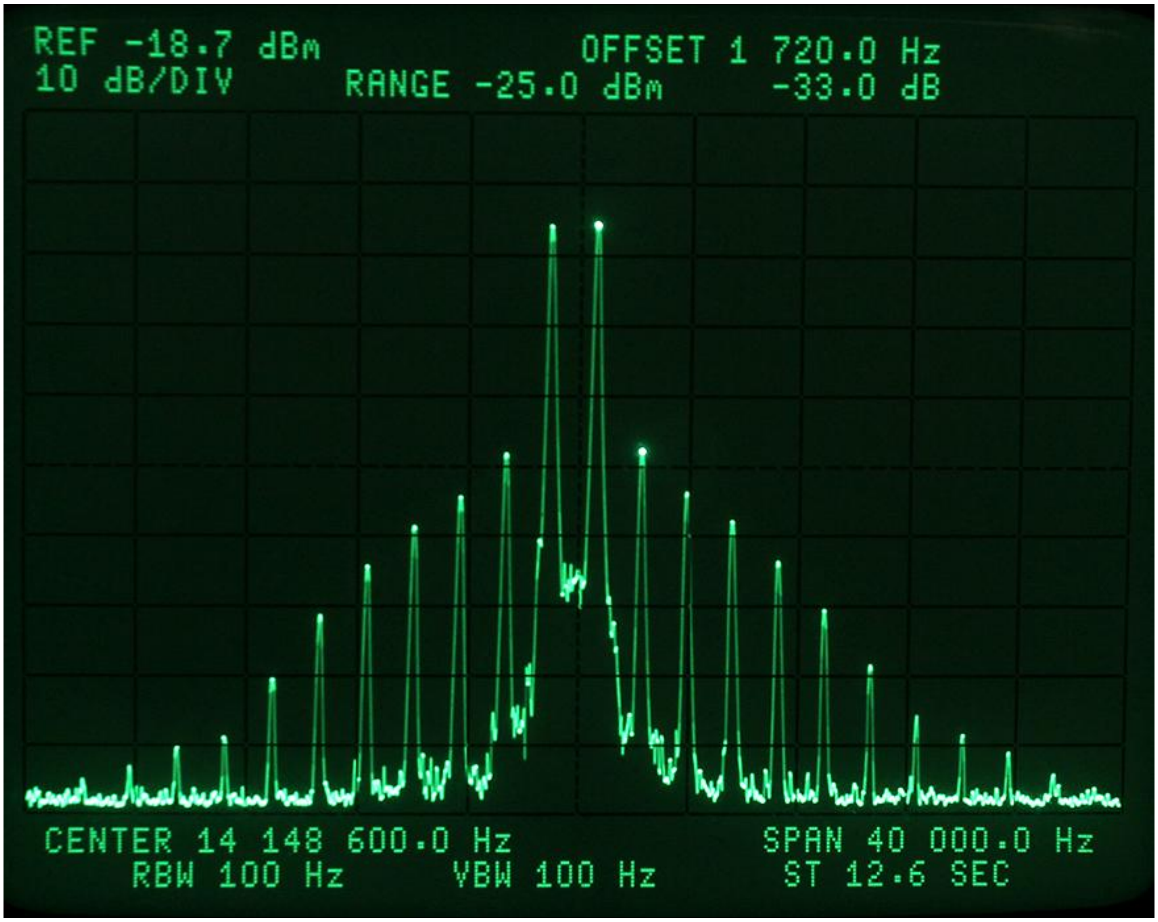
IMD reference one of the two tones, not PEP

Order	100 W	50 W	
3	-33.2	-33.0	dB
5	-40.7	-39.2	dB
7	-43.7	-43.5	dB
9	-47.5	-49.3	dB
11	-52.1	-56.4	dB
13	-57.8	-64.3	dB
15	-64.5	-71.5	dB

Add 6 dB to these numbers for PEP measurement method.



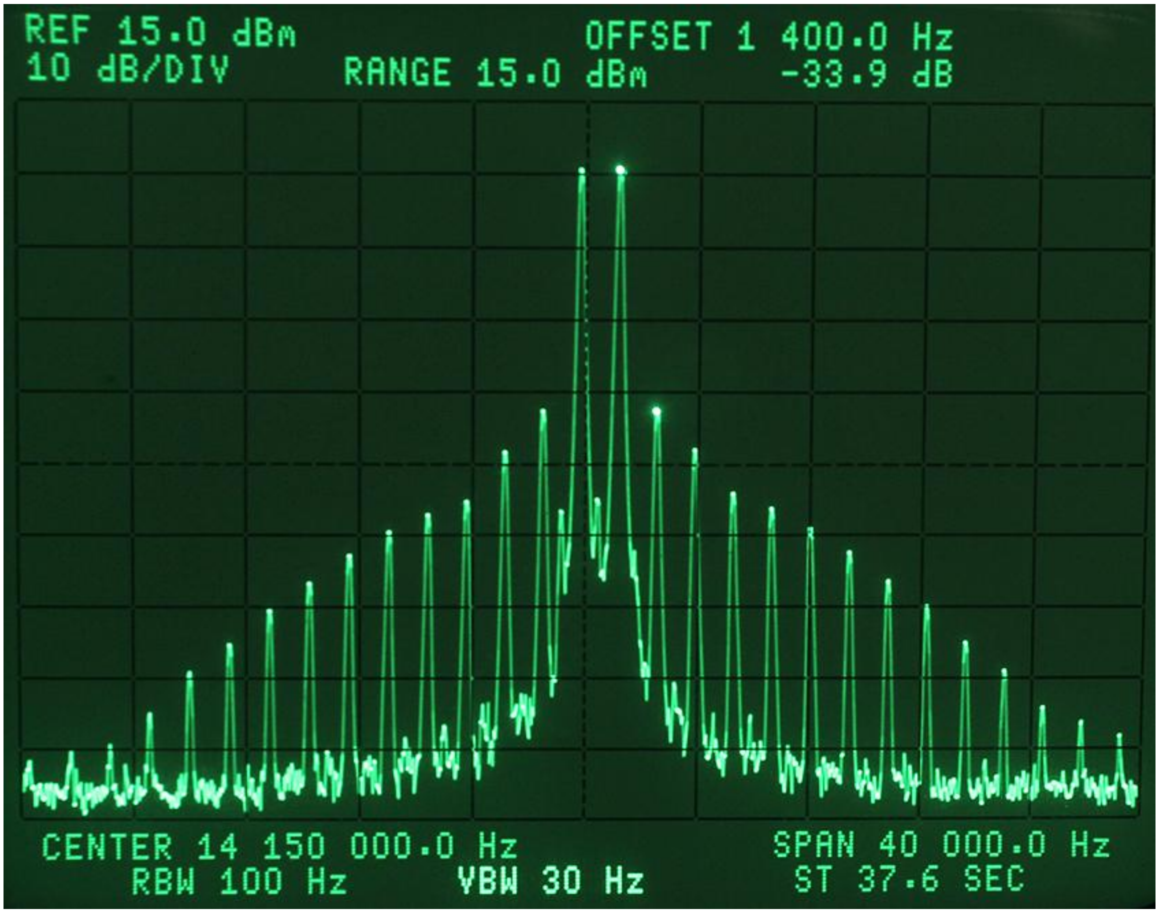
Screen capture from HP 3585A spectrum analyzer, odd-order intermodulation at 100 watts PEP.



Third-order intermodulation at 50 watts PEP.

Addendum - Phase noise of Sub Receiver on four bands in dBc / Hz:

Offset	20 M	15 M	30 M	17 M
2.5 kHz	-123	-121	-114	-111
5 kHz	-132	-130	-121	-120
10 kHz	-138	-136	-126	-126
20 kHz	-142	-141	-133	-133
30 kHz	-144	-143	-136	-135
40 kHz	-144.5	-144	-137	-137
50 kHz	-145	-145	-138	-137.5
70 kHz	-145.5	-146	-139.5	-139
100 kHz	-146.5	-146	-140.5	-140



Two tone test at 200 watts PEP. Third-order product down 33.9 dB from a single tone is excellent for a non-class A power amp. This would be rated as 39.9 dB by the ARRL or by Kenwood.

Overall comments:

The TS-990S will perform quite well in most any environment. Its 20 kHz dynamic range (DR3) is the highest I have measured on any transceiver. While the close-in dynamic range is Reciprocal Mixing Dynamic Range limited (RMDR), the values are all in excess of my minimum recommendation for CW operation of 85 dB.

SSB performance will not be impacted in any way by the RMDR values.

Transmit IMD on SSB is excellent at any drive level from 50 to 200 watts.

Having finished my lab testing of the TS-990S, hopefully I will be able to use this fine rig during the 2013 contest season before returning it to Kenwood.

Rev M

August 28, 2013