IC-705 User Evaluation & Test Report

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Iss. 2, Nov. 8, 2020.

Figure 1: The Icom IC-705.

Introduction: This report describes the evaluation of IC-705 S/N 12003625 from a user perspective. ***Appendix 1*** presents results of an RF lab test suite performed on the radio. I was also able to spend some time with the IC-705 in my ham-shack, and thus had the opportunity to exercise the radio's principal features and evaluate its on-air behavior.

1. Physical "feel" of the IC-705: The IC-705 was conceived as a lightweight portable HF/VHF/UHF transceiver which can be powered from an internal battery pack (BP-272 or BP-307) or from an external 13.8V DC source. RF power output is 5W on battery and 10W on external power. The case dimensions are 200(W) × 83.5(D) × 82(H) mm (excluding projections) and the radio with the BP-272 fitted weighs 1.16 kg.

The IC-705 features a large color touch-screen display similar to that of the IC-7300. This is a new departure in Icom's "portable" transceiver product line, offering easy band/mode selection and navigation through the radio's menus. The placement of many control functions on the touch-screen and in the MULTI knob menus has moved many controls off the front panel.

Owners of current Icom IF-DSP transceivers should find the IC-705 quite familiar, and should feel comfortable with it after a little familiarization with the touch-screen. In addition to the display, the front panel has a number of feature keys in location similar to those on other Icom radios as well as two knobs (Twin PBT, AF Gain + RF Gain/Squelch) and MULTI to the left and right of the display respectively. Pressing the MULTI knob opens a context menu on the right edge of the screen; this menu changes with the previously-selected mode or function, allowing adjustment of appropriate parameters. The learning curve will be minimal for owners of other Icom IF-DSP radios. The Twin PBT and MULTI controls are multi-turn and detented. The main tuning knob is large and has a knurled Neoprene ring and a rotatable finger-dimple; it turns very smoothly with minimal side-play.

The 2.5 mm MIC jack, and the 3.5mm PHONES jack, are on the left edge of the case, behind the front panel. The supplied HM-243 handheld speaker/mic or any other compatible electret or low-impedance dynamic mic can be plugged into the mic jack. (The +8V electret bias on the mic jack can be turned off when using a dynamic mic.) The BNC antenna socket and the grounding screw are also on the left side of the case.

The micro-SD card slot for memory storage and loading, recording and firmware upgrade is below the speaker/mic jacks. A screen capture function (enabled via menu) allows capture of the current screen image to the SD card as a PNG or BMP file by briefly pressing the POWER key. The image can also be viewed on the screen via menu.

Three 3.5mm jacks and a Micro-USB socket are located on the right edge of the case, behind the front panel. From the top down, the jacks are SEND/ALC, TUNER and KEY. The SEND line is low-level and bi-directional. The TUNER jack will interface with external tuners such as the AH-4 and compatible third-party units, as well as the planned AH-705 ATU. The KEY jack accepts a paddle, bug or straight key (configurable via menu).

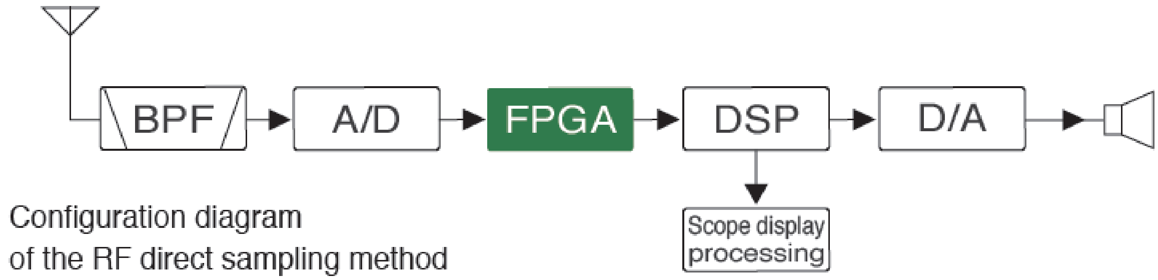
The Micro-USB socket (USB-B) allows PC connectivity via a suitable cable. The concentric +13.8V DC power socket is also on the right side of the case. The battery pack can be charged from the DC power socket or the Micro-USB port (the latter only when the radio is off).

The IC-705 is solidly constructed and superbly finished. Like other Icom radios, it conveys a tight, smooth, and precise overall feel. The ABS plastic case and front panel have a smooth, matte surface. The touch-screen display is the same size as that of the IC-7300. The display can be turned off to conserve battery power.

The battery recess on the rear panel accepts a BP-272 (2 Ah) or BP-307 (3.15 Ah) battery pack. The battery pack has two latches to secure it in the recess.

2. IC-705 architecture: Icom is the first Japanese amateur radio manufacturer to offer a family of amateur transceivers embodying direct-sampling/digital up-conversion SDR architecture. **In the receiver,** the RF signal from the antenna feeds a high-speed 14-bit ADC (analogue/digital converter) via a preselector. This is a set of bandpass filters which protect the ADC from strong out-of-band signals. The ADC digitizes a portion of the HF range defined by the preselector; the digital output of the converter feeds the Field-Programmable Gate Array (FPGA) which is configured as a digital down-converter (DDC) and delivers a digital baseband, 12 kHz wide and centered on 36 kHz, to the DSP which carries out all signal-processing functions such as selectivity, demodulation etc. A DAC (digital/analog converter) at the DSP output decodes the digital signal back to audio. Figure 2 is a simplified block diagram of the IC-705 receiver below 25 MHz.

Figure 2: Simplified block diagram of IC-705 receiver.



The FPGA also delivers a 1 MHz-wide digital video signal to the Scope Display Processing, which manages the screen displays, including the fast FFT spectrum scope, waterfall, audio scope and audio FFT (spectrum analyzer) as used in other Icom transceivers (7300 7610, 9700). The spectrum scope has a maximum span of ±500 kHz, adjustable reference level (-20 to 20 dB), video bandwidth and averaging, and minimum RBW ≤ 50 Hz.

A unique "touch-tune" feature allows quick tuning to a signal displayed on the scope by touching the scope or waterfall field to magnify an area, then touching the desired signal within that area.

In the transmitter, the audio codec converts mic audio to a digital baseband, which the DSP then processes further and the digital up-converter in the FPGA then converts to a digital RF signal at the transmit frequency. This signal is converted to analog by the high-speed 12-bit DAC to the RF excitation for the PA Unit.

Above 25 MHz, a heterodyne converter down-converts the RF signal to an IF in the 38.85 MHz range. This IF is then sampled by the ADC.

3. The touch-screen: The large (93 × 52 mm) color TFT **touch-screen** displays a very clear, crisp image, with excellent contrast and color saturation, and an LCD backlight. The home screen (see Figure 1) displays the current frequency in the upper field, the bar-graph meter in the middle and the spectrum scope in the lower field. The first two keys below the screen, MENU and FUNCTION, are unique to the IC-705. The third key, M.SCOPE, moves the spectrum scope to the middle field; a different screen, selected via the MENU key, can be opened in the lower field (e.g. a multi-function meter, RTTY decoder or CW keyer controls, depending on mode). The waterfall is activated via the EXIT/SET key at the bottom right of the home screen; a reduced-height scope and waterfall can be displayed on the home screen via an EXIT/SET menu parameter.

When the Twin PBT knobs are rotated, a bandwidth/shift pop-up appears, and the trapezoidal icon at the top centre of the screen changes, a dot appears to the right of the icon. Pressing the inner PBT knob clears the Twin PBT setting. Pressing the MULTI knob opens a menu with RF PWR, MIC Gain, COMP and MONITOR settings. A setting is changed by touching its icon and rotating the MULTI knob. The MULTI knob menus are context-sensitive; for example, pressing and holding the NB key activates NB, and displays NB settings when the MULTI knob is pressed. RIT and ΔTX are adjusted by pressing their respective keys on the top right of the front panel and rotating the MULTI knob without pressing it. In this mode, pressing the MULTI knob clears these functions.

Pressing and holding the Notch, NR and NB keys makes their settings accessible from the MULTI knob. These can be used to select notch width, NR level and NB parameters respectively. When MN is selected, a pop-up displays its width.

TPF (Twin Peak Filter) can be activated via the MULTI menu in RTTY mode.

The **menus** are somewhat akin to those in other current Icom DSP radios. I found the set-up process fairly intuitive after consulting the relevant user-manual sections in cases of doubt. Icom continues the use of a "Smart Menu" system which changes available functions in a context-sensitive manner based on the mode currently in use.

Different screens are selected by pressing the MENU key on the bottom left of the screen. Menu selections with default values can be returned to default by pressing and holding their DEF softkey. Many of the screens have a "Back" arrow key to return to the previous screen.

The MENU screen includes a "SET" icon which opens a list of the 705's configuration settings arranged in a hierarchy which is easily navigable. The desired line in the on-screen table can be selected via the MULTI knob or up/down arrows.

The FUNCTION key opens a screen with switches for functions such as AGC, COMP, IP+, MONItor, VOX, BK-IN etc. Some of these (NB, NR, Preamp/ATT, NOTCH) duplicate front-panel keys.

The QUICK key opens a context-sensitive Quick Menu for rapid configuration or default setting of various menu functions.

Touching the leading (MHz) digits of the frequency display opens a band-selection screen; the desired band is selected by touching its designator. Mode selection is similar; touching the current mode icon opens the mode-selection screen. Tuning steps for kHz and Hz are set by touch, or by touch/hold, on the respective digit groups.

The filter selection and adjustment procedure is similar to that on other Icom DSP radios. Touch the FIL-(n) icon to toggle between FIL-1, FIL-2 and FIL-3. Touch and hold this icon to adjust the filter bandwidth and select CW/SSB Sharp/Soft shape. All IF filters are continuously adjustable. As in other Icom IF-DSP radios, filters with 500 Hz or narrower bandwidth have the BPF shape factor, but a non-BPF filter can be configured via Twin PBT.

The Time-Out Timer feature limits transmissions to a preset duration (3, 5, 10, 20 or 30 minutes, selectable by menu.) RF PWR can be turned down to 0. This feature is useful when receiving via active antennas or mast-mounted preamplifiers without T/R switching, or to avoid damaging test equipment when conducting receiver measurements.

The AUDIO screen displays an audio FFT spectrum analyzer and oscilloscope very similar to those implemented in the IC-7851, IC-7800 (Firmware V3.00 and higher) and IC-7700 (V2.00 and higher). This feature is very helpful in setting up one's transmit audio parameters, and also for visual audio assessment of a received signal.

4. Receiver front end management: The P.AMP/ATT icon on the FUNCTION screen toggles between Preamps 1 and 2, and a 20 dB RF attenuator. The AF/RF/SQL control functions as an AF Gain control when not pressed; when pressed, it opens a context menu for selection of RF GAIN and SQL functions.

The input level limit for a direct-sampling receiver is the ADC clip level, where the digital output of the ADC is "all ones". When the ADC clips, the receiver can no longer process signals. Thus, the 705 provides means to prevent this condition from arising. When the ADC starts clipping, a red OVF (overflow) icon lights at the top left of the screen. At this point, rotating the RF Gain control counter-clockwise will extinguish OVF and restore normal operation. RF Gain should be set just at the point where OVF goes dark, otherwise weak-signal reception will be degraded. If required, ATT can be activated as well. When OVF lights, the preamp should be turned OFF. (In general, use of the preamp on 7 MHz and below is not recommended, as the band noise is almost always higher than the receiver's noise floor and the preamp will only boost band noise without improving signal/noise ratio.)

The IC-705 dos not have an IP+ (dither) function.

Being a current IC-7300/IC-7610 owner, I found that the IC-705's controls and menus fell readily to hand. A user familiar these radios, or with the IC-9700, should find the IC-705 very user-friendly and its learning curve manageable. The IC-705's default settings are very usable, allowing the radio to be placed in service with minimal initial set-up.

The IC-705 offers a configurable SWR Plot indicator with manual stepping (as in the IC-7300) rather than a sweep function.

An front-panel AUTO TUNE key "tunes in" CW signals rapidly and accurately.

Touching the currently-displayed meter scale toggles between scales. Touching and holding the meter scale opens the multi-function meter, which displays all scales simultaneously.

5. USB, WLAN & Bluetooth interfaces: The IC-705 is equipped with a micro-USB "B" port. The radio can be directly connected via the "B" port to a laptop or other PC via the supplied USB cable. This is without doubt one of the IC-705's strongest features. The USB port transports not only CI-V data, ***but also TX and RX PCM baseband*** between the IC-705 and the computer. As a result, the USB cable is the only radio/PC connection required. Gone forever is the mess of cables, level converters and interface boxes! This feature is now standard on all Icom HF radios released since 2009. An Icom driver is required in the PC; this is downloadable from the Icom Japan World website.

The WLAN interface supports connection to a PC, LAN or Internet router via Wi-Fi, for NTP time synchronization or for remote control via the Icom RS-BA1 V.2 software suite. As the IC-705 has a resident RS-BA1 server, a collocated PC is *not* required.

The Bluetooth interface supports connection to a compatible Bluetooth headset or Android data device (smartphone or tablet).

6. Filter selections and Twin PBT: As do the other Icom DSP transceivers, the IC-705 offers fully-configurable RX IF selectivity filters for all modes. Three default filter selections are available via the touch-screen for each mode, with continuously variable bandwidth via the FILTER menu. In addition, there are selectable Sharp and Soft shape factors for SSB and CW. The BPF filter configuration feature (for filter bandwidths of 500 Hz or less) operates in the same manner as on other Icom IF-DSP radios.

Pressing and holding the Twin PBT knob restores PBT to neutral.

The TPF menu item in the MULTI RTTY context menu selects the Twin Peak Filter (TPF) in RTTY mode. No CW APF (Audio Peak Filter) is provided. However, the CW RX LPF and HPF in the TONE SET menu are a reasonable alternative to the "missing" APF; their ranges are 100 - 2000 and 500 - 2400 Hz respectively. The HPF and LPF can be set to "bracket" the received CW tone in a tight 100 Hz audio bandwidth. The DEF softkey restores these filters to default (off).

7. BPF vs. non-BPF filters: As in other Icom IF-DSP radios, the IC-705 allows the user to select two additional shapes for 500 Hz or narrower filters, in addition to SHARP and SOFT. These are BPF (steeper skirts) and non-BPF (softer skirts).

To configure a BPF filter, select a 500 Hz or narrower CW, RTTY or SSB-D filter with Twin PBT neutral. To set up a non-BPF filter, select a filter with BW > 500 Hz, and narrow the filter to 500 Hz or less by rotating the Twin PBT controls. When Twin PBT is displaced from its neutral position, a dot appears to the right of the filter icon at the top of the screen.

8. Notch filters: The tunable manual notch filter (MN) is inside the AGC loop, and is extremely effective. The MN has 3 width settings (WIDE, MID and NAR); its stopband attenuation is at least 70 dB. The manual notch suppresses an interfering carrier before it can stimulate AGC action; it thus prevents swamping. To adjust the notch frequency precisely, press and hold the NOTCH icon (FUNCTION screen), then rotate the main tuning knob.

The auto notch filter (AN) is post-AGC. It suppresses single and multiple tones, but strong undesired signals can still cause AGC action and swamp the receiver. MN and AN are mutually exclusive, and AN is inoperative in CW mode. The NOTCH key toggles OFF – AN – MN. Touching and holding the NOTCH icon in MN mode opens the MN context menu next to the MULTI knob. MN position and width can then be adjusted by rotating the MULTI knob.

9. NR (noise reduction): The DSP NR is very effective. In SSB mode, the maximum noise reduction occurs at an NR control setting of 10. As NR level is increased, there is a slight loss of "highs" in the received audio; this is as expected. The measured SINAD increase in SSB mode was about 14 dB. For precise NR adjustment, press and hold the NR key, then rotate the MULTI knob.

10, NB (noise blanker): The IF-level DSP-based noise blanker is arguably one of the IC-705's strongest features. I have found it to be extremely effective in suppressing fast-rising impulsive RF events before they can stimulate AGC action within the DSP algorithm.

The NB completely blanks noise impulses which would otherwise cause AGC clamping. I found its performance comparable to that of the IC-7300 NB. The NB menu (threshold, depth and width) is accessed by pressing and holding the NB key. The NB works very effectively in conjunction with NR.

11. AGC system: The IC-705 has an in-channel AGC loop. The digital AGC detector for the AGC loop is within the DSP algorithm. Level indications from the detector are processed in the DSP, and control the DC bias on a PIN-diode attenuator at the RF ADC input. This architecture prevents strong adjacent signals from swamping the AGC, and allows full exploitation of the ADC's dynamic range.

The AGC menu is similar to that of other Icom IF-DSP radios. The Slow, Mid and Fast AGC settings are customizable via menu for each mode, and AGC can be turned OFF via menu.

12. Receive and transmit audio menus: The IC-705 TONE SET menu offers the same generous selection of audio configuration parameters as that of the IC-7300 and IC-7600: TBW (low and high cutoff frequencies), RX and TX Bass/Treble EQ, RX HPF and LPF, transmit compression, etc. All audio settings are grouped under the SET/Tone Control menu.

13. Metering: The on-screen bar-graph meter displays the S-meter at all times; touching the scale toggles between P_O, SWR, ALC and COMP. Touch and hold displays the multi-function meter.

14. TUNER function: Not tested due to lack of a compatible ATU.

15. RTTY decoder and memory keyer: The IC-705 features an on-screen RTTY decoder/display as well as an 8 x 70 chars RTTY memory keyer for transmitting short messages.

16. VFO/Memory management: **The** IC-705 offers the same VFO and memory management features as other current Icom HF+ transceivers: VFO/memory toggle and transfer, memory write/clear, memo-pad, Split, VFO A/B swap [A/B] and equalize [touch and hold A/B], etc.

17. Brief "on-air" report: Upon completing the test suite, I installed the IC-705 in my shack and connected it to multi-band HF/6m vertical antenna and then to my 2m/70cm vertical collinear antenna. Due to extremely poor HF propagation at my location, on-air HF tests were not feasible. Thus, tests with local stations were conducted on 2m and 70cm.

a) SSB: I chatted with a local Ham friend on 2m SSB, using the HM-243 speaker-mic and the IC-705's default audio settings. At 10W output, signals were 55 to 57, taking polarization loss into account; switching to 5W caused < 1 S-unit drop as expected but with no loss of intelligibility. Audio reports were excellent, and NR at 5 sufficed to reduce the band noise to a comfortable level.

As discussed in **10.** above, I found the NR very effective on SSB. Even at 10, NR did not attenuate "highs" excessively. NR is very effective in conjunction with NB, although in this test, NB was not needed.

The preamp (**≈** 10 dB gain) brought weak stations up to very comfortable copy without S/N degradation. The SSB filters and Twin PBT were excellent, as we have come to expect from other Icom DSP radios.

b) DV: I conducted a test with another local friend on 2m DV simplex with 10W output. Due to the distance between us (17 km), the path was subject to QSB and marginal at times. When copy was solid, signals were approx. 57 and audio quality was excellent. (NR was off, as it degrades DV receive audio quality.) The preamp was required for this test.

c) FM: I checked in on local 2m and 70cm repeaters, and found the receive audio very good. The distant station also provided a good audio report. The TONE and TSQL features worked very effectively. The preamp was on.

d) AM: In a quick check of AM reception, I listened to various MF and HF broadcast stations. A local station on 690 kHz and a music broadcast on 5995 kHz sounded good on the IC-705's internal speaker, but much clearer (as one would expect) on my SP-41 external speaker. I noted that the AM IF filters cut off quite steeply below 200 Hz, as in other Icom DSP radios.

The 9 kHz AM filter offered the best frequency response, but the 6 kHz setting sounded a little "smoother" and 3 kHz cut the "highs" excessively. The IC-705's Twin PBT is fully functional in this mode. Mid AGC was best for average to good signal conditions, but Fast AGC handled rapid selective fading more effectively. NR was quite effective in improving the S/N ratio of weak AM signals (but at the cos of some high-frequency audio response).

The NR did not distort the recovered audio. NR Level 6 was the "sweet spot", providing optimum noise reduction with minimal attenuation of highs. Higher NR settings cut the highs excessively. Above 10, the NR control had no further effect. (Note that the AM bass and treble EQ settings were both 0 dB, with HPF off.)

AN was effective in suppressing interfering tones and heterodynes, but MN caused some distortion when tuned across the signal. The reason for this is that MN suppresses the carrier in a manner similar to selective fading.

Slight hiss was evident when receiving weak AM signals, but NR largely suppressed it.

e) RTTY: I tuned in some 40m RTTY signals and was able to tune them accurately with the FFT tuning aid and decode them reliably using the internal decoder.

18. USB AF Output Level Check: During receiver testing, I checked the receive AF levels at the USB port using a level-meter program. All levels were well within specifications.

19. USB MOD Input Level Check: During transmitter testing, I also checked the AF input levels at the USB port using a tone-generator program, for 10W PEP output. All levels were well within specifications. To use the USB port, I installed the IC-705 Icom USB drivers (downloadable from the Icom Japan world-wide support site).

https://www.icomjapan.com/support/firmware_driver/

20. Case temperature: The radio showed no signs of excessive heating even after lengthy "key-down" phase noise testing at full output. The rear of the case was warm to the touch (temperature indicator at mid-range, 2 orange bars).

21. Concerns: Only two minor items were flagged:

- An "RF tail" when unkeying in QSK-CW mode. The duration of the tail is 0.5 to 1.5 ms at the preset power output plus the decay time of the code element (determined by the CW rise time setting). The initial steady-state portion is shorter at higher rise time settings.

- A 2.5 dB initial ALC overshoot during the white noise overshoot test (Test 20, p. 27). No significant overshoot was observed in SSB voice testing.

22. Conclusion: After a few days' "cockpit time" on the IC-705, I am very favorably impressed by its solid, refined construction, clear and informative display, easy familiarization experience, smooth operating "feel", impressive array of features and excellent on-air performance. This radio is unique in that it is a true, stand-alone* direct-sampling/digital up-conversion SDR in an attractive, compact package. Yet again, Icom has a winner with the SDR performance, intuitive touch-screen and the straightforward USB computer interface. This is certainly a lot of radio for its price category.

23. Acknowledgements: I would like to thank Ray Novak N9JA at Icom America, and Paul Veel VE7PVL and Jim Backeland VE7JMB at Icom Canada for making an IC-705 available to me for testing and evaluation.

**Stand-alone SDR: self-contained, not requiring a computer as a prerequisite for operation.*

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Update history:
Iss.1: Pre-release, October 30, 2020.
Iss. 2: Corrected 14 MHz DR3 data. November 8, 2020.

Appendix 1: Performance Tests on IC-705 S/N 12003625

As performed in my home RF lab, October 3 - 27. 2020.

A. HF/6m Receiver Tests

1: MDS (Minimum Discernible Signal) is a measure of ultimate receiver sensitivity. In this test, MDS is defined as the RF input power which yields a 3 dB increase in the receiver noise floor, as measured at the audio output.

Test Conditions: SSB 2.4 kHz **&** CW 500 Hz SHARP, ATT off, NR off, NB off, Notch off. AGC-M. Max. RF Gain. Levels in dBm. IP+ off except where shown.

Table 2: MDS (HF, 6m).

MHz	1.905		3.605		14.105		28.1		50.1		144.2		432.1	
Preamp	SSB	CW	SSB	CW	SSB	CW	SSB	CW	SSB	CW	SSB	CW	SSB	CW
Off	-123	-129	-122	-129	-120	-127	-119	-126	-120	-126	-125	-130	-123	-129
ATT					-114									
1	-133	-139	-133	-140	-131	-137	-131	-136	-130	-138	-137	-143	-136	-142
2	-134	-140	-134	-141	-133	-139	-132	-139	-133	-139				

1a: ADC Clip Levels. In this test, the receiver is offset +25 kHz above the test signal frequency and the input level required to light the on-screen **OVF** icon is noted.

OVF indication occurs only when a strong out-of-channel signal is present. In-channel signals stimulate AGC action which attenuates the signal at the ADC input.

Test Conditions: RX tuned to 14.1 MHz, test signal freq. 14.125 and 50.1 MHz*, CW 500 Hz SHARP, ATT off, NR off, NB off, Notch off. AGC-M. Max. RF Gain. Input level is gradually increased until the **OVF** icon just flickers.

**At 50.1 MHz (f_0 > 25 MHz), the heterodyne converter is in the signal path. Thus, ADC clip levels will change.*

Table 3: OVF (Clip) Levels.

	OVF (Clip) Level dBm	
Preamp	**14.125 MHz**	**50.1 MHz**
Off	-6.5	-7
1	-19.5	-20
2	-24	-24

1b: AM Sensitivity. Here, an AM test signal with 30% modulation at 1 kHz is applied to the RF input. The RF input power which yields 10 dB (S+N)/N is recorded (Table 4). At 0.9 MHz, readings are taken with the 16 dB MF Band Attenuator off and on. (This attenuator is valid only for $f \leq$ 1.7 MHz).

Test Conditions: ATT off, NR off, NB off, Notch off. AGC-M. FIL1 (9 kHz) AM Filter (FIL2, 6 kHz for Air Band).. Levels in dBm for 10 dB (S+N)/N.

Table 4: AM Sensitivity.

Preamp	0.9 MHz	3.9 MHz	14.1 MHz	118.5 MHz Air Band
OFF	-102	-103	-100	-105
1	-109	-113	-111	-118
2	-111	-114	-115	

Notes:

1. Very clean demodulation; full quieting ≈ -75 dBm (preamp off).
2. NR suppresses high-frequency hiss at low signal levels.
3. Unmodulated carrier at -94 dBm (preamp off, NR off) increases noise floor by 5 dB.

1c: 12 dB SINAD FM sensitivity. In this test, a distortion meter is connected to the PHONES jack, and an FM signal modulated by a 1 kHz tone with 3 kHz peak deviation is applied to the RF input. Input signal power for 12 dB SINAD is recorded (Table 5). For WFM, the peak deviation of the test signal is 45 kHz. FQ = fully-quieted.

Table 5: FM 12 dB SINAD Sensitivity in dBm.

Preamp	29.5 MHz	52.525 MHz	146.52 MHz	446.0 MHz	98.5 MHz WFM
Off	-106	-107	-113	-108	-105 (-99 FQ)
1	-118	-118	-124	-123	-116 (-110 FQ)
2	-120	-120			

1d: Squelch and TSQL (CTCSS) sensitivity: A carrier, unmodulated and then modulated by a sub-audible CTCSS tone, is applied and the input level at which the squelch opens is noted.

Table 6: FM Carrier Squelch Sensitivity in dBm.

Preamp	146.52 MHz	446.0 MHz
Off	-112	-112
On	-126	-126

- TSQL sensitivity: f_0 = 146.52 MHz. Tone = 100 Hz (1Z), peak tone deviation = 700 Hz.
  Tone squelch opens reliably at -118/-130 dBm (preamp off/on).

1e. Noise Figure. In this test, a calibrated noise source is connected to the antenna port via a precision DC - 2 GHz step attenuator, and the PHONES jack is connected to the RMS voltmeter. First, the antenna port is terminated in a precision 50Ω load and a 0 dBr receive audio reference set. Then, the noise source is connected and the noise loading adjusted for a +3 dBr audio level. The attenuator setting is noted. See Table 5.

As the noise source is calibrated, its noise power density PSD (-82 dBm/Hz) is known. Noise figure NF is derived as follows (modified Y-factor method):

NF ≈ PSD - ATT +174 where PSD = -82 dBm/Hz and ATT = attenuator setting in dB.

Test Conditions: 500 Hz CW, AGC Mid, ATT off, NR off, NB off.

Table 7: Noise figure in dB.

Band	Preamp	Meas. NF dB	NF calc. from MDS dB
50 MHz	off	22	21
	1	11	9
	2	9	10
144 MHz	Off	17	17
	On	6	4
432 MHz	Off	19	18
	on	7	5

2: Reciprocal Mixing Noise occurs in a direct-sampling SDR receiver when the phase-noise sidebands of the ADC clock mix with strong signals close in frequency to the wanted signal, producing unwanted noise products in the detection channel and degrading the receiver sensitivity. Reciprocal mixing noise is a measure of the ADC clock's spectral purity**.**

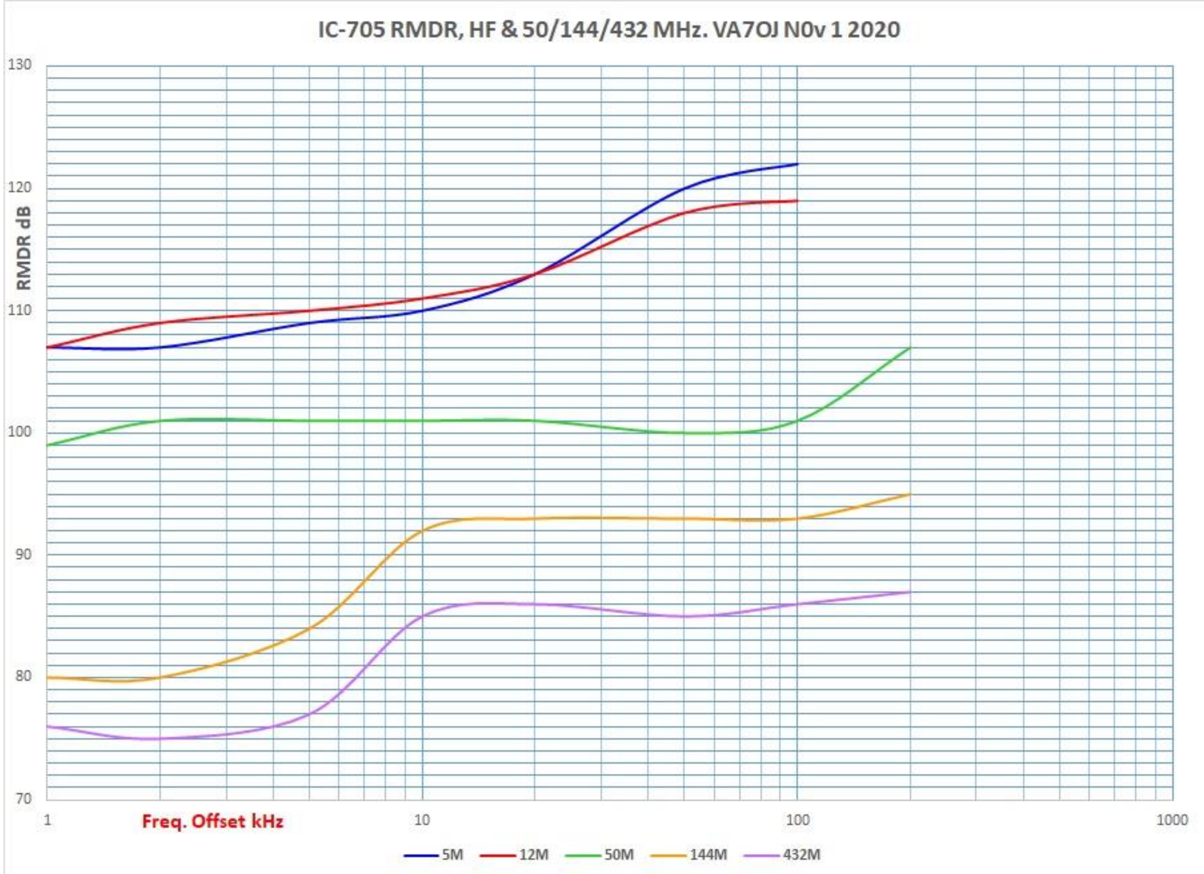
In the IC-705, the local oscillator of the heterodyne converter contributes to reciprocal mixing noise in the bands above 25 MHz.

In the HF test, a test signal from a high-quality 5 MHz OCXO with known low phase noise is injected into the receiver's RF input at a fixed offset from the operating frequency. The RF input power is increased until the receiver noise floor increases by 3 dB, as measured at the audio output. Reciprocal mixing noise, expressed as a figure of merit, is the difference between this RF input power and measured MDS. The test is run with preamp off. The higher the value, the better.

For the 50/144/430 MHz test, the signal source is a Rohde & Schwarz SMBV100A vector signal generator with low phase noise.

Test Conditions: CW mode, 500 Hz filter, preamp off, ATT off, NR off, AGC-M, NB off, max. RF Gain, positive offset. Reciprocal mixing *in dB* = input power – MDS *(both in dBm)*. Phase noise *in dBc/Hz* = - (RMDR+10 log 500) = -(RMDR + 27). ***Note:*** For Δf > 20 kHz, OVF lights before noise floor increases by 3 dB.

Figure 3: IC-705 RMDR.



3: IF filter shape factor (-6/-60 dB). This is the ratio of the -60 dB bandwidth to the -6 dB bandwidth, which is a figure of merit for the filter's adjacent-channel's rejection. The lower the shape factor, the "tighter" the filter.

In this test, an approximate method is used. An RF test signal is applied at a power level approx. 60 dB above the level where the S-meter just drops from S1 to S0. The bandwidths at -6 and -60 dB relative to the input power are determined by tuning the signal generator across the passband and observing the S-meter.

Test Conditions: 14.100 MHz, SSB/CW modes, preamp off, IP+ off, AGC-M, ATT off, NR off, NB off.

Table 8: IF Filter Shape Factors.

Filter	Shape Factor		6 dB BW kHz	
	Sharp	Soft	Sharp	Soft
2.4 kHz SSB	1.37	1.42	.2.52	2.43
1.8 kHz SSB	1.48	1.52	1.95	1.94
500 Hz CW	1.28	1.42	0.50	0.54
250 Hz CW	1.33	2.37	0.26	0.24

4: AGC threshold. An RF test signal is applied at a level 6 dB below AGC threshold, with AGC off. The signal is offset 1 kHz from the receive frequency to produce a test tone. The AF output level is observed on an RMS voltmeter connected to the PHONES jack.

Test Conditions: 14.100 MHz, 2.4 kHz USB, Preamp off, IP+ off, AGC M, ATT off, NR off, NB off. Initial RF input level -105 dBm.

With AGC-M, increase RF input power until AF output level increases < 1 dB for a 1 dB increase in input level. Measured values per **Table 8.**

Table 9: AGC Threshold.

Preamp	AGC Threshold dBm
Off	-92
1	-102
2	-107

5: Manual Notch Filter (MNF) stopband attenuation and bandwidth. In this test, an RF signal is applied at a level ≈ 70 dB above MDS. The test signal is offset 1 kHz from the receive frequency to produce a test tone. The MNF is carefully tuned to null out the tone completely at the receiver audio output. The test signal level is adjusted to raise the baseband level 3 dB above noise floor. The stopband attenuation is equal to the difference between test signal power and MDS.

Test Conditions: 14.100 MHz USB at ≈ -50 dBm (S9 + 20 dB), 2.4 kHz Sharp, AGC-M, preamp off, IP+ off, ATT off, NR off, NB off, MNF on, Twin PBT neutral.

Test Results: Measured MDS was -127 dBm per Test 1. Stopband attenuation = test signal power - MDS.

Table 10a: Manual Notch Filter Attenuation.

MNF BW	Test Signal dBm	Stopband Atten. dB
WIDE	-37	90
MID	-36	91
NAR	-37	90

5a: MNF Bandwidth. The receive frequency is now offset on either side of the null by pressing RIT and rotating the MULTI knob. The frequencies at which the audio output rises by 6 dB are noted. The **-6 dB bandwidth** is the difference between these two frequencies.

Table 10b: MNF BW.

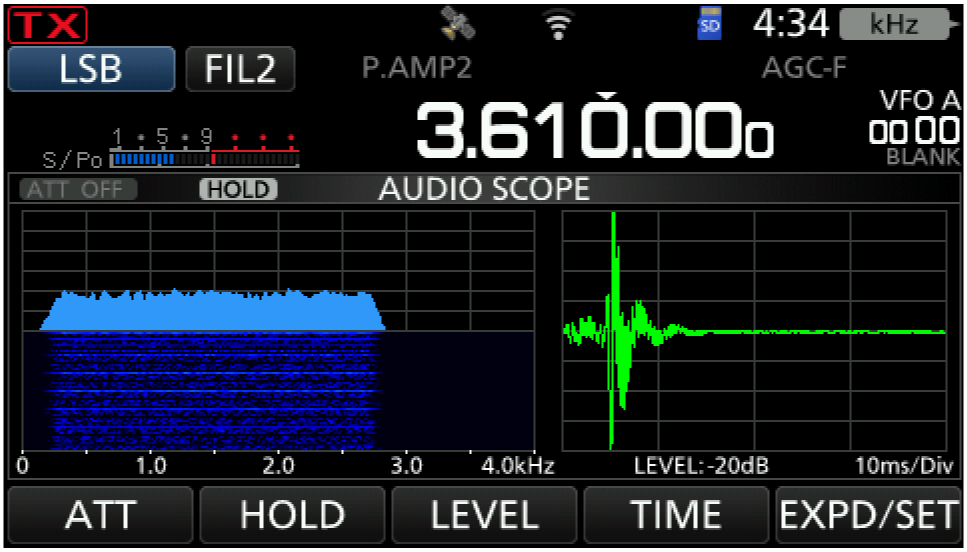
MNF -6 dB BW Hz	
Wide	18
Mid	12
Narrow	9

5b: Auto-Notch (AN) Check. AN completely suppresses AF tone at -5 dBm input level.

6: AGC impulse response. The purpose of this test is to determine the IC-705's AGC response in the presence of fast-rising impulsive RF events. Pulse trains with short rise times are applied to the receiver input.

Test Conditions: 3.6 MHz LSB, 2.4 kHz SSB filter (Sharp), NR off, NB off/on, Preamp off/1, AGC-F, with decay time set to 0.1 sec.

Figure 4: Audio scope display for AGC impulse response test.



Test with pulse trains. Here, the pulse generator is connected to the IC-705 RF input via a step attenuator. The IC-705 is tuned to 3.6 MHz, as the RF spectral distribution of the test pulse train has a strong peak in that band. AGC Fast (0.1 sec) and Preamp 2 are selected.

The pulse rise time (to 70% of peak amplitude) is 10 ns. Pulse duration is varied from 12.5 to 100 ns. In all cases, pulse period is 600 ms. The step attenuator is set at 23 dB. Pulse amplitude is $16V_{pk}$ (e.m.f.)

The AGC recovers completely within the 0.1 sec window; there is no evidence of clamping. NR softens the tick sound.

Table 11: AGC impulse response.

Pulse duration ns	Ticks	AGC recovery ms	S: Pre off	S: Pre 1
12.5	Y	≈ 100 (no clamping)	S9	S9
30	Y	≈ 100 (no clamping)	S9	S9
50	Y	≈ 100 (no clamping)	S9	S9
100	Y	≈ 100 (no clamping)	S9	S9

7: Noise blanker (NB) impulse response. As the IC-705's noise blanker is a DSP process "upstream" of the AGC derivation point, the NB should be very effective in suppressing impulsive RF events before they can stimulate the AGC. To verify this, the NB is turned on during Test 6 (above).

Test Conditions: NB on, Preamp 1 or 2, Level 50%, Depth 4 or 5, Width 68.

Table 12: NB impulse suppression.

Pulse duration ns	Ticks		
Preamp	Off	1	2
12.5	N	Light	N
30	N	"	N
50	N	"	N
100	Light	"	N

Next, NR is activated. With NR at 6, any residual artifacts are suppressed.

- As in other Icom IF-DSP radios, the NB mitigates AGC response to fast-rising RF events.

8: S-meter tracking & AGC threshold. This is a quick check of S-meter signal level tracking.

Test Conditions: 2.4 kHz USB, Preamp off, ATT off, AGC MID. A 14.100 MHz test signal at MDS is applied to the RF input. The signal power is increased, and the level corresponding to each S-meter reading is noted. (S9 readings are taken with Preamp off, 1 and 2 in turn on HF, and with Preamp off and on in turn on VHF/UHF).

Table 13a: S-Meter Tracking.

Freq. MHz	S1	S2	S3	S4	S5	S6	S7	S8	S9	S9+10	S9+20	S9+30	S9+40	S9+50	S9+60
14.1	-95	-92	-90	-87	-85	-82	-79	-76	-73	-62	-53	-43	-33	-23	-13
144.1	-106	-103	-101	-98	-96	-93	-90	-88	-85	-74	-65	-55	-46	-36	-26
432.1	-103	-100	-98	-95	-93	-90	-87	-85	-82	-73	-62	-53	-43	-33	-12

Freq. MHz	S9 P1	S9 P2
14.1	-83	-88
144.1	-97	
432.1	-97	

8a: Attenuator tracking. This is a quick verification of attenuator accuracy.

Table 13b: ATT Value.

ATT	Atten. dB
OFF	0
ON	20

9: Two-Tone 3rd-Order Dynamic Range (DR_3). The purpose of this test is to determine the range of signals which the receiver can tolerate while essentially generating no spurious responses.

In this test, two signals of equal amplitude P_i and separated by a 2 kHz offset Δf are injected into the receiver input. If the test signal frequencies are f_1 and f_2, the offset $\Delta f = f_2 - f_1$ and the 3rd-order intermodulation products appear at $(2 f_2 - f_1)$ and $(2 f_1 - f_2)$.

The two test signals are combined in a passive hybrid combiner and applied to the receiver input via a step attenuator. The receiver is tuned to the upper and lower 3rd-order IMD products ($2 f_2 – f_1$ and $2 f_1 - f_2$ respectively) which appear as a 600 Hz tone in the speaker. The per-signal input power level P_i is adjusted to raise the noise floor by 3 dB, i.e. IMD products at MDS. The Pi values for the upper and lower products are recorded and averaged. $DR_3 = P_i - MDS$.

DR3 is measured with IP+ off and on, to determine the effect of internal dither and randomization on front-end linearity.

Note: *IP_3 (3rd-order intercept) is not included here, as this parameter is irrelevant to a direct-sampling SDR. The transfer and IMD curves of the ADC diverge, so the intercept point does not exist.*

Test Conditions: Δf = 2 and 20 kHz, 500 Hz CW, AGC-S, ATT off, NR off, NB off, CW Pitch = 12 o'clock.

Table 14: DR_3 in dB.

	f_1 MHz/Δf kHz					
Preamp	**14.01/2**	**50.1/2**	**144.2/2**	**144.2/20**	**432.1/2**	**432.1/20**
Off	88	84	74	81	72	82
1	86	83	78	78	77	81
2	86	79				

9a: Two-Tone 2nd-Order Dynamic Range (DR_2) & Second-Order Intercept (IP_2). The purpose of this test is to determine the range of signals far removed from an amateur band which the receiver can tolerate while essentially generating no spurious responses within the amateur band.

In this test, two widely-separated signals of equal amplitude P_i are injected into the receiver input. If the signal frequencies are f_1 and f_2, the 2nd-order intermodulation product appears at ($f_1 + f_2$). The test signals are chosen such that ($f_1 + f_2$) falls within an amateur band.

The two test signals are combined in a passive hybrid combiner and applied to the receiver input via a step attenuator. The receiver is tuned to the IMD product ($f_1 + f_2$) which appears as a 600 Hz tone in the speaker. The per-signal input power level P_i is adjusted to raise the noise floor by 3 dB, i.e. IMD product at MDS. The P_i value is then recorded.

$DR_2 = P_i$ - MDS. Calculated $IP_2 = (2 * DR_2)$ + MDS.

Test Conditions: f_1 = 6.1 MHz, f_2 = 8.1 MHz, CW mode, 500 Hz filter, AGC off, ATT off, NR off, NB off, CW Pitch = 12 o'clock. DR_2 in dB; IP_2 in dBm.

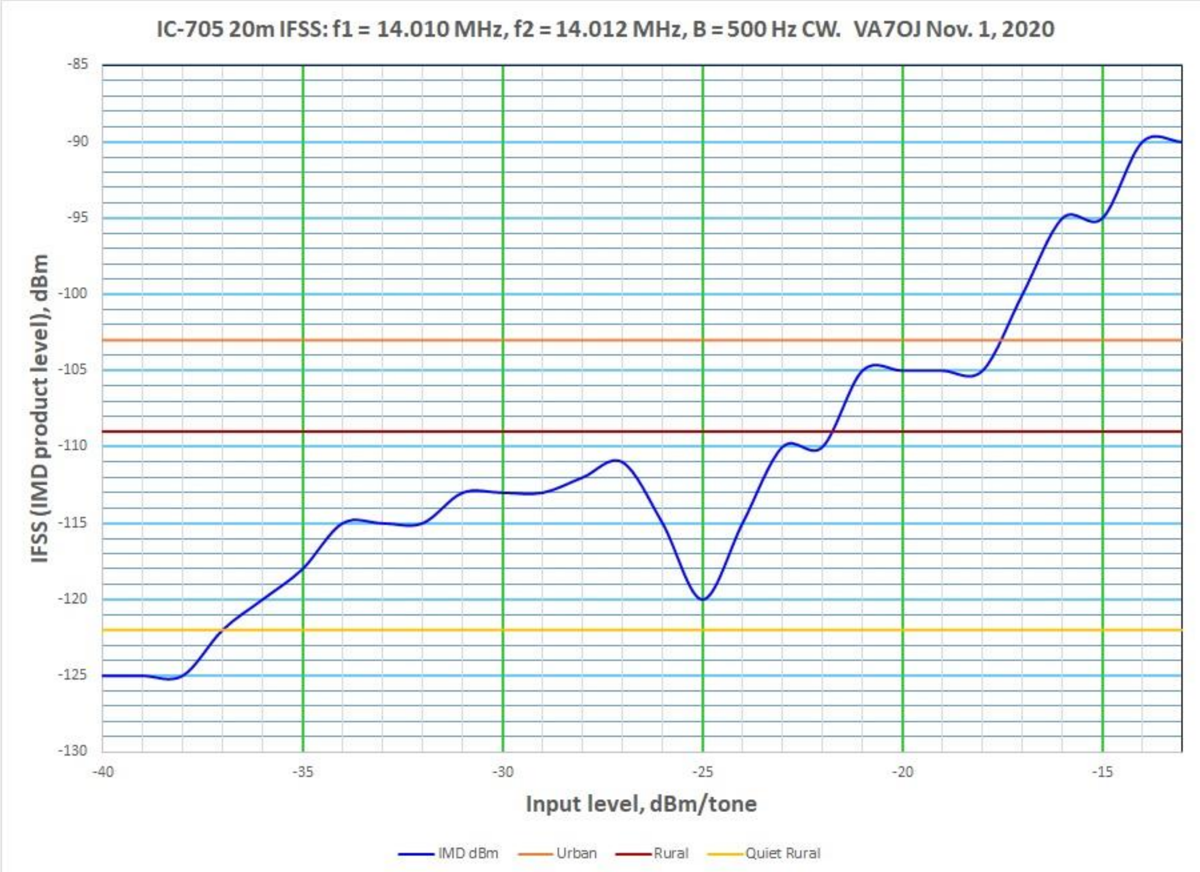
Table 15: 6.1/8.1 MHz DR_2.

MDS dBm, 14.2 MHz	DR_2 dB	IP_2 dBm
-137	100	+63

9b: Two-Tone IMD_3 (IFSS, Interference-Free Signal Strength) tested in CW mode (500 Hz), ATT = 0 dB, AGC Med. Test frequencies: f_1 = 14010 kHz, f_2 = 14012 kHz. IMD_3 products: 14008/14014 kHz. IMD_3 product level was measured as absolute power in a 500 Hz detection bandwidth at various test-signal power levels with IP+ (Dither/Random) off, on and on with Preamp 1. AGC off, ATT= 0 dB. The ITU-R P-372.1 band noise levels for typical urban and rural environments are shown as datum lines. The input level at the top end of each curve corresponds to -1 dBFS, or 1 dB below OVF (ADC clip) level. See Figure 5.

The IMD product level was derived by measuring the S/N ratio of the IMD product for each input level setting, and subtracting MDS.

Figure 5: IFSS (2-tone IMD_3) vs. test signal level.



Notes on 2-tone IMD_3 test: This is a new data presentation format in which the amplitude relationship of the actual IMD_3 products to typical band-noise levels is shown, rather than the more traditional DR_3 (3^{rd}-order IMD dynamic range) or SFDR (spurious-free dynamic range). The reason for this is that for an ADC, SFDR referred to input power rises with increasing input level, reaching a well-defined peak ("sweet spot") and then falling off. In a conventional receiver, SFDR falls with increasing input power.

If the IMD_3 products fall below the band-noise level at the operating site, they will generally not interfere with desired signals.

The IC-705 IFSS data is presented here as an adjunct to the traditional DR_3 test data. See ***Reference 1.***

10: Spectrum Scope Resolution Bandwidth. In a spectrum analyzer, the resolution bandwidth (RBW) determines how far apart in frequency two (or more) signals must be to be resolved into separate and distinct displays on the screen.

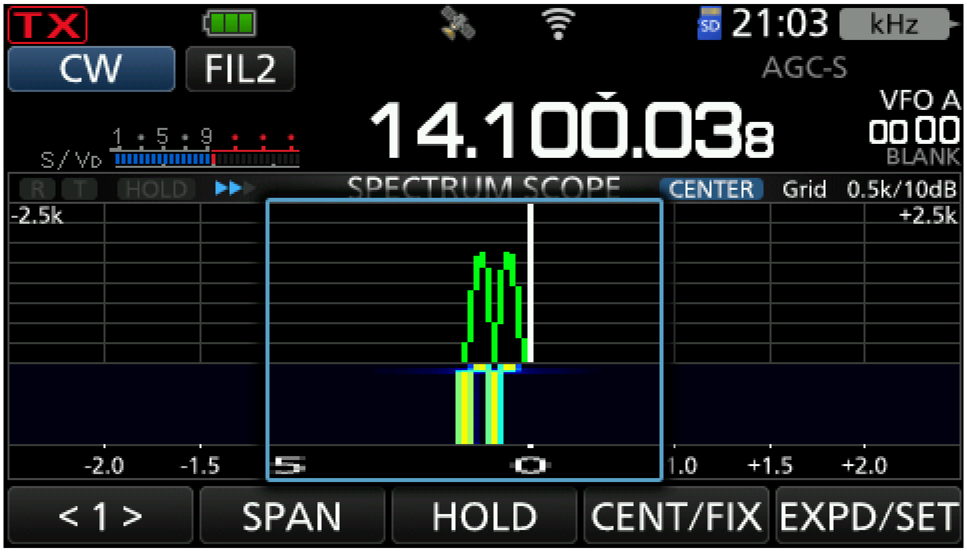
Test conditions: Test signals: f_1 = 10100 kHz, f_2 = 10100.100 kHz, CW, 250 Hz. Span = ± 2.5 kHz, VBW = Narrow, Averaging = 4, ATT OFF, REF LEVEL = +20 dB, preamp off. Waterfall on, speed MID (default).

To measure RBW, f_1 and f_2 are injected into the antenna input at a level sufficient to produce spikes whose vertical amplitude reaches the top of the scope grid.

f_2 is moved closer to f_1 until two distinct spikes are ***just*** observable. To facilitate adjustment, the signal spike image can be touched to open the zoom window.

Test result: Two signals can be clearly distinguished at 50 Hz spacing, i.e.50 Hz minimum RBW.

Figure 6a: Spectrum scope RBW (50 Hz).



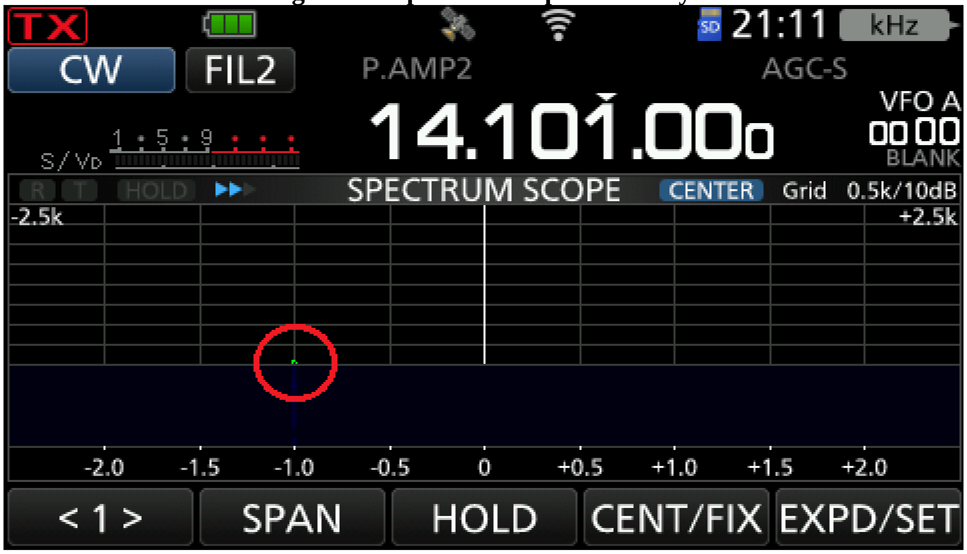
10a: Spectrum Scope Sensitivity. In this test, the RF input signal level is adjusted to produce a spike which is just visible above the scope "grass" level.

Test conditions: 14.100 MHz Span = ± 2.5 kHz, VBW = Wide, Averaging = 4, ATT OFF, REF LEVEL = +20 dB, Waterfall off. DSP filter setting is irrelevant.

Table 25: Spectrum Scope Sensitivity.

Minimum Visible Spike for Span = ± 2.5 kHz	
Preamp	**Level dBm**
Off	-111
1	-126
2	-131

Figure 6b. Spectrum scope sensitivity.



Notes on spectrum scope: Two refinements to the spectrum scope would enhance its usefulness as a BITE (built-in test equipment) feature:

- An option to display a vertically expanded scope field without the waterfall when EXPD/SET is pressed, The Audio Scope field can be expanded vertically in this manner.
- Extended scope dynamic range, to display signal amplitude from the noise floor to ADC clip level. This would greatly facilitate use of the scope as a signal-analysis tool.

11a: HF Noise Power Ratio (NPR). An NPR test was performed, using the test methodology described in detail in ***Ref. 1***. The noise-loading source used for this test was a noise generator fitted with bandstop (BSF) and band-limiting filters (BLF) for the test frequencies utilized.

$$NPR = P_{TOT} - BWR - MDS$$

where P_{TOT} = total noise power in dBm for 3 dB increase in audio output

BWR = bandwidth ratio = $10 \log_{10} (B_{RF}/B_{IF})$

B_{RF} = RF bandwidth or noise bandwidth in kHz (noise source band-limiting filter)

B_{IF} = receiver IF filter bandwidth in kHz

MDS = minimum discernible signal (specified at B_{IF}), measured at 2.4 kHz SSB prior to NPR testing

Test Conditions: Receiver tuned to bandstop filter center freq. $f_0 \pm 1.5$ kHz, 2.4 kHz SSB, ATT off, Preamp off, max. RF Gain, Preamp off, IP+ off, NR off, NB off, Notch off, AGC-S. Test results are presented in Tables 16a and 16b.

Table 16a: HF NPR Test Results (preamp off).

DUT	BSF kHz	BLF kHz	MDS dBm	P_{TOT} dBm	BWR dB	NPR dB
IC-705	1940	60…2044	-123	-19	29.2	75
	3886	60…4100	-122	-14	32.3	76
	5340	60…5600	-122	-14	33.6	74
	7600	6…8160	-120	-11	35.3	74
	11700	316...12360	-121	-14	37.0	70
	16400	316...17300	-122	-14	38.5	70

Note on NPR test: When testing NPR on other direct-sampling receivers, I have found that the noise loading drove the ADC into clipping before the AF noise output increased by 3 dB. Thus, I developed an alternative method in which the noise loading is set to 1 dB below clipping and the NPR read directly off the spectrum scope. The limited amplitude range of the IC-705 spectrum scope precludes that method, but on the IC-705 it was possible to obtain a 3 dB increase in AF noise output without ADC clipping. This allowed use of the "legacy" test method as described in ***Ref. 2.***

Even so, it was not possible to test NPR with the preamp on, as clipping occurred with these settings. Nonetheless, with preamp off I was able to obtain meaningful NPR values, which can be compared with those for other radios.

11b: 144/432 MHz Noise Power Ratio (NPR). An NPR test was performed, using the test methodology described in detail in ***Ref. 1***. The noise-loading source used for this test was the R&S SMBV100A vector signal generator in ARB mode, loaded with an NPR waveform generated using the R&S WinIQSIM2® and NPR software applications.

For this test, RF bandwidth B_{RF} = 1 MHz and notch width = 5 kHz. f_0 was offset by 50 kHz to move a generator artifact out of the notch.

Test Conditions: Receiver tuned to notch center freq. f_0 + 1.5 kHz, 2.4 kHz SSB, ATT off, Preamp off, max. RF Gain, Preamp off, IP+ off, NR off, NB off, Notch off, AGC-S. SMBV100A clocked from 10 MHz lab standard. P_{TOT} set to -1 dBFS. ***Test results:*** See Table 13 and Figures 7a, 7b and 7c.

Table 16b: 144/432 MHz NPR Test Results.

DUT	f_0 MHz	NPR Offset kHz	Rx MHz	P_{TOT} dBm	NPR dB
IC-705	144.2	50	144.2485	-29	**53**
	432.2	50	432.2485	-21	**55**

Note on NPR test: When testing NPR on direct-sampling SDR receivers, the noise loading is set to 1 dB below clipping and the NPR read directly off the spectrum scope. It was not possible to test NPR with the preamp on, as the added gain drove the ADC into clipping.

Figure 7a: 146 MHz NPR.

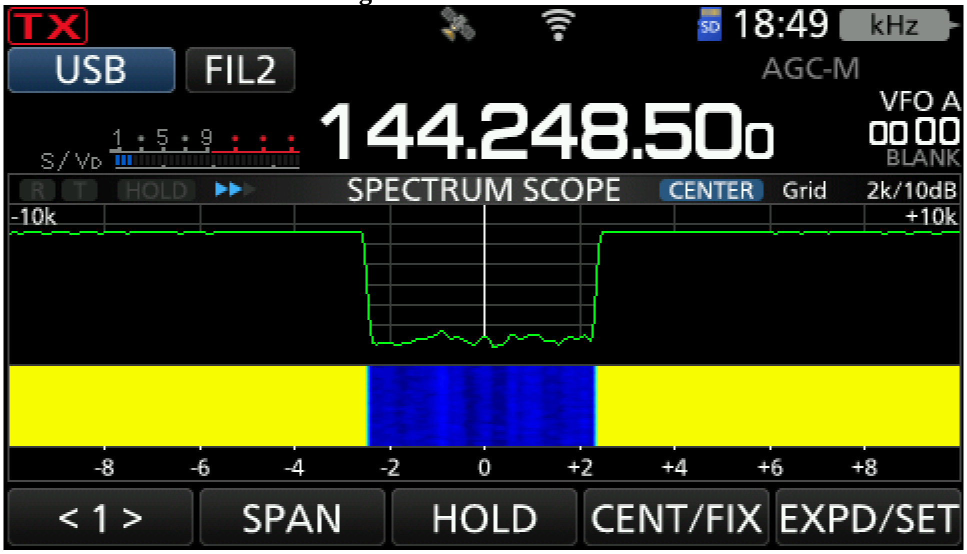
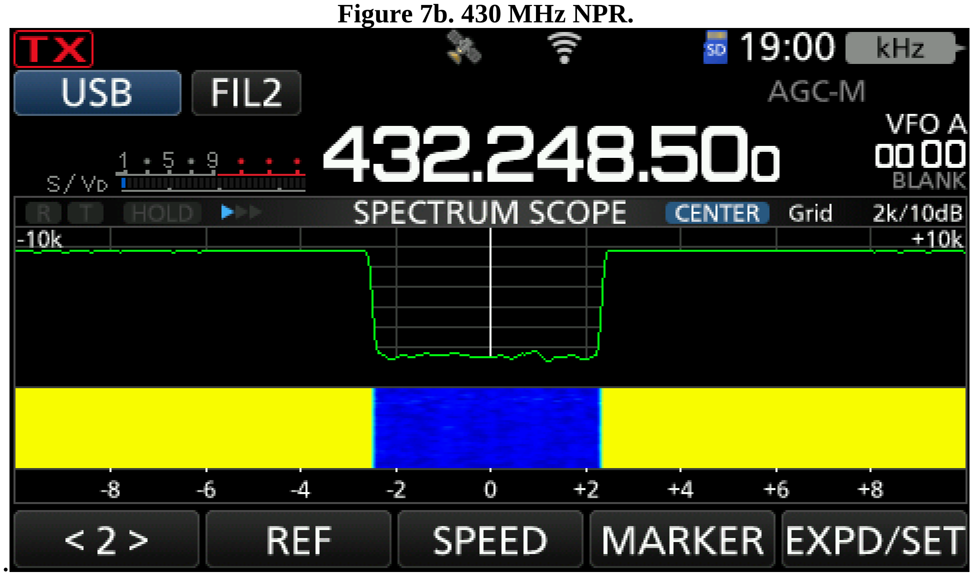


Figure 7b. 430 MHz NPR.



SMBV-100A NPR measurement limit ≈ 70 dB.

12a: Aliasing rejection. 25.000 MHz is the top of the IC-705 direct-sampling tuning range. In this test, a test signal at 29.950 MHz is applied to the antenna port and the IC-705 is tuned to its alias frequency (19.950 MHz). The test signal power is increased sufficiently to raise the AF output by 3 dB.

Test Conditions: Receive frequency 24.950 MHz, CW, 500 Hz. Test signal at 29.950 MHz applied to ANT input. ATT off, max. RF Gain, Preamp off, IP+ off, NR off, NB off, Notch off, AGC-S. RMS voltmeter connected to PHONES jack.

Test signal level = -30 dBm. No aliasing detected at 19.950 MHz.

Test Conditions for IF leakage & breakthrough: Receive frequency 25.1 & 38.85 MHz, CW, 500 Hz. MDS at 38.85 MHz: -126 dBm.

Test signal applied to ANT input. ATT off, max. RF Gain, Preamp off, IP+ off, NR off, NB off, Notch off, AGC-S. RMS voltmeter connected to PHONES jack. Adjust test signal level for a 3 dB increase in receive audio level.

12b: IF leakage. Receive frequency 25.1 MHz (heterodyne converter in-line). IF = 38.85 ± 0.5 MHz. Apply 38.85 MHz test signal at -30 dBm. No IF leakage detected.

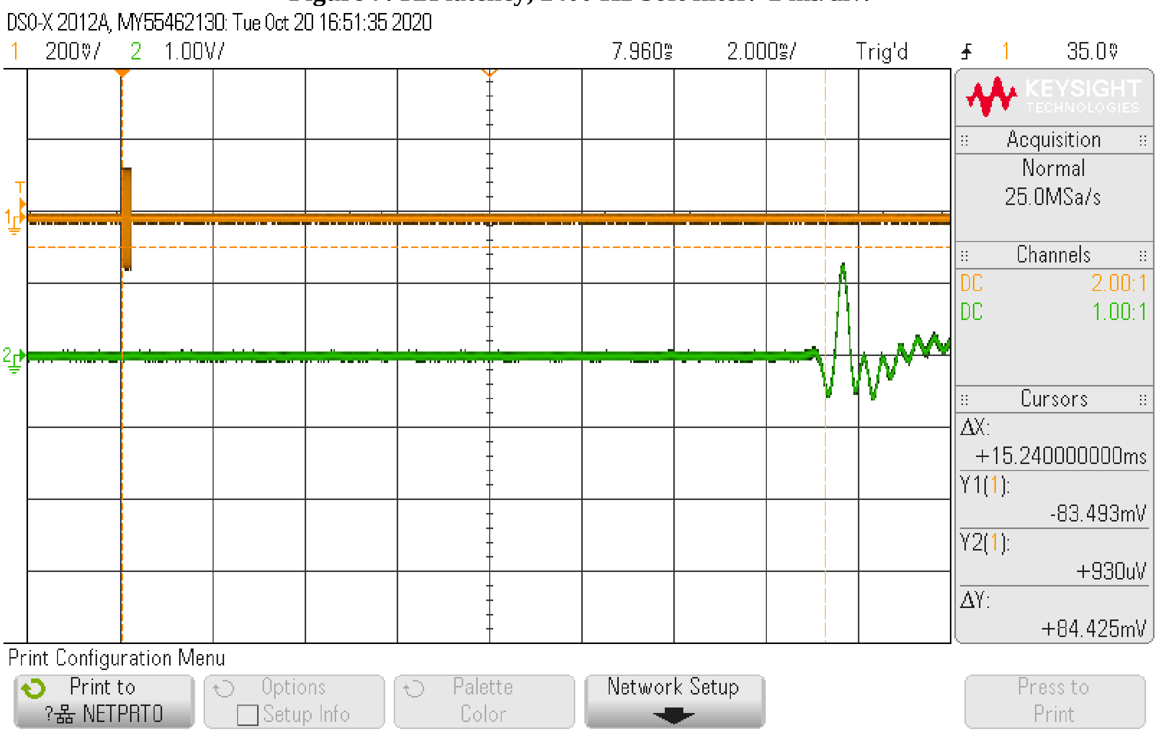
12c: IF breakthrough. Receive frequency 38.85 MHz (heterodyne converter in-line). IF = 38.85 ± 0.5 MHz. Apply 38.85 MHz test signal at -30 dBm. No IF breakthrough detected.

12d: Image rejection. Receive frequency 25.5 MHz. Apply test signal at 25.5 + 2(2 * 38.85) = 103.2 MHz, -30 dBm. No image response detected.

13: Receiver latency. Latency is the transit time of a signal across the receiver, i.e. the time interval between arrival of the signal at the antenna input and appearance of the demodulated signal at the AF output. Various aspects of receiver design exert a major influence on latency; among these are DSP speed and group delay across selectivity filters. As the DSP speed is fixed by design, we measure latency for various filter configurations (bandwidth and shape factor). Figure 7 illustrates an example.

To measure latency, repetitive pulses are fed to the DUT antenna input and also to Channel 1 of a dual-trace oscilloscope. Channel 2 is connected to the DUT AF output. The scope is triggered from the pulse generator's trigger output. The time interval between the pulses displayed on Channels 1 and 2 is recorded for each test case.

Figure 7: RX latency, 2400 Hz Soft filter. 2 ms/div.



Test Conditions: 14.1 MHz, Preamp off, AGC Fast, IP+ off, max. RF Gain, ATT off, NR off, NB off.

Table 17: Receive latency test results.

Mode	Filter BW kHz	Shape Factor	Latency ms
USB	3.6	Soft/Sharp	15.2/15.4
	2.4		15.4/15.2
	1.8		15.7/15.6
CW	1.2	Soft/Sharp	15.6
	0.5		18.8
	0.25	Sharp	21.8
	0.25	Soft	19.6
RTTY	2.4		15.2
	0.5		15.7
	0.25		20.7
USB-D	3.0	Sharp/Soft	15.2
	1.2		15.7
	0.5		18.7

14: NR noise reduction, measured as SINAD. This test is intended to measure noise reduction on SSB signals close to the noise level. A distortion meter is connected to the PHONES jack. The test signal is offset 1 kHz from the receive frequency to produce a test tone, and RF input power is adjusted for a 6 dB SINAD reading. NR is then turned on, and SINAD read at 30%, 50% and 60% (max.) NR settings.

Test conditions: 14.1 MHz USB, 2.4 kHz Sharp, AGC-M, preamp off, IP+ off, max. RF Gain, ATT off, NB off, Twin PBT neutral. Test signal at -122 dBm (6 dB SINAD)

Table 18: Noise reduction vs. NR setting.

NR Setting	0	1	2	3	4	5	6	7	8	9	10…15
SINAD dB	6	7	8	9	10	12	14	16	17	16	16 (max)

This shows an S/N improvement of 13 dB with NR at maximum for an SSB signal ≈ 2 dB above MDS. This is an approximate measurement, as the amount of noise reduction is dependent on the original signal-to-noise ratio.

15: Audio THD. In this test, an audio distortion analyzer is connected to the external speaker output. An 8Ω resistive load is connected across the analyzer input. An S7 to S9 RF test signal is applied to the antenna input, and the main tuning is offset by 1 kHz to produce a test tone. The audio voltage corresponding to 10% THD is then measured, and the audio output power calculated.

Test Conditions: 14.100 MHz, 3 kHz USB, AGC-F, ATT off, NR off, NB off, Preamp off. Offset tuning by -1 kHz.

Test Result: Measured audio output voltage = 1.50V rms.
Thus, audio power output = $\sqrt{[\,(1.5)^2/8]}$ = **530mW in 8Ω at 1 kHz**. (Spec. is 2W).

16: Spurious signals ("birdies"). The following spurious signals were observed with the ANT input terminated in 50Ω:

Table 19: Spurious signals in receiver.

Freq. MHz	Mode	Signal Type	S-meter rdg.	Remarks
1.095	USB	Tone	S0	
2.193			S0	
3.070			S0	
6.143			S0	
9.215			S0	
12.287			S0	
15.359			S0	
18.431			S0	
18.797			S0	
24.575			S0	
40.949			< S0	Weak
51.675			S1	6m
63.999			S0	
64.511			S3	
80.653			S0	
108.616			< S0	Weak
115.163			S0	Air Band
129.023			S0	Air Band
180.651			S0	
193.535			S0	

B. Transmitter Tests

17a: CW Power Output. In this test, the RF power output into a 50Ω load is measured at 3.6, 14.1, 28.1 and 50.1 MHz in RTTY mode, at a primary DC supply voltage of +13.8V and on internal battery (BP-272). A thermocouple-type power meter is connected to the IC-705 RF output via a 40 dB power attenuator.

Table 20a: CW Power Output. RF PWR = 100%.

Pwr Source	Freq. MHz	3.6	14.1	28.1	50.1	144.2	432.1
Ext. 13.8V	P_O W	10.6	10.8	10.8	10.5	10.1	10.3
	I_{DC} A	2.2	1.9	2.2	1.8	2.4	2.2
BP-272	P_O W	5.3	5.4	5.4	5.2	5.0	5.0
	I_{DC} A	1.6	1.4	1.5	1.4	1.7	1.8

RX/Standby: I_{DC} = 0.2 – 0.3A

17b. CW Power Output vs. DC Supply Voltage. Here, the RF power output into a 50Ω load is measured at 14.1MHz in RTTY mode as DC supply voltage is reduced. RF Power = 100%.

Table 20b. CW Power Output vs. Supply Voltage.

V_{IN} V	14.5	13.8	13.5	13.0	12.5	12.0	11.5	11.0
P_O W	10.8	10.8	10.8	10.8	9.6	8.5	8.1	5.4
I_{IN} A	1.9	1.8	2.0	1.9	2.0	1.9	1.8	1.5

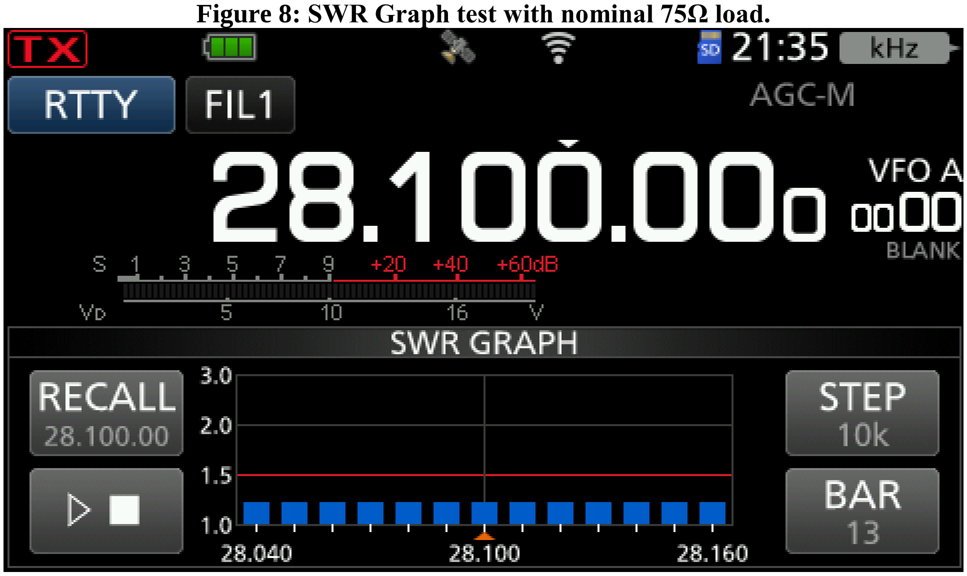
18: SWR Graph. The SWR Graph feature was tested with 50Ω and 75Ω resistive loads connected in turn to ANT1. The RF POWER setting remained unchanged when switching loads.

Test Conditions: 28.350 MHz RTTY. P_o =5W into 50Ω and 75Ω loads. Sweep range: 28.050 – 28.650 MHz.

At 75Ω, a flat SWR reading of 1.3:1 was obtained across the entire sweep. See Figure 8.

7

Figure 8: SWR Graph test with nominal 75Ω load.



19: SSB Peak Envelope Power (PEP). Here, an oscilloscope is terminated in 50Ω and connected to the IC-705 RF output via a 50 dB high-power attenuator. At 10W CW, the scope vertical gain is adjusted for a peak-to-peak vertical deflection of 6 divisions.

Test Conditions: USB mode, HM-243 mic connected, RF PWR 91%, Mic Gain 50%, COMP OFF/ON, TBW = WIDE, COMP at 5 (≈ 6 dB compression on voice peaks), SSB TX Bass/Treble set at 0 dB (default), supply voltage +13.8V.

Speak loudly into the microphone for full-scale ALC reading. Figures 9 & 10 show the envelope for 10W PEP, without and with compression respectively. ± 3 vertical divisions = 10W.

Figure 9: 10W PEP speech envelope, no compression.

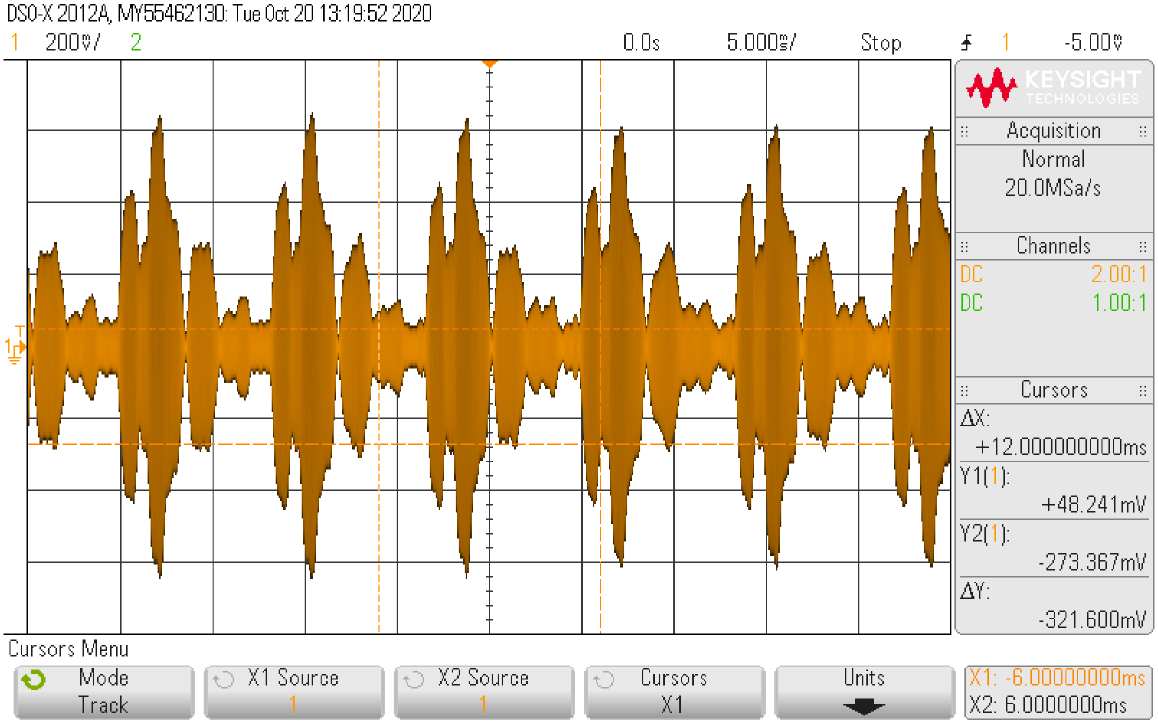
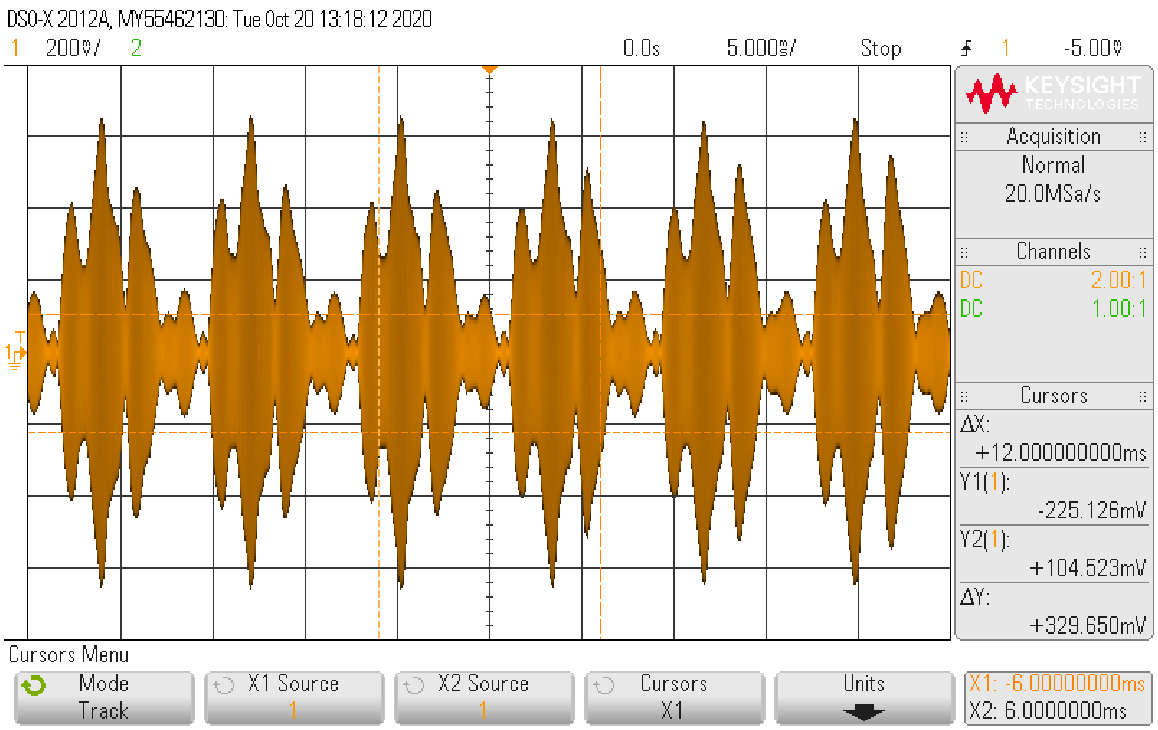


Figure 10: 10W PEP speech envelope, ≈ 6 dB compression.



Note that no ALC overshoot was observed in either test case.

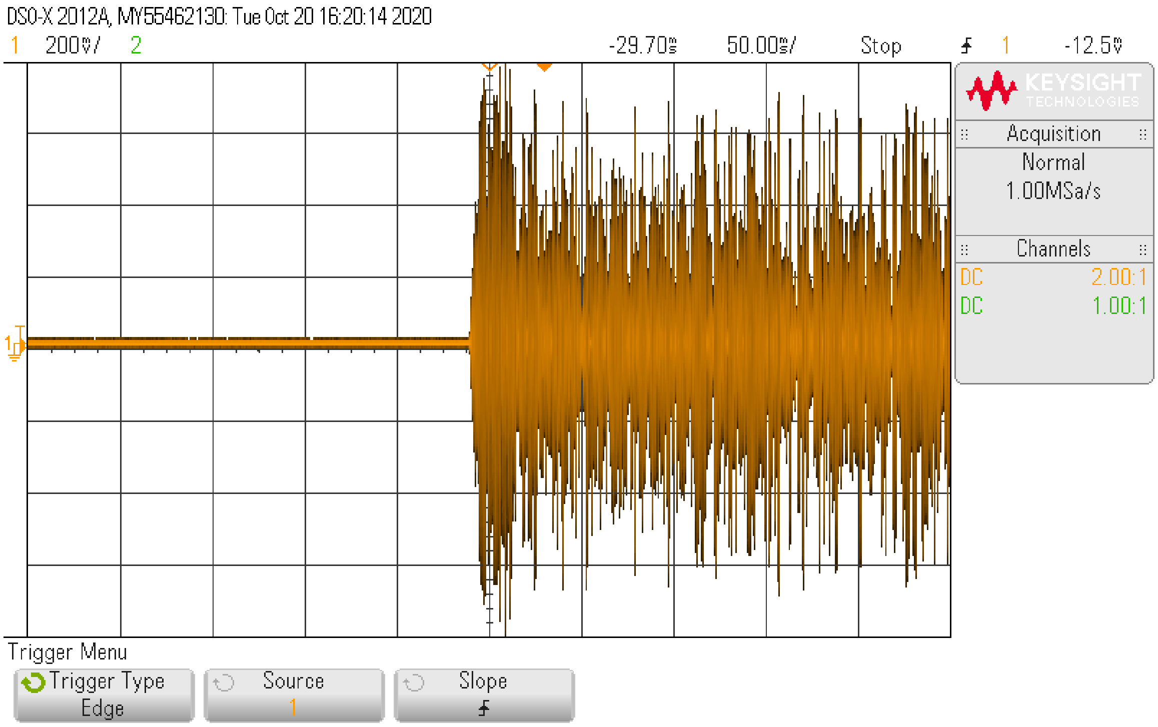
20: SSB ALC overshoot. A test was conducted in which white noise was applied via the USB port, and the RF envelope observed on an oscilloscope terminated in 50Ω and connected to the IC-705 RF output via a 50 dB high-power attenuator**.**

Test Conditions: 14100 kHz USB, COMP off, DATA OFF MOD = USB, USB MOD Level = 50% (default). Test signal: white noise. WIDE TBW (default value) selected. Supply voltage +13.8V.

Set P_o = 10W in RTTY mode. Select USB, then adjust USB Audio Codec device volume on computer for 50% ALC reading.

Test Result: Approx. 2.5 dB initial overshoot was observed, with approx.. 1.3 dB overshoot after keying.

Figure 11: 10W white noise test (±3 vert. div. = 10W PEP).

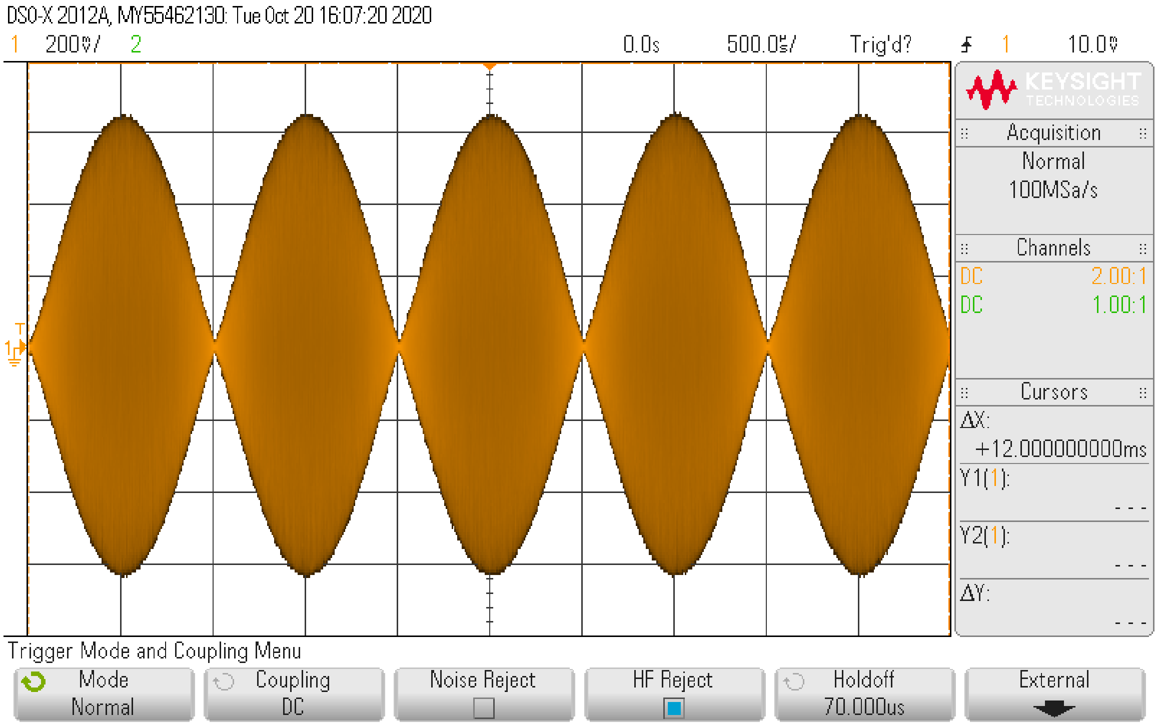


21: ALC Compression Check. In this test, a 2-tone test signal is applied to the USB port from a tone-generator program running on a laptop computer. An oscilloscope is connected to the IC-705 RF output via a 50 dB high-power attenuator. RF Power is initially adjusted for 10W output in RTTY mode.

Test Conditions: 14100 kHz USB, COMP off, DATA OFF MOD = USB, USB MOD Level = 50% (default). Test tones: 700 and 1700 Hz, at equal amplitudes. WIDE TBW (default value) selected. Supply voltage +13.8V.

Test Result: No flat-topping of the 2-tone envelope was observed (see Figure 11.)

Figure 12: 2-tone envelope, 10W PEP.



22: Transmitter 2-tone IMD Test. In this test, a 2-tone test signal is applied to the USB port from a tone-generator program running on a laptop computer. A spectrum analyzer is connected to the IC-705 RF output via a 60 dB high-power attenuator. RF Power is initially adjusted for rated CW output on each band in turn.

Test Conditions: DC supply 13.8V, measured at DC power socket. 3.6, 14.1, 28.1 and 50.1 MHz USB, DATA OFF MOD = USB, USB MOD Level = 50% (default). Test tones: 700 and 1700 Hz, at equal amplitudes. The -10 dBm reference level RL equates to rated CW output (= 0 dBc).

On computer, adjust USB Audio Codec device volume for 10W PEP (each tone at -6 dBc). Figures 13 - 19 show the two test tones and the associated IMD products for each test case.

Table 21. 2-tone TX IMD.

	2-tone TX IMD Products at Rated P_o						
IMD Products	**Rel. Level dBc (0 dBc = 1 tone)**						
Freq. MHz	**3.6**	**14.1**	**14.1/5W**	**28.1**	**50.1**	**144.2**	**432.1**
IMD3 (3rd-order)	-34	-35	-44	-31	-30	-28	-30
IMD5 (5th-order)	-45	-44	-43	-39	-38	-39	-34
IMD7 (7th-order)	-44	-54	-56	-54	-50	-51	-51
IMD9 (9th-order)	-54	-50	-56	-56	-56	-59	-61
	Add -6 dB for IMD referred to 2-tone PEP						

22a: Noise IMD Test. This test is similar to Test 26, except that a white-noise baseband is applied to the USB port from the tone-generator program. Spectrograms are captured at 10W and 25W PEP, as shown in Figure 17. Note that the IMD skirts are steeper at the lower power level.

Figure 13: Spectral display of 2-tone IMD at 3.6 MHz, 10W PEP.

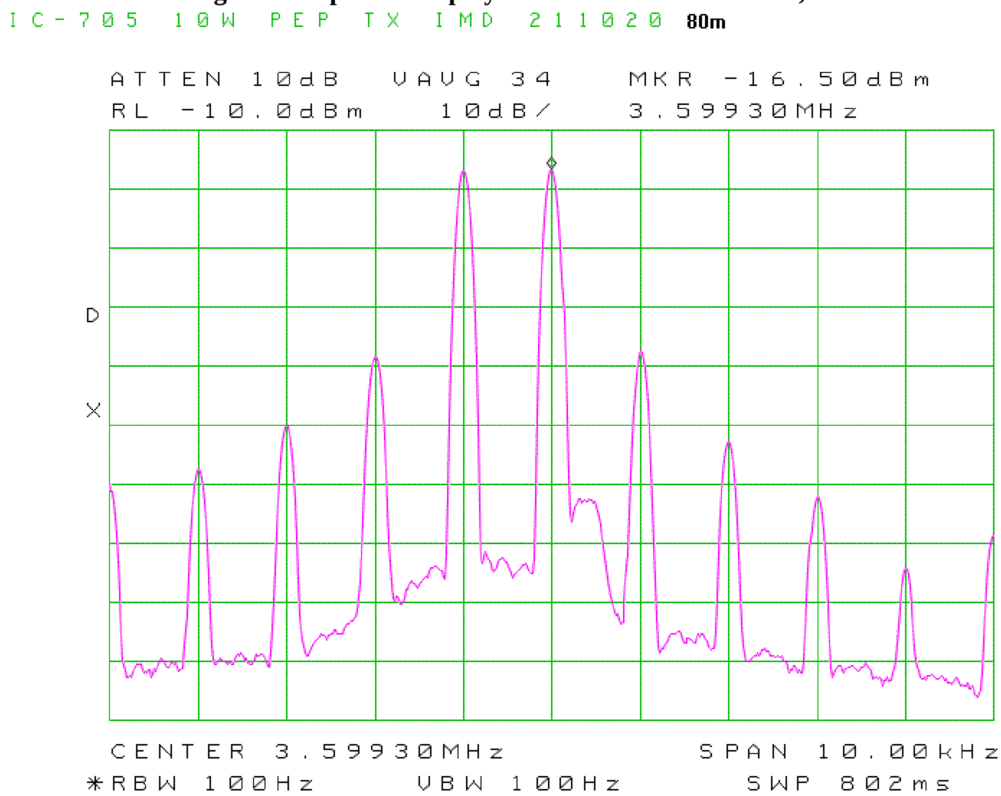


Figure 14: Spectral display of 2-tone IMD at 14.1 MHz, 10W PEP.

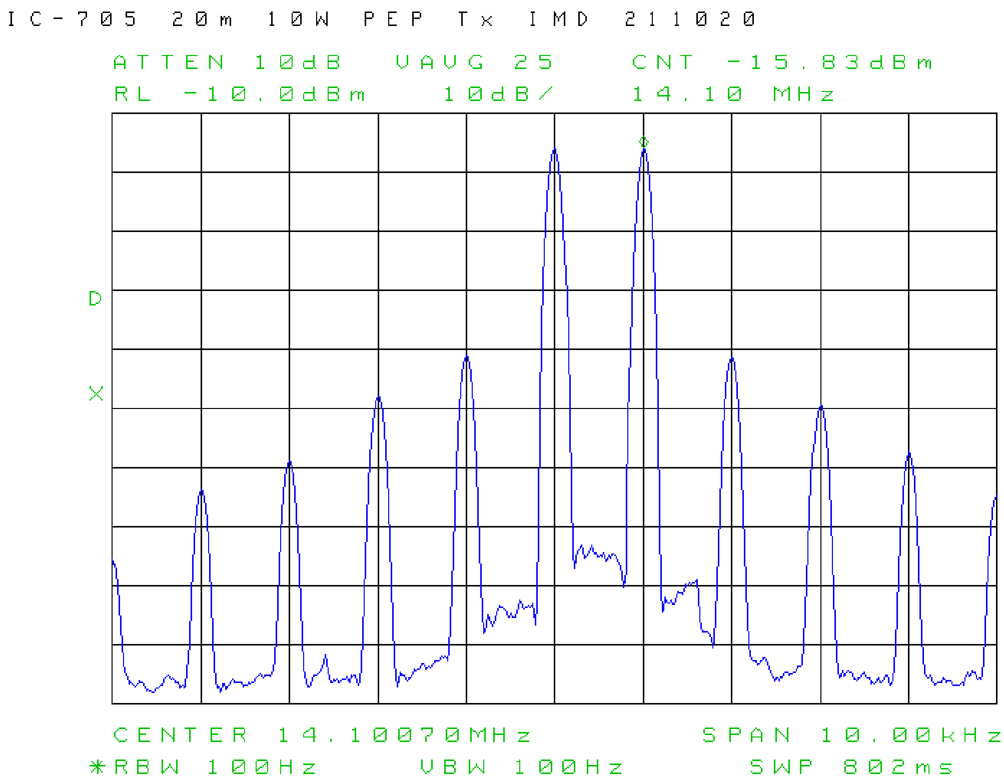


Figure 15: Spectral display of 2-tone IMD at 14.1 MHz, 5W PEP (battery).

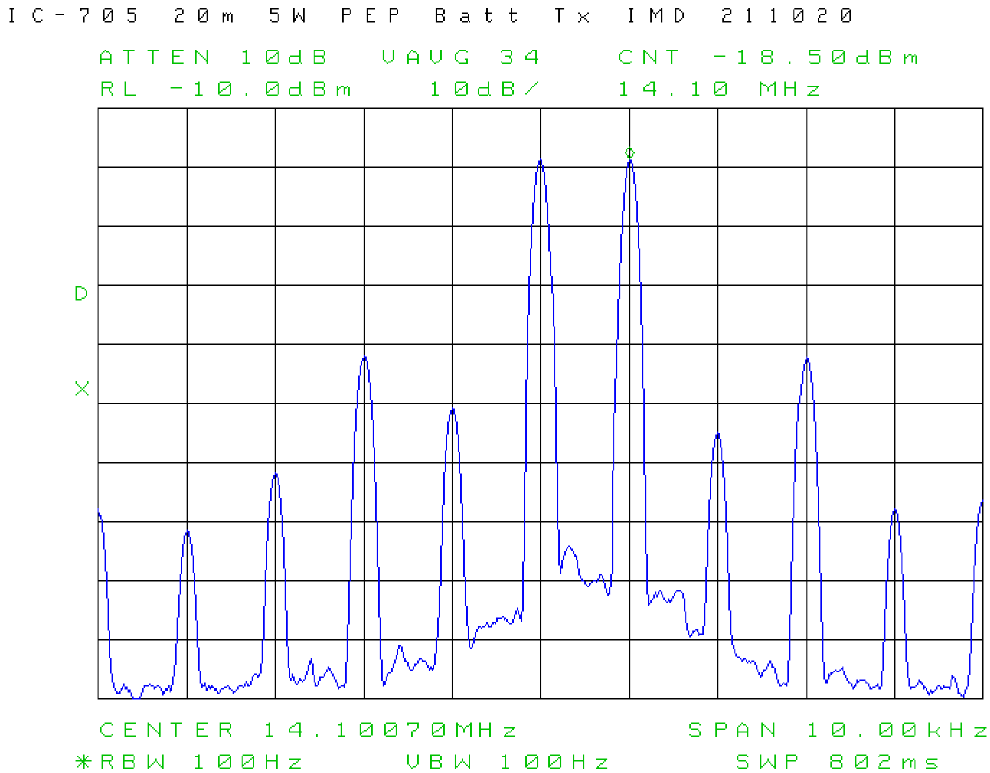


Figure 16: Spectral display of 2-tone IMD at 28.1 MHz, 10W PEP.

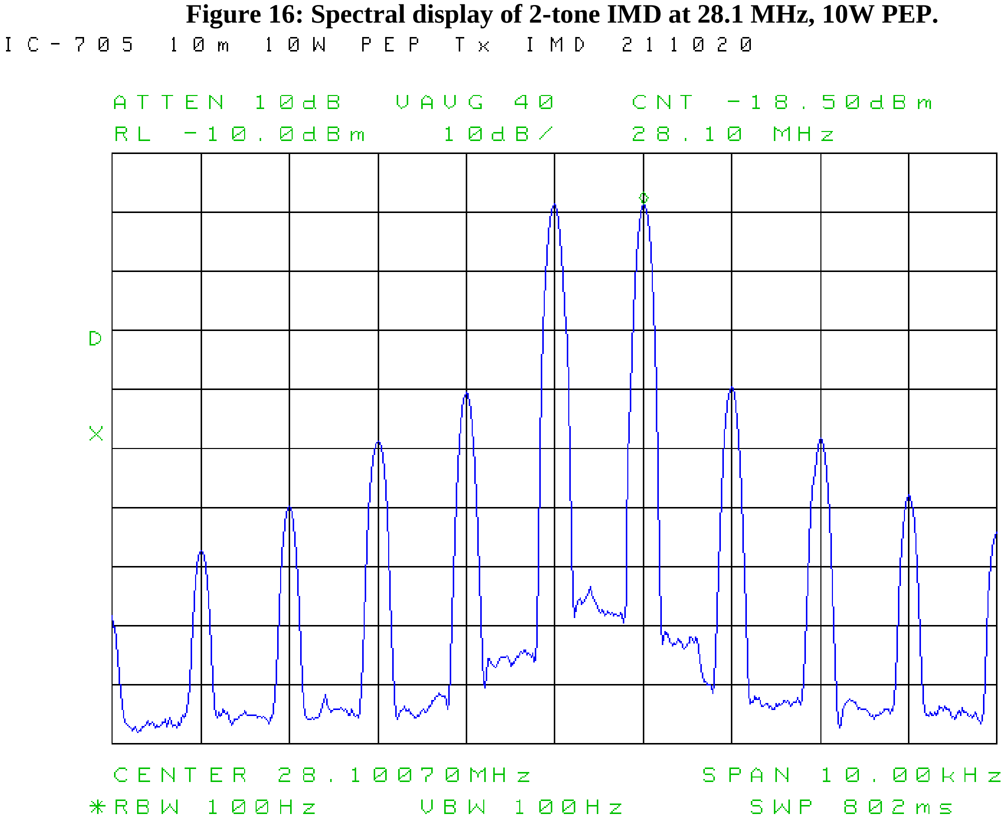


Figure 17: Spectral display of 2-tone IMD at 50.1 MHz, 10W PEP.

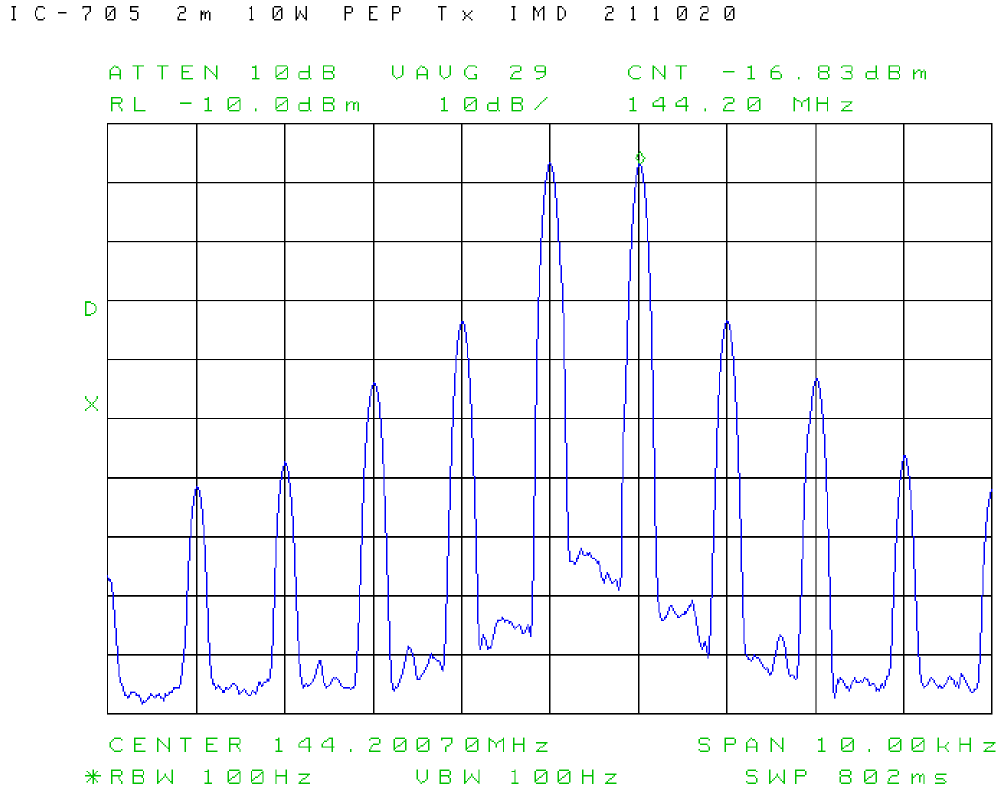


Figure 18: Spectral display of 2-tone IMD at 144.2 MHz, 10W PEP.

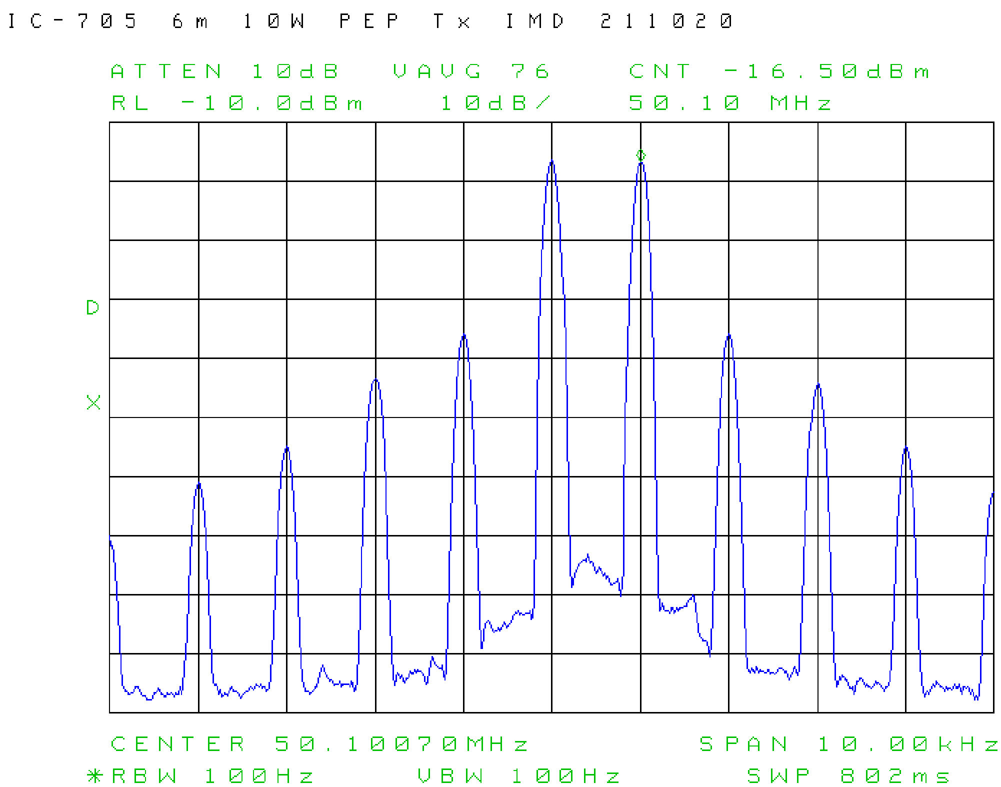


Figure 19: Spectral display of 2-tone IMD at 432.1 MHz, 10W PEP.

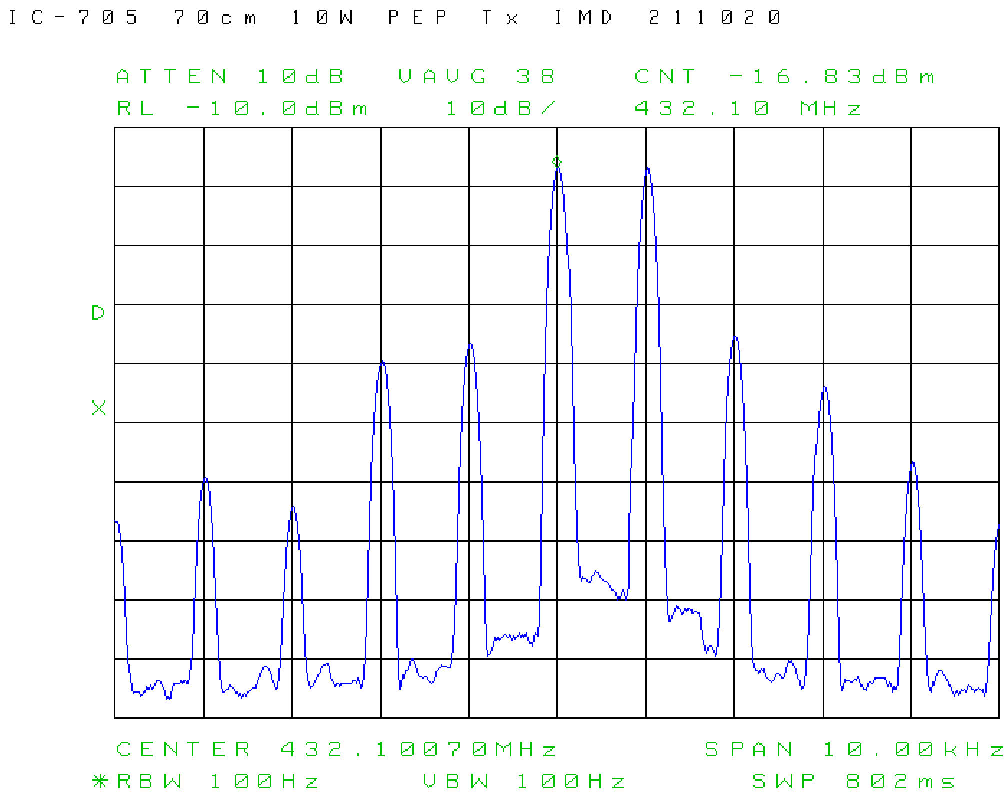
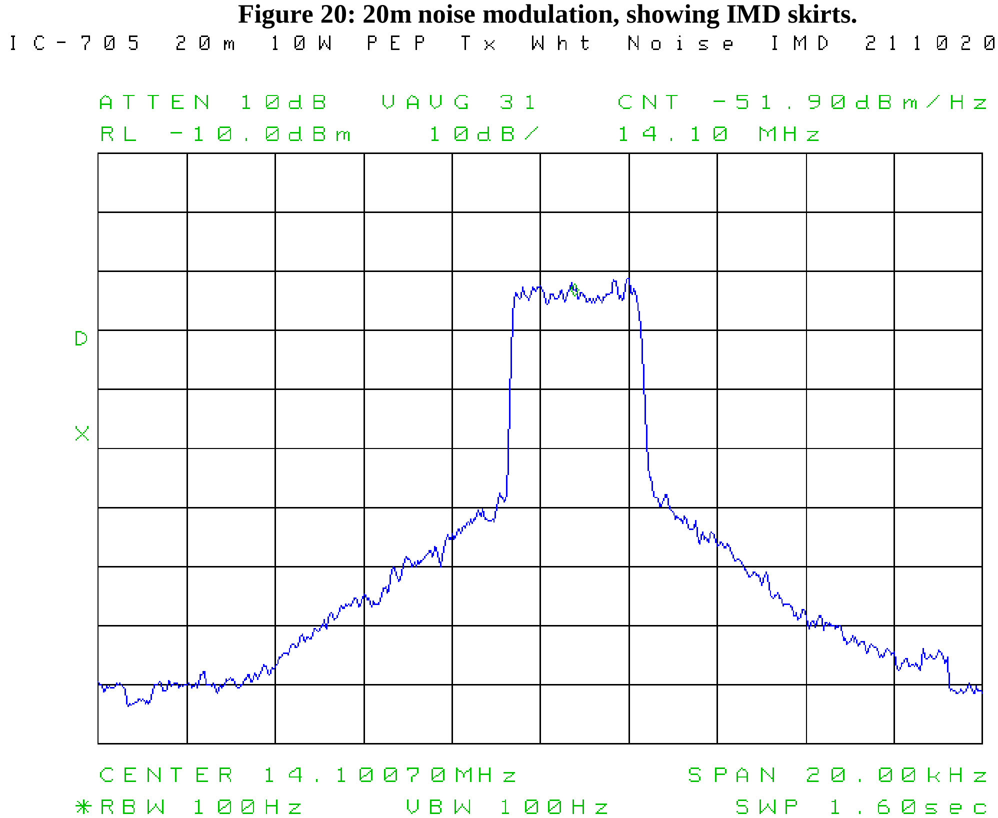


Figure 20: 20m noise modulation, showing IMD skirts.



23: AM sidebands and THD with single-tone modulation. As in Test 26 above, the spectrum analyzer is connected to the IC-705 RF output via a 50 dB high-power attenuator. On the IC-705, RF Power is adjusted for 2.5W resting carrier. A± 1 kHz test tone is applied to the USB port from the tone-generator program running on the laptop computer. The spectrum analyzer records the carrier and sideband parameters.

Test Conditions: 14100 kHz AM, 2.5W carrier output, DATA OFF MOD = USB, USB MOD Level = 50% (default).

On computer, adjust USB Codec device volume for -7 dBc test tone level (90% modulation.) Figure 17 shows the carrier and sideband levels. Calculated THD ≈ **2%**.

Figure 21: AM Sidebands for 90% Modulation.

```
IC-705 20m AM Sidebands 2.5W Carrier 211020

      DISCRETE SIDEBAND SEARCH RESULTS


      CARRIER FREQ:     14.10 MHz
      CARRIER POWER:    -14.8 dBm

      OFFSET FREQ    - OFFSET     + OFFSET
                       dBc          dBc
      -----------    --------     --------

       .998 kHz        -7.3         -7.2
      1.997 kHz       -43.8        -44.5
      2.996 kHz       -50.3        -49.8
      3.995 kHz       -86.2        -66.0
      5.003 kHz       -81.3        -76.8




      FOUND:    5 SETS OF SIDEBANDS
```

24: Transmitter harmonics & spectral purity. Once again, the spectrum analyzer is connected to the IC-705 RF output via a 60 dB high-power attenuator. RF Power is adjusted for rated CW output on each band in turn. The 0 dBm reference level equates to 10W. The spectrum analyzer's harmonic capture utility is started.

Test Conditions: 3.6, 14.1, 28.1, 50.1 MHz, RTTY, rated output to 50Ω load. Utility start and stop frequencies are configured as shown in Figures 19 through 26 inclusive. Harmonic data and spur sweeps are presented for HF/6m. It will be seen that harmonics and spurs are well within specifications.

Figure 22.

IC-705 80m Harmonics 10W CW 211020

HARMONIC MEASUREMENT RESULTS

FUNDAMENTAL SIGNAL: 3.600 MHz
-.5 dBm

HARMONIC	LEVEL dBc	FREQUENCY
2	-74.8	7.200 MHz
3	-92.0 *	10.80 MHz
4	-83.7	14.40 MHz
5	-88.8	18.00 MHz
6	-98.0	21.60 MHz
7	-100.5	25.20 MHz
8	-106.2	28.80 MHz

* MEASURED LEVEL MAY BE NOISE OR LOST SIGNAL.

TOTAL HARMONIC DISTORTION = 0 %
(OF HARMONICS MEASURED)

Figure 23.

IC-705 80m Spurs/Harmonics 10W CW 211020

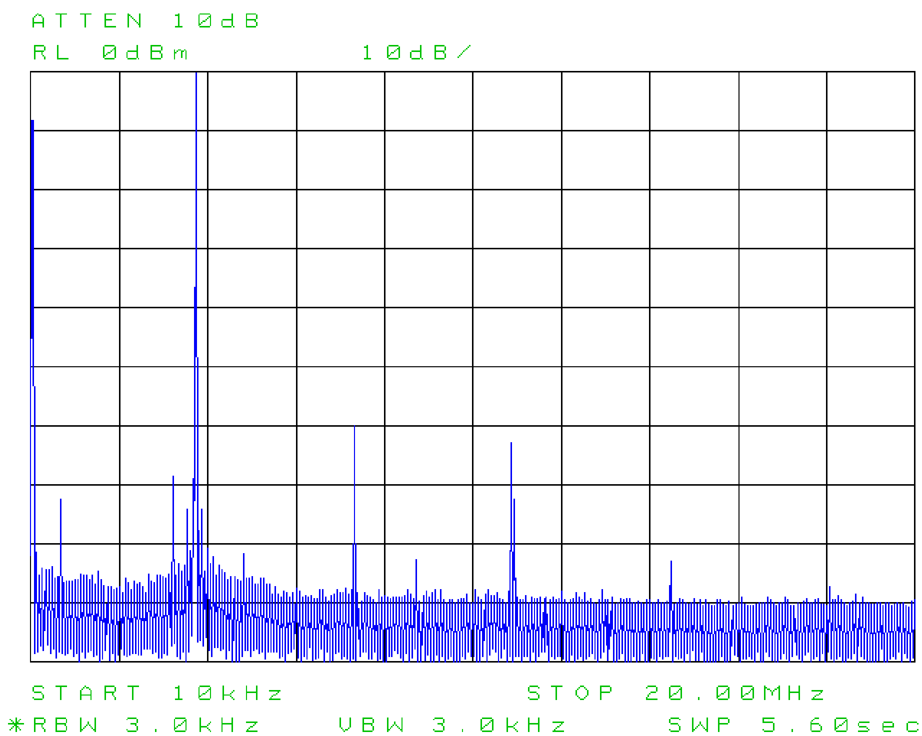


Figure 24.

IC-705 20m Harmonics 10W CW 211020

HARMONIC MEASUREMENT RESULTS

FUNDAMENTAL SIGNAL: 14.10 MHz
.3 dBm

HARMONIC	LEVEL dBc	FREQUENCY
2	-80.5	28.20 MHz
3	-83.8	42.30 MHz
4	-90.0	56.40 MHz
5	-88.0	70.50 MHz
6	-100.7	84.60 MHz
7	-111.3 *	98.70 MHz
8	-107.7	112.8 MHz

* MEASURED LEVEL MAY BE NOISE OR LOST SIGNAL.

TOTAL HARMONIC DISTORTION = 0 %
(OF HARMONICS MEASURED)

Figure 25.

IC-705 20m Spurs/Harmonics 10W CW 211020

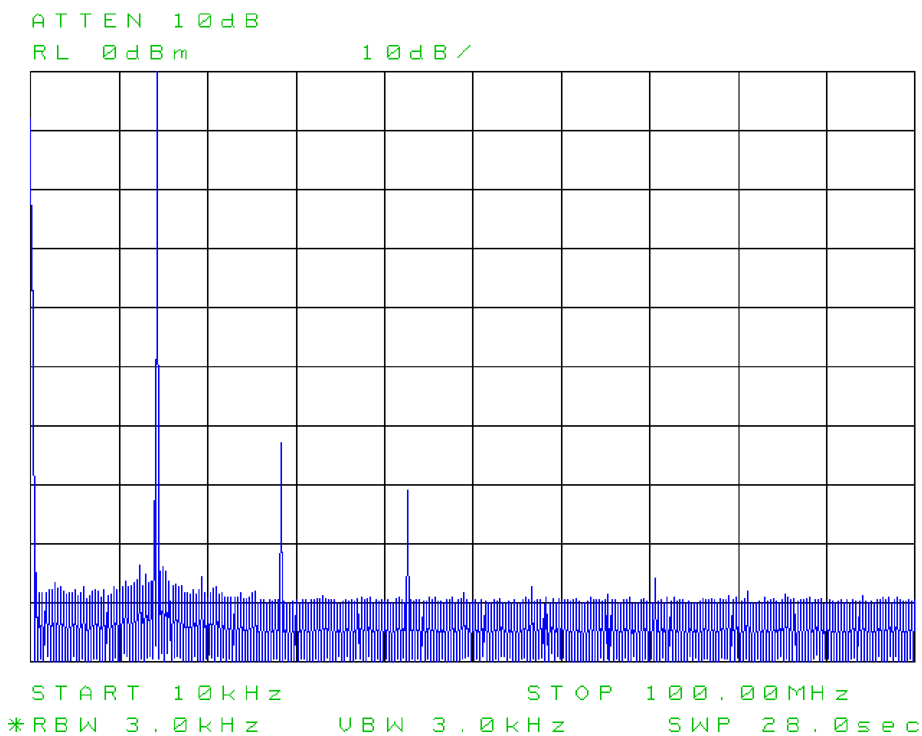


Figure 26.

IC-705 10m Harmonics 10W CW 211020

HARMONIC MEASUREMENT RESULTS

FUNDAMENTAL SIGNAL: 28.10 MHz
.2 dBm

HARMONIC	LEVEL dBc	FREQUENCY
2	-70.8	56.20 MHz
3	-77.3	84.30 MHz
4	-91.7	112.4 MHz
5	-90.3	140.5 MHz
6	-100.2	168.6 MHz
7	-93.7	196.7 MHz
8	-92.7	224.8 MHz

TOTAL HARMONIC DISTORTION = 0 %
(OF HARMONICS MEASURED)

Figure 27.

IC-705 10m Spurs/Harmonics 10W CW 211020

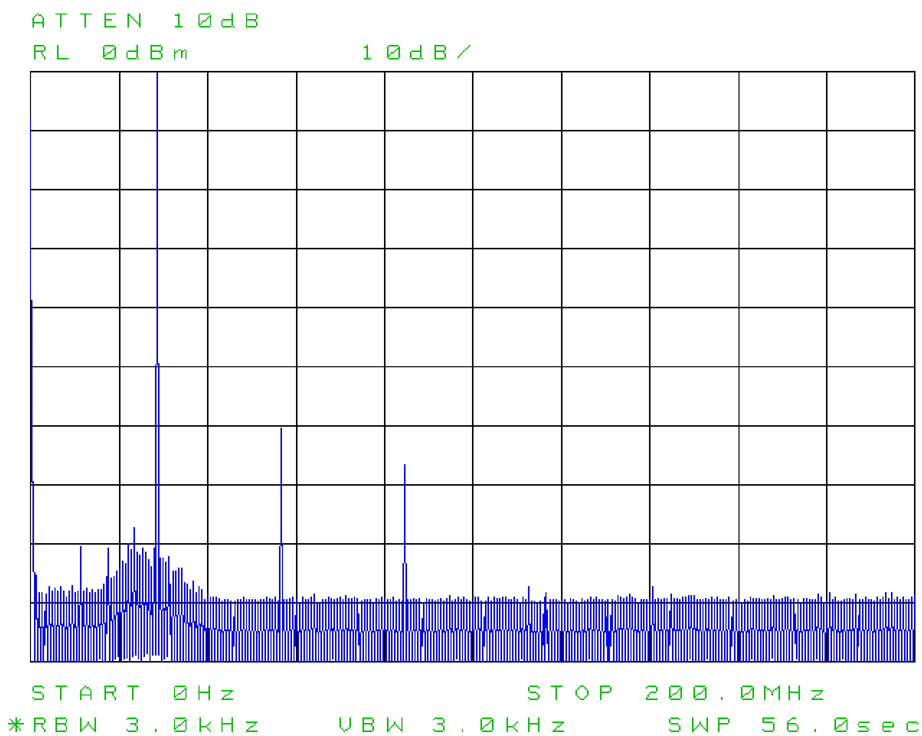


Figure 28.

IC-705 6m Harmonics 10W CW 211020

HARMONIC MEASUREMENT RESULTS

FUNDAMENTAL SIGNAL: 50.10 MHz
.2 dBm

HARMONIC	LEVEL dBc	FREQUENCY
2	-73.7	100.2 MHz
3	-73.7	150.3 MHz
4	-75.0	200.4 MHz
5	-80.3	250.5 MHz
6	-82.8	300.6 MHz
7	-91.3	350.7 MHz
8	-103.5	400.8 MHz

TOTAL HARMONIC DISTORTION = 0 %
(OF HARMONICS MEASURED)

Figure 29.

IC-7300 6m Spurs/Harmonics 100W CW 060416

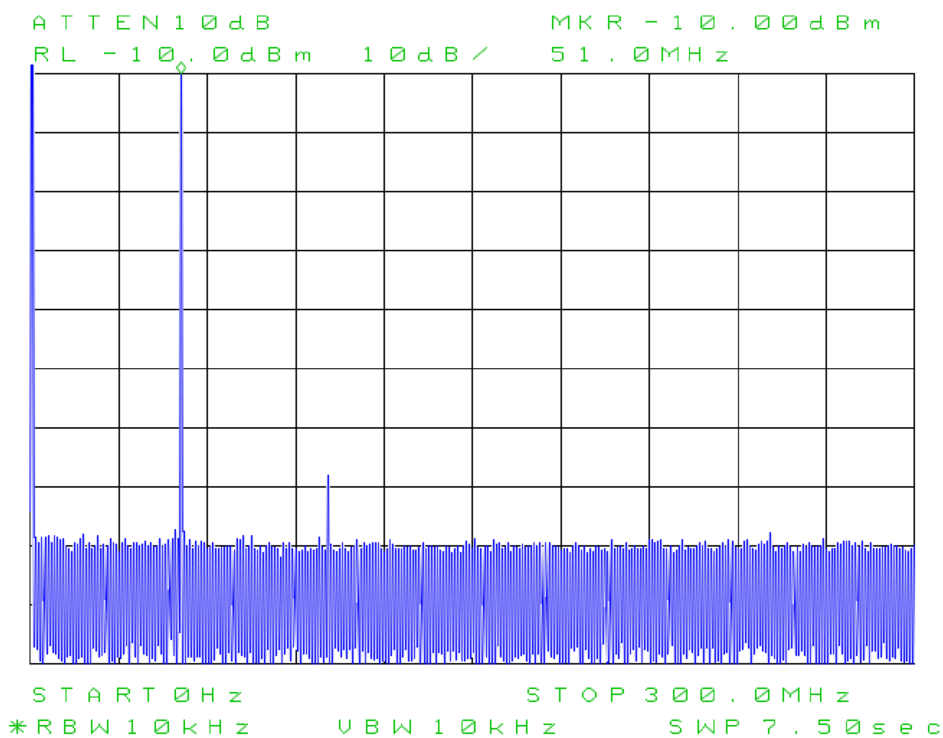


Figure 30.

IC-705 2m Harmonics 10W CW 211020

HARMONIC MEASUREMENT RESULTS

FUNDAMENTAL SIGNAL: 144.2 MHz
0 dBm

HARMONIC	LEVEL dBc	FREQUENCY
2	-64.7	288.4 MHz
3	-87.3	432.6 MHz
4	-76.8	576.8 MHz
5	-84.2	721.0 MHz
6	-101.2	865.2 MHz
7	-93.5	1.010 GHz
8	-84.8	1.154 GHz

TOTAL HARMONIC DISTORTION = .1 %
(OF HARMONICS MEASURED)

Figure 31.

IC-705 2m Spurs/Harmonics 10W CW 211020

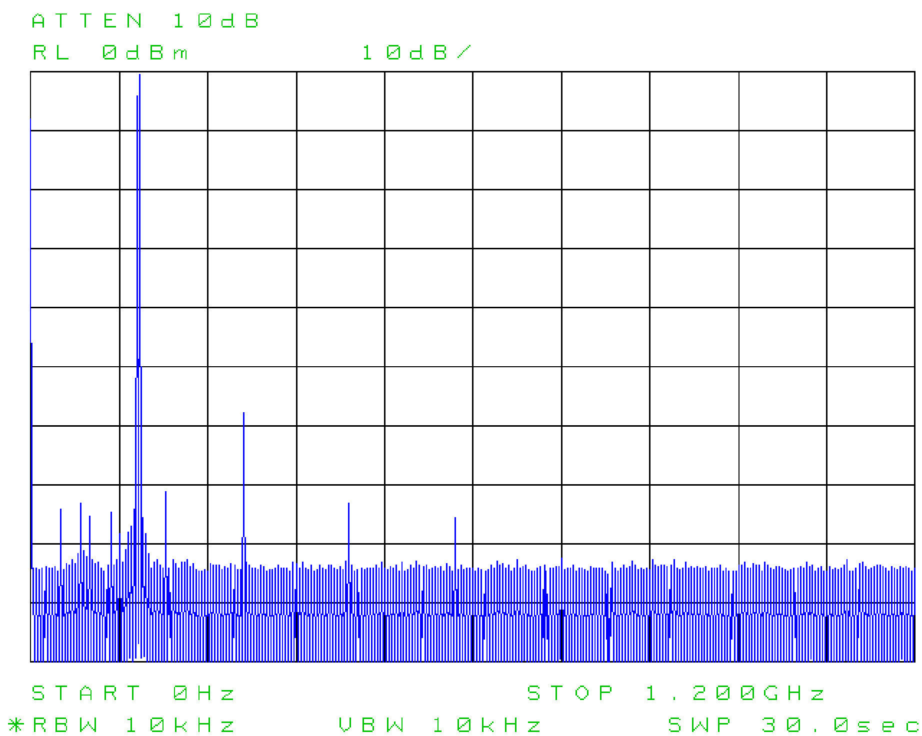


Figure 32.

IC-705 70cm Harmonics 10W CW 211020

HARMONIC MEASUREMENT RESULTS

FUNDAMENTAL SIGNAL: 432.1 MHz
-.3 dBm

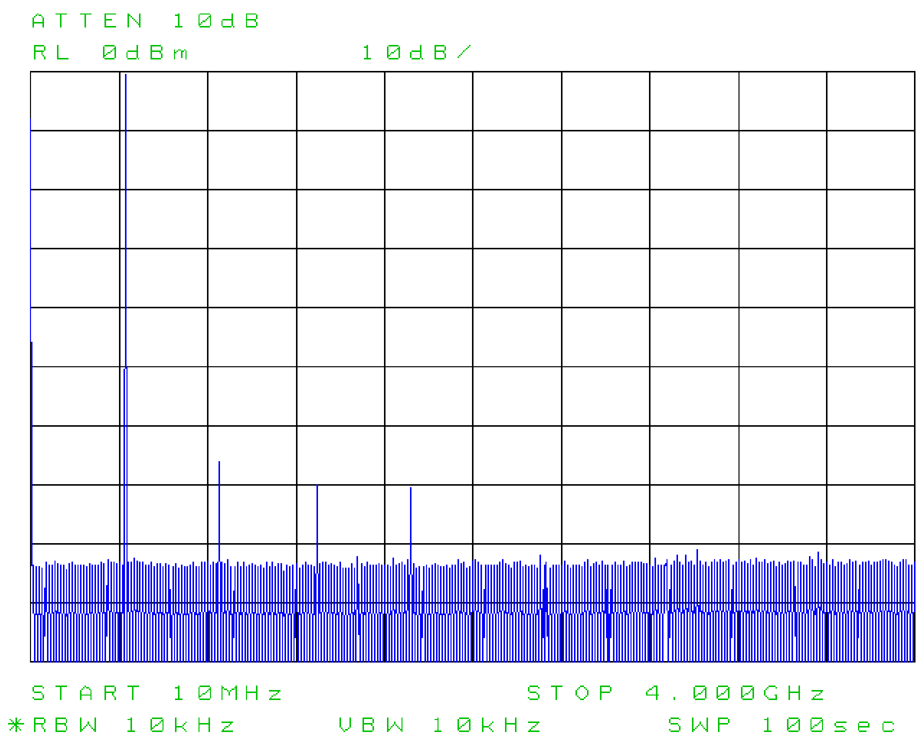
HARMONIC	LEVEL dBc	FREQUENCY
2	-63.5	864.2 MHz
3	-73.3	1.296 GHz
4	-71.5	1.729 GHz
5	-87.0	2.161 GHz
6	-86.2	2.593 GHz
7	-110.2 *	3.025 GHz
8	-110.0 *	3.457 GHz

* MEASURED LEVEL MAY BE NOISE OR LOST SIGNAL.

TOTAL HARMONIC DISTORTION = .1 %
(OF HARMONICS MEASURED)

Figure 33.

IC-705 70cm Spurs/Harmonics 10W CW 211020



25: Transmitted phase noise. A Rohde & Schwarz FSUP signal source analyzer is connected to the IC-705 RF output via a 40 dB high-power attenuator. Next. A phase noise sweep is run at 10W output on each band in turn at 10 Hz – 500 kHz or 10 Hz – 1 MHz offset.

Test Conditions: 3.6, 14.1, 28.1, 50.1, 144.2 and 432.1 MHz RTTY, 10W to 50Ω load.

Figure 34: Transmitted phase noise, 80m.

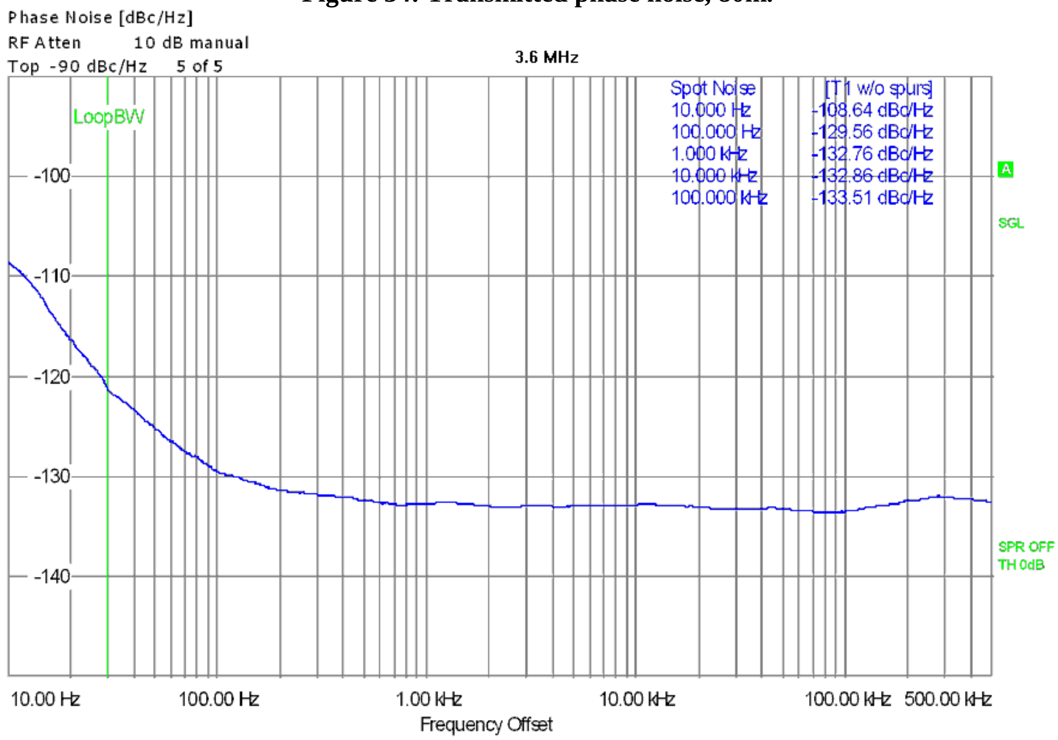


Figure 35: Transmitted phase noise, 20m.

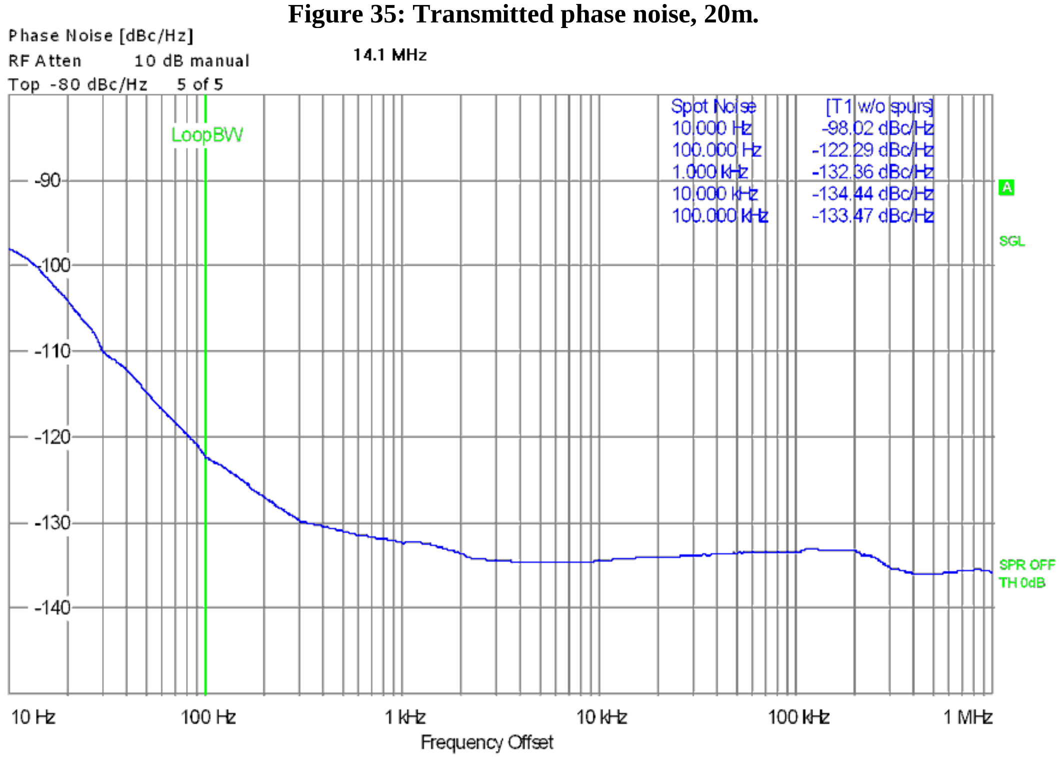


Figure 36: Transmitted phase noise, 10m.

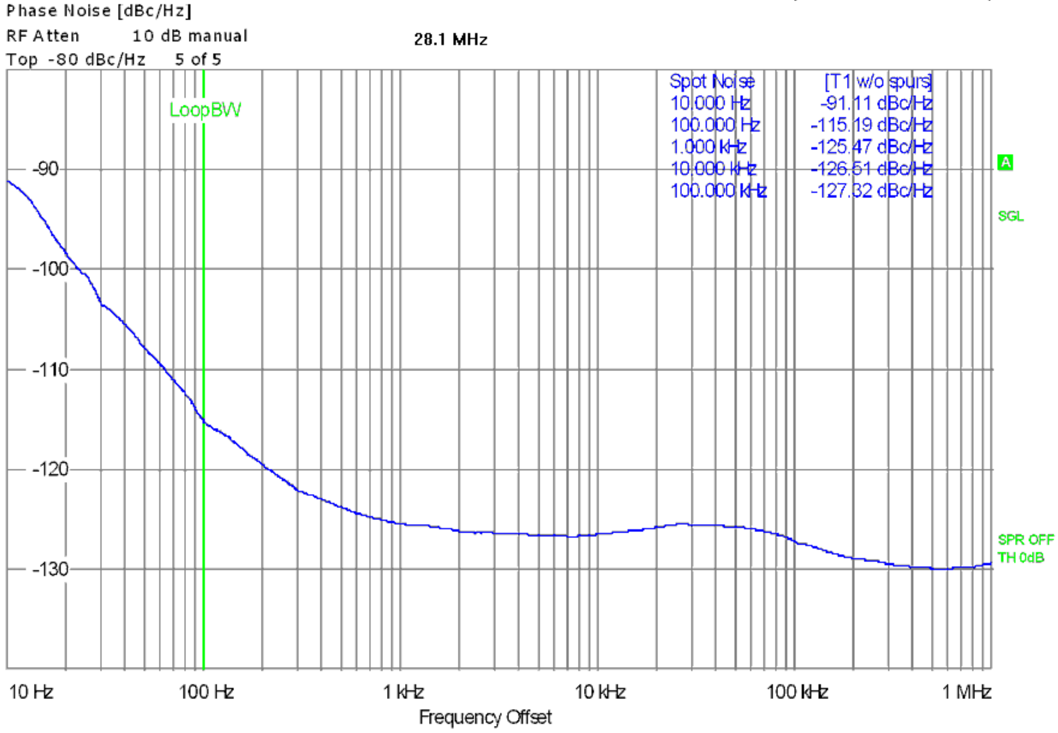


Figure 37: Transmitted phase noise, 6m.

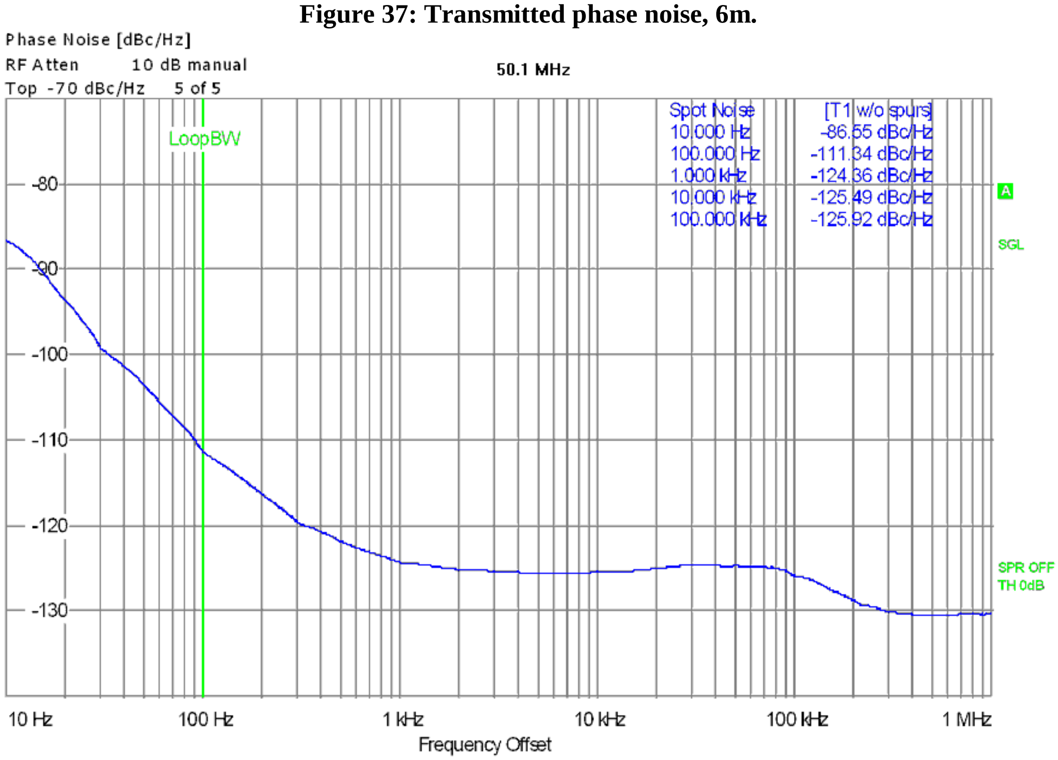


Figure 38: Transmitted phase noise, 2m.

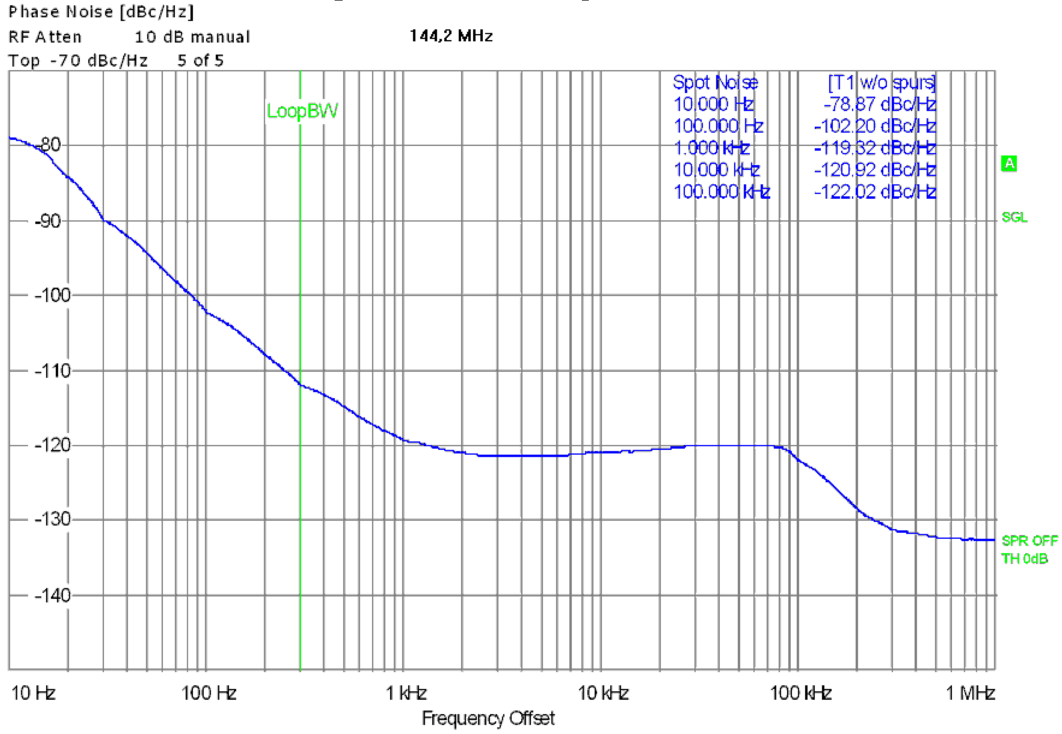
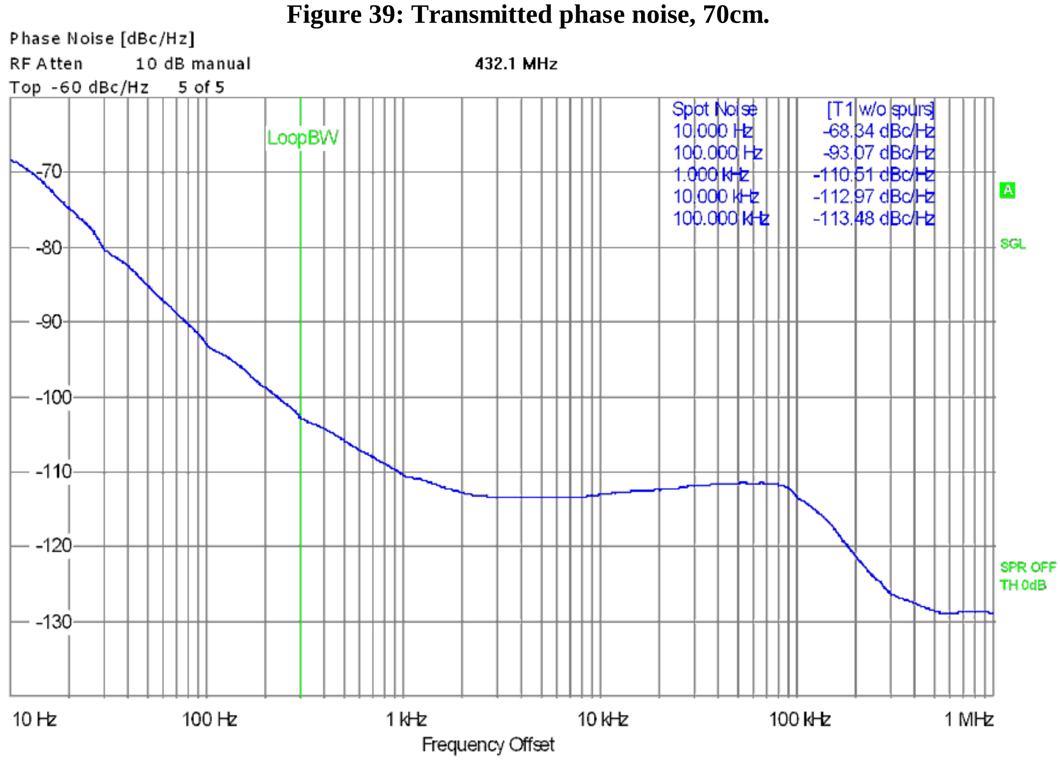


Figure 39: Transmitted phase noise, 70cm.



26: Spectral display of CW keying sidebands. The spectrum analyzer is connected to the IC-705 RF output via a 60 dB high-power attenuator. The -10 dBm reference level equates to 10W. A series of dits is transmitted at the highest keying speed.

Test Conditions: 14.1 MHz CW, 10W output to 50Ω load. Keying speed 48 wpm (KEY SPEED max.) using internal keyer. Spectrum analyzer RBW is 10 Hz, video-averaged. Sweep time < 4 sec. Figures 40 and 41 show the transmitter output ±5 kHz from the carrier at 2/4 and 6/8 ms rise-time, respectively..

Figure 40: Keying sidebands at 48 wpm, 2/4 ms rise-time 14.1 MHz, 10W.

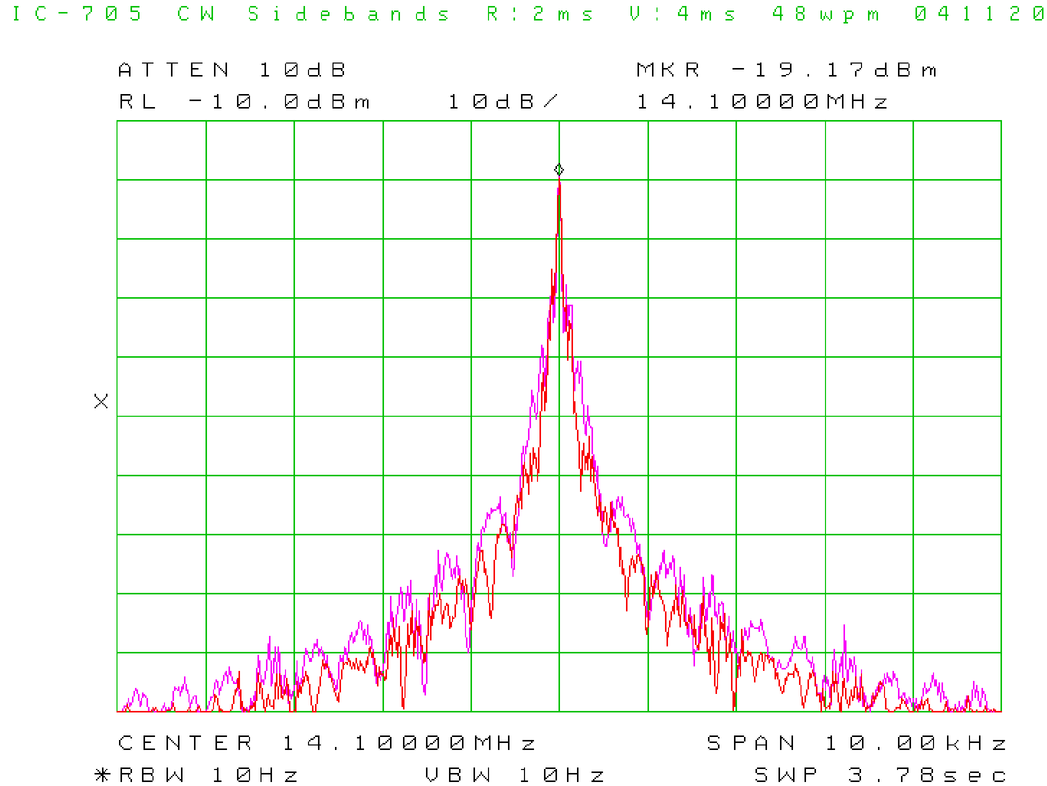
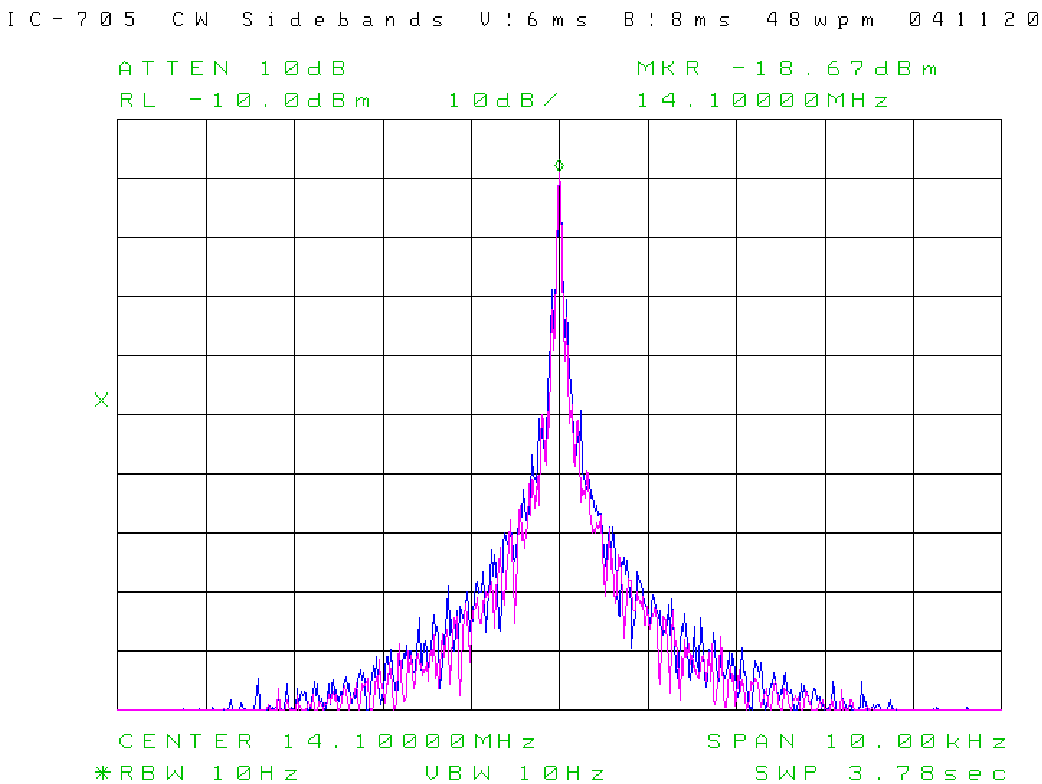


Figure 41: Keying sidebands at 48 wpm, 6/8 ms rise-time 14.1 MHz, 10W.



26a: CW keying envelope. The oscilloscope is terminated in 50Ω and connected to the IC-705 RF output via a 50 dB high-power attenuator. A series of dits is transmitted from the internal keyer at the highest keying speed (48 wpm) in semi-break-in mode (BK).

Test Conditions: 14.1MHz CW, 10W output to 50Ω load. CW rise time = 4 ms (default), TX DELAY (HF & 50M) OFF.

Figure 42: Keying envelope at 48 wpm, 2 ms rise time, 5 ms/div.

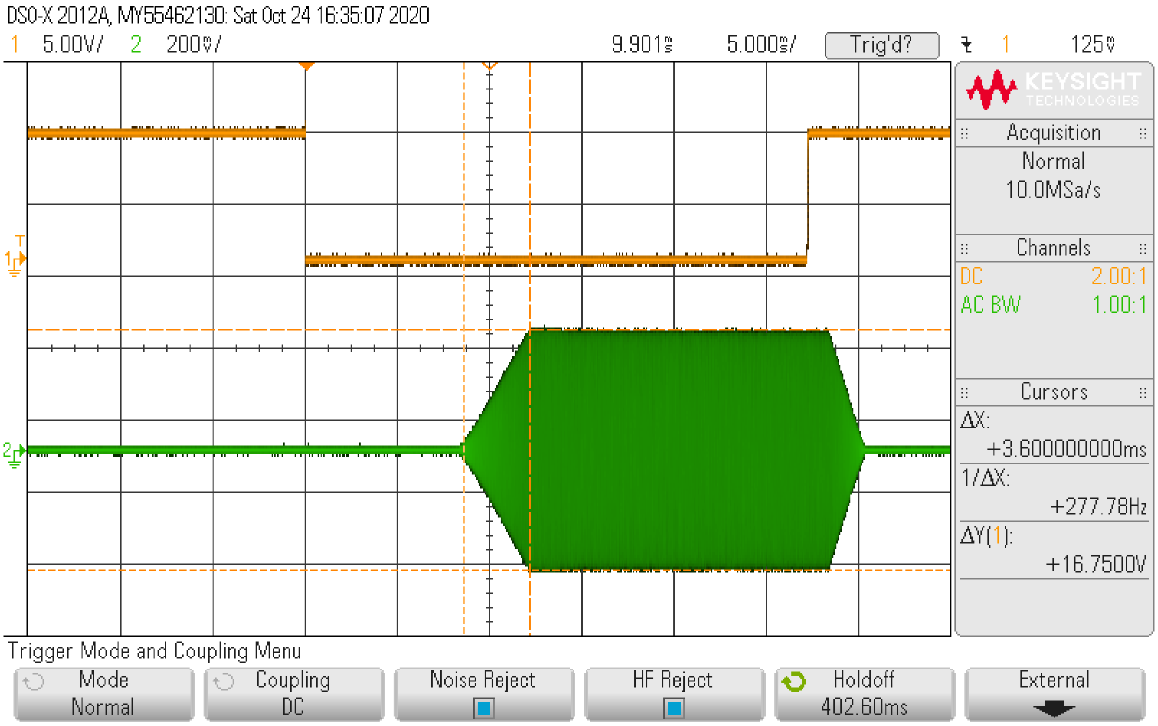


Figure 43: Keying envelope at 48 wpm, 4 ms rise time, 5 ms/div.

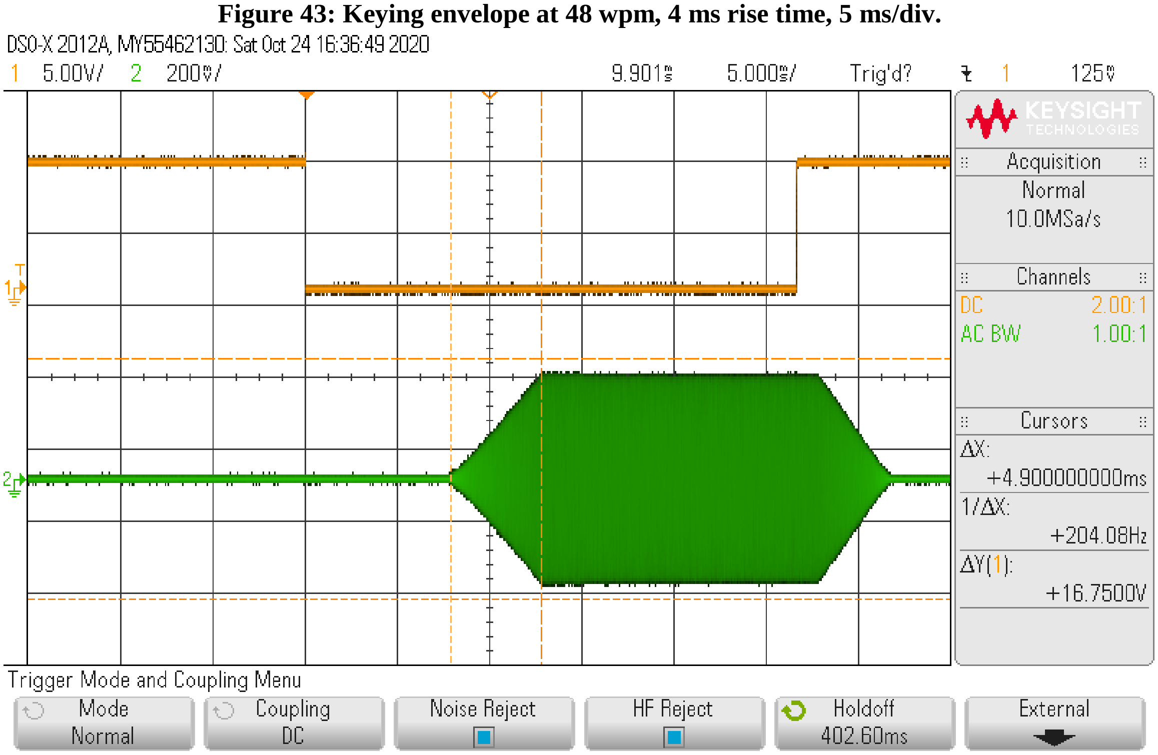


Figure 44: Keying envelope at 48 wpm, 6 ms rise time, 2 ms/div.

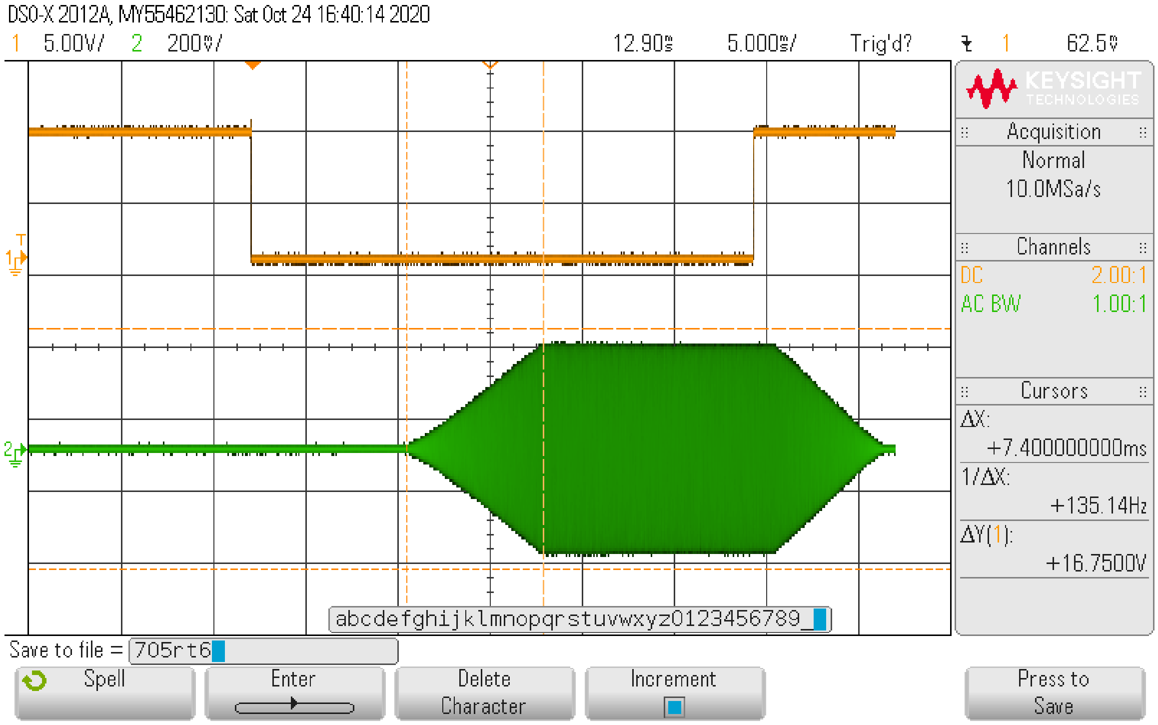


Figure 45: Keying envelope at 48 wpm, 8 ms rise time, 2 ms/div.

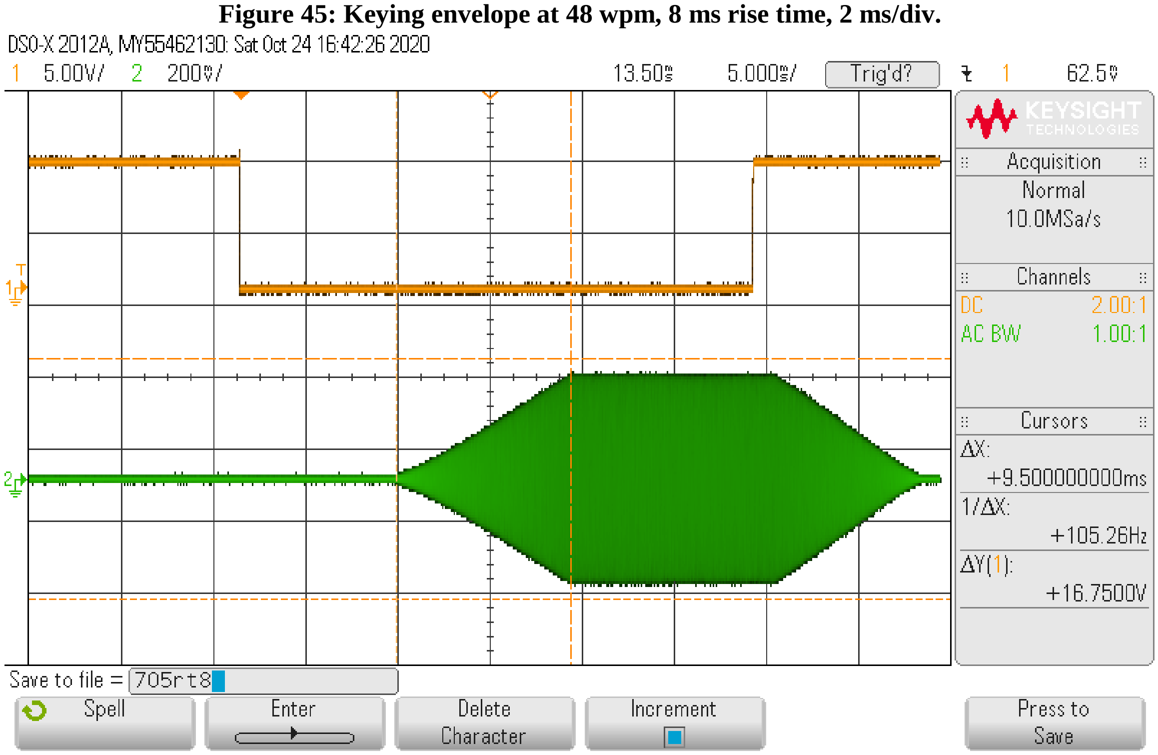
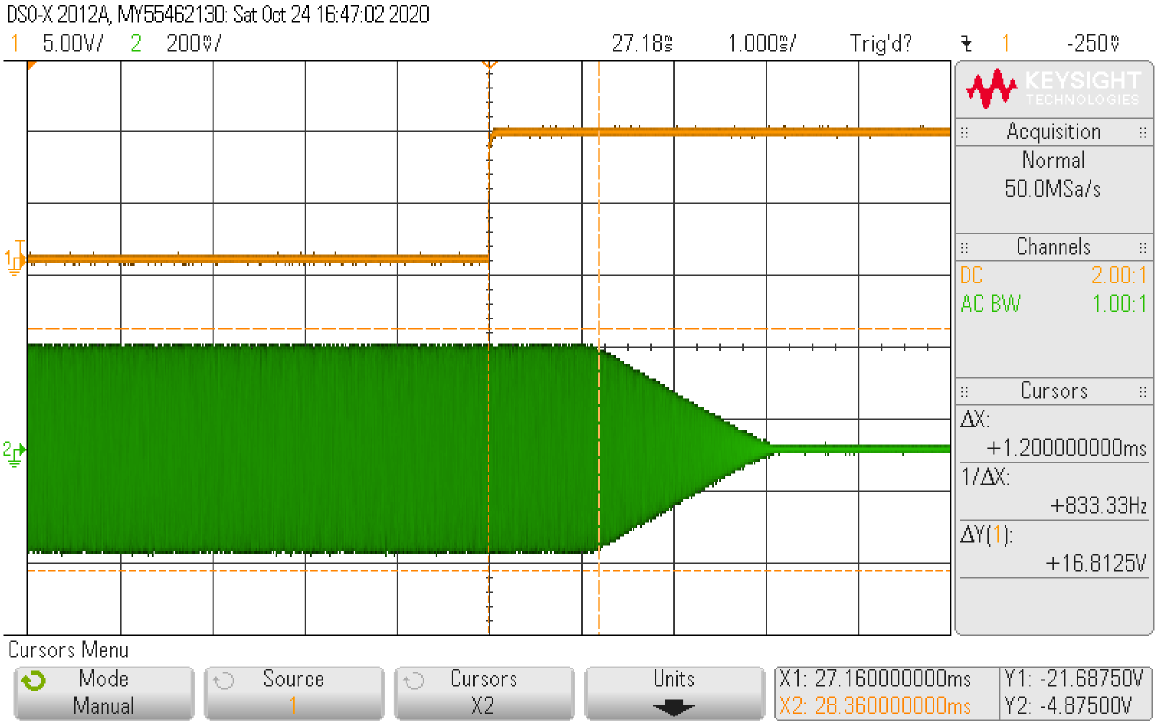


Figure 46: CW RF tail (1.2 ms + CW decay time). Decay time = rise time.



26b: CW QSK recovery test: This test was devised to measure the maximum speed at which the receiver can still be heard between code elements in QSK CW mode.

The IC-705 is terminated in a 50Ω 10W load via a directional coupler. A test signal is injected into the signal path via the directional coupler; a 20 dB attenuator at the coupled port protects the signal generator from reverse power. Test signal level is adjusted for S3…S5 at the receiver. As the coupler is rated at 25W max., RF PWR is set at 10W.

Test Conditions: 14.010 MHz, 500 Hz CW, preamp off, ATT off, NR off, NB off, F-BK on, rise time = 4 ms, RF PWR at 10W, KEY SPEED at 48 wpm (max.), CW Pitch default. Test signal at 14.0101 MHz. Sidetone = 600 Hz, received tone = 700 Hz.

Starting at minimum KEY SPEED, transmit a continuous string of dits and increase KEY SPEED until the received tone can just no longer be heard in the spaces between dits.

Test Result: In the current test, the received tone could still be heard distinctly at **≈ 16 wpm**.

27: USB MOD level for 10W output. The tone generator program in the laptop computer is set up to apply a 1 kHz test tone to the USB MOD input.

Test Conditions: 14100 kHz USB, DATA OFF MOD = USB, DATA-1 MOD = USB, USB MOD Level = 50% (default), TBW = WIDE/MID/NAR (default values), Bass/Treble = 0 dB (default), COMP off, test tone 1 kHz.

Perform test with DATA OFF MOD = USB, DATA-1 MOD = USB, USB MOD Level = 50% (default). 10W output was obtained with laptop tone generator level at 0 dB (nominal level) and USB MOD Level at 50%.

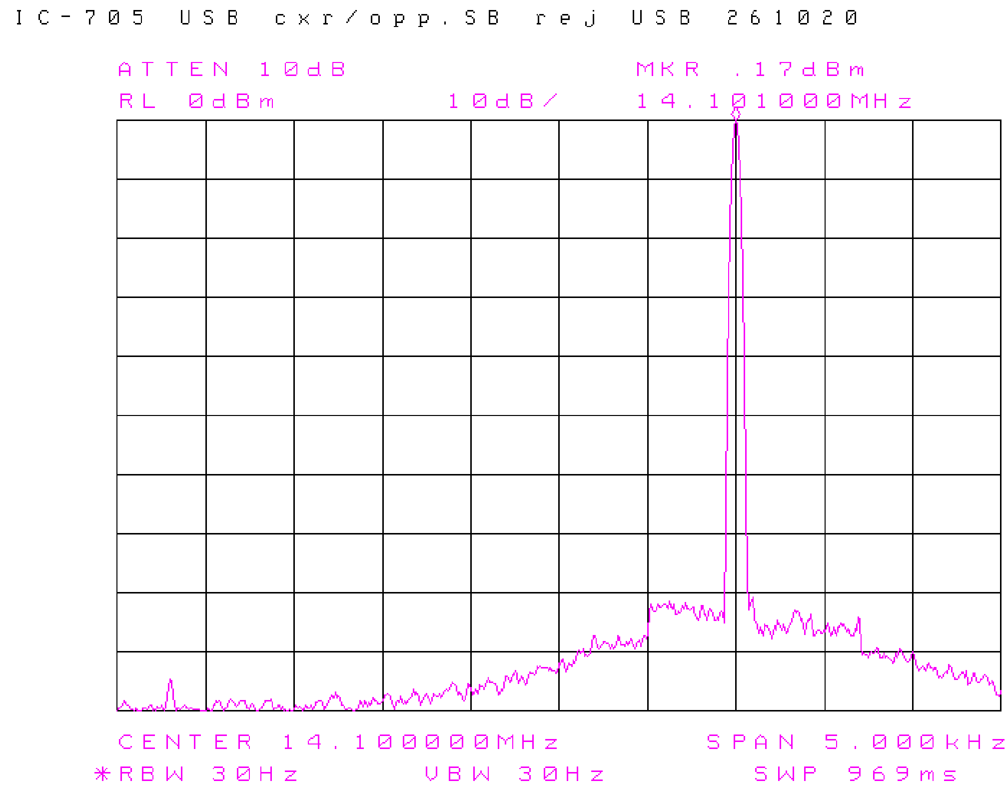
27a: Carrier and opposite-sideband suppression. A 1 kHz test tone is applied to ACC Pin 1, and then via the USB port. Carrier and opposite-sideband suppression are checked on the spectrum analyzer at 10W RF output for both cases.

Test Conditions: 14100 kHz USB, DATA OFF MOD = USB, DATA-1 MOD = USB, TBW = WIDE (default), test tone 1 kHz.

Adjust test tone level for 10W output. Read carrier amplitude at 14100 kHz, and opposite-sideband amplitude at 14099 kHz.

Test Results: For ACC and USB test-tone input, carrier and opposite sideband both < -80 dBc. See Figure 47.

Figure 47: Carrier & opposite-sideband suppression at 14.1 MHz.



27b: SSB transmit audio-frequency response via USB port. In this test, a white-noise baseband is applied to the USB port from a tone-generator program running on a laptop computer. The spectrum analyzer is connected to the IC-705 RF output via a 60 dB high-power attenuator.

Test Conditions: 14100 kHz USB, DATA OFF MOD = USB, USB MOD Level = 50% (default). Test signal: white noise. WIDE, MID and NAR TBW are at default values.

On computer, adjust USB Audio Codec device volume for 50% ALC reading. Using Marker on spectrum analyzer, measure frequency and relative amplitude at lower passband edge. Move marker "down" 6 dB and record frequency. Move marker "down" a further 14 dB and record frequency again. Repeat procedure for upper passband edge. The test data are shown in Table 22.

Table 22: Measured SSB TX lower and upper cutoff frequencies (via USB input).

TBW	Lower (Hz)		Upper (Hz)	
1 kHz = 0 dB ref.	-20 dB	-6 dB	-6 dB	-20 dB
WIDE	40	67	2950	3058
MID	133	242	2758	2850
NAR	358	433	2558	2633

28: FM deviation. The IC-705 output is connected to the RF IN/OUT port (75W max. input) of the communications test set. Voice and CTCSS peak deviation are checked.

Test Conditions: 146.520 MHz, FM, FIL1, RF PWR set at 10W.

Speak loudly into mic and read deviation. ***Test Result:*** Peak deviation = **4.3 kHz**.

Next, select CTCSS TONE = 100 Hz (1Z). Key IC-705 and read tone frequency and deviation on test set. ***Test Result:*** Tone frequency 100.05 Hz, deviation 530 Hz.

28a: CTCSS decode sensitivity. The test set is configured as an RF generator. TSQL (CTCSS tone squelch) is enabled in the IC-705 and the minimum RF input power and tone deviation at which the tone squelch opens are measured.

Test Conditions: 52.525 MHz, FM, FIL1, ATT off, CTCSS TSQL on, TONE 100 Hz (1Z). At test set, CTCSS tone deviation = 700 and 500 Hz.

Table 23: CTCSS Decode Sensitivity

Tone Dev. Hz	RF input level
700	-116
500	-115

29: Transmit latency. In this test, the tone generator program feeds short bursts of 1 kHz tone to the DUT USB MOD input and also to Channel 1 of a dual-trace oscilloscope. Channel 2 is connected via a high-power 50 dB attenuator to the DUT ANT socket. The scope is triggered from Channel 1. The time interval between the leading edge of the AF burst displayed on Channel 1 and that of the RF burst displayed on Channel 2 is recorded for WIDE, MID and NAR TBW settings. This interval is the transmit latency.

Test Conditions: 14100 kHz USB, 10W, DATA OFF MOD = ACC, ACC MOD Level = 50% (default). Test signal: tone burst. WIDE, MID and NAR TBW are at default values. Scope sweep 1 ms/div.

Figure 48: Transmit latency, WIDE TBW. Latency 5 ms.

Figure 49: Transmit latency, MID TBW. Latency 5 ms.

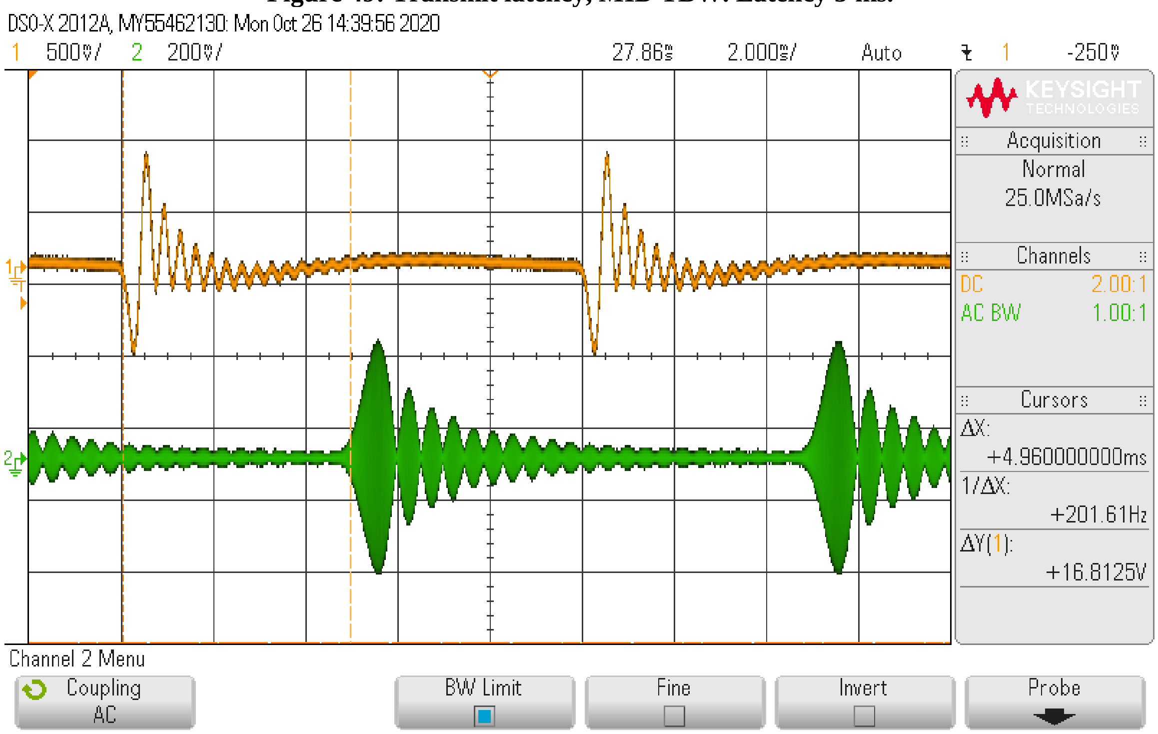


Figure 50: Transmit latency, NAR TBW. Latency 5 ms.

30. RTTY (FSK, F1B) Transmitted Signal Test. The spectrum analyzer is connected to the IC-705 RF output via a 60 dB high-power attenuator. The -10 dBm reference level equates to 10W. An FSK (F1B) RYRYRY string is sent from internal TX MEM RT1.

Test Conditions: 14.1 MHz RTTY, 10W output to 50Ω load. Spectrum analyzer RBW/VBW as stated in Figures 38 and 39. Figure 38 shows the transmitter output ±5 kHz from the carrier.

Next, the RYRYRY string is sent again and the occupied bandwidth measured using the OCC BW utility in the spectrum analyzer. Figure 39 shows the OCC BW test results. The theoretical occupied bandwidth (Occ. BW) and necessary bandwidth (Nec. BW) as defined in ***Ref. 3*** are calculated. Values: Occ. BW = 287 Hz, Nec. BW = 248 Hz.

Figure 51.

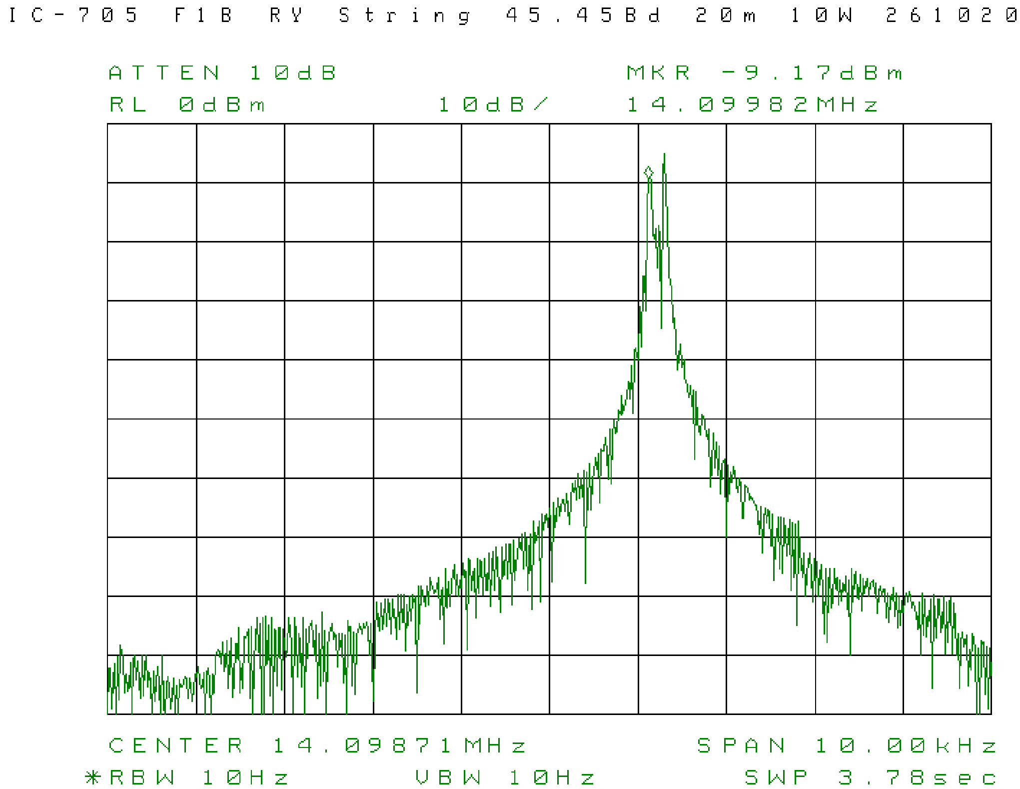
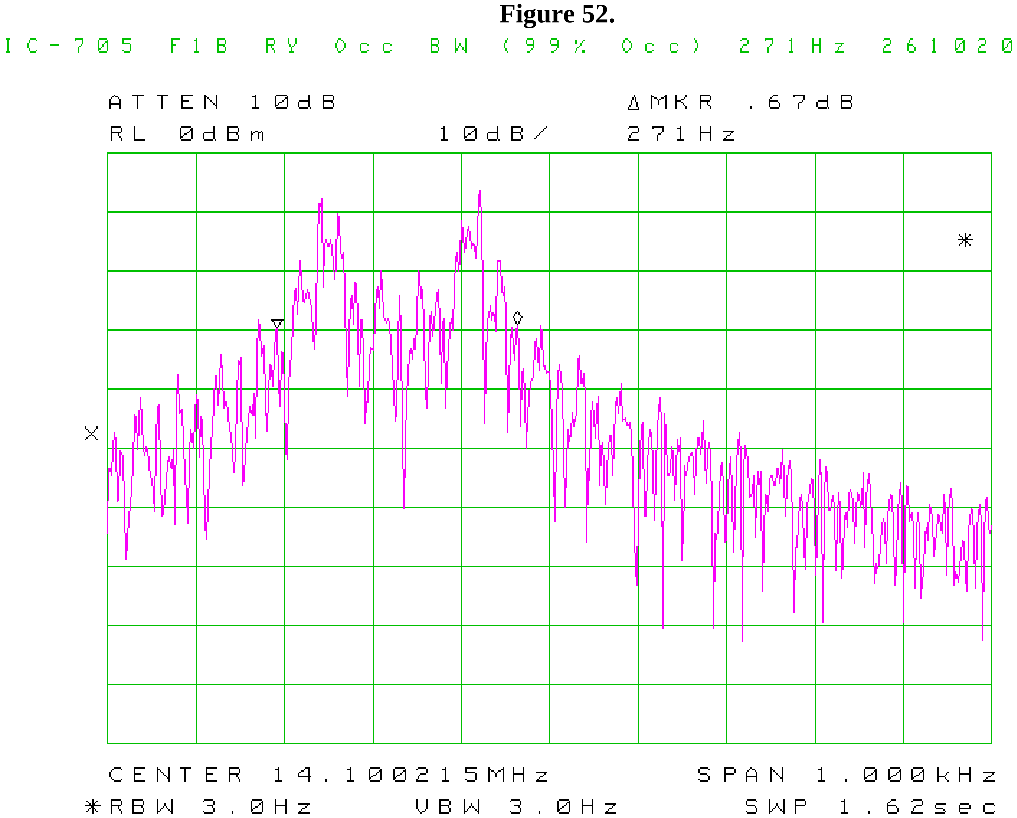


Figure 52.

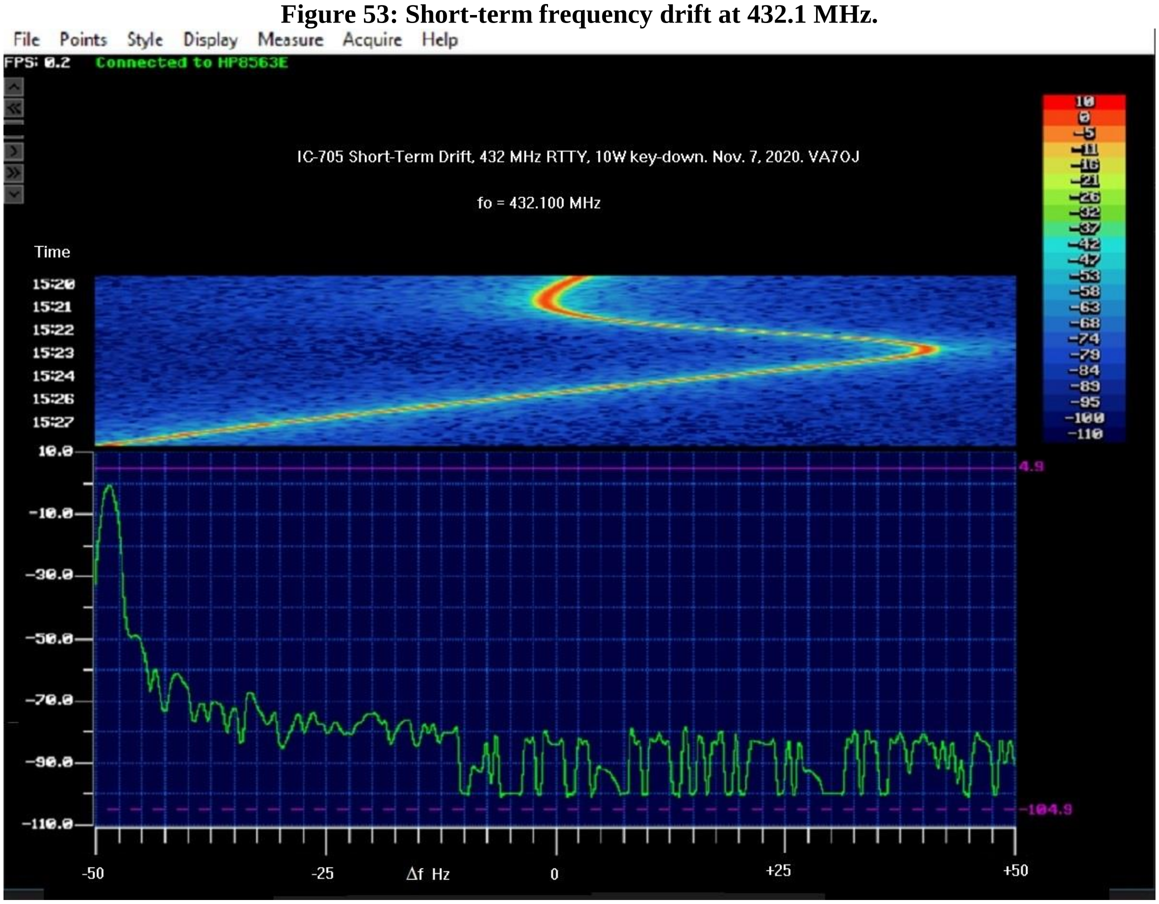


31: Short-Term Frequency Stability Test: In this test, the DUT RF port is connected via a 40 dB high-power attenuator to an HP 8563E spectrum analyzer clocked from the 10 MHz GPS-derived lab standard. The spectrum analyzer is connected to a laptop computer running a screen capture program which outputs a spectrogram and a waterfall display. The transmitter is keyed continuously for 7 minutes in RTTY mode at 10W output on 432 MHz, and the frequency drift and temperature indication recorded as shown in Figure 53. At the end of this test, the IC-705 indicator displayed 2 orange bars.

Test Conditions: 432.1 MHz, RTTY, 10W output.

Note: The spectrogram in the lower field of Figure 53 represents the spectrum of the transmitted signal at the instant when the capture program was manually halted.

Figure 53: Short-term frequency drift at 432.1 MHz.



32: References.

1. HF Receiver Testing: Issues & Advances”: https://www.ab4oj.com/test/docs/rcvrtest.pdf

2. “Noise Power Ratio (NPR) Testing of HF Receivers”: http://www.ab4oj.com/test/docs/npr_test.pdf

3. ITU-R Rec. SM.328-11, Annex 1, Sections 1.1, and 1.7

Oct. 30, 2020.