IC-7300MK2 – Test Report

The IC-7300 was unique when it was released in 2016. It was the first SDR transceiver at an affordable price and remains the best-selling transceiver of all time. However, the technology and performance of other manufacturers have since caught up, and ICOM is attempting to regain this position with the IC-7300MK2. Externally, the IC-7300MK2 looks almost identical to its predecessor but boasts significantly more features, such as the ability to connect an external monitor via HDMI, a built-in CW decoder/decoder, a separate antenna connector, a high-speed USB Type-C port, and perhaps most importantly, an integrated server with an Ethernet LAN connection. Additionally, the receiver features improved dynamic range (RMDR), and the transmitter has reduced sideband noise (SBN).

The RF characteristics of the transceiver will be tested below.

Measurements at the receiver

Sensitivity (MDS)

MDS (Minimum Detectable Signal) corresponds to the smallest detectable signal that is still perceptible within the background noise of a receiver. To measure the sensitivity, the generator and receiver (operating in CW mode, B=500Hz) are tuned to the same frequency, resulting in a superimposed tone of approximately 600Hz. The generator signal is then reduced until the audio output voltage on the voltmeter increases by a factor of only 1.414 (20log U2/U1), which corresponds to a (S+N)/N of +3dB. The receiver's sensitivity (MDS) then corresponds to the set level of the RF generator. For example, at f=7.1MHz, this results in an MDS of -131dBm/500Hz.

Figure 1: Measurement of sensitivity

The following sensitivities were determined in the bands from 1.9 to 50.1 MHz:

Settings: CW, RBW=500Hz, ATT off, NR off, NB off

	1.9MHz	3.7MHz	7.1MHz	14.1MHz	21.1MHz	50.1MHz
AMP off	- 131dBm	- 130dBm	- 132dBm	- 132dBm	- 132dBm	- 131dBm
AMP 1 on	- 141dBm	- 140dBm	- 141dBm	- 141dBm	- 141dBm	- 141dBm
AMP 2 on	- 141dBm	- 142dBm	- 143dBm	- 143dBm	- 142dBm	- 142dBm
IP+ on, AMP off	- 126dBm	- 127dBm	- 131dBm	- 131dBm	- 132dBm	- 131dBm

Table 1: Sensitivity (MDS) with/without preamplifier (AMP1/2) and IP+

Noise figure (NF) and noise factor (F)

Noise figure and noise factor are determined using a noise generator that produces a constant noise band from 0-100MHz with a noise voltage of 1mV.$_{eff}$/0- 100MHz=-47dBm/ 0-100MHz.
As an example, the receiver's noise figure is determined at fe = 14.2 MHz, SSB, B = 2.4 kHz. To do this, set the frequency to fe = 14.2 MHz and adjust the receiver's output noise to a fixed value (reference) of, for example, 100 mV (or 0 dB) on the RMS voltmeter using the volume control. Then connect the noise generator to the receiver and reduce the noise level using the attenuator until the voltage reading on the RMS voltmeter increases by a factor of √2 = 1.414, i.e., from 100 mV to 141.4 mV, or on a logarithmic scale from 0 dB to 3 dB (20 log 1.414 = 3 dB). The noise generator level then corresponds to the receiver's noise level.

Figure 2: Determination of noise measure and noise factor

This was done with a set attenuation of 30dB, resulting in a noise power of P.$_{Noise}$= -47dBm/ 100MHz - 30dB attenuation = -77dBm/100MHz and based on a 1Hz bandwidth

P_{Noise}= -77dBm - 10log100000000 = -157dBm/Hz

The resulting noise figure of the receiver is then calculated from the difference between the injected noise power of -158dBm/Hz and the theoretical noise limit of -174dBm/Hz.

Noise figure = -158dBm/Hz - (-174dBm/Hz) = 16dB

corresponding to a noise factor to be calculated of

Noise factor (F) = 10Noise figure/10= 1016/10= 40

In other words, the signal-to-noise ratio of a received signal deteriorates by 16dB, or a factor of 40, between the input and output of the receiver.

By adding preamplifiers (AMP 1/2), the noise figure is significantly reduced.

Settings: fe=14.2MHz, SSB, RBW=2.4kHz

	AMP off	AMP1 on	AMP2 on
Noise figure (FdB)	16dB	6dB	3dB
Noise factor (F)	40	4	2

Table 2: Noise figure and noise factor in the 20m band with and without amplifier

Note: The noise figure can only be determined using a calibrated noise signal. If a noise generator is not available, in practice the noise figure is often calculated using the sensitivity (MDS) and the equation "Noise Figure = MDS - 10 logRBW - (-174 dBm/Hz)" or, simplified for B=2.4 kHz, "Noise Figure = MDS + 140 dB". When using these equations, it is assumed that the "resolution bandwidth" and the "noise bandwidth" is the same, which is not the case in most instances. If these equations are used, errors of up to 2dB can occur.

Sideband noise (RMDR and SBN)

The RMDR (Reciprocal Mixing Dynamic Range) and SBN (Sideband Noise) values are among the most important criteria for a receiver. They describe the dynamic range loss of a receiver due to unwanted sideband noise. High levels of sideband noise can mask a small signal next to a large signal, effectively rendering a receiver "deaf." Increased sensitivity or improved selectivity is of no help in this situation. During the sampling process, the clock generator's SBN mixes with the received signal, potentially masking it with noise. Therefore, the clock generator's phase noise should be as low as possible (<-130 dBc/Hz) and the resulting RMDR as high as possible (>110 dB).

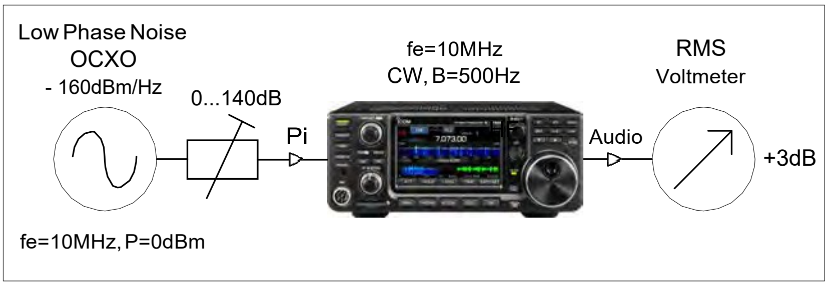


Figure 3: Measurement of RMDR and SBN

To determine the RMDR in the 40m band, a low-noise 10MHz signal (OCXO from KVG) is fed into the receiver and the receiver frequency is adjusted to fe=10MHz +/-1kHz.Then the signal power (Pi) is increased until the (S+N)/N at the voltmeter reached a value of +3dB above the receiver background noise of MDS=-132dBm/Hz (see Table 1).

This was done at a Pi of **-23dBm** from which a RMDR was calculated of

RMDR= Pi - MDS = -23dBm -(-132dBm) = 109dB

and a sideband noise (SBN) of

SBN = RMDR + 10logB = 109dB + 27dB = 136dBc/Hz

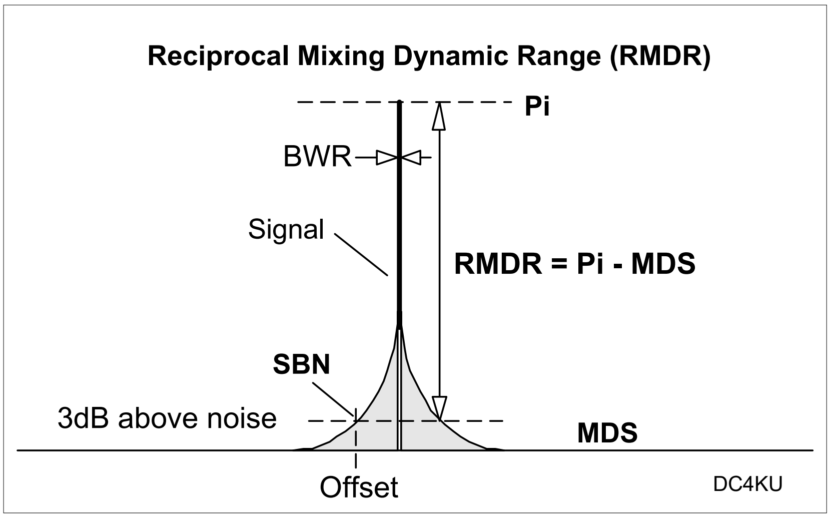


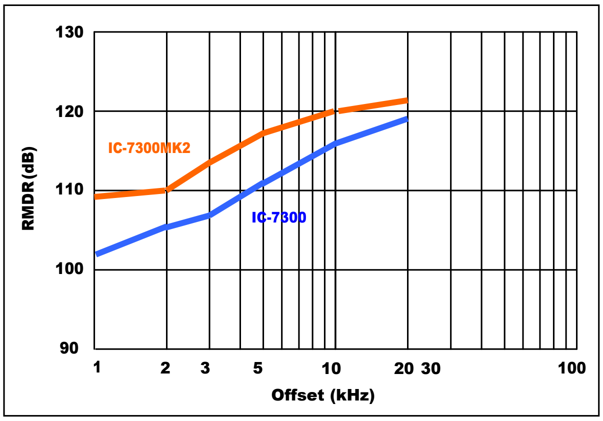
Figure 4: Determination of SBN and RMDR using a low-noise CW signal

Similarly, the RMDR and SBN are also determined at larger frequency offsets to the carrier **(Table 3)**, from which the curves in **Image 5** and **6.** The result is: the larger the RMDR or the smaller the SBN, the greater the receiver's dynamicrange.

Settings IC7300MK2: CW, B=500 Filter, Preamp off, Att. off, NR off, NB off, AMP off

Offset (kHz)	Pi (dBm)	RMDR (dB)	SBN (dBc/Hz)
1	- 23	109	- 136
2	- 22	110	- 137
3	- 18	114	- 141
5	- 15	117	- 144
10	- 12	120	- 147
20	- 10	122	- 149

Table 3: RMDR and SBN in carrier spacings from 1 to 20 kHz



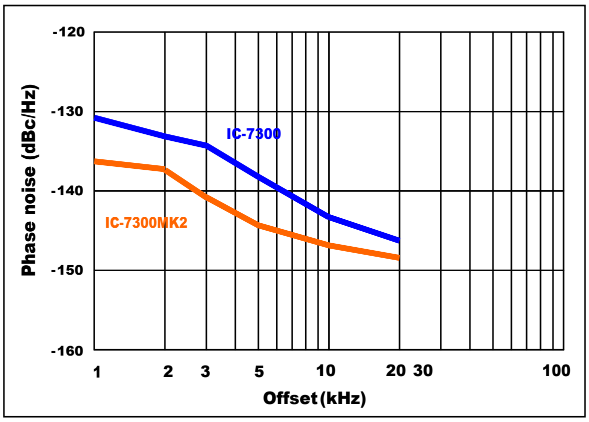


Figure 5: Curve of RMDR and phase noise as a function of carrier spacing (offset)

Result: The RMDR of the IC-7300MK2 is 7dB higher than that of the IC-7300 at a distance of 1 kHz.

IMD test, dynamics and IP+

The usable dynamic range of a receiver is limited by the noise floor for small signals and by the presence of intermodulation products for large signals. To determine the receiver's intermodulation immunity, two CW signals of the same level and small frequency separation of f1 =14.100MHz, f2=14.102MHz, delta f = 2kHz are combined with the receiver's RF input via a combiner and attenuator.

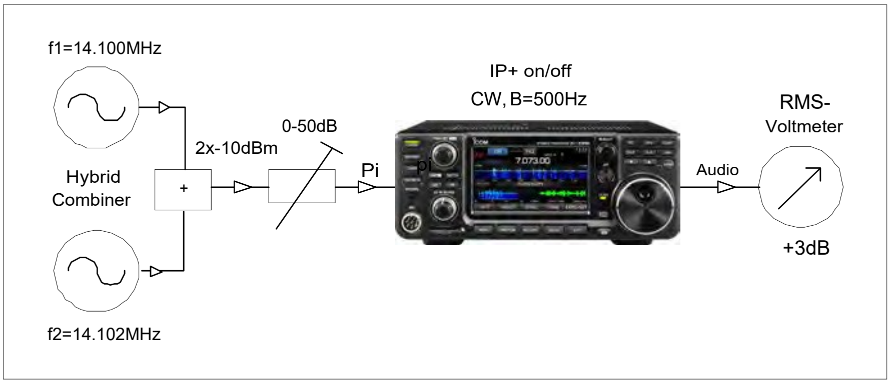


Figure 7: Measurement of 3rd order intermodulation (IMD)3) with a 2-tone signal

An audio voltmeter is located at the receiver's audio output, which measures the levels of the interference signals during a 600 Hz superposition tone. The level of the two-tone signal (Pi) is then increased until the third-order intermodulation interference at 2xf1-f2 and 2xf2-f1 appears at +3 dB above the background noise of MDS = -132 dBm/Hz (see Table 1) and, according to (S+N)/N=2, thus corresponds to the level of the background noise.

This was reached at a 2-tone level of Pi = 2 x -56dBm, from which a DR was calculated (3rd-order IMD Dynamic Range) results from

DR_3 = Pi - MDS = -56dBm - (-132dBm) = 76dB (blue curve).

The 2-tone level (Pi) is then gradually increased in 1dB steps and the resulting IMD_3-leveles are measured and noted, from which the IMD_3-curve (blue curve) in **Figure 8** results.

When "IP+" is activated, dithering/randomization occur in the A/D converter, causing the IM products to decorrelate and disappear into the noise. The first IMD_3-products with +3dB above the noise floor only occur at Pi=2x-39dBm, resulting in a dynamic range of

$DR_{3\ IP+}$ = Pi - MDS = -39dBm - (-131dBm) = 92dB (green curve).

The IM stability is therefore increased by 16dB with IP+. Another positive aspect is that the receiver noise only increases by 1dB (8dB for the IC-7300) when IP+ is activated. The highest dynamic range is achieved only in the so-called "sweet spot," at an input level of Pi = 2x -25dBm.

$DR_{3IP+max}$ = Pi - IMD = -25dBm - (-123dBm) = 98dB (green curve, red dot)

Settings IC-7300MK2: CW, BW 500Hz, Notch off, NB off, NR off, AGC off, IP+ on/off

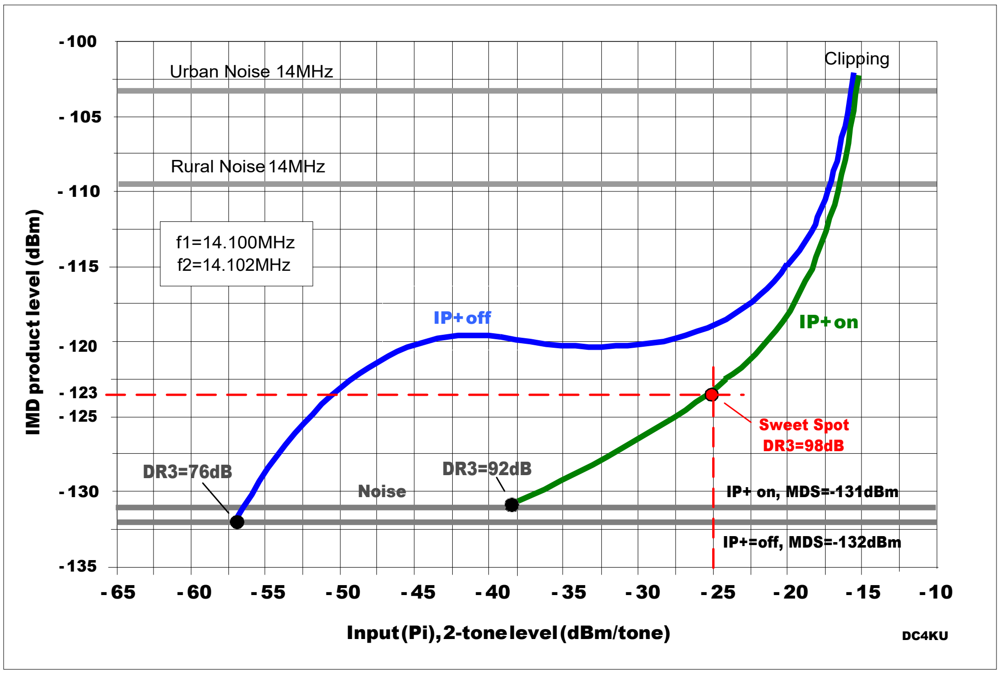


Figure 8: Interference-free dynamics as a function of the modulation (Pi)

Preamplifier	IP+ off	IP+ on
off	76dB	92dB
P.AMP1	76dB	93dB
P.AMP2	78dB	92dB

Table 4: DR3 as a function of IP+ and P.AMP

In the course of the curves, it is fundamentally important that both curves are below the Rural Noise (urban noise) or Urban Noise (rural noise), i.e. with the antenna switched on, the resulting IM products are always below the background noise and only appear as an interference product at levels greater than -15dBm (S9+58).
Note: Unlike analog receivers, direct sampling SDR receivers do not have a "1dB compression" or a "3rd order intercept point" (IP3). These features do not exist.

Dynamic range measurement using NPR (Noise Power Ratio)

Instead of a two-tone signal, the receiver uses a noise generator with white light. Noise leveled above a certain noise level **(4)**, the receiver becomes overloaded and generates intermodulation in the form of additive noise. To make this noise increase measurable and visible, a narrowband, steep notch filter (in this example, 2.4 MHz, B=10 kHz) is placed between the noise generator and the receiver. This filter completely suppresses the noise at its cutoff frequency (attenuation >100 dB), so that in the unloaded state, only the receiver's inherent noise (MDS = -131 dBm) is measurable at the filter's base. However, as soon as the receiver produces distortion (IM, harmonics, etc.), this becomes visible as a slight noise increase of 3 dB at the notch filter's base or on the RMS voltmeter.

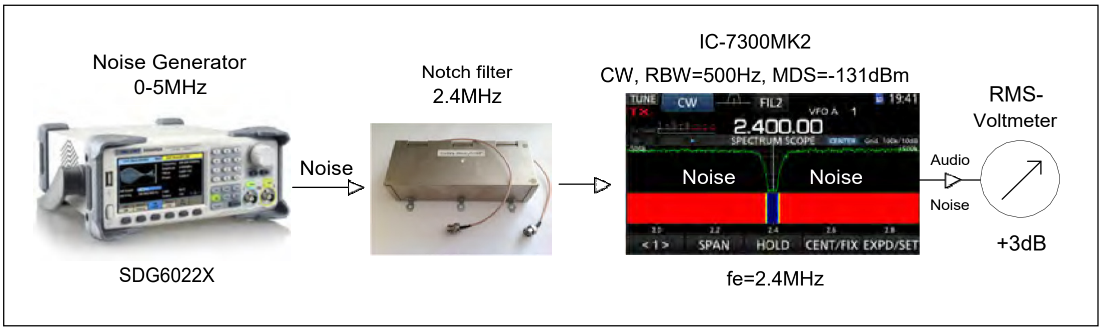


Figure 9: Measurement setup

The NPR of the IC-7300MK2 is determined below; the measurement setup is shown **Image9.** For this purpose, a noise band from 0 to 5 MHz is generated (SDG6022X) and its power (P_{TOT}) increased until the noise at the bottom of the notch filter rises by 3 dB, thus indicating the receiver's output limit. At a noise level of P_{TOT} = -14 dBm/0-5 MHz, the receiver generates distortion products that are +3 dB above its noise floor and, according to (S+N)/N=2, correspond to the determined sensitivity of -131 dBm/500 Hz. The difference between the injected noise power (P_{TOT}) and the sensitivity (MDS) of the receiver, corresponds to the NPR.

NPR = P_{TOT} - MDS = -54dBm – (-131dBm) = 77dB

with: P_{TOT}= -14dBm/5MHz = -54dBm/500Hz and MDS = -131dBm/500Hz

Measurements at the transmitter

RF output power of the transmitter

To determine the maximum RF output power (PEP), an 800Hz AF sine wave (CW signal) is applied to the microphone input and the RF output power (PEP) is measured across a 100W load resistor with -50dB coupling using a spectrum analyzer **(Image 10).** Since the selected filter bandwidth of the transmitter is 2.4 kHz and the analyzer operates with a span of 10 kHz. The harmonics of the modulation signal can also be measured within the filter, with a suppression of >60 dBc at 1600 Hz and 83 dBc at 2400 Hz.

This high harmonic separation shows that the transmitter's modulation is highly linear, resulting in clean and clear signal transmission (speech). At f = 14.1 MHz, the transmitter generates a maximum power of

Pa (PEP) = 0.22dBm + 50dB attenuation = 50.22dBm = 105.2 Watts

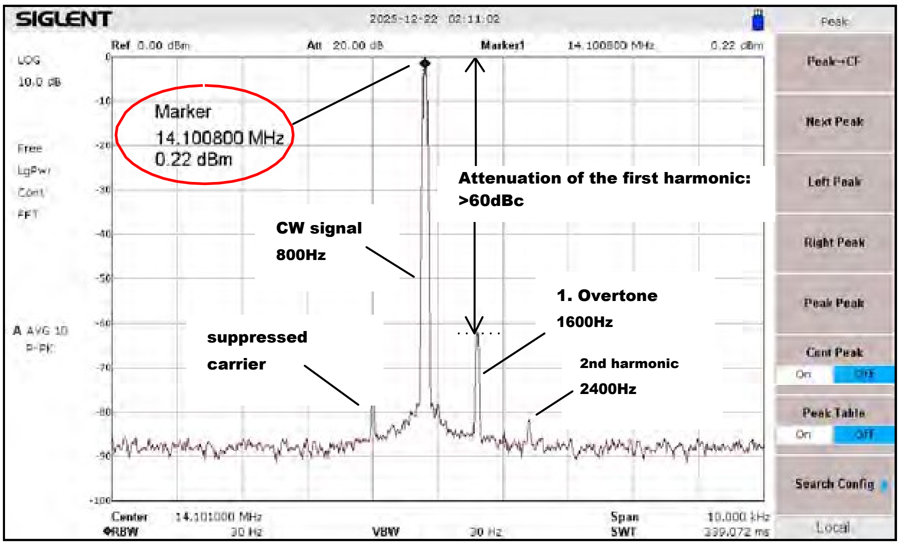


Figure 10: Max. RF output power in the 20m band, span 10kHz

Settings IC-7300MK2: SSB 2.4kHz, RF Power 100%, Mic Gain 20%, supply 13.8VDC

Frequency	3.6 MHz	14.1 MHz	28.1 MHz	50.1MHz
Maximum Power (PEP)	109.5	105.2W	102.3W	87.5W

Table 5: Maximum RF output power on the bands

Harmonic suppression of the transmitter

For this purpose, the analyzer's span is increased to 30MHz, so that the transmitted signal of f=14.1MHz and its first harmonic at 28.2MHz become visible on the screen **(Image 11)**. In this measurement

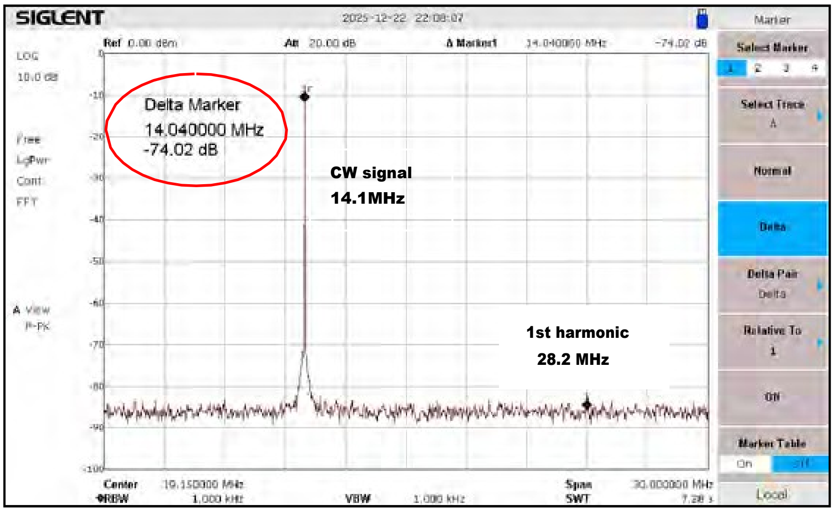


Figure 11: Useful signal of 14.1 MHz and 1st harmonic at 28.2 MHz, span 0-30 MHz

Care must be taken to ensure that the analyzer itself does not generate any harmonics that could distort the result. The harmonic separation of the analyzer itself must be at least 80 dBc. Therefore, an attenuation of 60 dB is inserted between the transmitter and the analyzer, ensuring that the analyzer operates in the linear region. The first harmonic of the carrier signal at 28.2 MHz is shown in the noise, with a suppression of >74 dBc. The harmonic suppression in the bands from 3.7 MHz to 50.1 MHz shows **Table 6.**

Settings: NF signal 800Hz, SSB 2.4kHz, RF power 100%, supply 13.8VDC, HF power 100Watt

Frequency	3.7MHz	14.1MHz	21.1MHz	28.1MHz	50.1MHz
suppression of 1. Overtone	80dBc	74dBc	68dBc	65dBc	80dBc

Table 6: Suppression of the transmitter's first harmonic on different bands

Intermodulation of the transmitter

The intermodulation of the transmitter is determined using a 2-tone audio frequency generator (f1=800Hz, f2=1200Hz, Delta f = 400Hz) **(Image 12)**. To do this, connect the 2-tone generator to the microphone input of the IC-7300MK2 and increase its summed level until the transmitter reaches its maximum power (PEP). A dummy load with a -50dB output (1mW) is connected to the transmitter's output, which routes the attenuated signal to a spectrum analyzer or oscilloscope.

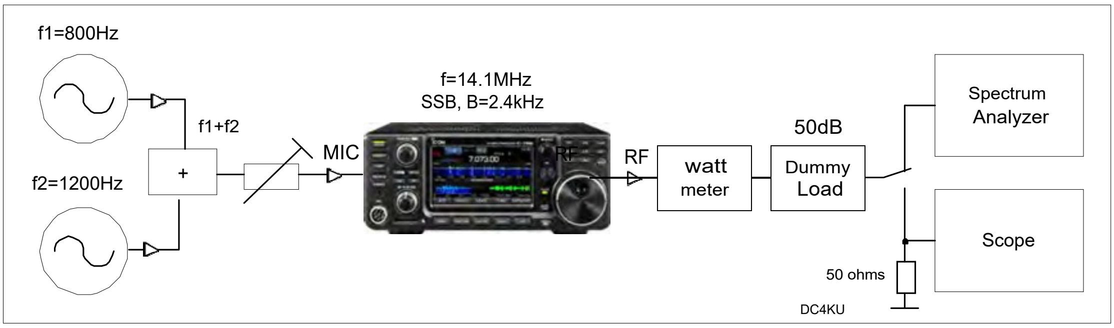


Figure 12: Measurement of transmitter intermodulation

Since the transmitter is driven by two closely adjacent AF sine signals of the same level, a so-called beat frequency occurs, in which the signals add up or cancel each other out **(Figure 13).** The average power of a 100W transmitter therefore only reaches 2 x 25 watts = 50 watts at its peak, which is 6dB below the transmitter's maximum power of PEP = 100 watts. Only at the maximum of the during beating, the voltage doubles, thus generating four times the power of a single tone, and only now does the transmitter produce a maximum power of 100 watts PEP.

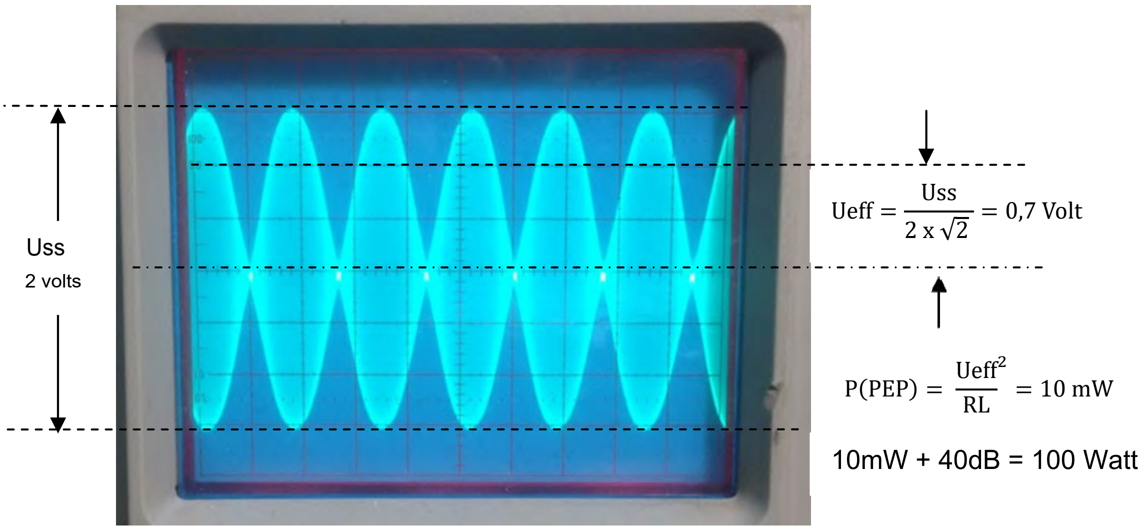


Figure 13: RF 2-tone signal with PEP = 100 watts on the oscilloscope

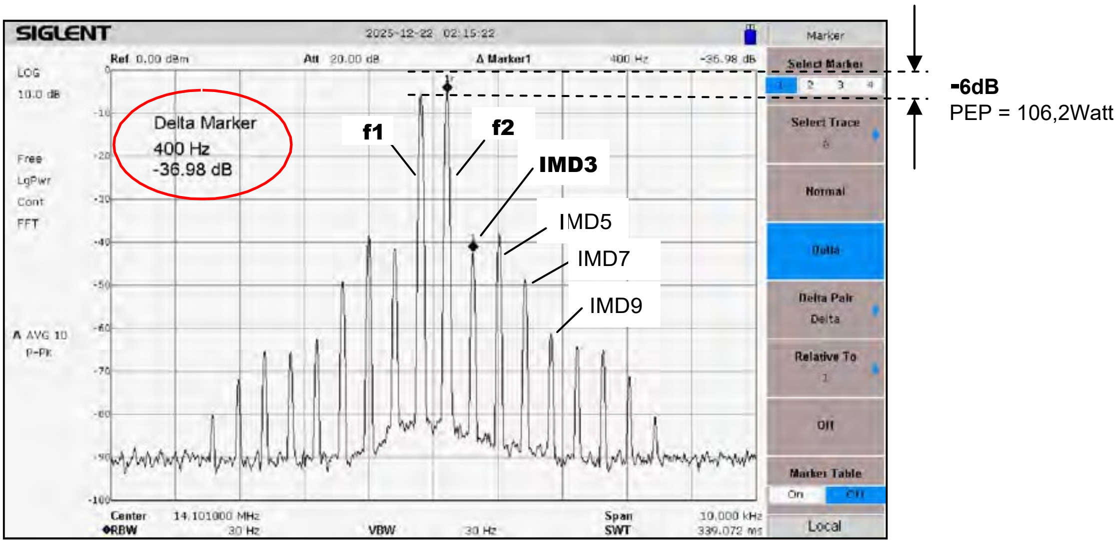


Figure 14: Intermodulation of the 2-tone transmitted signal at f = 14.1MHz, span = 10kHz

Note: If using a wattmeter to measure power, you must check whether the the wattmeter is calibrated in Average or PEP mode. If the wattmeter is set to Average, it will not display the peak value of 100 watts during this measurement, but only 50 watts.

Settings: Audio signals 800Hz and 1200Hz, SSB 2.4kHz, RF power 100%, supply 13.8VDC

Frequency	**3.6MHz**	**7.1MHz**	**14.1MHz**	**21.1MHz**	**28.1MHz**	**50.1MHz**
IMD3 spacing	38dBc	41dBc	37dBc	35dBc	30dBc	31dBc

Table 7: IMD_3 - Distances of the transmitter on the bands

The resulting intermodulation distortion of the transmitter at f =14.1MHz shows **Image 14.** The IMD_3 products are of particular importance because they are generated very close to the carrier signal, in this case at a distance of only 400 Hz. Good transmitters suppress IMD_3-Products at full control around.
For IMD values greater than or equal to 30 dBc, higher-order IMD products should decay relatively quickly to avoid interfering with adjacent channels. For the IC-7300MK2, IMD_3 is at spacing of 37dBc, the other IMD products (IMD 5, 7, 9…) decays faster than with the IC-7300. Even at a small frequency spacing of +/- 4 kHz, the IMD products are suppressed by >90dB and disappear into the noise. **Table 7** shows the determined IMD_3-Spacing on the different bands.

Measurement of intermodulation with a noise signal

The intermodulation of a transmitter can also be determined via a noise signal **(Image 15)**. For this purpose, a white noise band of, for example, 0-5 kHz is fed into the microphone input, and the transmitter is adjusted for maximum power by setting the noise amplitude. The result

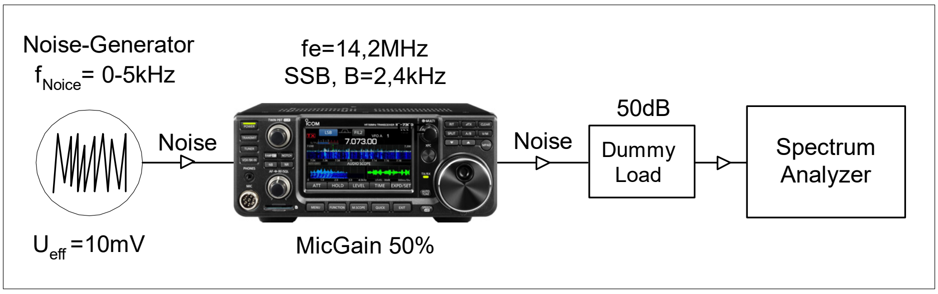


Figure 15: Measurement of transmitter intermodulation with noise

of the measurement with P=100W (yellow) and P=40W (violet) power shows **Image 16.** The almost rectangular block (envelope) in the middle of the spectrum shows the bandwidth of the SSB filter used (2.4 kHz), driven by white noise. At the base of the envelope, the IMD products start at intervals of approximately 32 dBc, their levels decreasing relatively rapidly towards higher and lower frequencies.

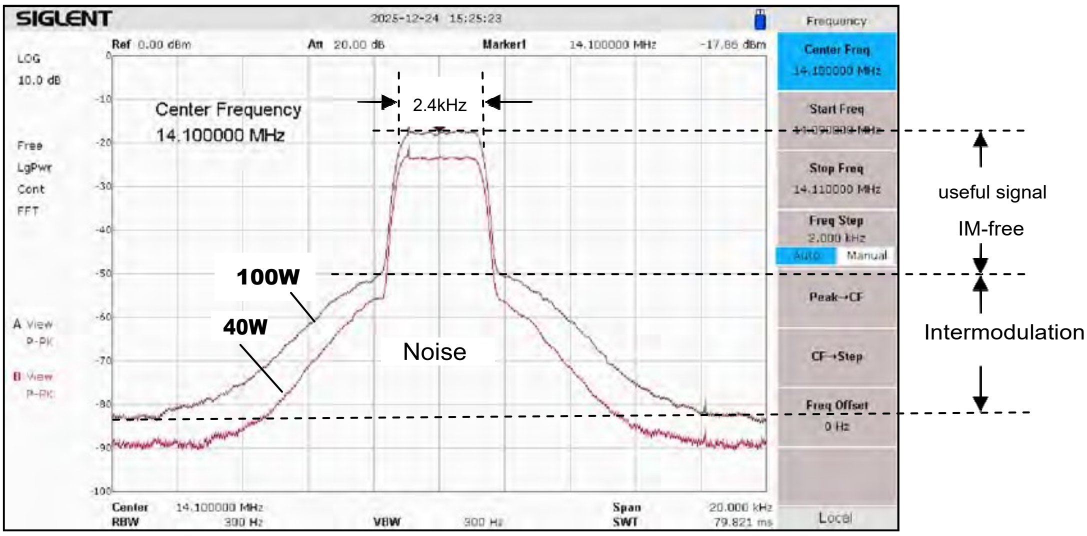


Figure 16: Noise signal at 100 watts (yellow) and 40 watts (violet), span 20 kHz

The measurement result with noise is much more informative than just two spectral lines because, in principle, a continuous spectrum with infinitely many spectral lines is displayed. The important aspect here is that the IM products to the left and right of the desired channel decay relatively quickly so that adjacent channels are not affected, which is the case with the IC-7300MK2. The IM distortion curves decay somewhat faster here than with the IC-7300.

TX sideband noise

The SBN (sideband noise, phase noise) of the transmitter is another important criterion for evaluating its quality. In the frequency domain, the phase noise of a CW signal becomes visible as noise sidebands to the right and left of the carrier **(Image 17).** If a transmitter has significant sideband noise, a nearby, weak signal can be masked in the reception range, causing the affected receiver to lose sensitivity. Therefore, the SBN of a transmitter (TX- SBN) should be as low as possible.

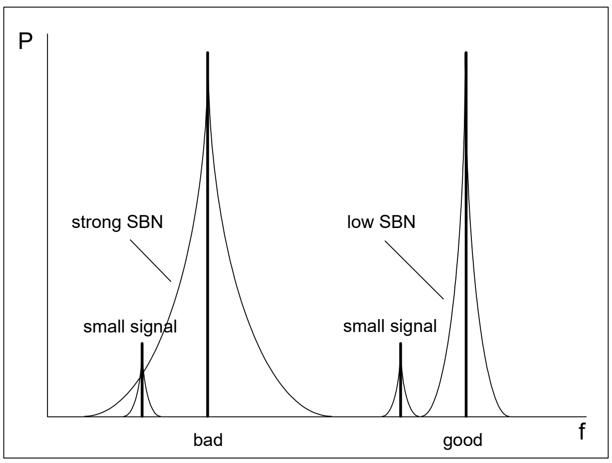


Figure 17: Water level loss in the adjacent canal due to SBN

A direct SBN measurement using a spectrum analyzer is unfortunately not possible because its dynamic range is insufficient. However, the measurement becomes possible using a narrowband notch filter, which suppresses only the carrier signal by up to 70 dB. In this example, I am using a **quartz notch filter (3)** in the 40m band (f_0=7.1617MHz, B=+/-1.2kHz) which only suppresses the carrier signal and allows the sideband noise to pass freely to the right and left of the filter stopband at a distance of >= +/- 1kHz **(Image 18)**.

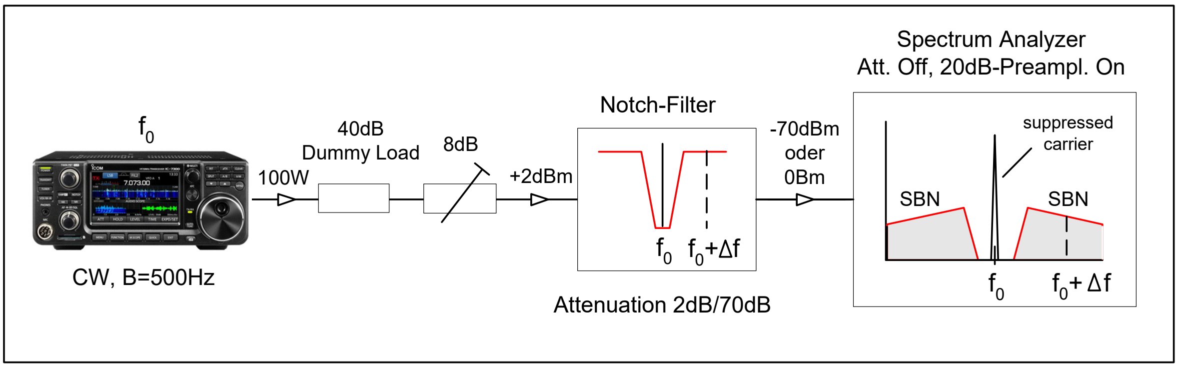


Figure 18: SBN measurement using a notch filter

First, the transmitter's 100W CW signal (RTTY) must be reduced to a low power of approximately 1mW using attenuators to prevent damage to the downstream electronics. Then, the carrier signal frequency must be adjusted to the filter's passband, for example, f_0+1kHz and adjust the resulting level at the output of the notch filter to a reference level of 0dBm via an adjustable attenuator.
Then adjust the transmitter's frequency to the center frequency (f_0) of the notch filter, which suppresses the signal by 70dB. Due to the strong signal suppression, the analyzer is now set to its maximum sensitivity of -162dBm/Hz, with 0dB attenuation and +20dB preamplifier engaged, without being overloaded! Everything that is now measurable to the left and right of the notch filter's cutoff frequency is the transmitter's sideband noise.

In the test, I used an IC-7300MK2 and an IC-7300, whose SBN was measured and recorded at intervals of 1, 3, 5, 10, 20, 50 and 100Hz relative to the carrier **(Table 8).** The resulting SBN curve shows **Image 19.**

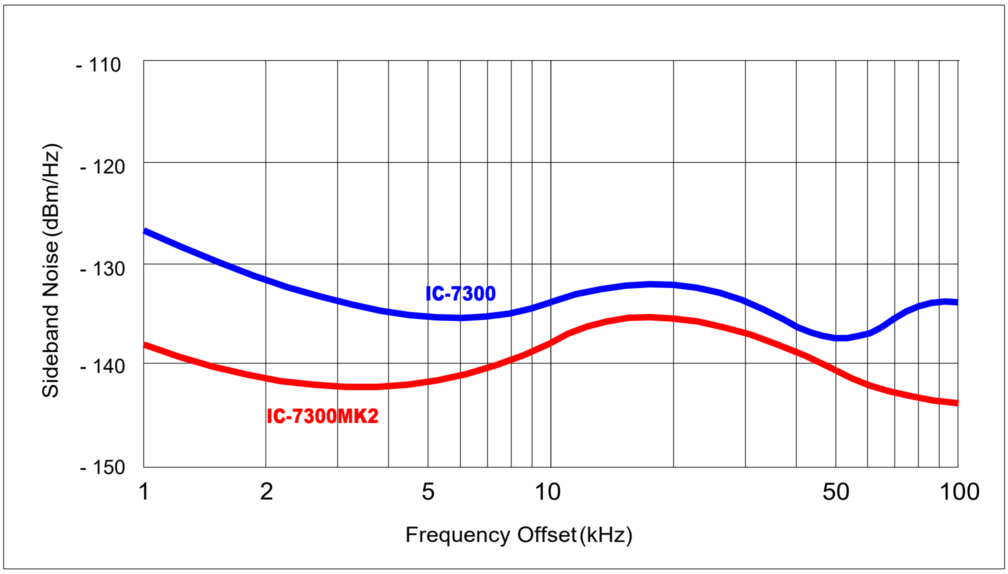


Figure 19: TX-SBN from the IC-7300MK2 and IC-7300 at an offset of 1...100kHz

Offset (kHz)	1	3	5	10	20	50	100
TX-SBN (dBm/Hz)	- 138	- 143	- 142	- 138	- 136	- 141	- 144

Table 8: TX-SBN in offsets of 1 to 100kHz

The waveforms of both transmitters show that the IC-7300MK2 exhibits significantly less noise near the carrier frequency than the IC-7300. At a 1 kHz offset, the difference is 11 dB, which is advantageous in practical operation. ICOM specifies a 12 dB improvement in its "TX Phase Noise" at this point in the IC-7300MK2 datasheet.

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Jan. 17, 2026, Rev. 5.2026

Literature

(1) IC-7300MK2-Basic Manual (German) Download
https://www.icomjapan.com/support/manual/4463/

(2) IC-7300MK2-Advanced Manual Download
https:// www.icomjapan.com/support/manual/4487/

(3) Notch filters for measuring purposes
CQ DL 5-2021, DC4KU
https://dc4ku.darc.de/Aufbau_Notchfilter.pdf

(4) Siglent SDG6022X Arbitrary Signal Generator
Funkamateur 5-2020, DC4KU
https://dc4ku.darc.de/SDG6022X-Test_DC4KU.pdf