

# Yaesu FT-710, Test Report



The FT-710 is a modern, direct sampling HF/50/70MHz transceiver and is characterized by the following features: HF direct sampling with dual-channel ADC (14-bit), 3DSS real-time spectrum scope, RMDR 113dB in 2 kHz distance, dithering signal, 4.3 inch touch screen color display, AESS (Acoustic Enhanced Speaker System), connection for external DVI-D monitor, antenna tuner and 100 Watt transmission power.

FT-710 and FT-DX1/101 are constructed differently (**Figure 1, 2**). The FT-DX10 is a hybrid SDR with analog mixer, LO, roofing filter and A/D conversion of the IF. The FT-710 is a direct-sampling SDR, which digitizes the RF signals directly. For this he uses the same twin ADC as in the FT-DX10 and the subsequent FPGA combines their digital signals in such a way that an overload occurs late. In addition, a dithering signal (noise) fed into the inputs of the ADCs generates a reduction in IMD3 interference (**1**).

**Figure 3** shows the Yaesu specifications of the FT-710, such as RMDR, BDR, IMD3 and TX-Phase Noise. The most important RF data of the receiver and transmitter are tested below. A detailed report on the function and handling of the FT-710 will be published in FUNKAMATEUR magazine 01/2023.

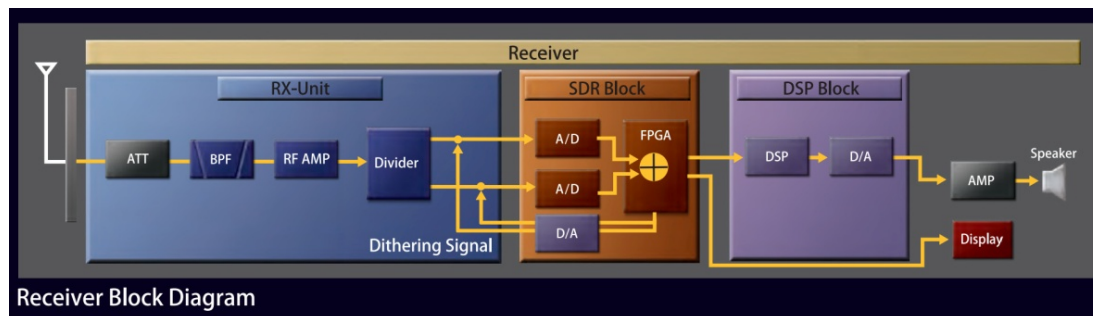


Figure 1: Yaesu block diagram of the FT-710, direct-sampling SDR

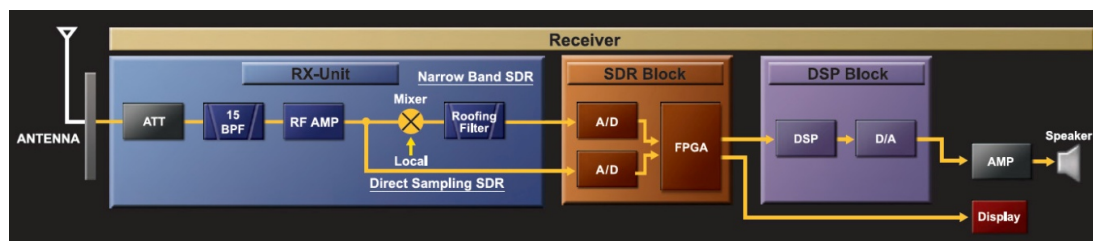


Figure 2: Yaesu block diagram of the FT-DX10, Hybrid SDR

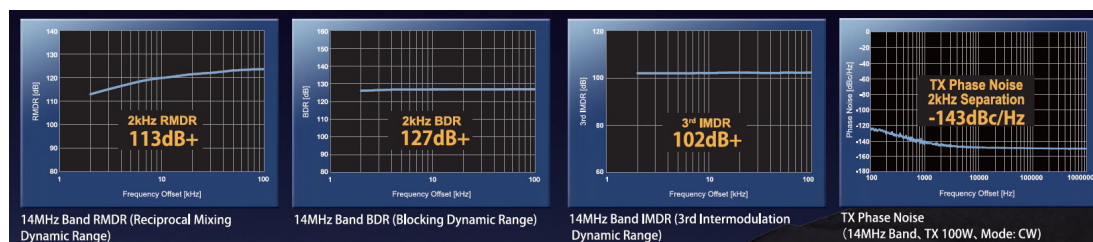


Figure 3: Yaesu specifications of the FT-710

## Receiver

### Sensitivity (Minimum Discernible Signal, MDS)

The sensitivity is defined as the size of the receiver noise floor (MDS, Minimum Discernible Signal). If a CW signal is applied to the input of the receiver whose level (Pi) raises the noise floor of the receiver by 3dB (voltage increase at the RMS voltmeter by a factor of 1.414), then the power of the signal according to  $(S+N)/N = 2$  corresponds to the noise floor of the receiver. Set the overlay tone (LF) at the loudspeaker to approx. 700Hz. For this measurement, a RF generator, a switchable attenuator and a calibrated RMS-voltmeter are required (**Fig. 4**).

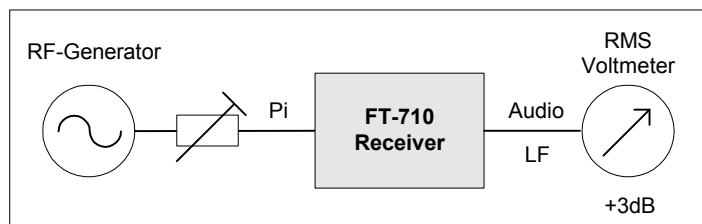


Figure 4: Measurement setup to determine the sensitivity

The following sensitivities (MDS) were measured in the frequency bands:

**Settings: BW=500Hz (CW)**

	1.9MHz	3.7MHz	7.1MHz	14.2MHz	21.2MHz	28.2MHz	50.1MHz
IPO	-123dBm	-125dBm	-126dBm	-126dBm	-127dBm	-127dBm	-128dBm
AMP1 (+10dB)	-132dBm	-135dBm	-136dBm	-136dBm	-136dBm	-136dBm	-138dBm
AMP2 (+20dB)	-141dBm	-142 dBm	-142 dBm	-142dBm	-142 dBm	-143 dBm	-141dBm

Table 1: Sensitivity (MDS) for CW, BW = 500Hz

**Settings: BW=2.4kHz (SSB)**

	1,9MHz	3,7MHz	7,1MHz	14,2MHz	21,2MHz	28,2MHz	50,1MHz
IPO	-117dBm	-119 dBm	-120 dBm	-120dBm	-121 dBm	-121 dBm	-122 dBm
AMP1 (+10dB)	-126dBm	-129dBm	-130dBm	-130dBm	-130dBm	-130dBm	-132dBm
AMP2 (+20dB)	-134dBm	-136dBm	-136dBm	-136dBm	-136dBm	-137dBm	-135dBm

Table 2: Sensitivity (MDS) for SSB, BW = 2.4kHz

### Noise Figure (NF)

With a noise limit value of -174dBm/Hz, the noise figure is calculated as follows: Noise Figure = MDS -  $10\log BW - (-174\text{dBm/Hz})$ . At BW=2.4 kHz, the following applies: Noise Figure = MDS + 140dB

Frequenz	1,9MHz	3,7MHz	7,1MHz	14,2MHz	21,2MHz	28,2MHz	50,1MHz
IPO	23 dB	21 dB	20 dB	20 dB	19 dB	19 dB	18 dB
AMP1 (+10dB)	14 dB	11 dB	10 dB	10 dB	10 dB	10 dB	8 dB
AMP1 (+20dB)	6 dB	4 dB	4 dB	4 dB	4dB	3dB	5dB

Table 3: Noise Figure

Result: The sensitivity is sufficiently good on all bands. In the higher bands, the preamplifier AMP1 can be switched on if required, whereby the distortion-free dynamics are not affected, as will be shown later.

The term "IPO" stands for "Intercept Point Optimization". This means the optimization of the 3rd order intercept point. However, an IP3 does not exist for direct scanning SDRs. Presumably Yaesu accidentally adopted this designation from an analogue, superheterodyne receiver.

### RMDR and SBN

Reciprocal Mixing Dynamic Range (RMDR) and Sideband Noise (SBN) are among the most important criteria of a receiver. Excessive sideband noise can mask a small signal next to a large signal and "deaf" a receiver. Greater sensitivity or better selection does no longer help here. During the sampling process, the SBN of the clock generator mixes with the received signal, so that the signal can be covered by the noise under certain circumstances. The phase noise of the clock generator should therefore be as small as possible ( $< -140\text{dBc/Hz}$ ) and the resulting RMDR as large as possible ( $> 110\text{dB}$ ). To determine the RMDR, a quasi noise-free carrier signal (10MHz OCXO from KVG) is fed into the receiver and its level ( $P_i$ ) is increased until a signal-to-noise ratio  $(S+N)/N$  of +3dB above the background noise (MDS) is obtained at a distance of 2 kHz (2).

From this the RMDR is calculated to  $\text{RMDR} = P_i - \text{MDS}$  and the SBN to  $\text{SBN} = \text{RMDR} + 10\log B$ .

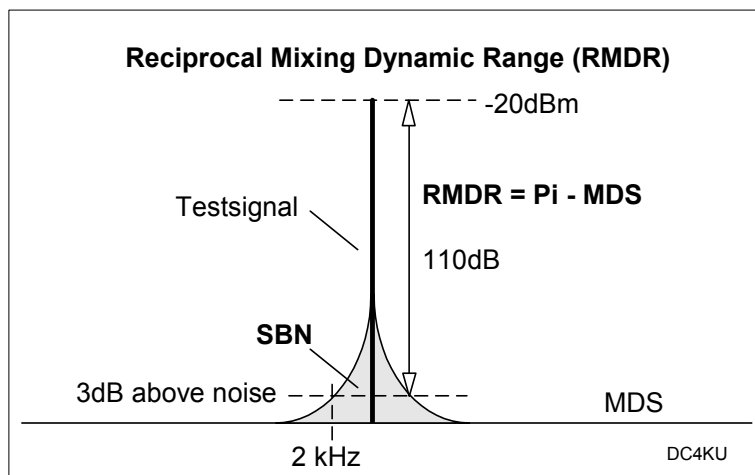


Figure 5: Determination of SBN and RMDR with a low-noise test signal

With an MDS of  $-136\text{dBm}$  at  $BW = 500\text{Hz}$  and an offset of  $2\text{kHz}$ , the FT-710 has an RMDR and SBN of

$$\text{RMDR} = P_i - \text{MDS} = -20\text{dBm} - (-136\text{dBm}) = 116\text{dB}$$

$$\text{SBN} = \text{RMDR} + 10\log B = 116\text{dB} + 10\log 500\text{Hz} = 116\text{dB} + 27\text{dB} = 143\text{dBc/Hz}$$

In the same way, the measurement is carried out at intervals of up to  $100\text{kHz}$  (Table 4), resulting in the measurement curves in Fig. 6.

Offset (kHz)	$P_i$ (dBm)	SBN (dBc/Hz)	RMDR (dB)
2	-20	143	116
5	-18	145	118
10	-17	146	119
20	-16	147	120
50	-15	148	121
100	-14	149	122

Table 4: RMDR and SBN in carrier spacing from 2 to 100 kHz

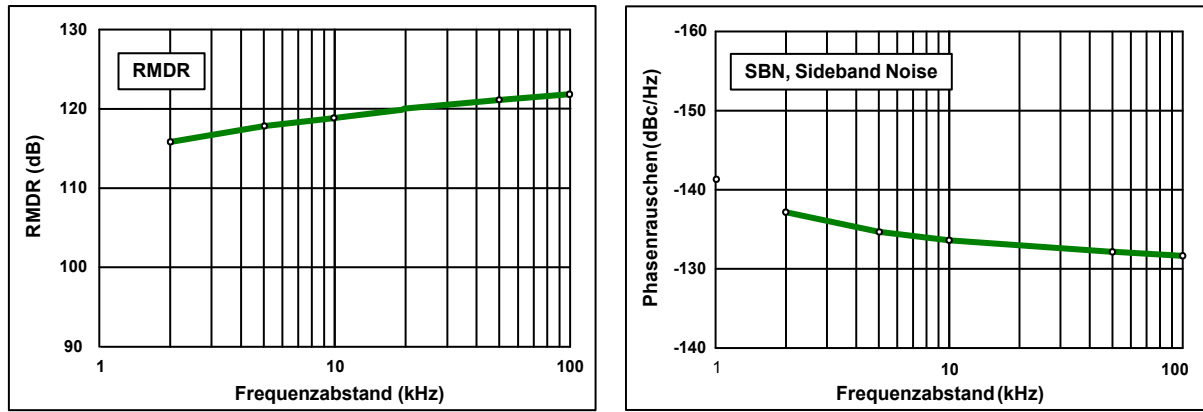


Figure 6: RMDR (left) and phase noise (right) at a distance of 2kHz to 100kHz from the carrier

Result: The RMDR and SBN of the FT-710 are very good. Small signals close to large signals are unaffected by the receiver's sideband (phase) noise.

**3rd Order Intermodulation (IMD3, DR3)**

To test the 3rd order intermodulation, the receiver is controlled with two equally large RF signals ( $f_1 = 14.200\text{ MHz}$ ,  $f_2 = 14.002\text{ MHz}$ ,  $\Delta f = 2\text{ kHz}$ ) and the intermodulation is measured at  $2 \times f_1 - f_2$  and  $2 \times f_2 - f_1$  (Figure 7). The level of the 2-tone signal is gradually increased in 1 dB steps up to the limit of the receiver and the resulting 3rd order intermodulation level is noted.

**DR3 = Pi - MDS**

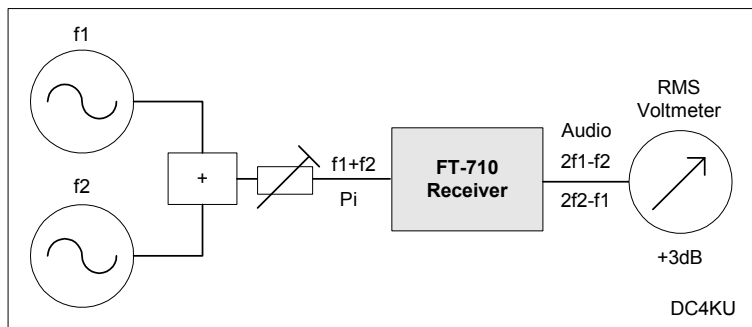


Figure 7: Measurement setup for IMD3 measurement

Table 5 shows the maximum achievable dynamic range (DR3), with and without a preamplifier.

Settings: BW 500Hz; IPO, AMP1, AMP2: on/off

Amplifiers	MDS	Pi	DR3
IPO	-126dBm	-19dBm	107dB
AMP1 (+10dB)	-136dBm	-29dBm	107dB
AMP2 (+20dB)	-142dBm	-39dBm	103dB

Table 5: DR3 of the FT-710 in the 20m band, with and without preamp, BW=500Hz

The course of the resulting intermodulation is shown in Fig. 8. Without pre-amplification, the FT-710 achieves a maximum, distortion-free dynamic range of 107dB (green curve). The dynamic is calculated as

**Pi - MDS = -19dBm - (-126dBm) = 107dB.**

This is excellent value. With AMP1 (+10dB) the receiver achieves the same dynamic range of 107dB, which proves the large-signal immunity of the amplifier and the bandpass filter. Only when both preamplifiers (AMP2, +20dB) are switched on does the dynamics drop by 4dB. Below the maximum IM-free level (sweet spot) there are no IM products above the receiver background noise, which is unusual because most SDRs already produce IM here. Dithering obviously shows its positive effect here. There is no OVF (overflow) display on the FT-710. The receiver also does not clip, but always remains below its limit of 0dBFS (full scale) thanks to a separate AGC. Blocking does not appear until  $P_i = +2\text{dBm}$  (1.6mW).

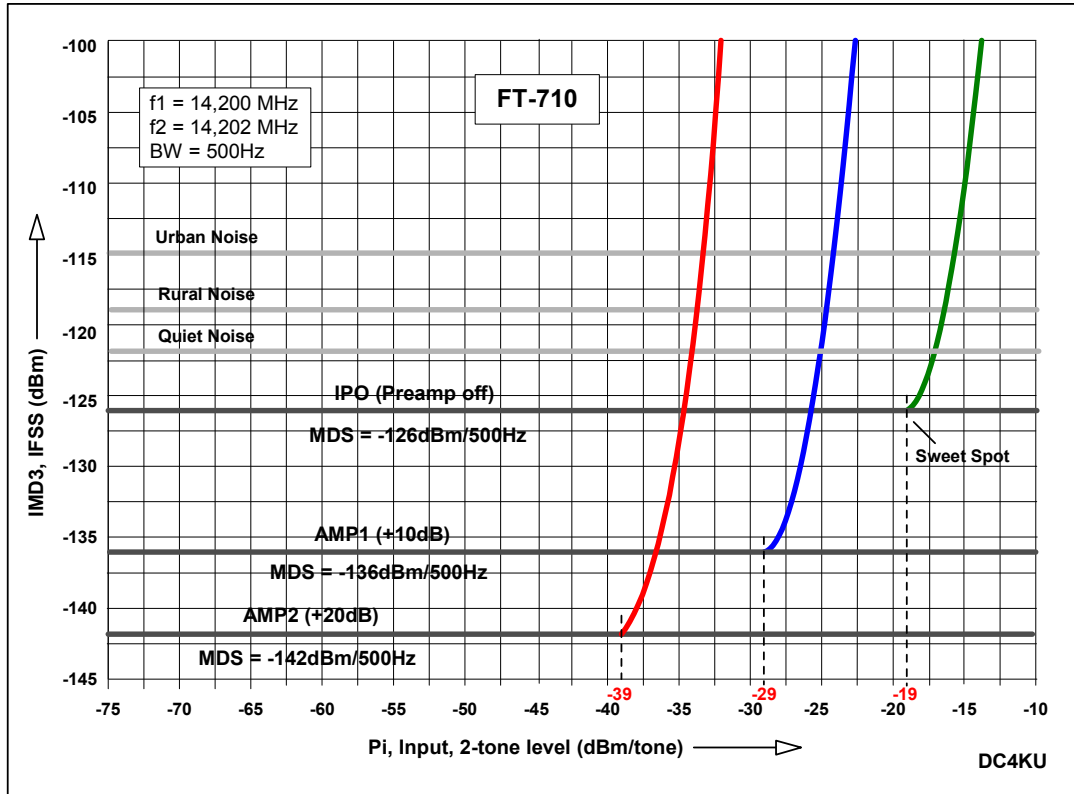


Figure 8: FT-710 - IMD3 history

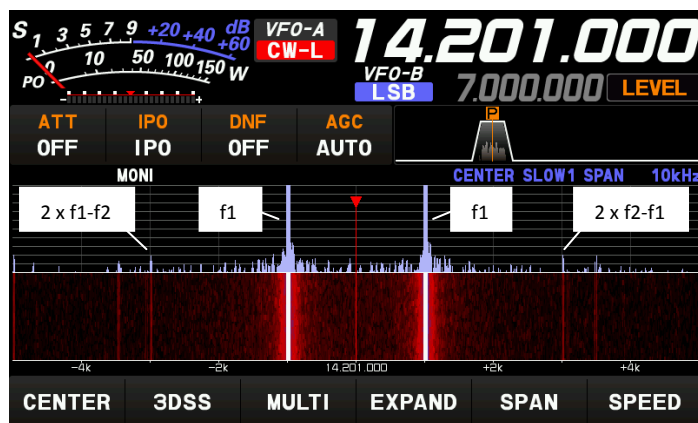


Figure 9: IMD3 interference signals arising at  $P_i = -19\text{dBm}$

Note on intermodulation: Theoretically, an A/D converter should not produce any intermodulation at all up to its limit (clipping). However, due to quantization errors, an A/D converter generates IM, but its magnitude does not follow any regularity. With "dither" one tries to keep the intermodulation as low as possible. With analog receivers, the intermodulation rises and falls by a factor of 1/3, which means that an IP3 can be calculated, which can be used to define and compare the large signal

immunity of receivers. However, there is no IP3 for digital receivers because the course of the intermodulation cannot be calculated. Most manufacturers have recognized this problem and only specify the sensitivity (MDS) and the phase noise (SBN) for direct-sampling SDRs, but no IMDR3. The only important and decisive factor is that all IMD3 curves up to the limit are always below the residential noise (urban noise) or rural noise line (rural noise) drawn in the diagram (Fig. 10). If this is achieved, the IMD3 interference products are no longer audible/detectable when an antenna is connected (3). The FT-710 meets this requirement.

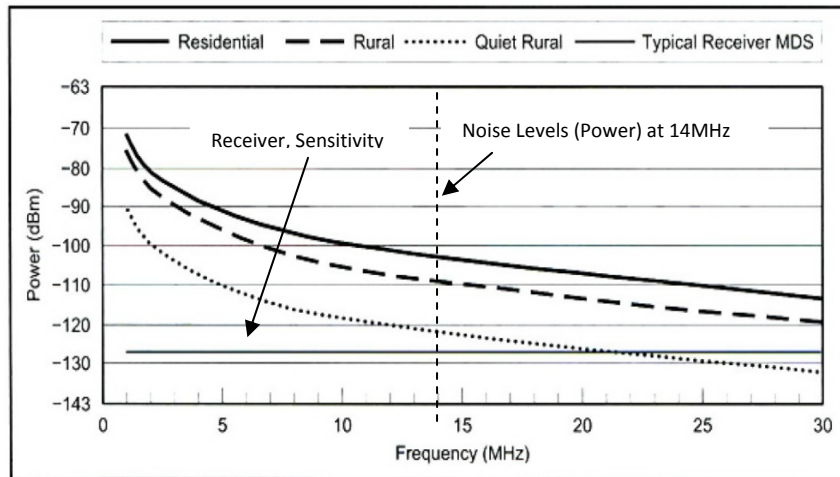


Figure 10: Type. External noise in urban areas (Residential, Urban) and in rural residential areas (Rural), Rec. ITU-R P.372-7, Radio Noise, ARRL Handbook

### 2nd Order Intermodulation (IMD2, DR2)

The 2nd order intermodulation indicates how high the suppression of the sum signal of two CW signals is. In the example, I use a 2-tone signal (Pi) at  $f_1 = 6.1\text{MHz}$  and  $f_2 = 8.1\text{MHz}$  and measure the unwanted sum signal at  $f_1 + f_2 = 14.2\text{MHz}$  (Table 6). With this measurement, the level of both signals is increased until the IMD2 signal appears above the noise with +3dB, ie the limit sensitivity (MDS) has been reached (DR2 = MDS). The DR2 dynamics (DR2, Dynamic Range 2nd Order) is then

$$DR2 = P_i - MDS.$$

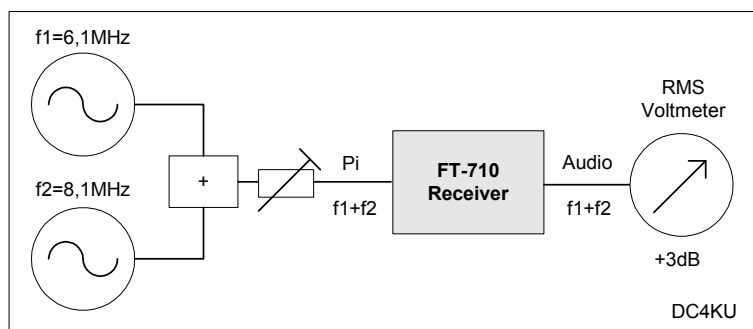


Figure 11: Measurement setup for IMD2 measurement

The FT-710 has a DR2 dynamic range of 104dB, with and without a preamplifier.

Amplifier	MDS	Pi	DR2
IPO	-126dBm	-22dBm	104dB
AMP1	-136dBm	-32dBm	104dB

Table 6: 2nd order dynamics (DR2)

Settings:  $f_1=6.1\text{MHz}$ ,  $f_2=8.1\text{MHz}$ ,  $f_{1+2}=14.2\text{MHz}$ ,  $\text{BW}=500\text{Hz}$

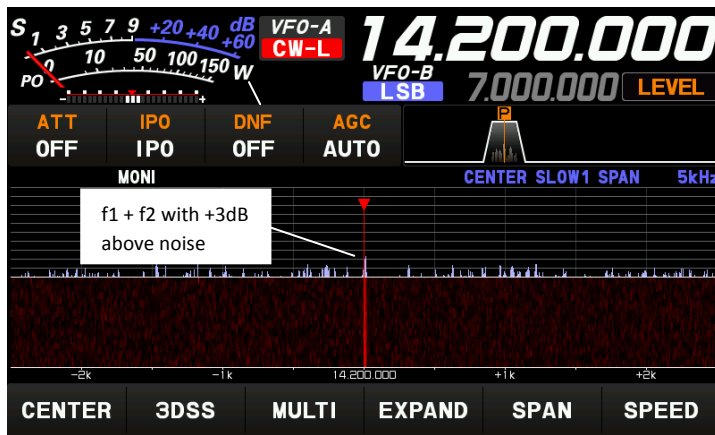


Figure 12: DR2 interference signal at  $P_i = -22\text{dBm}$ , IPO

Result: The 2nd order dynamics of a good receiver should be  $>100\text{dB}$ , which the FT-710 achieves. At  $P_i = -22\text{dBm}$  ( $S_9+51\text{dB}$ ) an interference signal of  $+3\text{dB}$  is generated above the noise floor at  $14.2\text{MHz}$ . This results in a DR2 of  $-22\text{dBm} - (-125\text{dBm}) = 103\text{dB}$ . With AMP1 activated, the DR2 is  $-32\text{dBm} - (-135\text{dBm}) = 103\text{dB}$ . Turning on AMP1 ( $+10\text{dB}$ ) has no effect on the receiver's large signal strength.

**BDR (Blocking Dynamic Range)**

The Blocking Dynamic Range of a receiver is reached when an unwanted signal becomes so large that a small signal at a distance of  $2...20\text{kHz}$  loses amplitude (S/N) by  $1\text{dB}$ .

**BDR = Blocking Level - Noise Floor (MDS)**

In principle, blocking (desensitization) only occurs with analog, superheterodyne receivers; direct-sampling radios do not have this effect (Figure 13). If the maximum level of an ADC is reached at  $0\text{dBFS}$  (full scale), it is almost immediately limited and further reception is no longer possible. This effect is known as "clipping" and usually occurs at around  $-10\text{dBm}$  with direct sampling SDRs.

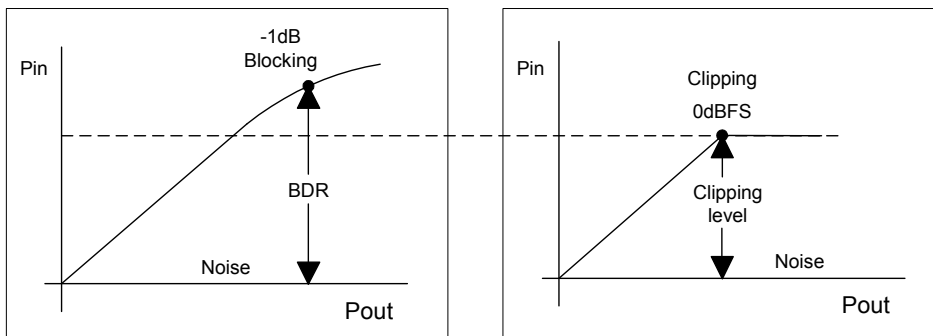


Figure 13: Analog blocking (left) and digital clipping (right)

With the FT-710, however, the blocking process is different. It has a special AGC that prevents the RF level at the input of the ADC from reaching the control limit of  $0\text{dBFS}$ . Clipping is therefore not achieved and no warning message appears if the receiver is overloaded, as with the IC-7300 (OVF). Instead, the FT-710 reduces its dynamic range with high signals, similar to an analogue receiver. Yaesu defines the BDR of the FT-710 at a dynamic loss of  $1\text{dB}$ . This occurs at an input level of  $+2\text{dBm}$  (IPO,  $\text{BW}=500\text{Hz}$ ,  $14.2\text{MHz}$ ), which results in a BDR of

**BDR = Blocking Level - MDS =  $+2\text{dBm} - (-126\text{dBm}) = 128\text{dB}$**

Result: The FT-710 can hardly be overdriven (blocked) and its BDR reaches the vicinity of analog receivers. Hybrid SDRs and superheterodyne receivers can reach a BDR of up to 140dB.

**Noise Power Ratio (NPR)**

The intermodulation immunity of a receiver can also be determined using the noise power ratio (NPR) (4). The input of the receiver is no longer connected to CW signals driven, but with white noise of constant power.

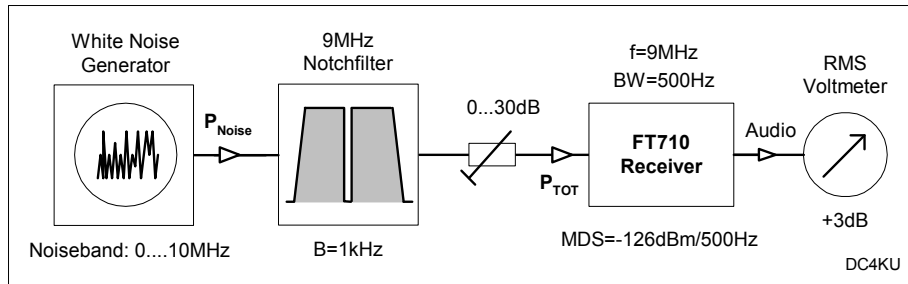


Figure 14: NPR measuring station

The test setup consists of a noise generator (0-10MHz), 9MHz notch filter (BW=1kHz) and an adjustable attenuator. As an example, Figure 15 shows a 0dBm noise spectrum with different noise bandwidths of 50MHz, 100MHz and 200MHz.

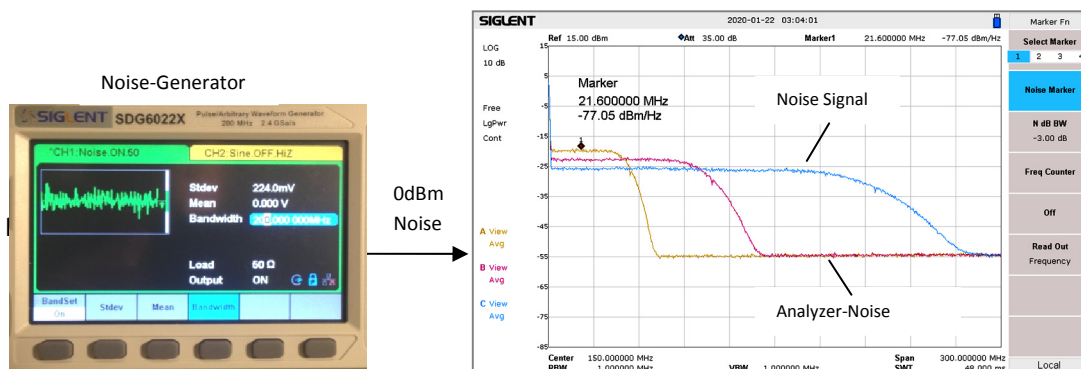


Figure 15: Noise signal with 0dBm power at 50MHz, 100MHz and 200MHz noise bandwidth

The receiver is tuned to the center of the notch filter (8.999640MHz) and receives only the noise floor of the receiver at this point. Subsequently, the noise level (P<sub>Noise</sub>) is increased until a noise rise of +3dB can be seen in the base of the notch filter as well as on the RMS voltmeter. At this point, the intermodulation generated is equal to the receiver sensitivity (Noise = MDS) and the difference of applied noise power (P<sub>TOT</sub>) to sensitivity (MDS) is equal to the NPR.

For the FT-710, this occurs at a noise level (P<sub>TOT</sub>) of -7dBm. From this, its NPR is calculated as

$$NPR = P_{TOT} - BWR - MDS = -7dBm - 10\log 10MHz/500Hz - (-126dBm) = 76dB$$

with:

P<sub>TOT</sub> = noise power (related to 10MHz noise bandwidth)

BWR (Bandwidth Ratio) = 10log B<sub>RF</sub>/B<sub>IF</sub> = 10log 10MHz/500Hz = 43dB

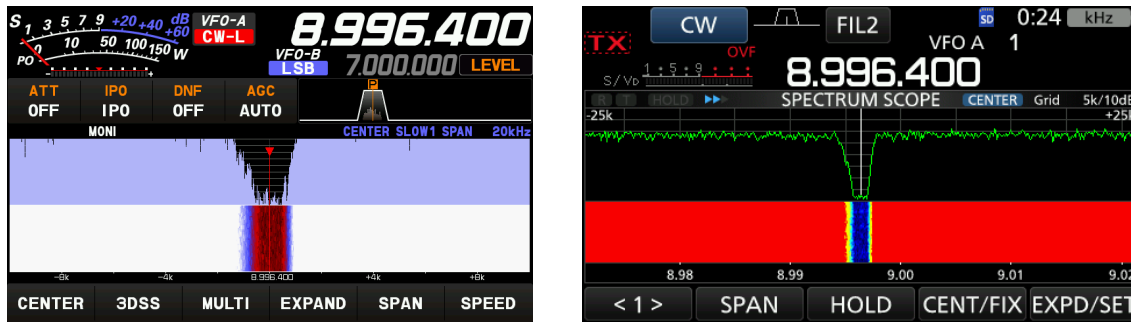
MDS = -126dBm

Note: Normally the NPR can be identified by the noticeable increase in noise in the base of the notch filter. However, this is not possible on the FT-710 because its spectral display does not have an "AVERAGE" function. Instead, it only shows a wild wriggling of spectral lines, making it difficult to identify small signals in the noise. The FT-DX10/101 has the same problem. Furthermore, the display



only has 50dB dynamics (standard). **Fig. 16** shows the difference between an NPR measurement on the FT-710 (without average) and on the IC-7300 (with average and 80 dB dynamic).

**Settings: BW=500Hz, PIO**



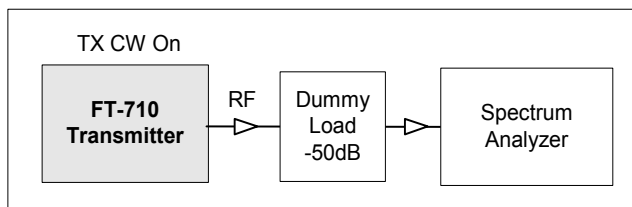
**Figure 16: NPR measurement on the FT-710 (left) and on the IC-7300 with "average" (right)**

Result: With an NPR of 76dB, the FT-710 is in the range of good SDR receivers. Simple SDRs only achieve 40 to 50dB here. For comparison: FT-DX10: 78dB, IC-7300: 76dB

**Transmitter**

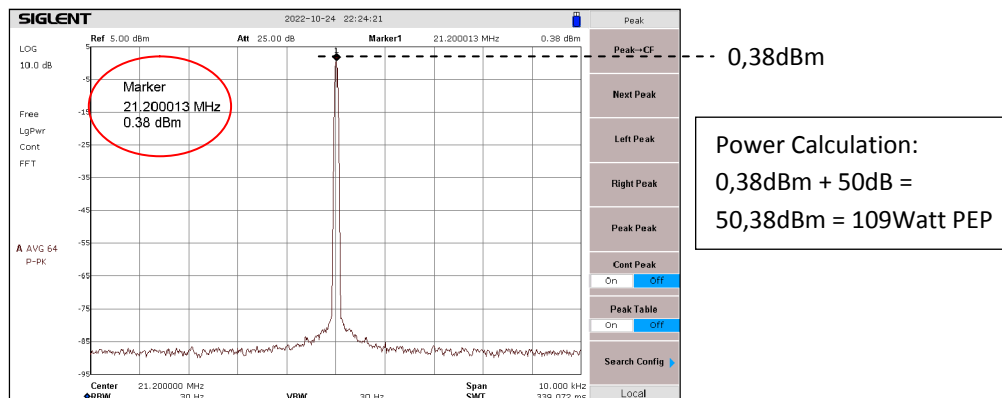
**HF Output Power**

To measure the HF output power, the transmitter is connected to a spectrum analyzer via a 100 watt dummy load (-50dB output) and the maximum power of a CW signal is determined using this (**Fig. 17, 18**). The harmonic separation of the second harmonic (2xf) is measured in the same way. Power was supplied via a 13.8V/32A power pack.



**Figure 17: HF power measurement using a CW signal**

**Settings: CW 500Hz, RF power 100%, supply 13.8VDC, dummy load 60dB**



**Figure 18: HF output power at 21.2MHz**

**Table 7** below shows the maximum transmitter RF output power in the individual bands and the suppression of the 2nd harmonic.

Frequency	1.9MHz	3.7MHz	7.1MHz	14.2MHz	21.2MHz	28.2MHz	50MHz
RF Power, PEP	115.8W	112.9W	110.9W	114.3W	109.1W	109.6W	100.7W
Suppression 2nd harmonics	68dB	67dB	77dB	76dB	90dB	78dB	72dB

Table 7: RF output power (W) and 2nd harmonic rejection (dB)

**Intermodulation of the transmitter (TX-IMD)**

To measure the intermodulation of the transmitter, connect the microphone input to an AF 2-tone generator (f1=800Hz, f2=1200Hz) (Figure 19) and set the microphone voltage so that the transmitter reaches its maximum output power (PEP). The IMD3 distances can be determined directly from the spectrum of the analyzer (Fig. 20).

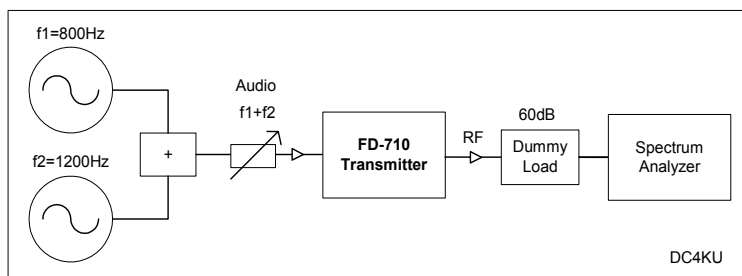


Figure 19: IMD measurement at the transmitter

Since the transmitter is driven with two equally large, closely adjacent AF signals, there is a beating in which the signals add up or cancel each other out. With a PEP power of 109 watts, the levels of the two carrier signals are therefore 6 dB below the peak power, at 54.5 watts.

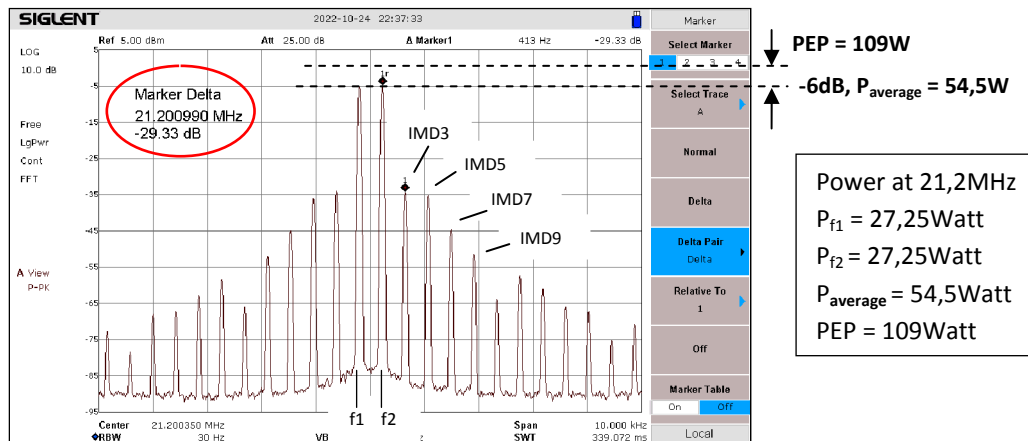


Figure 20: Intermodulation of the transmitter at 21.2 MHz: IMD3 = 29.3dB

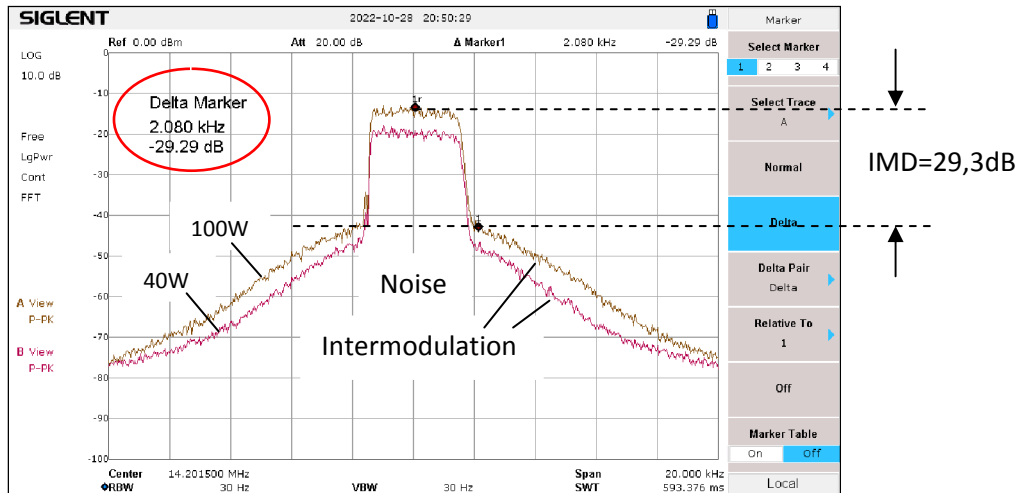
Determined IMD3 distances of the transmitter in the individual bands:

Frequency	1.9MHz	3.7MHz	7.1MHz	14.2MHz	21.2MHz	28.2MHz	50MHz
IMD3 distance	27.2dBc	28.1dBc	30.0dBc	29.2dBc	29.3dBc	28.3dBc	24.6dBc

Table 8: Transmitter IMD3 results

The occupied bandwidth and intermodulation of a transmitter can also be determined via a noise signal (5). A low-frequency, white noise band is fed into the microphone input as a modulation signal and the transmitter is adjusted to maximum power. Figure 21 shows the result of the measurements. The almost rectangular block (envelope) in the middle of the spectrum shows the bandwidth of the used SSB filter, dominated by white noise. Theoretically, both flanks should run steeply down to the

background noise, but unfortunately they don't do that in practice. The first IMD products appear at a distance of around 30dBc, the level of which decreases only slowly in the direction of higher and lower frequencies. The achieved IMD-distance at 100 W and 40 W is identical.

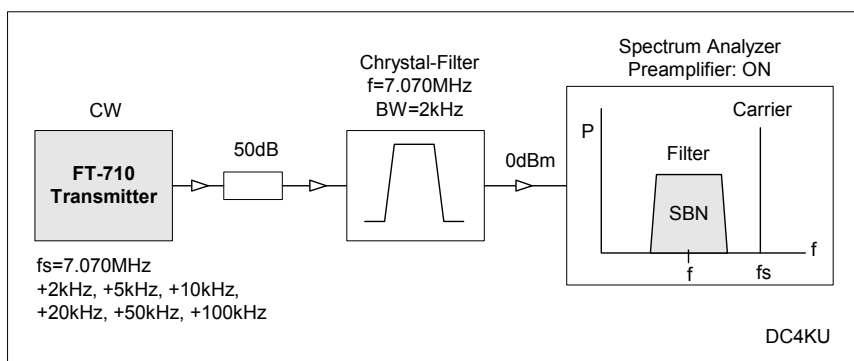


**Figure 21: Transmitter noise signal at 100 watts (yellow) and 40 watts (purple), 14.2MHz (SSB)**

Due to the injected noise, individual spectral lines are no longer displayed, but a cumulative spectrum consisting of many IMD products. For this reason, an IMD measurement with noise is much more realistic than with only 2 signals. The procedure, on the other hand, is also harsh and rigorous, similar to the NPR measurement on receivers. It is important that the IMD products to the right and left of the user channel drop off relatively quickly so that adjacent channels are not disturbed.

**Transmitter Sideband Noise (TX SBN, TX Phase Noise)**

The sideband noise (composite sideband noise) of a transmitter should be as low as possible so that neighboring, small signals are not disturbed by it (6). A quartz filter (7.07 MHz, BW=2 kHz), spectrum analyzer and terminating resistor (-50dB) are used to measure the TX-SBN (Figure 22). The analyzer is tuned to the center frequency of the filter and the CW signal from the transmitter is set at a distance of 5 to 100kHz from the filter center frequency. At this distance, the transmission signal is strongly suppressed by the edge of the filter and only the noise of the transmitter from 7,070MHz > = +/-2kHz is allowed to pass.



**Figure 22: Measurement setup for transmitter SBN measurements in the 40m band with a spectrum analyzer**

Because the transmission signal is attenuated by 90dB outside the filter, the analyzer can be set to 0dB attenuation and +20dB pre-amplification and thus achieves a measurement limit of -160dBm/Hz. As an example, Figure 23 shows the measurement of the TX sideband noise at a distance of 5 kHz from the carrier at an output power of 100 watts.

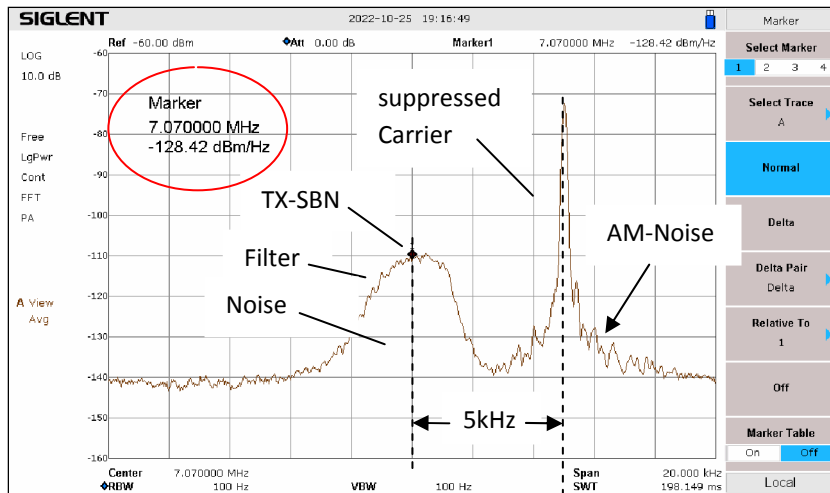


Figure 23: SBN measurement at 5 kHz offset to the carrier, SBN = -128.4dBc/Hz

Table 9 shows the determined SBN of the transmitter at 100 and 50 Watts of power, at distances from 2.5 to 100 kHz to the carrier and Figure 24 shows the SBN curve. If the power is reduced to 50 Watt, the SBN increases by about 5 dB.

Transmitted Composite Noise at 100W and 50W

Offset kHz	SBN in dBc/Hz 100 watts	SBN in dBc/Hz 50 watts
2.5	-125	-120
5	-128	-122
10	-129	-124
20	-130	-125
50	-132	-128
100	-135	-130

Table 9: Cumulative TX-SBN

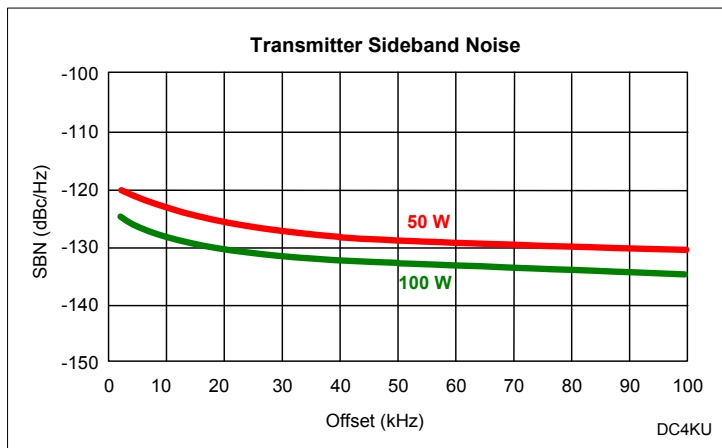


Figure 24: Course of the TX-SBN with 50 and 100 Watt power

Note: The TX-SBN consists of phase-noise and amplitude-noise. For the FT-710, AM noise is the strongest component, approximately 15dB above the phase noise, increasing the transmitter's cumulative sideband noise by that amount. In the data sheet, Yaesu specifies a **TX phase noise** of **-143dBc/Hz** at a distance of 2 kHz (see Figure 3). This is correct, but it only affects the phase noise. However, the cumulative sideband noise (Phase noise + AM noise) acts at the output of the

transmitter. Accordingly, the SBN of the transmitter is only **-125dBc/Hz** (100 watts) at a distance of 2.5 kHz and only **-130dBc/Hz** at a distance of 20 kHz. But both are still good values.

### Characteristic values of transceivers

**Table 10** shows the determined characteristic values of some HF transceivers. When comparing, it should be noted that the FT-DX10 is a hybrid transceiver, but the FT-710, IC-705, IC-7300 and SunSDR2DX are direct-sampling SDRs.

	Receiver				Transmitter	
	MDS BW 500Hz	RMDR Offset 2kHz	IMD3 Delta f 2kHz	NPR	IMD3 800/1200Hz	TX SBN Offset 20kHz
<b>FT-710</b>	<b>-126dBm</b>	<b>116dB</b>	<b>107dBc</b>	<b>76dB</b>	<b>29dBc</b>	<b>-130dBc/Hz</b>
<b>FTDX-10</b>	-134 dBm	116 dB	110 dBc	78 dB	27 dBc	-132 dBc/Hz
<b>SunSDR2DX</b>	-133 dBm	111 dB	105 dBc	76 dB	33 dBc	-142 dBc/Hz
<b>IC-7300</b>	-133 dBm	106 dB	100 dBc	76 dB	36 dBc	-127 dBc/Hz
<b>IC-705</b>	-124 dBm	109 dB	98 dBc	76 dB	36 dBc	-127 dBc/Hz

**Table 10: Characteristics of various transceivers in the 20m band**

### Summary

The FT-710 is a good HF/50/70 MHz Transceiver with excellent HF data. With the FT-710, Yaesu joins the group of direct-sampling SDRs for the first time and need not fear the comparison. It's an all-round successful transceiver.

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