

IC-7610

Technical Report

Volume 3



~ Introduction ~

So far, Volumes 1 and 2 have basically discussed the main attributes of the IC-7610: the RF direct-sampling method and RMDR. The final part, Volume 3, will continue the discussion, focusing on the individual circuits and features incorporated in the IC-7610.

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The excellent reception performance of the IC-7610 is largely due to the RF direct sampling method, but the front end from the antenna connector to the A/D converter must also be considered. This is because the A/D converter, which is the entry-point to the RF direct sampling scheme, has a maximum allowable level for the amount of input signal. When this allowable level is exceeded (clipping), distortion occurs.

There are signals at various levels in the composite signal coming from the antenna, but they are presented to the A/D converter as the sum of electrical powers. In other words, even if each radio signal is below the tolerance limit of the A/D converter, the total power level of the mix of many radio signals may exceed the maximum allowable input level of the A/D converter.

As a means for restricting the bandwidth of the front end, so as to not exceed the maximum input level of the A/D converter, a Digi-Sel tracking preselector and a bandpass filter group with 13 filters are used.

In addition, even in Dualwatch operation in different bands and /or modes, which was previously provided only in our highest-end transceivers, the IC-7610 utilizes two independent and identical front-end circuit configurations, in order to maintain the same performance in the MAIN band and the SUB band.

Here, the analog circuits that underpin the receiver performance and functions of the IC-7610 will be discussed.

MAIN/SUB, two independent front-end systems with Digi-Sel circuit

In the IC-7610, a Digi-Sel unit (see Fig. 01-01), which tracks the operating frequency, is used in the MAIN band for the 1.8, 3.5, 5, 7, 10, 14, 18, 21, 24 and 28 MHz bands, and is placed in front of the bandpass filters (BPF). An identical Digi-Sel is used in the SUB band.



Figure 01-01 Digi-Sel unit

The Digi-Sel circuit has a sharp peak characteristic to exclude unintended signals as much as possible, and operates as a preselector according to the operating frequency. This attenuates strong signals adjacent to the target signal, and suppresses third order distortion caused by those signals.

This sharp peak characteristic is obtained at the expense of a slight insertion loss, but the loss is compensated for by placing a post-amplifier immediately after the filter. This post-amplifier has a high dynamic range design with current feedback and minimal gain. When turned ON, this amplifier does not affect the strong input characteristics of the receiver.

The Digi-Sel is a simple (1-pole) filter group, comprising a combination of a high-Q coil and capacitor. The center frequency of the filter automatically tracks the operating frequency. The MAIN and Sub Digi-SEL modules are enclosed in separate shielded housings to ensure sufficient isolation.

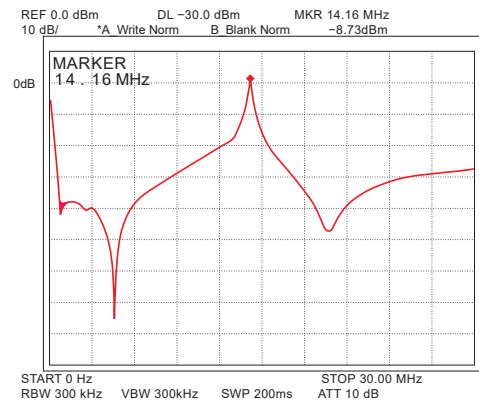


Figure 01-02: Filter Characteristics of Digi-Sel

Figure 01-03 is the basic circuit of the preselector. There are 4 selections for C1/C5, 16 for C2/C4, 7 for L1, and 2048 for C3. From these selections, the optimum combination according to the receive frequency is instantly selected, and the circuit is set in the relay chain. The combination of LC's for each receive frequency is stored in the memory of the Digi-Sel unit. This memory can store about 380 points in the 1.8~28 MHz range. The combination of LC's varies, depending on the operating band, but changes with a minimum 2 kHz step on the low HF bands.

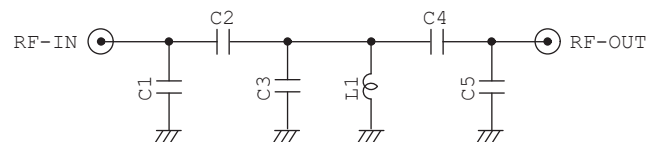


Figure 01-03 Basic Circuit of Preselector

The center frequency of the Digi-Sel fitted in the IC-7610 can be manually adjusted by using the [MULTI] dial according to the operating situation.

13-section filter group

The 13-section filter group is another design feature whose purpose is to eliminate many undesired radio signals entering the receiver from the antenna port. The IC-7610 has a low-pass filter (LPF) with a 0.5 MHz cutoff frequency, and a bandpass filter (BPF) group, which divides the 0.5~60 MHz range into 12 contiguous bands, each with its own filter. The signal from the antenna is routed through one of these 13 filters according to the receive frequency.

Table 01-01: Filter List

Filter band (MHz)	Filter type
0.03~0.499	LPF
0.50~1.599	BPF
1.60~1.999	BPF
2.00~2.999	BPF
3.00~3.999	BPF
4.00~5.999	BPF
6.00~7.999	BPF
8.00~10.999	BPF
11.00~14.999	BPF
15.00~21.999	BPF
22.00~29.999	BPF
30.00~60.00	BPF
50.00~54.00	BPF

Digi-Sel is designed to have sharp peak characteristics at the expense of some insertion loss in order to eliminate undesired signals adjacent to the target signal. The BPF is designed to have minimum insertion loss so as not to impair the noise figure NF (sensitivity) of the receiver, while at the same time eliminating unwanted off-channel signals causing second-order intermodulation distortion (IMD) and similar impairments.

Second order IMD is the intermodulation distortion caused when the sum or difference product of two out-of-band signals at frequencies f_1 and f_2 is equal or close to the receive frequency f_{rx} of the target signal. For example, as shown in Figure 01-04, there are two signal components $f_1 = 4.100$ MHz and $f_2 = 10.100$ MHz, so $(f_1 + f_2) = 14.200$ MHz may be generated by a mix in a nonlinear circuit. In a more extreme example, where $f_1 = 0.100$ MHz and $f_2 = 14.100$ MHz, the IMD product will be the same.

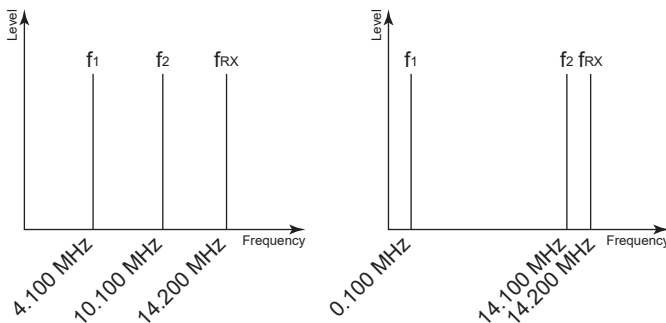


Figure 01-04 Second-order intermodulation distortion examples

However, either f_1 or f_2 is less than one-half, or more than twice the frequency of the secondorder distortion product (14.200 MHz in the above example). Thus, for optimum second-order IMD rejection, it is necessary to ensure that

the BPF has sufficient attenuation in the bands $\leq f_{rx}/2$ and $\geq 2f_{rx}$, where f_{rx} is the receive frequency.

Figure 01-05 is a BPF characteristic diagram for the 11.00 ~ 14.999 MHz band installed in the IC-7610. Applying the above example, a response curve with $f_1 = 4.100$ MHz, $f_2 = 10.100$ MHz and $f_{rx} = 14.200$ MHz superimposed is shown in Figure 01-06.

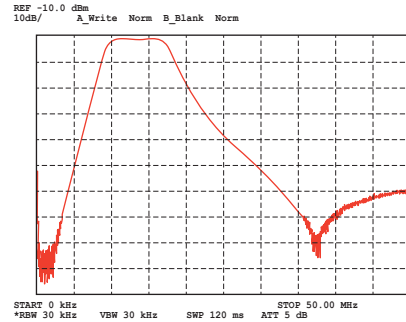


Figure 01-05: BPF Characteristic for 11.0 ~ 14.999 MHz Band

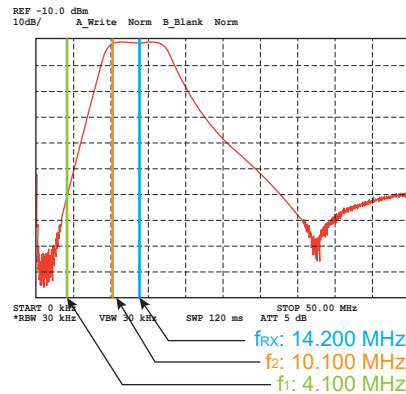


Figure 01-06 Elimination of second-order IMD in BPF for 11.0 ~ 14.999 MHz band

As can be seen from this figure, the f_2 component is not attenuated because it is within the BPF passband. However, since f_1 is in the region where it is sufficiently attenuated, the second-order distortion product level is reduced. Also, if the Digi-Sel preselector characteristics described above are overlapped, the characteristics as shown in Figure 01-07 are obtained. From this, one can see that the reception characteristics of the IC-7610 analog stage are excellent.

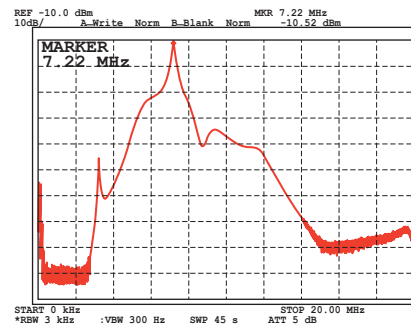


Figure 01-07: Frequency response chart from antenna via Digi-Sel to BPF output (example: 7 MHz band)

Antenna IN/OUT switching circuit (Diversity compatible)

The IC-7610 is equipped with RX-ANT IN/OUT ports to which an external original receiving preamplifier and/or filter can be connected. As these ports consist of two BNC connectors, physical strength, impedance matching and reliability are dramatically improved as compared to conventional RCA jacks. Also, since the connection setting of these IN/OUT ports can also be stored in the antenna memory, the user is also relieved of troublesome switching operations.

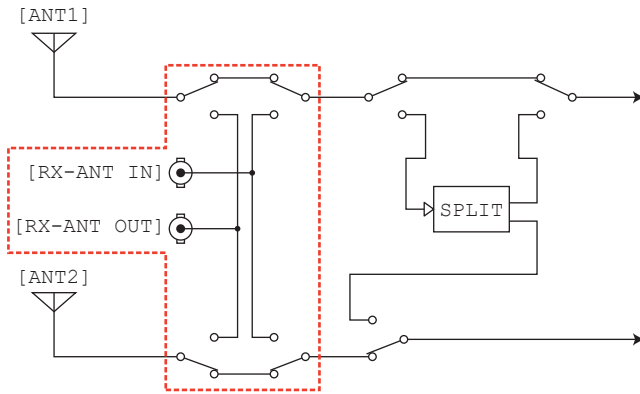


Figure 01-08: RX-ANT IN/OUT switching circuit block diagram

Here is one example of how to use the RX-ANT IN/OUT ports. Most operators have experienced fading. This is a phenomenon in which the signal intensity periodically fluctuates when the same signal is continuously received, but one of the factors of the signal-strength fluctuation when the radio waves are reflected by the ionosphere is random rotation of the polarization plane.

As a countermeasure against this fading, there is a method for separately routing the recovered audio from the receiver connected to the vertically polarized antenna and the receiver connected to the horizontally polarized antenna to the left and right channel of the headphones at the same time. This method is called diversity reception. However, until now it was difficult to synchronize the receivers to the phase difference between the two received signals. In the IC-7610, with its separate receivers, fading can be reduced simply by connecting a receiving antenna whose polarization is different from that of the transmit/receive antenna (polarization diversity) to the RX-ANT IN port.

For example, if the transmit/receive antenna is horizontally polarized, try connecting a vertically polarized antenna to the RX-ANT IN port. After setting the frequency and mode to be monitored on the MAIN band, set the same frequency and the same mode on the SUB band with the quick Dualwatch function (holding down the [DUAL-W] key for about 1 second) to enable the SUB band. Touch and hold the [ANT] key in the multi-function key group for about 1 second to select ANT 1/R or ANT 2/R.

The ability to provide diversity reception is also one of the benefits of the IC-7610's high-precision master clock system, which is common to both the MAIN and SUB bands. If diversity reception is attempted with general-purpose direct-sampling receivers using separate clocks, it will be apparent that diversity reception, which phase-synchronizes the two audio outputs accurately is very difficult, due to the phase difference between the A/D converter clocks.

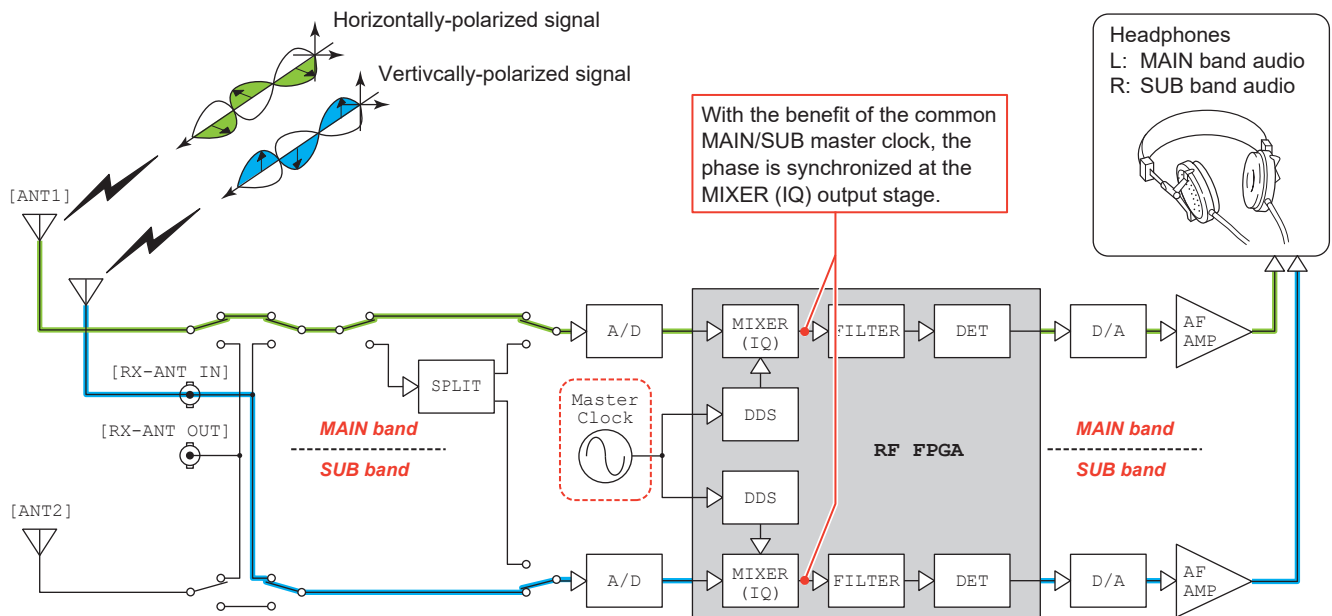


Figure 01-09: Concept of diversity reception

Splitter circuit

This is an important circuit that is essential for Dualwatch operation with one antenna.

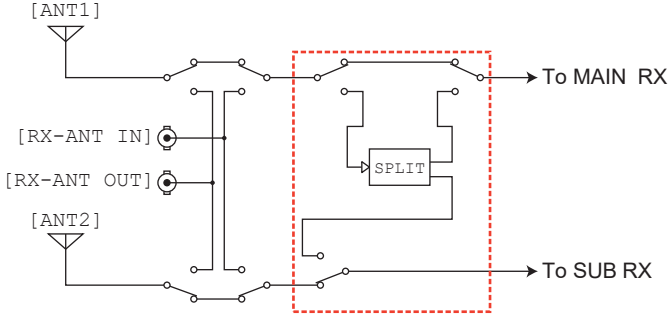


Figure 01-10: Splitter circuit block diagram

Figure 01-10 shows that ANT 1 is selected for the MAIN band, and ANT 2 is selected for the SUB band. In Split operation and Dualwatch operation, when ANT 1 is selected in the MAIN and SUB bands, ANT 1 can be switched to route the received signal to the splitter circuit through the relay. (See Fig. 01-11.)

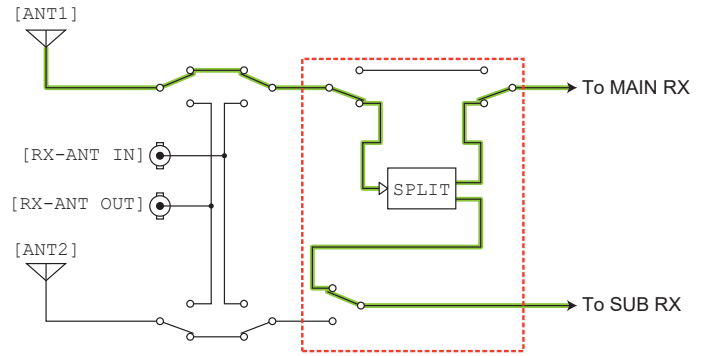


Figure 01-11: Signal path when ANT 1 is used in both bands

When the splitter circuit is in-line, its insertion loss is offset by the high-dynamic-range correction amplifier in the subsequent stage. You can also use ANT 2 in both MAIN and SUB bands.

About A/D & D/A Converter

As explained in Volume 2, A/D converters that can sample up to 130 MHz based on the sampling theorem for A/D conversion of RF signals are used in both the MAIN and SUB bands. The digitized RF signal is batch-processed by the FPGA, converted to analog by the D/A converter, and output from the speaker as an audio signal.

Here, the A/D converter and D/A converter utilized in the IC-7610 will be considered.

As explained earlier, the device selection of the A/D converter is based on the sampling theorem. However, the sampling theorem is for the conversion speed (= sampling rate) required for digital conversion. Even for A/D and D/A converters, most of the on-chip circuit elements other than those handling digital signals are analog elements. Therefore, consideration similar to that given to transistors and FETs is required. For this reason, the focus has been on SNR (Signal/Noise Ratio) and SFDR (Spurious-Free Dynamic Range) that affect dynamic range as well as sampling rate as a key point of device selection, and comparing and examining these parameters for each device.

In general, it is easy to pay attention to the number of bits as defining the performance of the A/D converter, but SNR and SFDR are important factors for direct-sampling receivers.

SNR stands for Signal-to-Noise Ratio, equivalent to S/N ratio or S/N. Units are usually expressed logarithmically as 'dB', but 'dBFS' is used when signals are compared to full scale values. (Full scale = A/D converter clip or saturation level, where digital output = "all 1's".)

Even the A/D converter contains noise (quantization noise) in the output signal. This quantization noise is influenced by the resolution, that is, the number of bits (N), and can be expressed as $SNR = 6.02N + 1.76$ (dB)* as the theoretical value, but in reality it is lower than the theoretical value.

*Calculation formula when there is no noise other than quantization noise, and a sine wave signal is input.

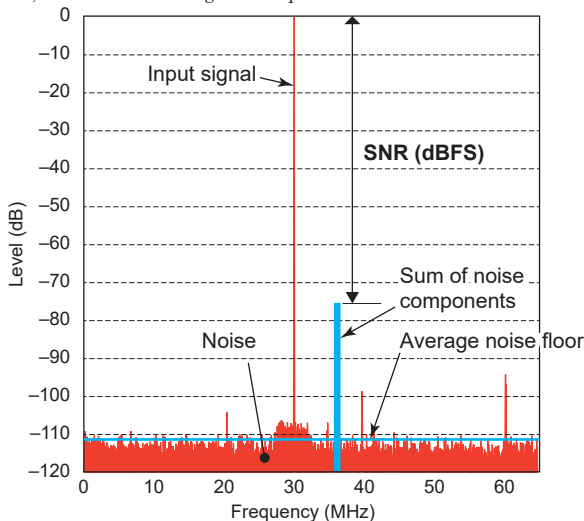


Figure 02-01 Basic SNR

SFDR stands for Spurious Free Dynamic Range. Spurs (spurious components) also occur in the A/D converter due to its nonlinearity. The SFDR value of the A/D converter is expressed as the level ratio of the largest component and the carrier among the spurious signals generated when the carrier is input. Since the unit is logarithmically based on the carrier (= carrier), it is common to use 'dBc', but it is sometimes expressed simply logarithmically in 'dB'.

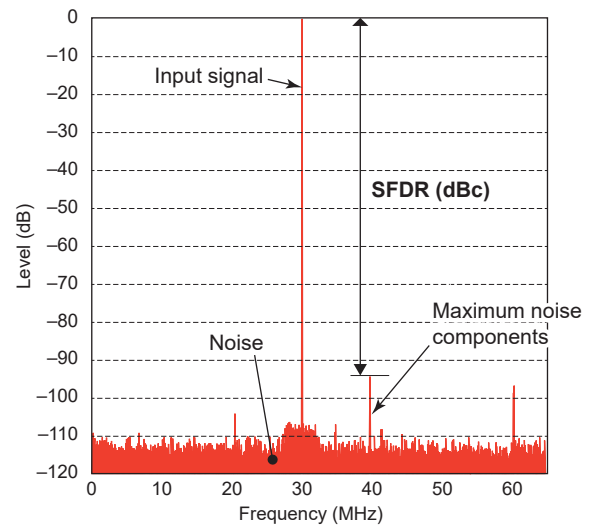


Figure 02-02: SFDR Basics

As a result of comparing and verifying various A/D converters, for the IC-7610 Icom selected the 16-bit LTC2208 A/D converter, which gives priority to SNR performance, SFDR and SNR etc. After weighing these parameters against bit count, Icom selected the Intersil ISL5961 14-bit D/A converter. The IC-7610's excellent transmitter composite noise performance has vindicated that choice.

As a digression, the noise floor is extremely low due to the synergistic effect of employing an A/D converter with high SNR characteristics and a master clock with excellent phase noise characteristics. About this, some IC-7610 owners have asked Icom "No noise can be heard when no antenna is connected. Is the IC-7610 is really working?".

There are two versions of these converters, one for consumer use and the other for industrial use. In the IC-7610, Icom specified the highly reliable, higher quality industrial version.

The A/D converter is 16-bit, whereas the D/A converter is 14-bit. The question will surely arise: 'If a 16-bit device is also used for the D/A converter, will the performance improve more?' After due consideration, Icom selected the D/A converter for the IC-7610 on the basis of SNR and SFDR, rather than the number of bits.

(continue to the next page)

Specifically, there are 14-bit devices with even better SNR and SFDR performance than 16-bit devices. For A/D and D/A converter performance, SNR and SFDR are also important. As shown in the performance comparison in Figure 02-03, the most balanced part was selected, based on factors other than just the number of bits.

In addition, during the process of component evaluation and selection, we found 10/12-bit devices with even higher performance parameters than some 14-bit or 16-bit devices, including SNR and SFDR.

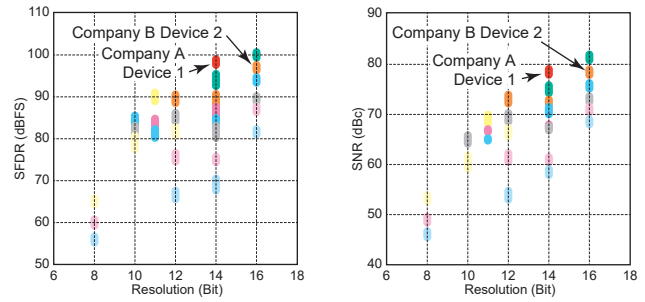


Figure 02-03 Performance comparison charts for device selection

About FPGA

FPGA stands for Field Programmable Gate Array, and it can be said that the FPGA is the heart of the IC-7610. The FPGA carries out highly complex signal processing operations in one device. Volumes 1 and 2 also briefly explain FPGA functionality, but in this volume we will examine it in more detail.

FPGA is a device in which the structure of digital circuits can be changed programmatically. For example, even if an oscillator is usually configured by a digital circuit, it can be reconfigured as a filter or a mixer by changing a program. For example, the output frequency of an oscillator, a center frequency, a bandwidth, a characteristic, and so on can be changed by programming as required. The FPGA is a multipurpose device, which can be said to be a collection of digital circuits. The programs that operate the FPGA are stored in an external Flash ROM.

Although this is not explicitly shown in Fig. 02-04, the IC-7610 performs DSP processing within the FPGA as well. 'DET' (detection stage) is in the DSP block configured in the FPGA.

Icom has cumulatively developed signal processing technology with a DSP for over 20 years. However, in the process of pursuing higher functionality, including simultaneous reception of two signals, and receiver performance with wider dynamic range, the amount of digital signal processing required in the dedicated DSP device has increased significantly, and the processing building-blocks also became much more complex. Therefore, the search for the best platform has led to the adoption of large-scale FPGA, which has gained attention in recent years. As a result, with the IC-7610, processing circuit configuration can be controlled by software simultaneously with signal processing, thus ensuring flexibility for the future.

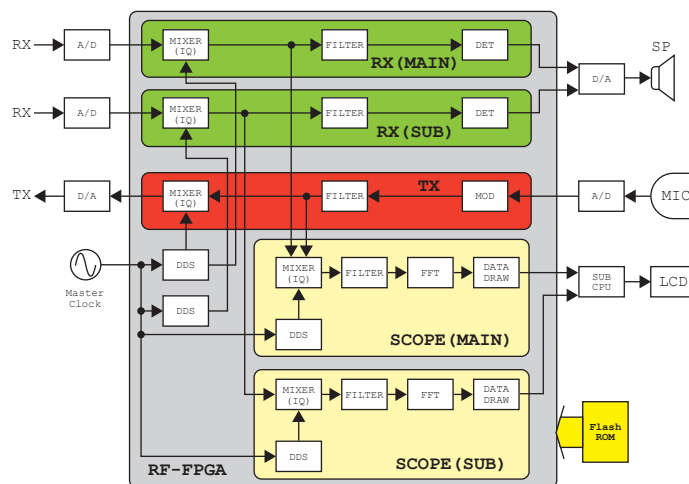


Figure 02-04 FPGA Internal Block Diagram and ROM

Spectrum scope circuit

The spectrum scope of the IC-7610 has been dramatically improved in all performance aspects such as bandwidth, resolution and speed, as compared to the IC-7600.

Table 02-01 Scope Performance Comparison

	IC-7610	IC-7600
Frequency span	5 kHz to 1000 kHz	5 kHz to 500 kHz
Resolution* ¹	Minimum about 1 dot* ²	Minimum about 20 dots* ³
Sweep speed	Up to 29.3 screen/s* ⁴	Up to 4 screen/sec* ⁵
Dynamic range	100 dB	70 dB
Noise floor level	-30 dB μ V	-19 dB μ V

*¹ When receiving a single carrier, the number of display dots with 60 dB bandwidth
 *² When VBW / RBW = NARROW
 *³ When SPAN = 500 kHz or more, SPEED = SLOW
 *⁴ SPEED = FAST
 *⁵ When SPAN = 20 kHz or more, SPEED = FAST

Here, we will explain the principle that makes this difference. First, the scope circuit is as shown below in simplified form.

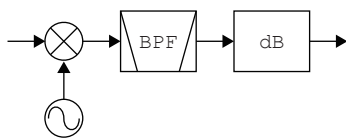


Figure 02-05 Basic block diagram of scope circuit

In the IC-7600, a swept-type scope was used. The swept-type scope converts the input signal to be displayed by changing (sweeping) the output frequency of the local oscillator driving the mixer.

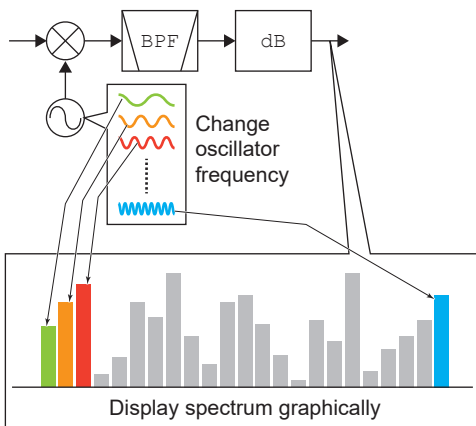


Figure 02-06 Scope of IC-7600 (Swept-type)

In other words, the signal spectrum is depicted while changing the oscillation frequency with one circuit. In a swept-type scope, the sweep speed is limited, depending on the characteristics of the filter, in order to preserve the drawing precision, for example the vertical amplitude accuracy. The sweep speed is inversely proportional to the filter bandwidth (resolution bandwidth). Increasing the resolution (using a narrower filter) slows down the sweep speed, and when using a broadband filter to increase the speed, the resolution will decrease. To balance these

conflicting effects, the maximum of 4 screens/sec*⁵ in the IC-7600 is the point where both accuracy and speed could be satisfied.

The IC-7610 has adopted the FFT scope technique. FFT is an abbreviation for Fast Fourier Transform, which derives a spectrum from an input signal by calculation. If an equivalent block diagram is used to illustrate the operation of this FFT in simplified form, it will look like Figure 02-07.

As a result, the spectrum within the screen can be depicted with high speed and high accuracy, achieving a sweep speed of up to 29.4 screens per second*⁴.

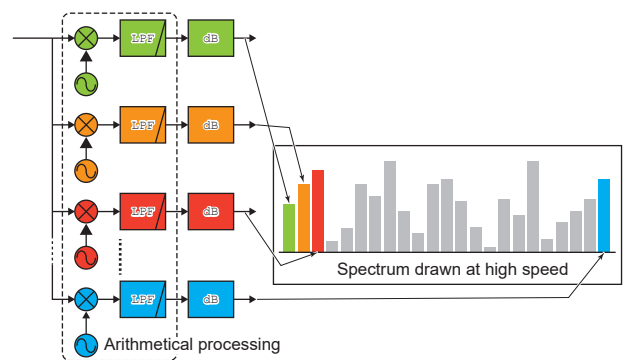


Figure 02-07 FFT operation diagram (equivalent)

The sweep speed is equal to 30 fps (frame per second) as used in general television broadcasting, but it shows how smoothly the changes in the band are portrayed.

Subsequently, although we are considering the spectrum scope dynamic range and noise floor level, these are greatly related to the performance of the A/D converter used in the IC-7610 and the phase noise characteristic of the master clock. When the scope dynamic range is captured, the IC-7600 was 70 dB, whereas in the IC-7610 it increased by 30 dB to reach 100 dB.

We explained earlier that SFDR and SNR show dynamic characteristics in measuring the performance of the A/D converter. This SFDR defines the spectrum scope's upper dynamic range limit, while the SNR and master clock phase noise characteristics define the lower limit (noise floor.)

The frequency span and the resolution are realized by the combination of the 800 × 480 pixel* high resolution LCD incorporated in the IC-7610 and the FFT technique.

*The external (DVI) video output supports selectable 800 × 600 and 800 × 480 pixel resolution.

Relay-type antenna tuner

The IC-7610 has a built-in relay-type antenna tuner covering the 1.8~29 MHz bands and the 50 MHz band. Compared to the variable-capacitor antenna tuner that was fitted to the IC-7600, the tuning speed has become much faster. The built-in tuner also covers the 5 MHz bands tuning. (USA version only)

In addition, even when the antenna is damaged by wind storms or the like, even when it becomes incompatible with the built-in antenna tuner, the user can enable the 'emergency communication (tuner)' mode,* which broadens the coverage range so that it can be used temporarily. Normally, tuning operation is not started when the antenna SWR is $\leq 1.3:1$. But in this mode, tuning is started even if the SWR is $> 1.3:1$, and a minimal temporary antenna is substituted for the normal antenna.

*In order to protect the antenna tuner from damage due to the poor matching condition, the transmitter output is limited to 50 W.

Speaker box with a new design

Icom believes that the mid-price category is the one most in demand in the amateur marketplace. To that end, the IC-7610, which is positioned in the middle class among Icom HF transceivers, is equipped with Digi-Sel, two independent receivers supporting Dualwatch in different bands and different modes, pursuit of the highest RMDR, and an advanced FFT spectrum scope. These features reflect the best efforts of Icom engineers in the evolution of function and performance.

Signals are processed digitally almost without passing through any analog circuits. For that reason, we can realize an ideal frequency response and keep group delay distortion at a minimum. In speech quality as well, we will reproduce the transmitted voice faithfully to an extent not comparable with an analog transceiver. The faithfully-reproduced signal is amplified by the low distortion audio amplifier and then output from the built-in speaker. This built-in speaker is also an example of Icom's engineering commitment.

The speaker is an electronic component that converts an electrical signal to sound, and it consists of a magnet, a coil, and a diaphragm. Creating a high quality sound is a challenge. Especially in a long-duration contest, we believe that listening fatigue will invariably result from exposure to high-pitched sounds, mixed sounds and chirping sounds, even for a short period of time. Icom's engineers believe that optimization of the audio subsystem for the reproduction of the vocal range is important.

As a result of our electro-acoustical research, we have designed a dedicated speaker box equipped with a cone-type speaker. The cone-type speaker can adjust the range to be reproduced, depending on the angle of the diaphragm. Therefore, we use speakers designed with a diaphragm angle adjusted to the range that we wish to reproduce most.

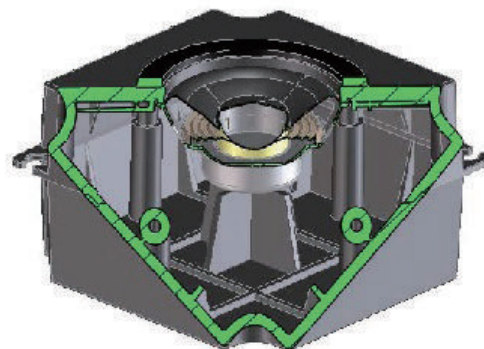


Figure 03-01 Speaker box of IC-7610 (sectional view)

In addition, we examined the material of the speaker box and determined the capacity according to the characteristics of the speaker. In addition, by providing strength reinforcement ribs inside the speaker box, unwanted incidental sound caused by the ringing and resonances in the box is suppressed. Thanks to these commitments, the built-in speaker, as well as a dedicated external speaker, has realized a clean, easy-to-hear sound quality.

New-concept RF preamplifiers

The RF preamplifier is an additional circuit, which is effective when weak signals are received on a high band with little external noise, or from a small antenna with low gain.

Compared to the VHF/UHF bands, the ambient (band) noise level is much higher on the HF bands, so there is no need for an extremely low noise figure (NF) when using a reasonably efficient antenna. For this reason, Icom set the gain distribution such that the best dynamic range can be obtained after achieving the necessary sensitivity with the preamplifier OFF.

In addition, we provide two types of preamplifiers, Preamplifier 1 and Preamplifier 2. Preamplifier 1 improves NF while minimizing the decrease in dynamic range, while Preamplifier 2 has relatively high gain and gives top priority to NF improvement. The user can select Preamplifier 1 or 2 according to their operating conditions.

Although this part has not changed from the past, we should note that in the IC-7610, the preamplifier subsystem is not just an additional circuit, but based on the idea of a scheme for optimizing the gain distribution of the radio according to the operating situation, by using the gain distribution processing within the FPGA to correct the increased total gain (See Figure 03-02).

Therefore, when the preamplifier is turned ON while a weak signal is being received, the deflection of the S-meter does not change, but the signal emerges at a higher level so that it can be more easily heard.

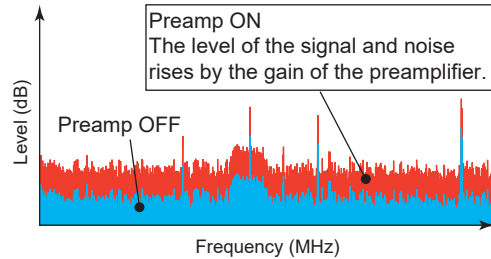


Figure 03-03: Preamplifier operation (conventional method)

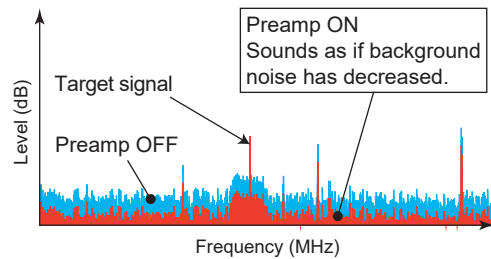


Figure 03-04: Preamplifier operation in IC-7610.

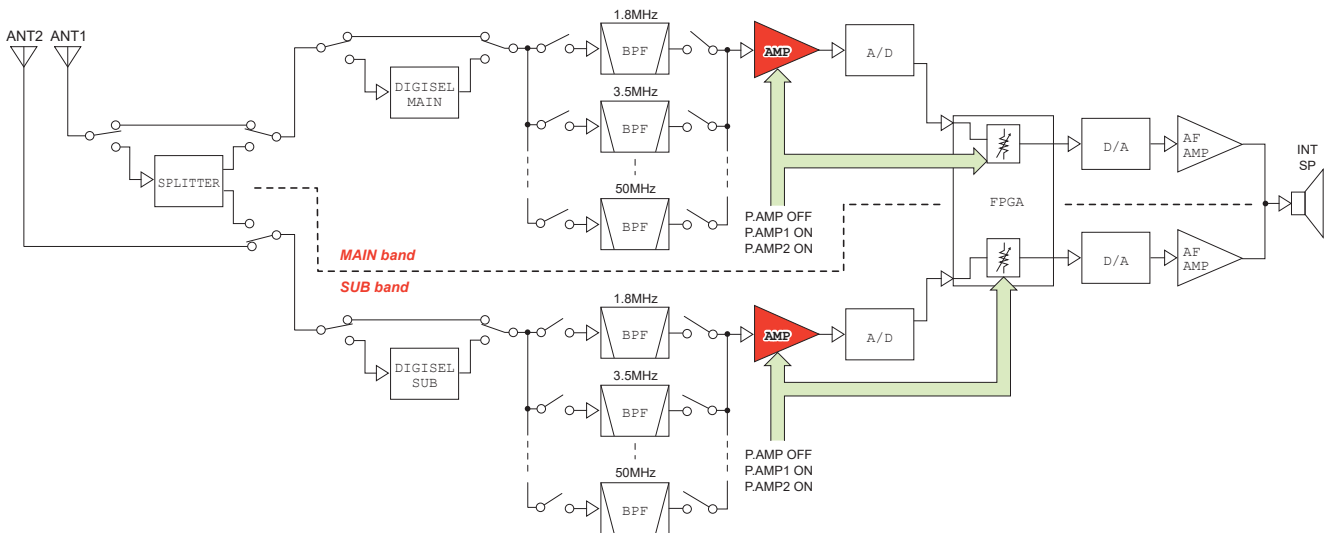


Figure 03-02 Receiver block diagram showing preamplifiers & downstream gain-distribution adjustment

~ In Conclusion ~

Icom's HF transceiver line has been a technology leader from the start, employing a solid-state transmitter final stage, a CPU, full-digital PLL, DDS, up-conversion topology, the industry's first integral spectrum scope, improved RMDR with a high C/N oscillator, and more. Now we have capped these achievements by the adoption of an RF direct sampling SDR architecture, which has been a significant design change and a game changer.

In addition, in recent years, the linkage between an amateur HF radio and a personal computer, offering new capabilities, such as log management software, data communications such as JT65, FT8, and so on, and antenna control, has become indispensable. In such circumstances, the IC-7610 has a variety of external ports comparable to the flagship IC-7851, such as the USB port, the LAN port, and so on, in addition to the REMOTE port, which has ensured compatibility with the conventional model.

In addition to the extensive CI-V (Command Interface - V [Five]) command set, which has evolved over the years, Icom is planning to offer Dualwatch remote operation, and an I/Q (In-phase/Quadrature) interface corresponding to the baseband output. Icom has used the CAT (Computer Aided Transceiver) system in HF products for more than 30 years, and is a pioneer of remote control in the amateur radio industry.

As with CI-V, the combination of state-of-the-art RF technologies accumulated over many years and the RF direct sampling system, which can be viewed as a paradigm shift in HF radio design, along with PC connectivity, have given the IC-7610 high performance comparable to the highest class transceivers. We have successfully realized the essential elements of a high-level competition-grade transceiver.

Count on us!

