AN AFFORDABLE APPROACH FOR EXTENDING THE SDR CONCEPT OVER THE X RADIO BAND

Nicolae CRISAN
Technical University of Cluj-Napoca, Romania
Communications Department
Phone: 0264401241

Abstract: **In this paper several technical solutions are proposed to extend SDR technology to X microwave band, at low cost. This extension requires a hardware combination of modules, most of them readily available on market from commercial suppliers. The great advantage of the proposed system lies on its ability to process digital signals from X band on the PC after several frequency down conversions. To make the X band accessible a set of measures is proposed that aim to transform a complex problem with a high degree of nonlinearity in a simple linear problem by omitting some parameters.**

Keywords: *Software Defined Radio, Down-converter, X-band, Microwaves.*

I. INTRODUCTION

In recent years an increasing number of researchers are using digital signal processing techniques to achieve superior results, in accordance to the wireless communications systems requirements. Mobility, the most demanded characteristic, offered only by the wireless communication systems, is currently a challenge for the imagination and professionalism that pushes engineers to the limit. The major problem at this stage is the "*hunger*" for digital processing techniques which ensure increasing data rates in the present context where hardware and software complexity plays a key role [1] (smart phone, evolvable radio, and cognitive radio).

From this perspective engineers and researchers are looking further for more adaptive devices such as SDR (software defined radio) platforms that would enable measurements and implementations of their ideas, especially the ones that are related to software implementations (C, C + +, C #, SIMULINK and so on). Although tempting, software only oriented research is not a good choice even for a software developer in the context of signal processing techniques.

Typical problems encountered by specialists in early stage of a SDR platform acquisition are:

- Exorbitant prices of dedicated experimentation platforms [2],
- Operational frequency band of some affordable SDR platforms are often inadequate for the requirements imposed by the radio scenarios,
- Hardware and software incompatibilities of all kinds at different levels between the hardware platforms and software versions,
- The need to purchase additional licenses or modules available only from the source.

These problems often determine the fact that the original contributions to remain at the stage of simulations or in the best case at the level of DSP implementation under the limitations of numerical conversions.

However, the reality shows that many of the mathematical models based on SISO or MIMO are not accurate enough. Environmental effects upon the propagation and nonlinear device effects could influence specific parameters of the signal that cannot be easily taken into account outside the experiment.

The paradigm incompleteness of any mathematical model that was demonstrated by Austrian mathematician K. Gödel implies that any mathematical formalism which is based on false statements arrives at a true proposition only if it is wrong. Furthermore, a mathematical formalism is essentially inconsistent if it is not axiomatic [3].

This paper hopes to open new possibilities for researchers who want to get closer to the experimental approach. This is the first step in building their own modular experimental SDR platform. A modular configuration of the platform is imagined here, to be extendible toward IF&RF chains using only general - purpose hardware modules. Besides the advantages of digital signal processing, researchers can put under test their own mathematical models to counteract the effects of IF&RF chains or to take into account the environmental effects upon X-band signal (8-12 GHz) [4]. Also, a modular system is proposed, that can be easily extended to other microwave bands, with minimal changes.

The paper is organized in seven sections including the introduction and conclusions. Section II starts with the identification of the main problems, then presents the main ideas of the proposed solutions. Sections III to VI follow are following the proposed solutions in reversed order.

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II. PROBLEM IDENTIFICATION OF THE PROPOSED SOLUTION

This section aims to identify key issues that arise on cheap SDR systems in X microwaves radio band. Solving these problems, one could easily build a SDR system of his own, possibly following a sketch and some simple instructions. The main problem is to translate the frequency of a signal from the X radio band to a much lower frequency within the range of a digital to analog convertor (ADC). The problem seems so difficult at a first glance.

Engineering today becomes a complex issue dealing mostly with nonlinear problems but transforming these into linear problems. These linear problems become easy to implement in terms of price and resources by omitting some negligible parameters. A similar approach is considered in this paper that it starts from the observation that exaggerated prices of SDR platforms are mainly due to the fact that are not widely used or mass produced. This is the case of converters (ADC) and signal processors (DSP) designed for broadband signal processing. Nevertheless an extremely low price ADC is available for example on any PC sound card. The sound card, indispensable to a PC, supports signal sampling frequencies of: 48, 96 or 192 kHz depending on performance and price. After many years of optimizations these sound boards are capable to apply FFT and IFFT transforms within tens of milliseconds.

The maximum frequency of the input signal cannot be greater than half the sampling frequency listed above. A signal of 8 kHz is processed easily on a sound card. In spite of the fact that sound card is capable of processing successfully the IF signal there are no down-converters available on the market, that translate signal from 10 GHz to sound card frequency range. The problem is that it takes costly frequency conversions and the use of multi-stage mixers leads to IM (image frequency) rejection problems. Mixers are difficult to be used in cascade and often the value of the IF (intermediate frequency) doesn't match the input requirements of the next stage.

The problem seems to be very difficult and becomes difficult for non-specialists in microwaves. Also, one may notice that there is no mixer available on the market, that works with IF's in the range of the sound board. This is because the image frequency is harder to reject at lower frequencies with cheaper filters. In other words we cannot solve the problem by using only one mixer module even if it changes the frequency in two or three steps. Concatenated modular devices are hindered by problems like: the impedance mismatching, signal level range mismatching and IF mismatching.

The SDR system proposed here must be one that uses only modular building blocks that are produced in large scale only. Such a device that would meet almost all these requirements is a transceiver which is widely used. These transceivers can be found easily and are used in civil engineering. Equipment should be chosen so that the RF input frequency to be as high as possible and IF as smaller as possible. The highest frequency currently used by low-cost transceivers is up to 570 MHz. They operate in the UHF band between 300-570 MHz, where series of mixers provide IF output signal in-between 400 to 570 MHz. The problems with impedance matching disappear because these devices all have 50 ohm input impedance. Input signal level problems are avoided because of the good sensitivity below 1 μV and thanks to the AGC floors that provides the appropriate signal level to down converter stages internally.

But one can observe that a new problem arises. The problem is related to the lower IF signal which is inaccessible to a port. At most this IF is between 455kHz for MA and 10.7 MHz for FM. Frequency of 10.7 MHz is really inaccessible in most cases, but the 455 kHz IF signal is easy to find for transceivers that have optional sockets for ceramic IF filters. These sockets are available to the user after lifting the lid of the transceiver. Manufacturers give details on how users can replace the optional filter with a more efficient one. The ceramic filter exchange is often a common procedure that is made in a service room by a technician.

This optional socket provides the 455 kHz IF modulated signal to one available and easy to access pin. From 455 kHz IF frequency to 1-8 kHz audio frequency unfortunately no commercial mixer products are available. This problem can be solved only by building our own mixer that rejects the image frequency and the most available choice is toward a digital IQ mixer that has no need for any special tuned circuits. It will come back to this problem in section 3.

Let us list the solutions identified so far:

1. Using the sound card and the PC as SDR-core
Drawbacks: We can process only very narrow band signals between 0-96 KHz,
2. The use of the transceiver as a down-converter from 300-570 MHz to 455 KHz,
Drawbacks: Intervention at the optional ceramic filter socket for extracting the lowest IF signal,
3. Designing and building of an IQ mixer for 455 KHz IF by simply using logical components without any tuning adjustments.
Drawbacks: The use of logic circuits simplifies the mixer but they are noisier,
4. Using a common X-band transverter that provides an IF output signal in-between 300-570 MHz
Drawbacks: moderate price (300-400 EU).

The problem reduces its complexity by: avoiding the broadband signals processing, using only transceivers with optional ceramic filter socket, using logic circuits only for translating the lowest IF frequency into the audio frequency range.

The question that emerges is whether we cut too much the complexity. Always depends on the application, sometimes certain experiments not necessarily need a broadband SDR (antenna arrays processing for example). In terms of noise, narrowband SDR is often better than broadband. Previous solutions will be addressed in the following sections, but in reverse order.

III. CHOOSING THE TRANSVERTER

It is not a very difficult task to choose a narrow band transverter from those available on the market. It must meet all requirements such as: desired working frequencies and appropriate signal power range for the next stage.

An affordable microwave device from Kuhne satisfies all these requirements at a reasonable price [5]. In X microwaves band two transverters (see Table 1) were identified as being acceptable, but there are many other devices that allow this frequency extension to other radio bands. For good frequency stability in X band, Kuhne makes available an input port for stabilizing the local oscillator frequency with a reference of 10 MHz signal which is synchronized via GPS. As default there is a thermal stabilized quart crystal which is useful only for experiments. More details including a block diagram and a top view of the transverter assembly are available from the source [5].

Table 1.

Type	RF Input [MHz]	IF Output [MHz]	Output power [mW]
MKU 10 G3	10368-10370	144-146	200
MKU 10 G3 432	10368-10370	432-434	200

Dawn-converters with the IF signal of 432 MHz, better gives actual figures of the transceivers of trade. A *Horn* antenna, widely used in satellite reception, (LNB) can be attached to the input (see Figure 1). To do this, one has to remove the circuit from a LNB and connect a 50 ohm coaxial cable between the antenna and the transverter input (RF IN-MKU10G3). Horn antenna can remain attached to the parabolic reflector or can be used without reflector for indoor measurements only. Coaxial line should not be longer than 10-15 cm, and must be as thin and flexible as possible. Output signal (IF OUT) is in the power range that allows the connection to the next stage (Figure 1).

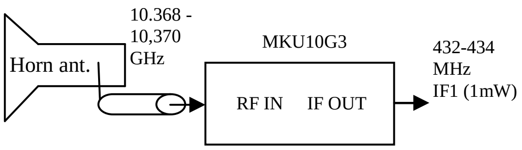

Figure 1. Block diagram of the first down-converter.

In order to avoid connection problems some considerations following the basic procedures according to the work at extremely-high frequencies must be taken into account. Due to the cable loss at 10 GHz the quality of the transmission line must be as higher as possible.

IV. CONFIGURING THE TRANSCEIVER

This section presents the transceiver configuring because many stations are programmable. For example FT 859D is a portable transceiver designed by YAESU [6]. FT-857D allows input signals up to maximum 570 MHz. Also two available sockets for optional ceramic filters are available.

In figure 2 changes made on slot 1 of the transceiver are shown. The device allows the switching between the FI filters (in CFIL mode) but the socket is empty (blind switching – grounded pins deceive the transceiver software to believe that there is a ceramic filter inserted in the socket). The FT857D is turned on into the CFIL mode to only make the IF2 signal available to pin 4. From pin 4 of the socket1 the IF2 signal is applied to a coaxial line.

In addition a tuned frequency controlled by means of CAT interface is available through a serial port directly from PC. This CAT control interface can be used as an advantage, in which case, one needs additional software to automatically control the transceiver.

A MAX232 integrated circuit converts voltage levels (CAT interface - see Figure 2) from ± 15V (serial port levels) to compatible TTL level (0-5V). To supply the MAX232 serial interface the circuit 74LS05 was used. Figure 2 shows connections between modules.

Transceiver interfacing with PC is optional but a CAT convertor is useful anyway for SDR platform automation. This interface allows the COM port to read the currently tuned frequency directly from the transceiver. This feature is particularly useful for synchronizing the PC display frequency with the FT-857D tuned frequency.

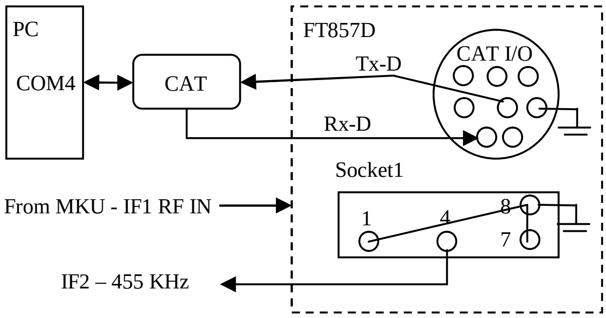

Figure 2. Block diagram of the second down-converter.

Commands through the CAT interface are described in the user manual of the transceiver. All modern transceivers have many CAT commands of this type to allow a PC to plays the role of the remote control. For example, through the serial interface five ASCI codes must be sent. The first four bytes are representing the data that the transceiver are sending back (are reserved for transceiver) and the last byte is the request. In Table 2 trough COM4 are sending four bytes of zero and the request for the tuned frequency value (the fifth byte in ASCI code).

The transceiver is responding by sending the acknowledgement to the PC, the tuned frequency (432.300 MHz see Table 3) and the current operating mode 0A (PSK digital reception).

Table 2

Data1	Data2	Data3	Data4	Mode
0	0	0	0	03

Table 3

Data1	Data2	Data3	Data4	Mode
43	23	00	00	0A

In this way the PC spectrum could be in total agreement with the RF value of the input signal (from X band) not with the IF1 frequency value (figure 1).

$$f_{RF} = 432.3 + 9936 = 10368.3\ MHz \qquad (1)$$

From Table 1it results that, if the signal offered by the *Horn* antenna in X band has a frequency of 10368.3 MHz than the transceiver must be tuned over the 432.3 MHz (IF1 range).

V. THE IQ DIGITAL MIXER

The IQ digital mixer is not raising special problems because it does not require any frequency tunings. Also, it is running at low frequencies, the problems specific to high frequency are avoided; however the image frequency rejection is still required.

The image rejection problem is best described in Hilbert space when two signals I (in phase component) and Q (in quadrature component) are used to form a complex signal. In Hilbert space after a -90 degree shift, the positive frequencies get multiplied by –1 and the negative by +1 according to:

$$\sin\left(\omega t-\frac{\pi}{2}\right)=\frac{(-j)e^{j\omega t}-e^{-j\omega t}(+j)}{2j} \qquad (2).$$

Image problem is avoided if the I component is delayed (with -90 degree shift) and added to the Q component. For the sum signal (OUT – see Figure 4) all images and inputs signals (LO and f) have opposite signs (see equation 2 and Figure 3). Figure 3 shows the image rejection process taking into account the block diagram from Figure 4. Dash lines show components of the form $e^{-j\omega t}$.

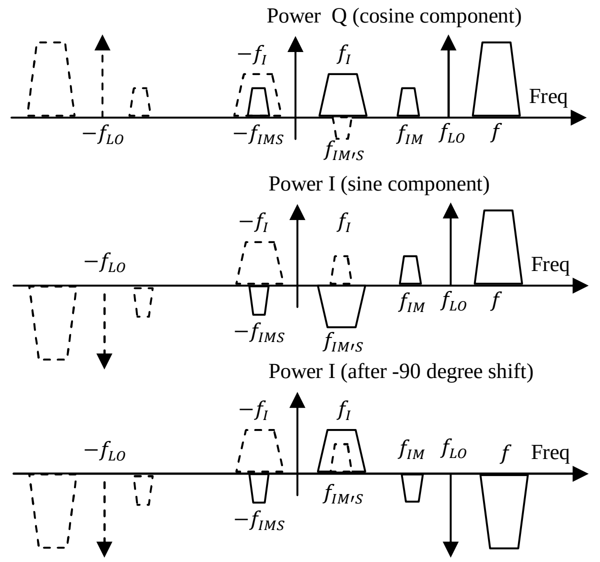

Figure 3. IQ Spectrum –The Image IMG'S problem avoidance - all positive frequency components get multiplied by –1 and negative components (dash) by +1.

The chosen solution is known as the IQ mixer and uses two cells as those shown in Figure 4. BMix1 and BMix2 are two simple balanced mixers, each driven by the same local oscillator but with 90 degrees shift between signals. A delay stage along the path I reverses (mirrors) the spectral component corresponding to the most unwanted component the IMG'S. This component is placed within passband of the IF filter. Thus, by adding the two I and Q signals the image frequency is rejected from the sum signal. The block diagram is not complicated but requires two tuned circuits (one for each delay stage). This contradicts the assumption made in section 2, where we stated that the goal was to avoid all tuned circuits.

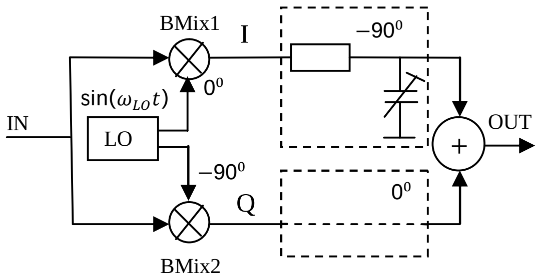

Figure 4. IQ-Mixer.

All tunings can be canceled if we observe that the IF2 frequency is very low (from figure 2 IF2 is only 455kHz). In this case we can replace the LO sinusoidal signal with a rectangular one and also balanced mixers diodes with four switches. We can do this because in theory we know that the output signal for the balanced mixer is of the form:

$$I=INs=IN\left(\sum_{i=1}^{\infty}\frac{2}{i\pi}sin\left(\frac{i\pi}{2}\right)cos(i\omega_{LO}t)\right)$$

$$Q=-INs$$

Where: $IN=Vcos(2\pi ft)$,

$$s=\begin{cases}+1;\ v_{LO}>0\\-1;\ v_{LO}\leq 0\end{cases}$$

This happens only if the On/Off switching delay is much smaller than the input signal time period 1/f. This condition is satisfied for the frequency of 455 kHz. Instead of the balanced mixers Bmix1 and BMix2 in Figure 5 a TTL analog multiplexer switching circuit can be used, such as 74HC4052.

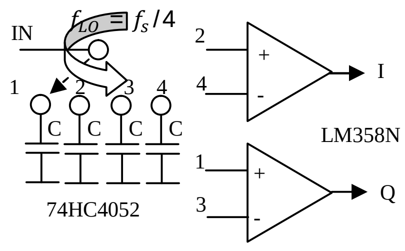

Figure 5. IQ-Digital Mixer.

Two rectangular TTL compatible signals in quadrature of phase can drive the switching. The quadrature signals are obtained by dividing the frequency of a quartz (XTAL).

In figure 5 in the presence of an input narrow band signal (IN) with the spectrum depicted in figure 6, the difference between f_{LO} signal and the side bands (USB and LSB) must fit the sound card frequency range (0-8KHz).The PowerSDR program is working on sound cards with 7300 and 4300 Hz frequency differences in default mode. The signal frequency range provided by YAESU FT-857D (IF2) is in-between 453.5 and 456.5

KHz. In order to use PowerSDR in required frequency range that differences must be in the domain of the two limits (7300 and 4300 Hz). This is happening when f_{LO} is 460.8 KHz.

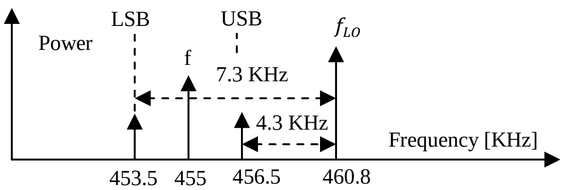

Figure 6. Signal spectrum (I)

Then we have $f_s = 4f_{LO} = 1.8432\ MHz$ the rectangular TTL signal that results by dividing the frequency of a 3.6864 MHz crystal by 2. The IC 74HC74 provides two out of phase divided signals at its Q and $\bar{Q}$ output pins. A standard divider was used. Along the I receiving chain shown in Figure 4, the signal supports a delay that leads to a phasor tilt with -90^o. Both the delay and the addition are implemented by software after I and Q signals sampling (on the PC sound board) and ensures an image frequency rejection of at least -70 dB [7].

All C capacitors from Figure 4 were taken into consideration in the design stage must keep constant the voltage of the k sample ($k \in N^*$) for a duration equal to three sampling periods. Therefore the RC constant, with respect of the input resistance (R) from the operational amplifier input, will be:

$$\tau = RC \gg \frac{1}{f_{LO}},$$

Assuming a resistance value of $R = 10\ M\Omega$ the capacitor value results: $C = 21.7\ nF$. Both OAs, integrated within the LM358N chip, use a negative feedback to compensate the loss effect of cables or to offer a signal in the required range of the sound board. This is also possible by using software gain adjustments directly on the sound board interface that depends mainly by the transceiver's IF2 level.

VI. SDR-core on sound board

From now on the signal of maximum 7300 Hz can be processed on a PC after its acquisition using the sound board. The PC processor acts as a DSP unit with some processing delays because of the FFT digital filters latency that depends on the PC processing power. This latency can be measured using the transceiver output signal as reference. This is not the main concern here but for voice the processing delay on PC could be annoying (on a PC- i7 is under 1 second).

In figure 7 the power spectrum is represented almost instantly using the sound board and the PC processor unit [8]. The received signal via USB (upper side band with suppressed carrier) has its side band in-between 10.3688904 and 10.368891 GHz. In reality, before the PC signal acquisition via sound board, the carrier frequency has been translated in-between 4300 and 4700 Hz. In figure 7 the PowerSDR graphical interface is shown.

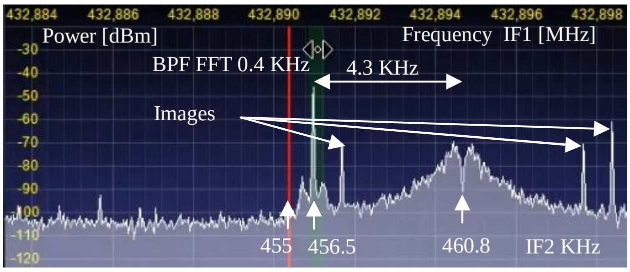

Figure 7. Signal spectrum on PC.

The PowerSDR is an open source program [8] and in figure 8 one can see more details about its graphical interface. Some adjustments have been made along abscissa in terms of the displayed frequencies because this program is not designed to display the IF1 frequency in default mode. For this a frequency adjustment with 9936 MHz according to the first down conversion (see equation 1 - $f_{RF} = 432.891 + 9936 = 10368.891\ MHz$) has been applied (some minor modifications in the program source).

Figure 8. PowerSDR program interface.

VII. CONCLUSIONS

In this paper several low-cost solutions are identified to extend SDR technology to X microwave band. This extension requires a combination of hardware modules most of them available on the market. The great advantage lies in the ability to process digital signals from X band directly to the PC after many down conversions and using the PC sound card for signal acquisition.

It was intended that young researchers working on in the field of signal processing have the possibility to write software on PCs in order to process signals from microwave domain without great effort. The paper provides technical details that are handy to anyone and in terms of practical realization or cost are feasible. It was intended also that a non-specialist in microwaves to have access to Extremely High Frequencies (EHF) band. In order for all these to be possible an innovative combining but affordable, put together several module that pave the way towards microwaves signal processing thanks to one efficient IQ mixer at very low frequencies. This IQ mixer was identified as the missing link between the available down-converters on the market and the sound card.

To solve the problem of access to X band a set of measures is proposed, that aim to transform a complex problem with a high degree of nonlinearity in a simple linear problem by omitting some parameters. Thus the problem was simplified by: reusing resources of the PC hardware, the usage of general purpose down-converters, some hardware modifications and implementations. The main drawback of these simplifications results from reducing the bandwidth of the SDR.

This work leaves open the issue of SDR bandwidth and offers new directions for future developments with consistent solutions for wide bandwidth signal processing on cheap platforms. Also, by an innovative way of interconnecting modules, offers the possibility of extending the SDR concept in other bands with minor changes to one of the module seen in section 3. Topics addressed in this paper are of great interest in this moment especially at universities that are working on SDR technology improvement at different levels.

Technical solutions may also be of great interest to developers for remotely monitoring, using extremely high frequencies, especially due to their physical properties.

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