EFFICIENT USE OF MOBILE RADIO CHANNELS II

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Abstract

This paper is focused on the use of mobile radio channels, comparing the efficiency of analog double-conversion superheterodyne receiver and software radio. The task of mutually comparing both technologies is made difficult by the possibility of implementing various decoding algorithms. Hence, the criterion of the dynamic range is being postulated as a basis of comparison. The data-bearing signal which got degraded in sequel of unfit parameters – those which in their sum characterize the dynamic range of the receiver – cannot be renewed and faultlessly decoded any more.

Keywords

software digital radio, transceiver, dynamic range, noise figure, noise, spurious frequency, phase noise, spectral density, third order intercept point, superheterodyne, analog-to-digital converter, digital down converter, direct digital synthesizer, digital signal processor

1. Introduction

With the rapid advances of wireless communication services, demands for the radio data transceiver performance have grown as well and the new concept of software-defined digital radio transceiver has started to receive much interest. There is a number of reasons for replacing analog circuits and processing with digital solution, as shown in the following text. Software radio allows easy reconfiguration for the implementation of different air interfaces on a given hardware platform.

In many communication applications, the spectral purity of the processed signal is of primary concern. The land mobile communication systems call for a dynamic range in the vicinity of 100dB. The analog superheterodyne receiver structure as invented in 1917 by Major Edwin H. Armstrong is being used to meet such dynamic parameters. Receiver design is a complex task, and there are many eventualities that may be chosen among the number of conversions and intermediate frequencies and filters, demodulation techniques, etc. A software radio performs the same functions as an analog superheterodyne receiver, but the basic analog functions have been replaced with their digital equivalent.

Because a software radio with a digital radio circuitry consists in a sampled data system, all the issues involved in sampling must be considered. The spurious frequencies thus arisen fold back into the Nyquist bandwidth, which makes them unfilterable and lowers the communication system´s dynamic range, while the analog receiver parts mostly produce higher order harmonics which can be filtered.

In fact, a fundamental technical problem of software radio is the dynamic range.

2. Method of Comparison between Analog and Software Transceivers

There are a number of ways to compare and measure analog and software radio performances. Despite the variety in radio communication systems, their performances can be rated by a relatively small number of measurements. Primarily analog and software radio applications are concerned with the dynamic range. Many factors and mechanisms implemented in the final DSP stages, affecting the overall software radio performance, can be bridged over to measure the dynamic range objectively in comparison with analog radio communication systems. This paper does not address the issues of demodulation and decoding techniques.

This paper focuses on the dynamic range parameter because the dynamic range performance is becoming increasingly important in radio efficiency rating in the present wireless communications arena. The goal of this paper is to achieve an understanding of fundamental differences between limits of analog and software radio dynamic performances, and to arrive at a feasible construction of a software radio data transceiver for use in land mobile services.

3. Appointing the Dynamic Range Requirements.

Obviously, there are two points to consider when evaluating the dynamic range of a receiver. First, noise parameters (including phase noise of local oscillators in analog radio and phase jitter of sample frequency generators in software radio, respectively) are measured, and second, third order intercept point is evaluated. Perhaps the real question is whether the third order intercept point of a software digital radio can be calculated to this effect, because the distortion products of analog-to-digital converters do not vary as a function of incoming signal amplitude.

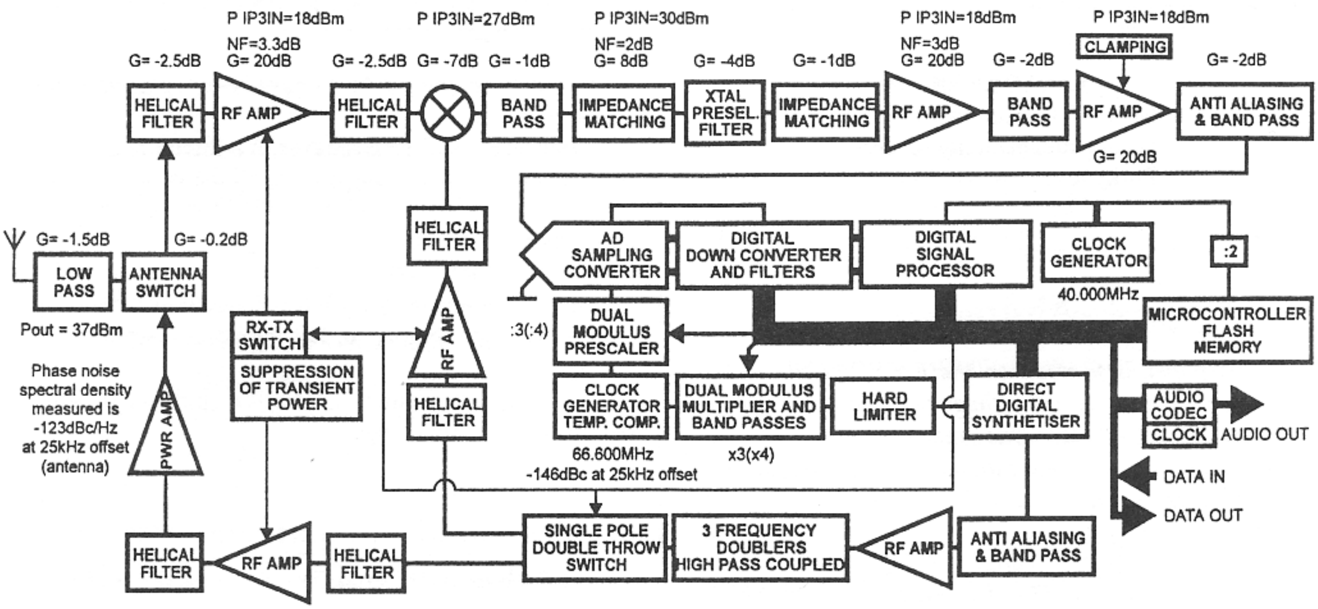

Fig. 1 The experimental software data transceiver block diagram

The European Telecommunication Standard 300113 (ETS) covers the minimum characteristics of data transmission systems considered necessary in order to make the best use of the available frequencies [4]. The minimum limits of spurious response rejection (at any frequency separated from the nominal frequency of the receiver by two channels or more it shall not be less then 70 dB) and blocking or desensitisation (the blocking ratio for any frequency within the specified ranges shall not be less than 84dB, except at frequencies on which spurious responses are found) determine the out-of-band receiver performance. In parallel with receiver dynamic performance, the power of any spurious transmitter emissions shall not exceed the value of –36dBm from 9kHz up to 1GHz (our band of interest). The carrier power is supposed to be 37dBm. Thus, the transmitter spurious free dynamic range shall not be less than 73dB.

4. Analog Radio Data Transceiver

In the analog radio transceiver design from 1997 I have tried to take advantage of the then actual analog design technologies to expand the performance and capability of a licensed, narrowband data transceiver. The radio data transceiver was designed to operate in a packet switching networks, such as gas field and water distribution automation systems, and on-line transaction processing applications. The analog transceiver utilizes surface mount technologies, double conversion superheterodyne, two high performance dual frequency synthesizers to provide a superior level of transceiver performance and reliability in the 400-470 MHz frequency range. In order to minimize switching time losses, as needed in half duplex mode, there are two independent local voltage controlled oscillators and two auxiliary VCOs. Diagnostic functions measured include received signal strength value, various voltage levels, and internal temperature. Radio diagnostics information is available from anywhere on the network. Fig. 2 demonstrates the dynamic performance of the receiver part.

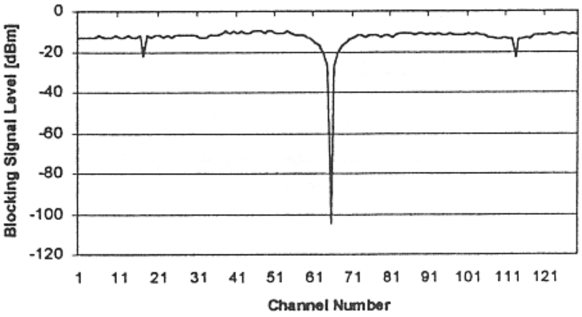

Fig. 2 The analog radio blocking rejection

5. Experimental Construction of a Software Digital Transceiver

The experimental software digital transceiver design is shown in Fig. 1. The Analog Devices chipset, analog-to-digital converter AD6600 (AD6644), digital down converter AD6620, direct digital synthesizer AD9852 and SHARC digital signal processor ADSP21061, is used in transceiver design. [1]

5.1 Receiver Design Notes

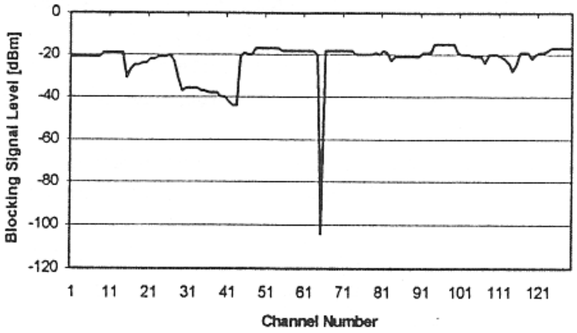

Fig. 3 Software digital radio blocking rejection, before optimization

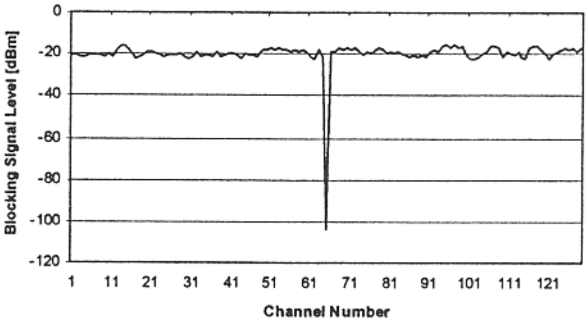

Fig. 4 Software digital radio blocking rejection optimized

The noise figure of rf wideband front-end (the same block as in analog transceiver) measured is 8 dB and the input third order intercept point calculated is found to be 14 dBm, using two tones method.

The theoretical signal-to-noise ratio for an analog-to-digital converter is limited [1] [2] [3] by aperture uncertainty, dynamic non-linearity of converter and thermal noise, as shown in a simple equation (1).

$$SNR = -20\log\left[\left(2\pi f_{if\ anal}\, t_{j\ rms}\right)^2 + \left(\frac{1+\varepsilon}{2^N}\right)^2 + \left(\frac{V_{noise\ rms}}{2^N}\right)^2\right]^{\frac{1}{2}} \qquad (1)$$

where	SNR	is signal-to-noise ratio in dB
	$f_{if\ anal}$	is intermediate analog freq. in Hz
	$t_{j\ rms}$	aperture uncertainty
	ε	is average dynamic non-linearity
	$V_{noise\ rms}$	is thermal noise in least significant bits
	N	number of bits of ADC

From the AD6600 datasheet, the typical SNR is given to be 59dB. The aperture uncertainty, measured by the degradation in SNR at analog input frequency 180MHz, was found to be 0.90ps rms. In an experimental digital transceiver, the noise figure of the digital core is calculated to be 44dB in a 16kHz bandwidth. True limitation in a software digital receiver is the spurious free dynamic range, which degrades the receiver performance long before the noise limitation is reached. The configurable sampling frequency generator minimizes the effect of spurious signals. The dynamic performances before and after optimization are shown in Fig. 3 and Fig. 4, respectively.

5.2 Transmitter Design Notes

The spectral quality of a direct digital synthesizer system can be externally influenced. The main factor is the phase noise of the clock source. The phase noise spectral density of DDS clock generator is –146dBc/Hz at 25kHz offset. The DDS output spurious content exceeds that of a clock frequency generator. The overall frequency multiplication by 6.44 increases the phase noise power of transmitter by 16.18 dB (20log(6.44)). The phase noise governed dynamic range is given by

$$DR_{\Phi} = P_{PNSD} + 10\log B \qquad (2)$$

where	P_{PNSD}	is the phase noise spectral density in dBc/Hz at any offset
	B	is the bandwidth in Hz

For narrow bandwidths at large offsets, little error is obtained by approximating the phase noise slope to a straight line. The adjacent channel power measured in a 16kHz bandwidth was found to be 75dB below the carrier power (37dBm). The spurious frequencies limit the transmitter dynamic performance long before the phase noise limitations is reached. As stated in 5.1., the configurable clock generator minimizes the effect of unwanted signals (Fig. 5).

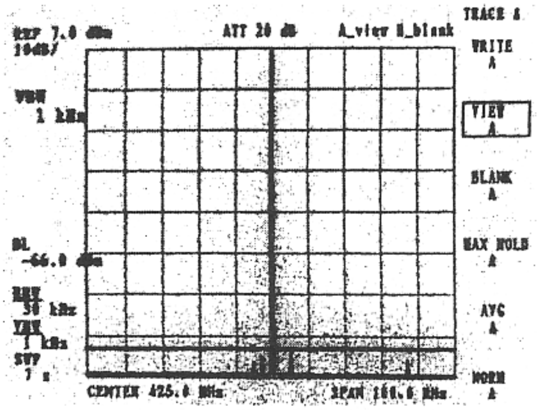

Fig. 5 Transmitter output spectrum (30dB attenuator used)

6. Noise, Spurious Frequencies and Dynamic Range

The thermal noise quantity calculation in the bandwidth of the signal of interest is the first place to start in the receiver's signal level diagram. When proposing a level diagram of a software digital radio, we face a situation which is much more difficult. The lower limit of the dynamic range is delimited by the presence of jamming signals the bulk of which cannot be rigorously and verbatim designed as noise.

The probable linguistic origin of the term noise refers to the Provençal word noyse, nosa, or nausa, and its older root might have consisted in Greek nausia – seasickness, i.e. a disordered state caused by haphazard and at-random motions of a ship. Moreover, the Latin verb nocere (to do harm), which resounds in Engl. nuisance, might have played a role in the development of the term 'noise'. Also, the Czech word šum, meaning 'noise', is an old cognate of the verb šupěti meaning 'to be anxious', implying haphazardness and randomness (anxiety as a sequel of unforeseeable random stress). Hence, randomness and harm-causing haphazardness are main traits of a signal which might be characterized as 'noise'.

Spurious signals decreasing the dynamic range of a software digital radio arise in sequel of non-linearities occurring in the conversion of the signal from the analog to the digital domain and contrariwise. The fundamental error engendered by the conversion mechanism results from the quantization principle itself – it is the quantization error. Namely, the quantization effect produces an error which is often considered as noise. This term is applicable only under the assumption that the sampling frequency and signal frequency are unrelated, otherwise the quantization noise becomes "very colored" and the term spurious signal gets more actual. This condition of frequency unrelatedness is valid for most other dynamic non-linearities which appear in sequel of the applied converters' architecture.

In order to get an optimum dynamic range of the software digital transceiver, a very apt device consists in a spectral analyzer. Together with a communication tester, which measures the degradation of receiver's SINAD sensitivity in the process of measuring the blocking capability, it forms a diagnostic set, on the basis of whose information functions the algorithm of the configuration of the proposed and realized experimental software digital transceiver.

7. Conclusions

Basing on values arrived at in realized measurements, the proposed original experimental construction of a software radio data digital transceiver (Fig. 1) may be estimated to be one of the feasible constructions of a modern narrow-band data third-generation communication advice. The use of direct digital frequency synthesis circuits, implying frequency multiplication as a local oscillator for the input converter, as well as the use of a configurable frequency divider for the deduction of indispensable sampling frequencies, are inherent parts of the proposed original solution. The robust quality of the method of pointing up mutual configurations of the sampling frequency, the NCO frequency, the clock frequency of DDS and the DDS frequency itself, has been verified on 16 various groups of 256 channels with a separation of 25 kHz operating within the limits from 420 up to 470 MHz (Fig. 3, 4, 5; the nominal center frequency is 425MHz). From a broader point of view, the method of pointing up optimum frequency relations among the individual generators of auxiliary frequencies might by used also when aiming at the construction of a broad-band software transceiver, in which case, however, it would be necessary – at least when the quick 12-bit AD converters disponible in our time be used - to implement the dither, e.g. by using an additive AWGN-source, filtered through the low pass.

It is evident that the time is coming when a whole group of applications of communication technologies will be solved by means of a universally annexed software transceiver, whose structure will be initially dependent on the width of the operating band of the communication advice. The classical analog radio technology focuses on solving the input frequency down converter, whose output function will henceforward increase. The block formed by the input converter, digital mixer and digital intermediate frequency circuits - whose functions, realized in an analog superheterodyne, formed the principal parts of a receiver – nowadays tends to be designed, in some papers, by the term 'air interface'. The main bulk of substantial functions of a radio data transceiver, i.e. the transfer of the signal into the baseband, channel filtration, equalization and demodulation (decoding), are carried out by means of a digital signal processing. This, at the same time, enables the use of adaptive mechanisms which may enact corrections of frequency and phase characteristics of the radio channel in the real time. The software digital radio may be, in my view, esteemed to be the most profound change in the structure of the superheterodyne since the time of its discovery by Armstrong.

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Karel DANĚK was born in Nové Město na Moravě, Czech republic, in 1961. He received the Ing (MSc) Degree from the Technical university of Brno, Dept. of Telecommunication in 1984. His present interests are in the land mobile radio communications, rf and software digital radio circuit design.