A RECONFIGURABLE LOW IF-ZERO IF RECEIVER ARCHITECTURE FOR MULTI STANDARD WIRELESS SYSTEMS USING A RECONFIGURABLE FILTER

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ABSTRACT

The existence of a large number of wireless standards motivates the investigation of a multi-standard wireless receiver architecture that uses the same hardware to meet performance requirements. This paper presents an architecture of a reconfigurable receiver operating at both Low-IF and Zero-IF modes for GSM-1800 and UMTS-2100 wireless standards. The reconfigurability in the RF front-end part is achieved by a reconfigurable filter based on a dual mode resonator with the possibility of using MEMS switches to tune the center frequency and the bandwidth of the preselector filter. System-level analysis and derivation of block-level specification for the specified standards are developed to design the receiver. Simulation results of both system-level analysis of the reconfigurable receiver and circuit design of the reconfigurable filter are presented and discussed. Simulation results indicate that the designed receiver meets the minimum requirements specified in GSM-1800 and UMTS-2100 wireless standards with a good margin.

KEYWORDS

Multi-standard, Zero-IF, Low-IF, reconfigurable filter; dual mode resonators, microstip, system simulation.

1. INTRODUCTION

The simultaneous need for global roaming and all-in-one wireless phones has resulted in a demand for handsets which can receive multiple standards and meet the modern requirements of the wireless devices such as low cost, high integration and high performance [1].

Achieving multi-standard receiver with previous features has been the subject of many recent research. Sampling receivers [2, 3] and wide band receivers using wide band LNA [4] were proposed solutions as multi standard receivers; however they have moderate linearity and poor matching.

A tunable quadrature band pass charge sampling filter and a time varying matching network based on impedance translation were used to form a tunable receiver front end [5], although it enhances the linearity and matching but it also increases the complexity of the receiver.

To meet the modern requirements, a multi standard receiver is proposed in this paper. A Low IF-Zero IF architecture that suits wireless devices is used [6]. A dual mode microstrip resonators filter forms the pass band filter; this kind of filters offers size reduction, ease of fabrication, integration and high selectivity, which improves the receiver's linearity [7]. RF MEMS switches are used with the dual mode microstrip resonators filter to form a reconfigurable filter with tunable center frequency and bandwidth to accommodate to the different standards [7].
The designed receiver is simple, effective and low cost, which are the desired characteristics for the wireless devices.

In this context, the design and analysis of the proposed RF front-end receiver are presented. Then, a brief summary of the two wireless standards and the overall receiver specifications required for each standard are provided. The proposed Low-IF Zero-IF receiver is then examined. A brief description of the reconfigurable dual mode resonator filter in which MEMS switches can be used and other components of the receiver are presented. System-level simulation results are also presented and discussed to make sure that the proposed receiver is valid.

2. THE RECONFIGURABLE RF FRONT-END (RFFE) RECEIVER

Our work, the design of a reconfigurable RF-FE receiver, has been the subject of many papers and dissertations around the world ([1], [6], [8], [9] and [10]). In this section our motivation to do this work is expressed, and its novelty is highlighted when compared to other work.

Two important ideas had to be considered in designing the multi-standard receiver: the first idea was about the architecture of the receiver. Since Zero-IF and Low-IF architectures are more suitable for high integration level [6], a Low IF-Zero IF architecture was used. However, choosing the suitable architecture (Zero-IF or Low-IF) for the suitable standard is essential in order to improve the receiver performance (section 4).

The second idea was about how to achieve multi-standard function. Generally, a dual standard operation is enabled through two separate parallel receiver chains (Figure 1). Obviously, this is not a cost-efficient solution, and it increases the size [8].

To overcome this problem, some solutions were developed. One of these solutions was done by using a silicon varactor-tuned band pass filter (BPF) connected with a tunable six-port demodulator to design a reconfigurable front end direct conversion receiver for GSM and WLAN bands (1.9 and 2.4 GHz). The tunable demodulator is composed of a tunable six port junction in connection with four RF power detectors [9]. Although this BPF offers high selectivity, it requires using two different sets of voltage supply and the insertion loss degrades as varactor capacitance increases due to the mismatch and varactor diode equivalent series resistances [9].
Another proposed solution was achieved by using dual behavioral resonator (DBR) topology to design an electrical tunable filter which can switch between UMTS, WiFi and LTE reception bands. The DBR topology is based on the parallel association of two stubs, this gives a band pass response. For controlling central frequency and bandwidth independently, varicap diodes were implemented at the end of each stub [10].

Micro-Electro Mechanical Systems (MEMS) switches facilitate building reconfigurable filters to cope with different standards, and to obtain good performance [7]. Then multi-standard receiver could be designed without increasing its size or cost.

The researchers in [8] gave an example of using RF MEMS switches to design a reconfigurable FBAR filter for multi-standard RF front-end receiver. Although this filter has unique advantages such as high frequency operation and high quality factor, the technology FBAR may not be available everywhere and it is not easy to fabricate.

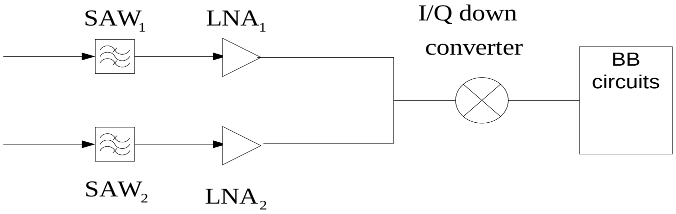


Figure. 1. Classical approach for dual standard RF front-ends.

However, in this paper we propose using one RF-FE block, instead of two separate parallel receiver chains. In addition, we use dual mode resonators as a reconfigurable filter to deal with different standards. The reconfigurability of the filter is achieved by simulating the use of MEMS switches. This solution is characterized by size reduction, high selectivity and being easy to implement and integrate in microstrip technology.

3. OVERVIEW OF GSM1800 AND UMTS 2100 STANDARDS

Table 1 shows the receiver frequency bands of GSM-1800 and UMTS-2100. UMTS-2100 has a channel of 5 MHz bandwidth while GSM-1800 has a 200 KHz channel bandwidth.

Table 1. Receiver frequency bands for GSM1800 and UMTS2100.

Standard	**Parameter**	**Specification**
GSM-1800	Downlink frequency band Rx (MHz)	1805 to 1880
UMTS-2100	Downlink frequency band Rx (MHz)	2110 to 2170

The two standards have different specifications known as the minimum performance requirements [11], [12]. These requirements mainly specify the receiver sensitivity, inter-modulation characteristics, adjacent and alternate channel selectivity, blocking characteristics, and spurious emission.

From these different specifications, a set of specifications suitable for the two standards at the same time was derived. It was done by selecting the most stringent requirements of each parameter. Table 2 shows the common specifications of the multi-standard receiver to work in accordance with the two standards.

Table 2. Required specifications of the multi-standard receiver.

Requirements for the reconfigurable receiver	
Noise Figure (dB)	< 7.2
IIP2 Mixer (dBm)	≥ 35
IIP3(dBm)	≥ -14.7
Image rejection (dB)	≥ 30
Blocking characteristics	The designed receiver must satisfy blocking characteristics defined in [11], [12].

4. LOW IF-ZERO IF MULTI-STANDARD ARCHITECTURE

It is preferable to use Zero-IF architecture when dealing with systems that have wide channel bandwidth like UMTS-2100, because removing DC offset by using DC notch filter or AC coupling will not cause a significant damage [1]. The narrow channel bandwidth in GSM-1800 makes this architecture unattractive due to the removal of significant part of the signal when removing DC offset. Thus, using Zero-IF architecture is suitable for UMTS-2100 while using Low-IF architecture will be more suitable for GSM-1800[1].

The Low-IF architecture is similar to the Zero-IF architecture, except that there is an AC coupling or DC notch in the Zero-IF to remove the DC offset. And there is an image rejection circuit in Low-IF to drop the image signal out.

In order to reduce size and cost, a common RF-FE receiver that can be configured to operate as Zero-IF for UMTS-2100 and Low-IF for GSM-1800 was designed. This can be achieved by using a digital dual quadrature converter in the digital base band block of the Low IF receiver to cope with the image rejection. Moreover, the AC coupling or DC notch filter was dropped from the Zero-IF architecture. The DC cancellation was achieved by means of I/Q down converter, as shown in section (5). Figure 2 shows the architecture of the proposed receiver. This architecture is based on high-dynamic analog-to-digital converter (ADC). It helps to relax the restrictions on the automatic gain control system (AGC) which is concentrated on the RF amplifiers. By using fixed and low gain baseband amplifiers, this architecture may have less I and Q mismatch and less DC offset issue [13].

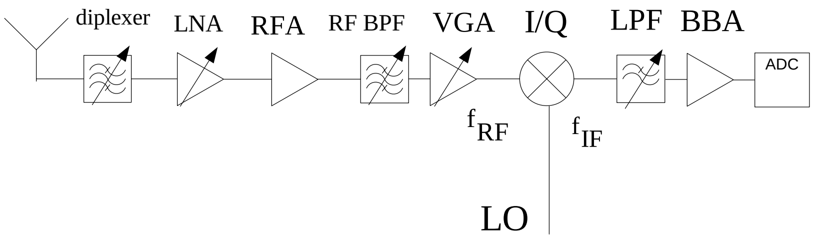


Figure 2. The architecture of the proposed receiver.

5. RFFE BUILDING BLOCKS DESIGN

5.1. RECONFIGURABLE DUAL MODE RESONATORS

The filters based on dual mode resonators were designed to be reconfigurable. The reconfigurabilty process consists of tuning the filters' center frequency and bandwidth to achieve multi-band selection according to the two standards.

Recently, dual-mode microstrip resonators have been increasingly used for designing reconfigurable microwave filters. They have the advantages of ease of fabrication, integration, low loss, and high selectivity in addition to low cost [7].

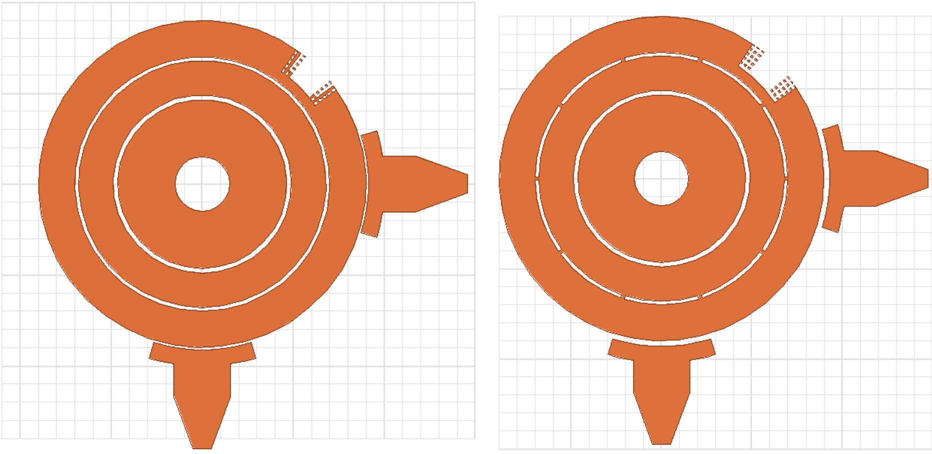
Dual mode resonators have symmetric structure (it's a ring in our case) and support two orthogonal degenerate modes of resonance. By inserting a perturbation (eg. cut) into the structure of the resonator, the two modes are coupled and tuned to form a resonant filter [7].

The bandwidth of the filter could be changed by adjusting the dimensions of its perturbation element, while tuning its center frequency could be accomplished by changing the center radius of the ring.

Usually, RF switches are used to achieve geometric tuning, so they can be used to change the dimensions of the cut and the center radius of the ring. Nowadays, RF MEMS switches are considered as a suitable choice to achieve fine tuning, because of their small size, simple circuit model, zero power consumption and low insertion loss [7].

In this work, two filters were simulated to represent the changing cut size and center radius instead of implementing RF MEMS switches (they were considered as an ideal short-circuit),

Figure 3 shows these two filters.



(*a*) (*b*)

Figure 3. Layout of two designed filters simulated with substrate has h= 3.06 mm, $\varepsilon_r = 3.58$ and tang δ=0.0035, (a) the center frequency and bandwidth agree with GSM-1800, (b) the center frequency and bandwidth agree with UMTS-2100.

For the filter "a", the outer ring was separated from the middle one. This configuration acts as an OFF state of RF MEMS switches between the two rings. The center radius of the outer ring was set to comply with the standard center frequency of the GSM band. While the ON state of the RF MEMS was represented by connecting the outer ring with the one in the middle (filter "b"). This connection decreases the center radius of the resulted ring, then the center frequency of the filter increases reaching the standard center frequency of the UMTS band. In the same way, the bandwidth of the reconfigurable filter is tuned by means of the RF MEMS switches placed in the cut region.

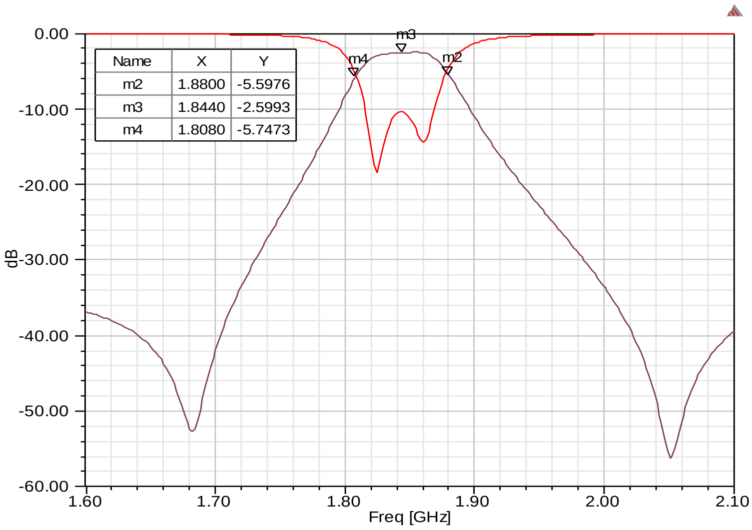
Figure 4 shows the simulation results of this filter by using an electromagnetic simulator. The insertion loss (S21) and reflection coefficient (S11) of the filters are also shown in this figure.

5.2. RF AND BASEBAND CIRCUITS.

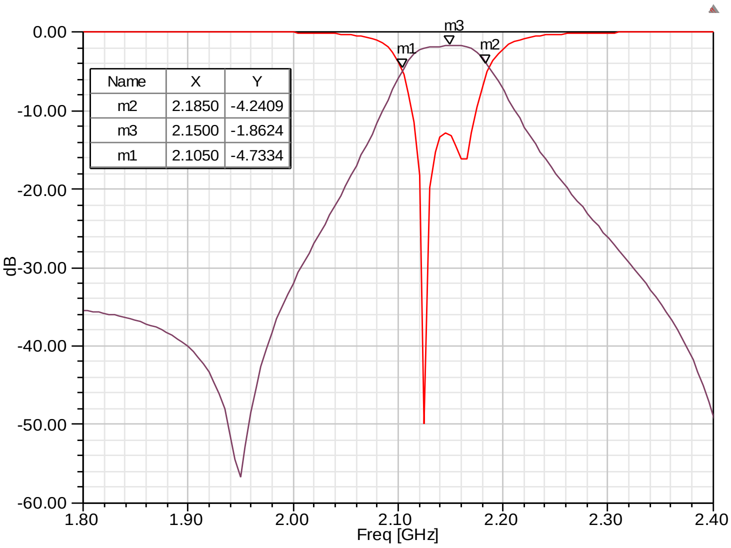
Both diplexer and RF BPF were designed to be reconfigurable filter with dual mode resonators to achieve high selectivity against transmission leakage and other interferers.

ADC plays an important role in this design. Because of its large dynamic range (80 dB or 13 bits), low order baseband LPF and fixed-gain baseband amplifiers could be used. In addition, the dynamic range of the AGC system could be relaxed to only 53dB in spite of the fact that the required dynamic range for the designed receiver is about 100 dB (with margin).

Low noise amplifier (LNA) and variable gain amplifier (VGA) form the AGC system. The 53 dB dynamic range results from the two gain-stepped LNA and the one gain-stepped VGA. This configuration makes AGC system simple and efficient.



(a)



(b)

Figure 4. S11 and S21 simulation results of the designed filter. (a) filter "a". (b) filter "b".

The characteristics of the I/Q down converter affect directly the performance of the receiver. This converter should have a suitable second order intercept point IIP_2 (more than 35 dBm as specified in table 2) since I/Q down converter dominates the second order distortion in Zero-IF architecture [13]. The I/Q down converter should offer enough isolation between its ports to reduce signal leakage. In our design, the DC cancellation was achieved by the I/Q down converter which offers this feature by means of a signal control coming from the digital domain. Table 3 shows the characteristics of the used amplifiers and I/Q down converter. These amplifiers and I/Q converter form the RFFE of the receiver.

Table 3. Specifications of amplifiers and I/Q down converter of the RFFE receiver

Block	**Parameters**	
LNA	High gain (dB)	11
	$NF_{high\_gain}(dB)$	2.5
	$IIP_{3\_high\_gain}(dBm)$	25
	Mid gain (dB)	2
	$NF_{mid\_gain}(dB)$	8
	$IIP_{3\_mid\_gain}(dBm)$	27.5
	Low gain (dB)	-12
	$NF_{low\_gain}(dB)$	21
	$IIP_{3\_low\_gain}(dBm)$	28
VGA	High gain (dB)	10
	$NF_{high\_gain}(dB)$	4.5
	$IIP_{3\_high\_gain}(dBm)$	29
	Low gain (dB)	-20
	$NF_{low\_gain}(dB)$	30
	$IIP_{3\_low\_gain}(dBm)$	59
RFA	Gain (dB)	15
	$NF(dB)$	4
	$IIP_3(dBm)$	12
BB_ amplifiers	Gain (dB)	36
	$NF(dB)$	28
	$IIP_3(dBm)$	20
I/Q down converter	Gain (dB)	2.5
	$NF(dB)$	12.7
	$IIP_3(dBm)$	25.7
	$IIP_2(dBm)$	60
	RF / LO Isolation (dB)	58

Low pass filter (LPF) forms the channel filter in both Zero-IF and Low-IF. Since the bandwidth of the channel in GSM-1800 differs from that in UMTS-2100, the cutoff frequency of the LPF should be tunable to obtain 200 KHz for Low_IF case and 2.5 MHz for Zero-IF. An active fourth order chebyshev filter was employed in both I and Q channels, and the tunability was accomplished by using switches as shown in Figure 5.

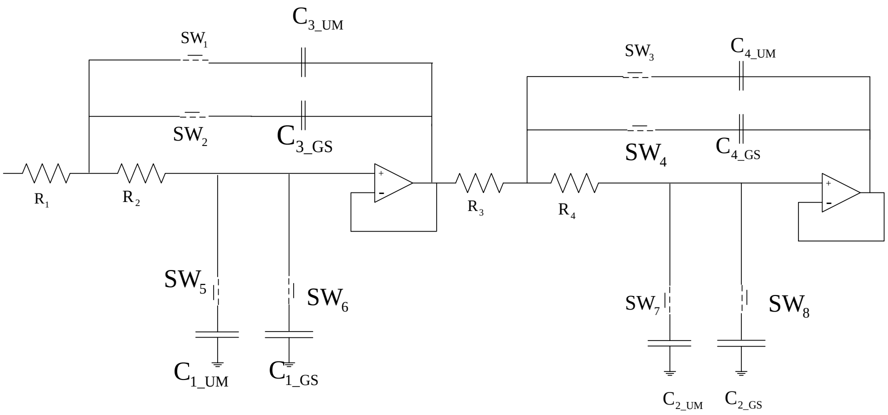


Figure 5. Tunable LPF circuit.

6. Simulation Results

The simulation results for GSM-1800 are presented and compared with the minimum requirements defined in the GSM-1800 standard.

Figure 6 shows the building receiver. The assigned values to the components' parameters of the receiver are the same as the real ones to make the simulation closer to the reality. The simulation results include noise figure, third order input intercept point, sensitivity and blocking characteristics.

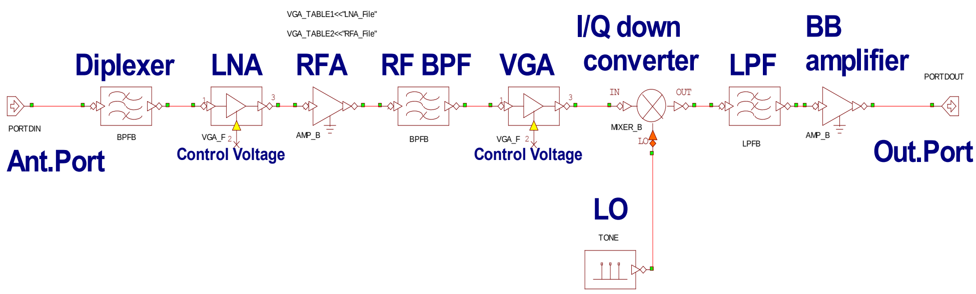


Figure 6. Block diagram of the simulated receiver.

6.1. Noise Figure (NF)

Table 2 shows that the noise figure of the receiver should be less than 7.2 dB. Figure 7 shows the new value of the NF after each component of the designed receiver, the overall noise figure is 5.7 dB. This value means that the design has a margin of about 1.5 dB.

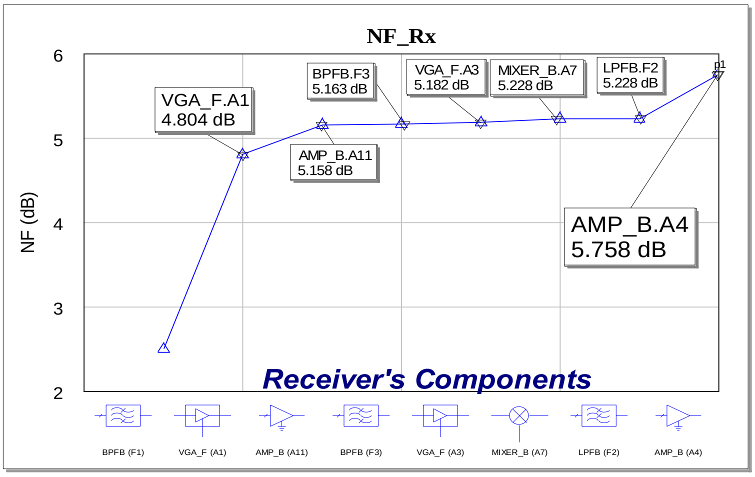


Figure 7. Simulated NF of the receiver.

6.2. THIRD ORDER INPUT INTERCEPT POINT (IIP_3)

Table 2 shows that the desired IIP_3 of the receiver is greater than -14.7 dBm. Figure 8 shows the new value of the IIP_3 after each component of the designed receiver. The overall IIP_3 is -14.23 dBm which meets the requirement. The resulted IIP_3 indicates that the margin is only about 0.5 dB. This is because the gain in the RF block was forced to be high to cope with the low sensitivity defined in UMTS-2100 (-117 dBm [12]).

6.3. SENSITIVITY

The sensitivity of a wireless mobile receiver is defined as the weakest RF signal power that can be processed to develop a minimum signal-to-noise ratio for achieving a required bit error rate (BER) by the system [13]. GSM-1800 standard defines the sensitivity as -102 dBm for BER=10^{-3}. The result of simulation is shown in Figure 9. This result indicates that for $CNR_{\min} = 8\ dB$ which meets the specified value of BER [9], the sensitivity of the designed receiver is -104.7 dBm, and then there is a margin of about 2.7 dB.

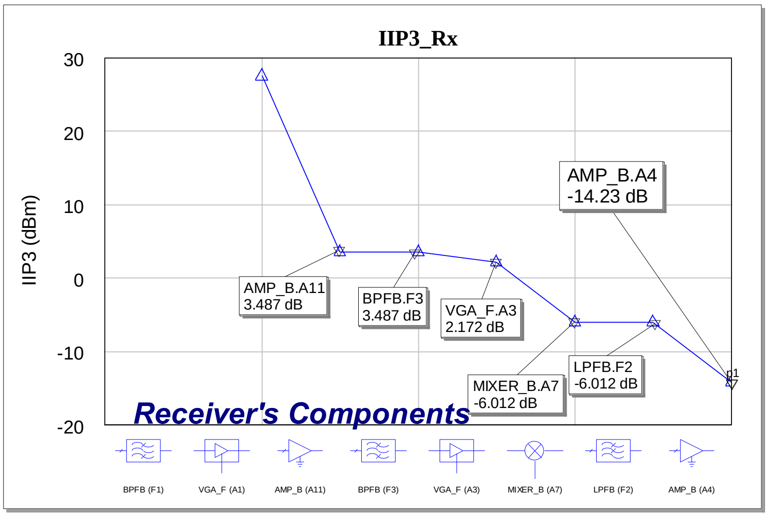


Figure 8. Simulated IIP_3 of the receiver.

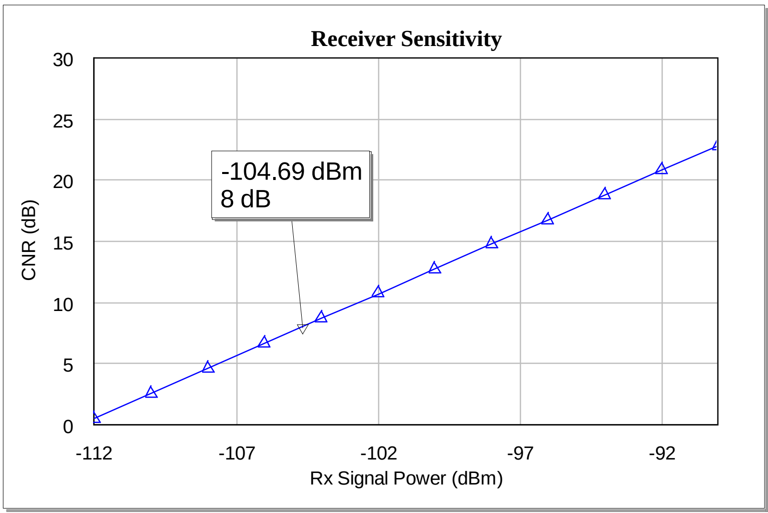


Figure 9. Simulated sensitivity of the receiver.

6.4. BLOCKING CHARACTERISTICS

The blocking requirements set by the standard are shown in table 4, with the condition that the desired signal level is -99 dBm [12]. Figures 10 and 11 show the allowed interferer's level at the given offset frequency (from the center frequency) for each value of the carrier to interferer and noise ratio (CINR). For CINR=8 dB the results of simulation indicate that the proposed receiver meets the blocking requirements with a good margin.

Table 4. GSM blocking requirements.

Offset Frequency (MHz)	**Allowed** $I_{blocking}$ (dBm)
0.6-1.6 MHz	-43
1.6-3.0 MHz	-33
>3 MHz	-26

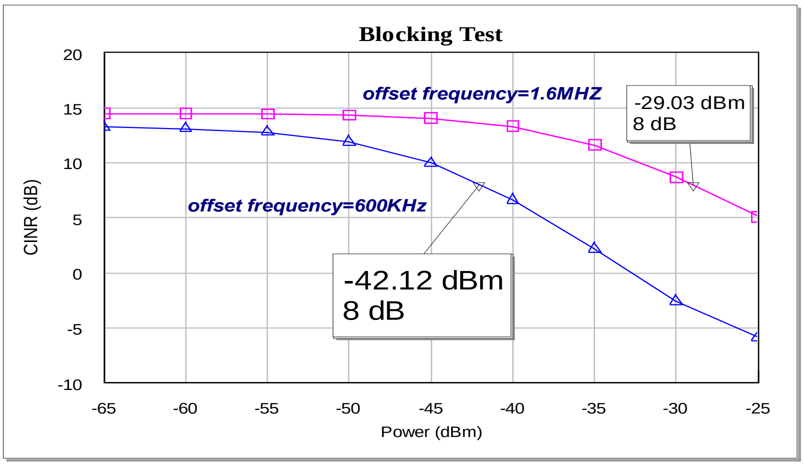


Figure 10. Simulated blocking characteristics for offset frequency 1.6 MHz and 600 KHz.

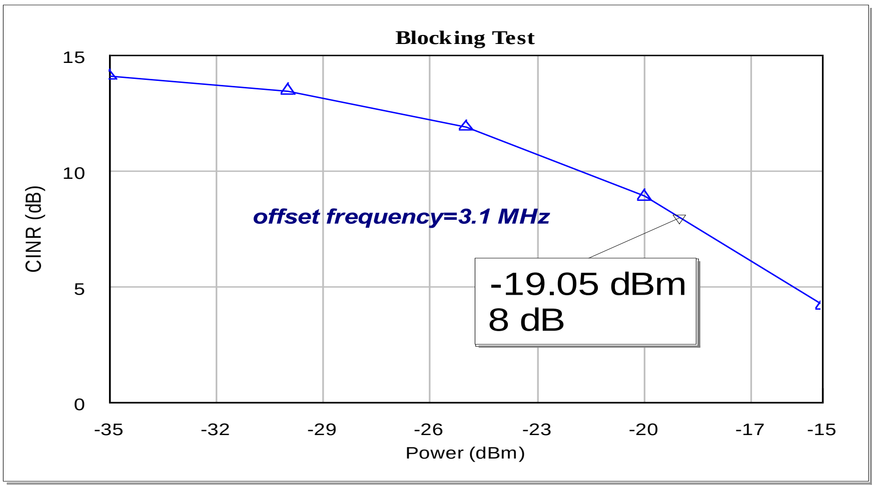


Figure 11. Simulated blocking characteristics for an offset frequency more than 3 MHz.

7. Conclusion

A dual-standard RF front-end receiver based on reconfigurable dual mode microstrip band pass filter has been proposed. The specifications of the multi-standard receiver which are suitable for both GSM-1800 and UMTS-2100 standards were defined. The simulation of the proposed band pass filter and the characteristics of the other components of the receiver were presented. Finally, a simulation of the whole system was shown. This simulation shows that the proposed design meets the required specifications with a good margin for NF, sensitivity and blocking characteristics.

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