A Repeater Prototype for the *UMTS* Network Radio Sub-System

Pedro Miguel Cabral, Daniel Pedro Ferreira, Nuno Borges Carvalho and José Carlos Pedro
Instituto de Telecomunicações, Campo Universitário, 3810-193 Aveiro, Portugal
e-mail: pcabral@av.it.pt, a17230@alunos.det.ua.pt, nborges@ieee.org, jcpedro@ieee.org

Abstract

This paper describes the design, implementation and test of a *Repeater* for the *UMTS* Network Radio Sub-System integrated on an engineering degree project.

As starting point, we explain all design stages emphasizing specifications and architecture compliant with *ETSI* [1] documents. After that, implementation is addressed given particular importance to critical points as: frequency synthesis and gain control. Finally, we describe all tests made to validate our initial assumptions.

I. INTRODUCTION

Nowadays, a *Repeater* constitutes a crucial low cost solution to guarantee the desirable coverage of "dark" regions.

A *Repeater* is then an active bidirectional physical device, whose function is to catch, amplify and re-transmit one, or a group of channels of the *UMTS* Radio Sub-System.

It will be located between the Base Station and the Mobile, re-establishing the signal level necessary for the proper operation of all the network devices implicated. It can be divided into two links: one that connects the Base Station to the Mobile – the *UpLink*; and another that makes the inverse connection - *DownLink*.

General *Repeater* specifications and architecture are addressed in Section II, which then led to its implementation (Section III). Section III details the major parts of the work done, providing justifications for the results obtained (Section IV). Finally, Section V summarizes the main conclusions of this work.

II. *REPEATER* SPECIFICATIONS AND ARCHITECTURE

A. Specifications

The specifications adopted for the *Repeater* are compliant with *ETSI* documents [1] that regulate the *UMTS* System. Table I presents all main specifications that the *Repeater* must obey:

Table I *Repeater* specifications

		ETSI Specifications	
		UpLink 1920 – 1980 MHz	*DownLink* 2110 – 2170 MHz
Gain	G_{min}	50 dB	
	G_{Max}	80 dB	
$Pout_{Max}$		12 dBm	30 dBm
Bandwidth		3,84 MHz programmable for any channel within the band	
NF		8,5 dB	
ACPR		45 dB	35 dB

It should be noted that the 30dBm maximum output power value need not be fulfilled. On one hand, it is not fundamental that such power value is provided (the specifications are for maximum output power level while there are various field applications where a lower power *Repeater* is desirable), and, on the other hand, the specified maximum can always be reached by simply adding an output power booster (available on the shelf), if needed.

B. Architecture

The architecture chosen for the *Repeater* is presented in Fig. 1:

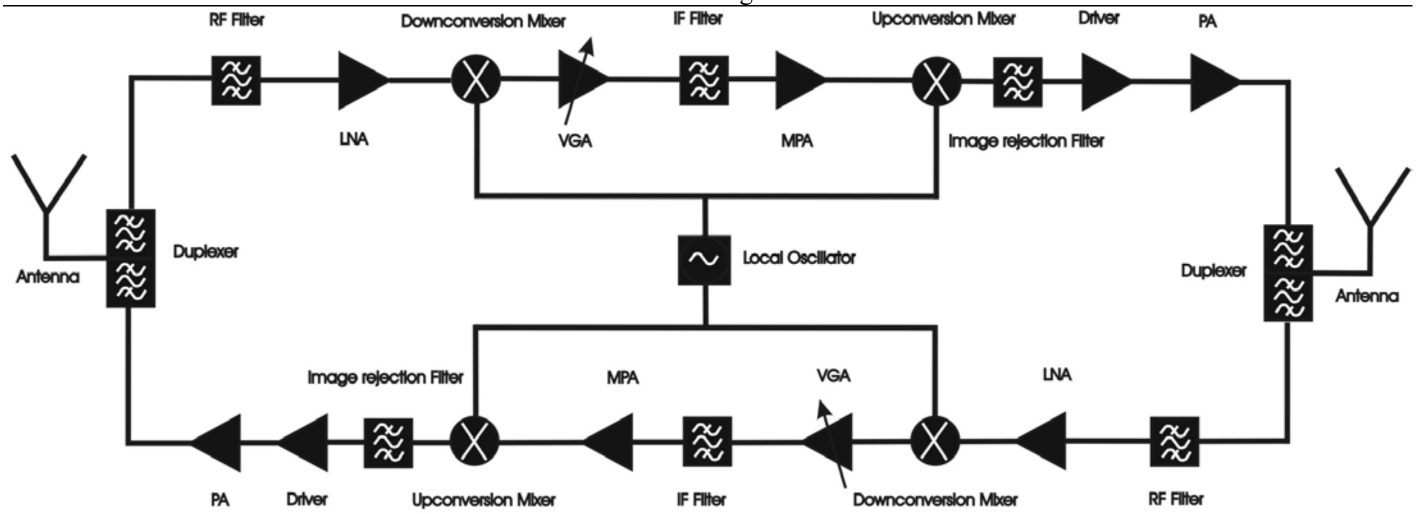

Fig. 1 Global *Repeater* architecture

Each link shares a super-heterodyne transceiver topology. The RF signal is first converted to an intermediate frequency, IF, where the wanted channel is isolated by a Saw filter of 5 MHz bandwidth (the European *UMTS* standard has 3.84MHz channel bandwidth), amplified with Automatic Gain Control (30 dB of gain variation) - and then converted back to the original RF frequency by a Local Oscillator, LO.

For guaranteeing a prospective competitive final price, only one LO synthesizer was used for both links.

In accordance with the functional diagram of Fig. 1, each of these links can be understood as being divided into the following three main stages:

Low Noise Front-End: This first stage is intended to filter the whole *UMTS* band from any potential blocker. It also amplifies the RF signal (with low noise factor) before it is then converted to an UHF IF;

Intermediate Frequency Block: In this section, the desired channel selection and amplification is performed, according to a pre-defined automatic gain control pattern;

Power Stage: After the signal has been converted back from IF to the original RF frequency position, it is filtered (to eliminate all spurious components originated in the up-conversion process) and amplified in a power amplifier. Strict distortion figures have to be guaranteed, no matter the actual output power value which can be chosen.

III. *REPEATER* IMPLEMENTATION

After having established the Repeater architecture, all main devices were fully tested in individual MIC (Microwave Integrated Circuit) boards.

We now present the implementation of the frequency synthesizer as well as the unit of Automatic Gain Control.

A. Frequency Synthesizer

As we said before, only one Oscillator is necessary to convert *UMTS* frequencies (RF) to IF frequencies, and vice-versa, on both links (*DownLink* and *UpLink*).

The choice of the range of frequencies that the Local Oscillator had to cover, took into account, on one hand, the frequencies of all *UMTS* channels that the *Repeater* is supposed to cover and, on the other hand, the center frequency of the chosen IF filters ($f_{IF\,UpLink}$ = 380 MHz and $f_{IF\,DownLink}$ = 570 MHz).

Therefore, we used a Local Oscillator capable of synthesizing frequencies between 1540 MHz and 1600 MHz, enabling operation at each of the *WCDMA* channels.

The synthesizer was built around the IC Si4133W from *Silabs*. This chip is programmable through a series interface, externally controlled by three lines. To control this communication interface a *PIC* (*Programmable Integrated Controller*) *PIC16F876*, by *MicroChip*, was used.

Fig. 2 shows a flowchart explaining PIC operation to achieve expected LO operation.

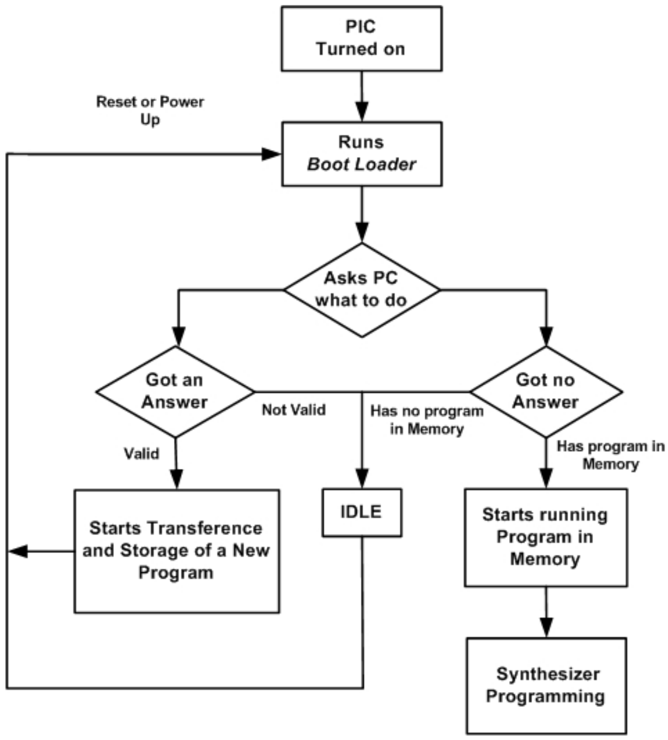

Fig. 2: *PIC* operation flowchart

B. Automatic Gain Control

As we said before, the *Repeater* should allow a gain control margin of about 30 dB. The AGC sub-system implemented is composed of three devices:

Variable Gain Amplifier (VGA) voltage controlled;

Power Sensor (PS) that, given a certain sample of the output signal, produces a voltage that corresponds to the total integrated power on its bandwidth;

Level Shifter that transforms the PS output voltage into the level required at the VGA input.

Fig. 3 shows that the gain (the slope of the tangent line to the curve in each point) actually diminishes from the maximum level (80 dB) to the minimum (50 dB) providing a gain variation of 30dB in the whole 45dB power input level span.

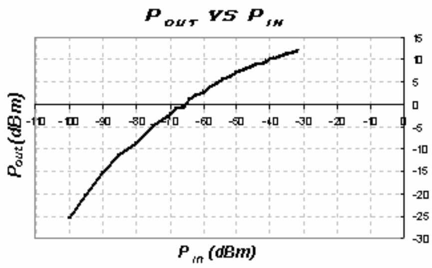

Fig. 3: AGC Operation: P_{out} vs P_{in}

With this mechanism, it is possible to enlarge the *Repeater* input power operation range and, at the same time, guarantee the maximum output power level required.

After all the IC's were tested, a complete link was formed by simply connecting the individual MIC boards.

The overall functional behavior was considered good, and so each one of the links was designed, implemented and built. Fig. 4 and 5 show each link prototype as well as the main signals involved.

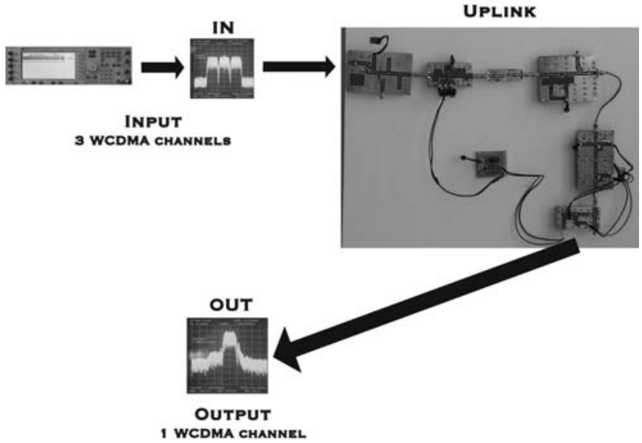

Fig. 4: Picture of the complete *UpLink* prototype

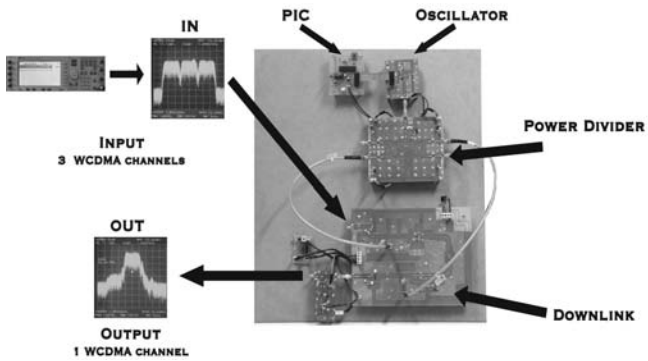

Fig. 5: Picture of the complete *DownLink* prototype

After both links were separately tested, they were finally assembled.

IV. PERFORMANCE RESULTS AND DISCUSSION

A. UpLink

As this Repeater project was conceived for the *UMTS* system, three *WCDMA* channels were placed at the *UpLink* input, in order to emulate the spectrum assigned to a certain operator. The expected result is the amplification of the center channel (for example) and the correct attenuation of the other two channels.

The following pictures illustrate how the implemented and tested *Repeater* is indeed capable of amplifying a *WCDMA* channel rejecting the other adjacent channels. Fig. 6 depicts the *UpLink* observed performance.

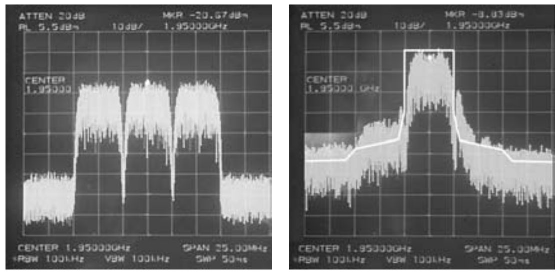

Fig. 6: Input and Output signals with mask for the *UpLink.*

As we can see in Fig. 6 the center channel is actually selected while the other two are attenuated by about 40dB. We can also see a comparative representation between the spectrum obtained and the mask imposed by *ETSI*.

Comparing the observed results with the ETSI mask specs, the adjacent channel rejection provided by the IF filters is insufficient. This result was already expected, since it is due to the fact that the used IF filters were not specifically designed for that purpose. As referred above, they provide an IF bandwidth of 5MHz, while the channels only occupy 3.84MHz. Nevertheless, contacts with the filter supplying company have shown that special filters can be actually designed and produced if a sufficient number of *Repeater* prototypes justifies the design investment.

Linear behavior results in the *UMTS UpLink* band (1920 – 1980 MHz) showed that this link is well matched in the whole *UMTS* band and that it presents the expected gain, as seen in Fig. 7. In fact, that figure shows measured port matching as characterized by input return loss ($|S_{11}|_{dB}$) and output return loss ($|S_{22}|_{dB}$).

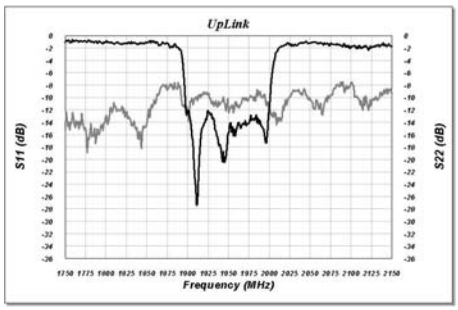

Fig. 7: Detail of *UpLink* $|S_{11}|_{dB}$ **(Black)** and $|S_{22}|_{dB}$ **(Grey)** for the band of interest

To test the non-linear distortion behavior, ACPR was measured. Obtained figure of ACPR=45dB meet the desired specification of nonlinear distortion (see Table I).

The spurious emissions were also measured and agree with *ETSI* specifications.

B. DownLink

The tests made for the *DownLink* were identical to the ones made for the *UpLink*, and so only the main differences between the two will be now presented.

The following pictures illustrate how the implemented *Repeater* prototype is capable of amplifying a *WCDMA* channel, rejecting the other adjacent channels. Fig. 8 reports on the observed *DownLink* performance.

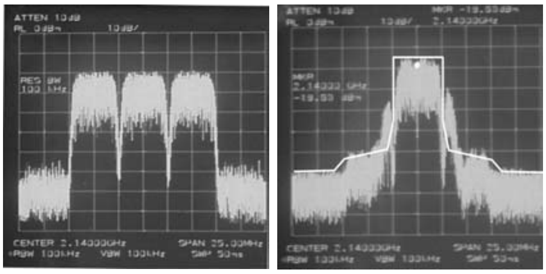

Fig. 8: Input and Output signals with mask for the *DownLink.*

As we can see in Fig. 8, the center channel is again conveniently selected while the other two are rejected. We can also see a comparative representation between the spectrum obtained and the mask imposed by *ETSI*.

Linear behavior results in the *UMTS UpLink* band (2110 – 2140 MHz) showed that this link is matched in the whole *UMTS* band and that it presents the expected gain. Fig. 9 depicts measured port matching as characterized by input return loss ($|S_{11}|_{dB}$) and output return loss ($|S_{22}|_{dB}$).

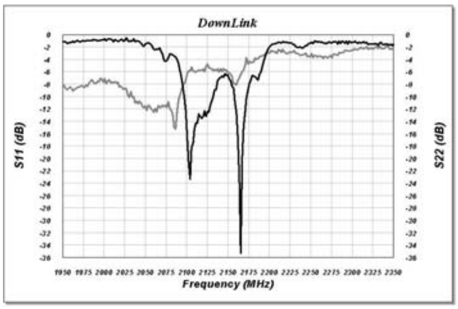

Fig. 9: Detail of *DownLink* $|S_{11}|_{dB}$ **(Black)** and $|S_{22}|_{dB}$ **(Grey)** for the band of interest

To evaluate the non-linear distortion behavior, ACPR was measured. The obtained result of ACPR=35dB meet the desired specifications stated in Table I.

The spurious emissions were also measured and agree with *ETSI* specifications.

C. Complete Repeater

For the complete *Repeater*, one *WCDMA* signal formed by three channels was first introduced at the *UpLink*. Then, another *WCDMA* signal formed by three channels was introduced at the *DownLink*. The input and output signals observed were very similar to the ones obtained with the two links separated.

Table II compares the specifications with the Experimental results:

Table II *Repeater* specifications vs Experimental Results

		ETSI Specifications		*Experimental Results*	
		UpLink 1920 - 1980 MHz	*DownLink* 2110 – 2170 MHz	*UpLink* 1920 - 1980 MHz	*DownLink* 2110 – 2170 MHz
Gain	G_{min}	50 dB		52 dB	
	G_{Max}	80 dB		81 dB	
$Pout_{Max}$		12 dBm	30 dBm	12 dBm	12 dBm
Bandwidth		3.84 MHz programmable for any channel within the band		5 MHz programmable for any channel within the band	
NF		8,5 dB		8,5 dB	
ACPR		45 dB	35 dB	45 dB	35 dB

V. CONCLUSIONS

A laboratory prototype of a *Repeater* for the *UMTS* system has been designed, implemented and fully tested.

As shown in Table II, the experimental results were considered very promising for a future industrial prototype, since the tested *Repeater* showed a performance that was compliant with *ETSI* specifications.

Eventual future enhancements should focus on customized filters for UMTS applications. Besides that, remote programming may also be an addition that might give this prototype an extra market advantage.

The preliminary budget estimation lead to a final cost that was considered very competitive with the prices of identical devices already available in market.

VI. REFERENCES

[1] “3rd Generation Partnership Project (3GPP) Technical Specification Group”, in www.etsi.org, Documents:

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ETSI TS 125 104 V4.0.0 (2001-03)
ETSI TS 125 143 V4.0.0 (2001-03)
ETSI TR 125 956 V4.0.0 (2001-03)

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