LimeRFE – A Software Definable RF Front-End Module for SDR Platforms

Branko Bukvić, Mihajlo Božović, Zako Arsović, Dušan Grujić, Milan Savić

Abstract – This paper presents a software-definable RF front end module for SDR platforms. The Lime RF Front End (LimeRFE [1]) is an open hardware front end module with appropriate amplification and filtering [2], as well as supporting circuitry to augment the SDR platforms, providing a complete solution that addresses real life applications ranging from HAM (radio amateur) radio to standards-compliant cellular network implementations. Measurement result examples are also presented.

Keywords – Software Defined Radio, HAM Radio, Software-Definable RF Front-End.

I. Introduction

Radio frequency (RF) front-end provides the essential functionality for any radio system, by providing the amplification and filtering which are necessary in real-life applications. There can't be a completely software defined radio system without the software configurable, flexible RF front-end. LimeRFE provides exactly this functionality, a software-definable RF front-end module for SDR platforms. It supports most of radio amateurs bands (HF band, 6 m, 4 m, 2 m, 1.25 m, 70 cm, 33 cm, 23 cm, 13 cm and 9 cm bands), several cellular bands (Band 1, 2, 3, 7 and 38) and, additionally, the whole frequency spectrum from 1 MHz up to 4 GHz is covered with 2 wideband modules installed on the board (1 – 1000 and 1000 – 4000 MHz bands). The LimeRFE board comprises Software Defined Radio concept [3]. It relays on versatile hardware which is capable to operate under the several different standards, which means it can support different frequency bands, operating powers, modulation schemes, etc.

Section II gives a brief introduction of the LimeRFE board. Basic hardware schematics and software controlling tools, together with some implementation details, are explained in this section. Measurement result examples are presented in Section III, including 4G signal results. Also small signal gain (Gain), noise figure (NF), intermodulation product of 3rd order (IP3) and characterization of 1dB compression point (P1dB) were performed for the receiver and transmitter paths of the LimeRFE. Finally, a conclusion was given in Section IV.

II. Description of the LimeRFE Board

A. Hardware

A picture of the LimeRFE board is given in Fig. 1. The board dimensions are 125 x 162.5 mm.

Fig. 1. Picture of the LimeRFE board

Table I gives all frequency bands supported by the LimeRFE.

TABLE I
LimeRFE Frequency Bands

HAM		**Cellular**	
Band	*Freq.* [MHz]	*Band*	*Frequency* [MHz]
HF	1.8 – 30	Band 1*	2110 – 2170 / 1920 – 1980
6 & 4 m	50 – 70	Band 2*	1930 – 1990 / 1850 – 1910
2 m	144 – 146	Band 3*	1805 – 1880 / 1710 – 1785
1.25 m	220 – 225	Band 7*	2620 – 2690 / 2500 – 2570
70 cm	430 – 440	Band 38	2570 – 2620
33 cm	902 – 928	**Wideband**	
23 cm	1240 – 1325	*Band*	*Frequency* [MHz]
13 cm	2300 – 2450	WB 1000	1 – 1000
9 cm	3300 – 3500	WB 4000	1000 – 4000

* Freq. for cellular bands 1, 2, 3 and 7 are in format Downlink / Uplink

Block diagram of the LimeRFE RF part is shown in Fig. 2. HAM and Wideband transmitters are grouped in the bottom, cellular transceivers are located in the centre, while the upper part presents the receiver paths.

Authors are with Lime Microsystems d.o.o, Bulevar Mihaila Pupina 10A/I, 11070 Belgrade, Serbia. E-mail: b.bukvic@limemicro.com

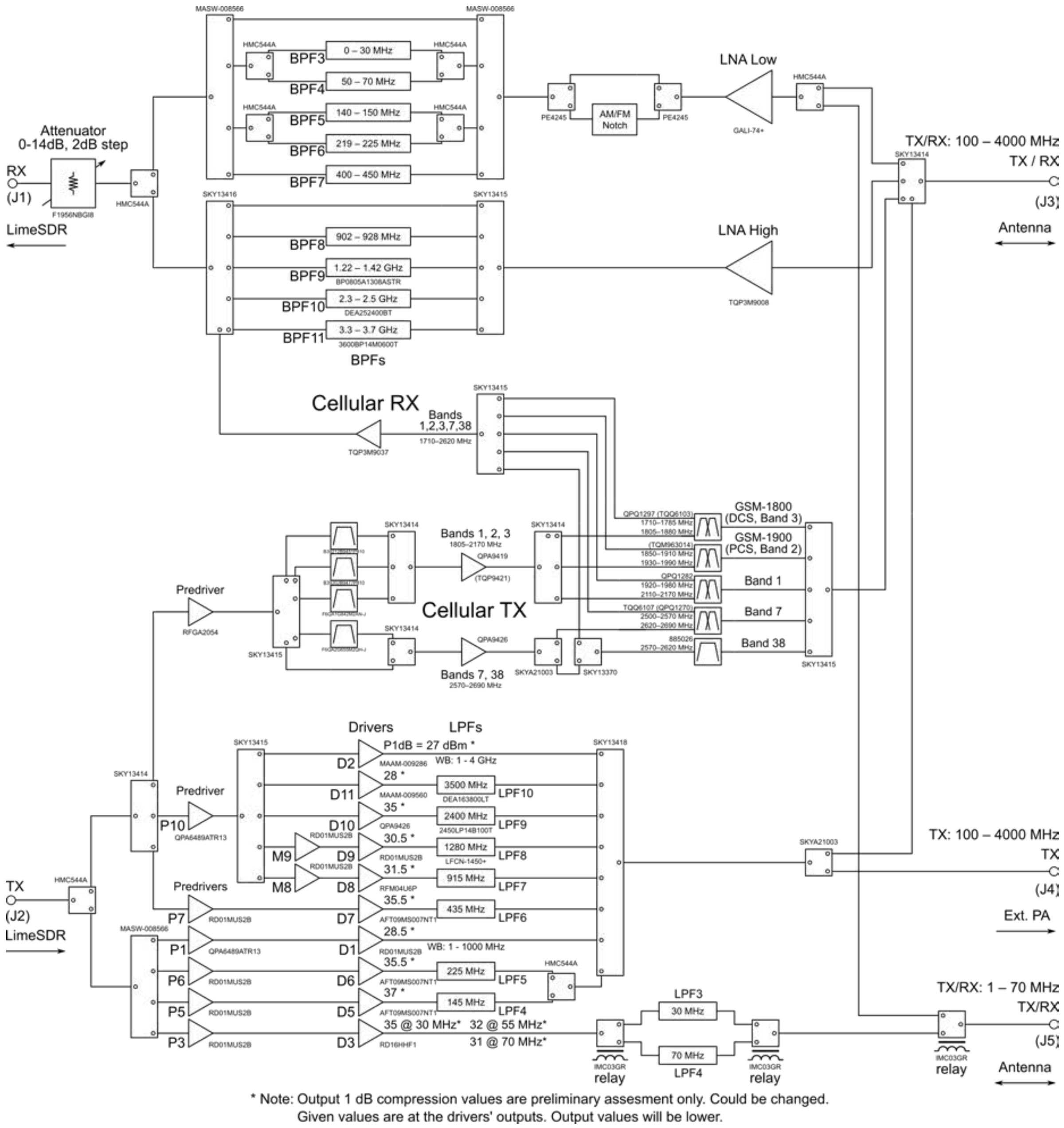

Fig. 2. Block diagram of the LimeRFE RF part

PCB stackup is given in Fig. 3, bellow. Top and bottom substrates are Rogers 4350B, with thickness of 500 μm (20 mil). Rogers 4350B was preferred over standard FR4 due to better control of thickness and substrate properties, as well as lower dielectric loss at higher frequencies. Metalization thickness was not of great importance for this design, so common thickness of 18 μm (0.5 oz) was used. All RF lines are realized as grounded coplanar waveguides. Between top and bottom layers, there are three 200 μm thick RF4 substrates, enabling total of 6 layers. Top and bottom two layers are used mainly for RF lines, while the inner two layers are used for digital signal routing and supply distribution. All vias are implemented as filled through-hole. The total board thickness is 1.6 mm.

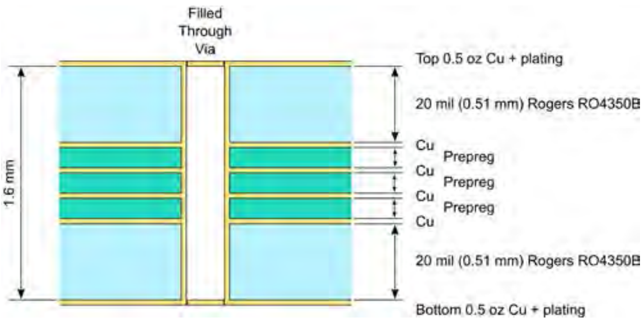

Fig. 3. Stackup of the LimeRFE board

Components are placed on both sides of the board, while the large heatsink occupies the most of the bottom side.

LimeRFE board includes the SWR meter subsystem (Fig. 4). Forward and reflected signals are to be provided from the external directional coupler. There is an option to measure power at the output of the power amplifiers in the cellular bands using on-board couplers.

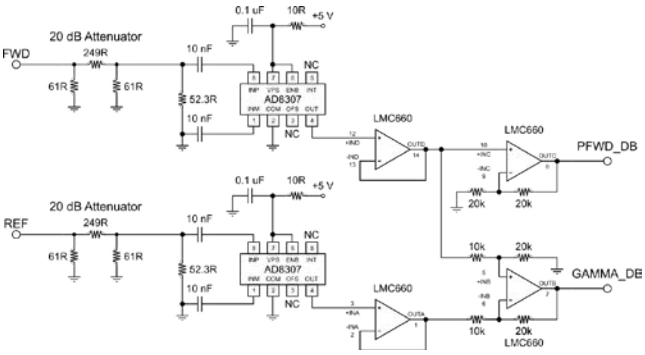

Fig. 4. LimeRFE SWR subsystem

Complete board was designed so that standard off-the-shelf components are used. However, the performance in HF bands, as well as in 6 and 4 m bands, can be further improved by using add-on balun board [4] shown in Fig. 5.

Fig. 5. Picture of LimeRFE add-on balun board

Next hardware block consists of digital circuits for controlling RF parts (select desired frequency band, turn on/off particular power amplifier and LNA, select appropriate filter, SMA connector, etc.). LimeRFE utilizes Arduino Nano – compatible microcontroller (ATmega328), and is programmable via Arduino IDE [5]. MCU (by data, clock and reset signals) drives 11–bytes shift register which stores the control bits. Control of the shift register requires only few of the MCU IO (input/output) pins, while others are used for time-critical controls. Voltage level shifters, USB communication circuit are also part of this hardware block.

Another part of the LimeRFE, denoted as GPIO subsystem, provides level shifters and relay drivers intended for communication and control of other parts of the complete radio system (e.g. external power amplifiers) by the SDR platform, making the use of an additional board with this functionality [6] obsolete.

Bias subsystem comprises several DC–DC convertors and voltage regulator units providing required supplies (2.5 V, 3.3 V, 5 V, 7.5 V and 12 V).

B. Controlling Software Tools

LimeRFE is supported by the LimeSuite [7], an open-source multi-platform software for control of the Lime Microsystems' SDR platforms. Library with API functions for control automation is also provided.

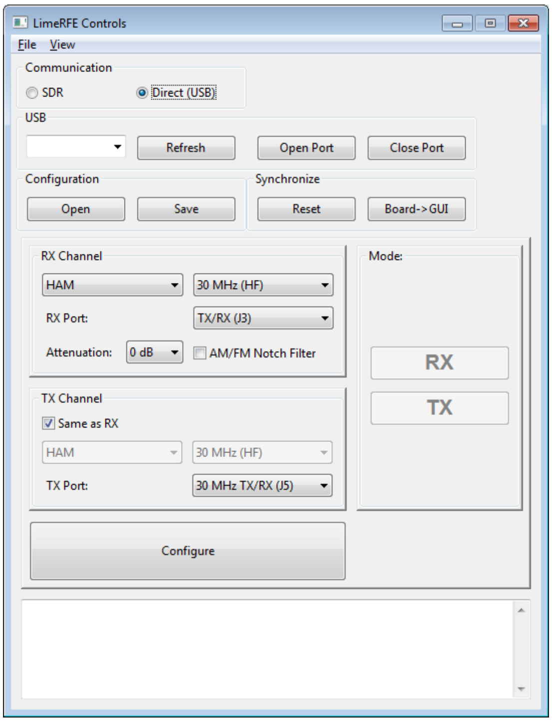

Fig. 6. LimeRFE controls GUI module

Further details of the LimeRFE are available in [8].

III. MEASUREMENT RESULTS EXAMPLE

Measurements were performed on the test-bench shown in Fig. 7. The test-bench consists of Agilent E8267D signal generator, Agilent E4440A spectrum analyser, Rigol DP832 DC supply unit, Agilent 346A noise source, and a PC. Measurements were automated using Python scripts.

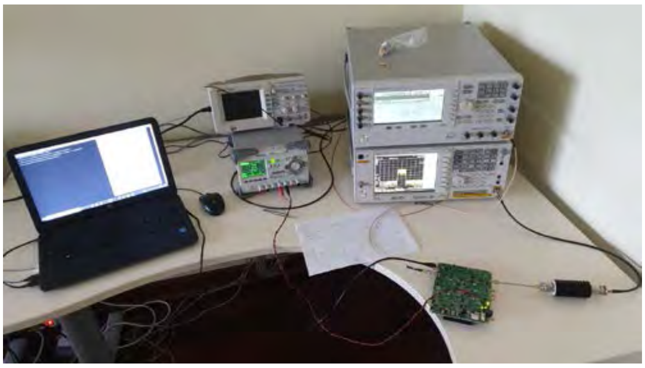

Fig. 7. Picture of the test-bench with the LimeRFE as device under test (DUT)

Small signal gain measurements were performed on receiver and transmitter paths of each of the bands of the LimeRFE board. Measurement results for 430 – 440 MHz (70 cm) HAM band receiver are given in Fig. 8.

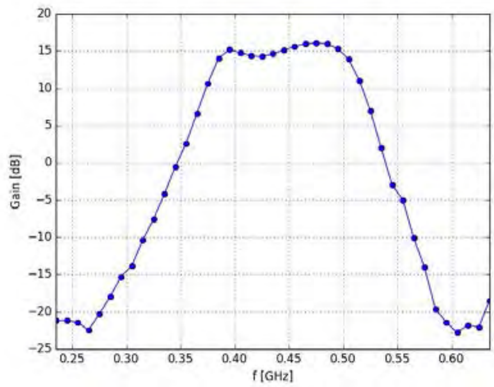

Fig. 8. Gain measurements for receiver in HAM 430 – 440 MHz (70 cm) band.

NF measurements were performed for receiver paths in each of the bands. For these measurements, additional Agilent 346A noise source was used as noise reference. Measurement results for receiver in HAM 900 – 928 MHz (33 cm) band are given in Fig. 9.

Noise figure measurements for each frequency point were performed twice, in order to estimate measurement accuracy.

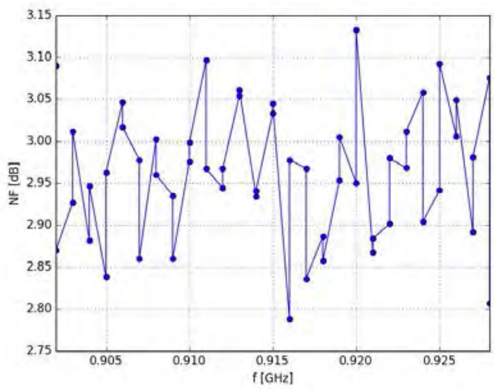

Fig. 9. NF measurements for receiver in HAM 902 – 928 MHz (33 cm) band.

IP3 measurements were performed for receiver paths in each of the bands. Measurement results for receiver in Cellular Band 7 are given in Fig. 10.

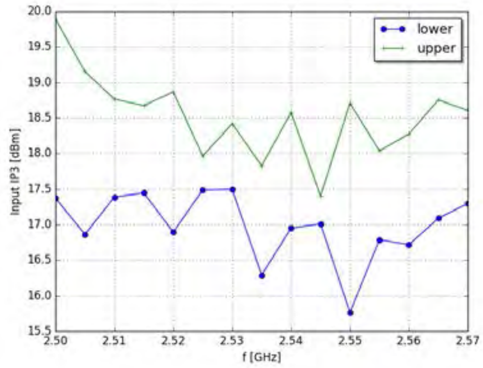

Fig. 10. IP3 measurements for receiver in Cellular Band 7.

P1dB measurements were performed on transmitter paths of each of the bands. Fig. 11 presents Gain vs input power, while Fig. 12 gives output power vs input power for HAM 2 m band. In Fig. 13 measurement results of output power at 1 dB compression point and saturation power vs frequency are presented.

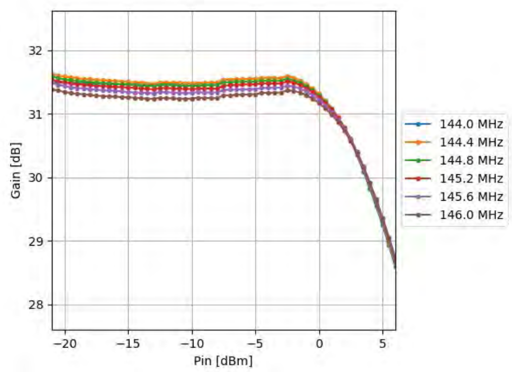

Fig. 11. Gain vs Pin measurements for different frequencies, for transmitter in HAM 145 MHz (2 m) band.

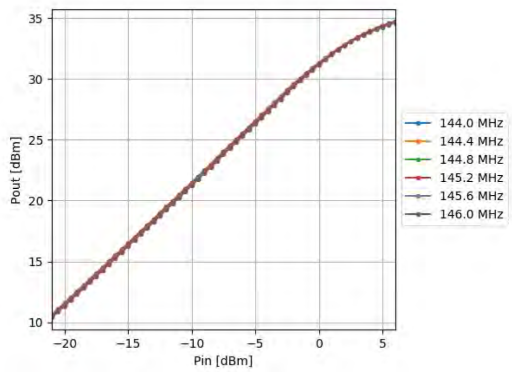

Fig. 12. Pout vs Pin measurement results for different frequencies, for transmitter in HAM 145 MHz (2 m) band.

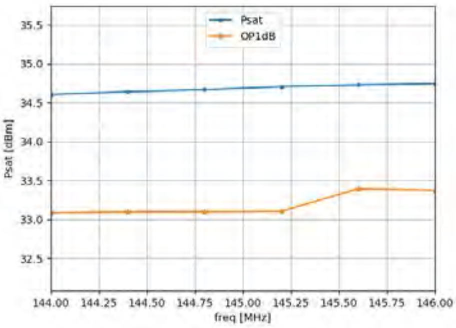

Fig. 13. Output power at 1 dB compression point and saturation power vs frequency measurement results for transmitter in HAM 145 MHz (2 m) band.

Measurements with LTE signals were performed for each of the cellular bands. Adjacent Channel Power Ratio (ACPR) measurements for Cellular Band 2 are shown in Fig. 14. Test signal LTE TM3.1 with 20 MHz bandwidth was used. It can be noted that for the modulated output power of 23 dBm ACPR is better than -49 dBc.

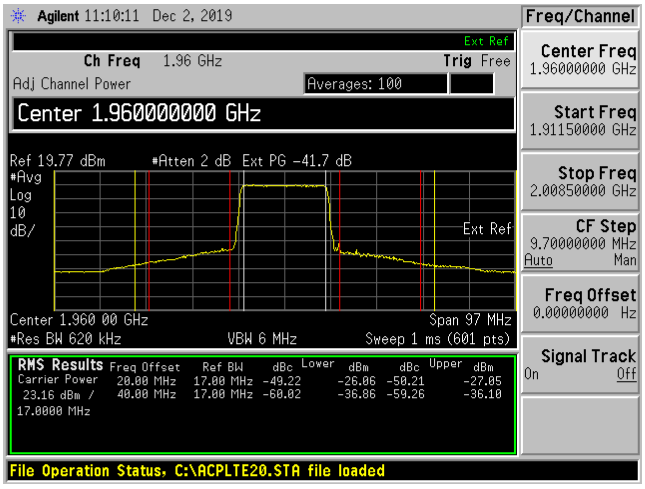

Fig. 14. Cellular Band 2 ACPR measurement results

IV. Conclusion

This paper presented the LimeRFE board – a software-definable RF front-end module for SDR platforms. Since it follows the software defined radio paradigm, it is easily reconfigured for operation in desired frequency band. This board can be connected to any of the Lime microsystems' SDR family platforms, as well as with any SDR platform in general, providing a full radio solution for numerous applications, from HAM radio to standards-compliant cellular networks.

Combination of a general purpose computing platform, SDR capable transceiver, and open-source software-definable RF front-end will provide open, compact, and affordable all-round radio platform. With proper software support from the community it will provide unprecedented benefits. By combining LimeNET-Micro [9] with LimeRFE such a platform is readily available (Fig. 15).

Fig. 15. LimeNET Micro & LimeRFE – all-round, open, compact and affordable radio platform

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