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AUTOMATIC SIGNAL RECOGNITION FOR A FLEXIBLE SPECTRUM MANAGEMENT

Niclas Björsell [1], *Pasquale Daponte* [2], *Luca De Vito* [2], *Sergio Rapuano* [2]
[1]ITB/Electronics, University of Gävle, Gävle, Sweden, niclas.bjorsell@hig.se
[2] Department of Engineering, University of Sannio, Benevento, {daponte, devito, rapuano}@unisannio.it

Abstract – The paper presents the prototype of an automatic digital modulation classifier, to be used for signal recognition in frequency bands managed in a flexible way. The prototype is based on a Data Acquisition System, consisting of an Analog-to-Digital converter embedded in an evaluation board, a frame grabber and a Personal Computer. The modulation classifier is able to recognize the most used digital modulations. An experimental validation of the realized prototype in a radio environment is also provided.

Keywords: modulation classification, spectrum management.

1. INTRODUCTION

The use of signal classification within radio communication will grove of importance since future usage of the spectrum for wireless communications will be available for a wider variety of services and applications. In today’s environment, electronic communication services are offered over a variety of electronic communications networks (e.g. different types of mobile, fixed and broadcasting networks), using a variety of terminals.

The demand for certain services (such as mobile and Internet) has grown far beyond earlier predictions, and developments in radio technology have resulted in more efficient methods of sharing spectrum among different systems and users. Innovation requires rapid access to spectrum for individuals and service providers. This has resulted in a need for greater flexibility in the use of spectrum resources for wireless electronic communications.

At the same time, the spectrum originally intended for distinct electronic communication services is now being used for services which compete against each other. This implies that a wide range of electronic communication networks and electronic communication services may be offered on a technology and service neutral basis. However, certain technical requirements to avoid interference should be met, to ensure that the spectrum is used in an effective and efficient way, and that the authorization conditions do not distort competition.

The European Union is moving in the direction of a more flexible utilization of the spectrum [1] and, for this purpose, it created a specific work group, called Radio Spectrum Policy Group (RSPG), with the aim of come to a new Wireless Access Policy for European Communications Services (WAPECS). In its opinion [2], the RSPG indicated the technology neutrality and the service neutrality as some of the objectives to reach a more flexible spectrum utilization.

In a flexible spectrum management scenario, in which several technologies and services can be present at the same time, an effective spectrum monitoring could be achieved by recognizing the signals which occupy the spectrum. For this purpose, the use of signal classification will play an important role.

Moreover, some researchers propose a model of spectrum usage, based on an opportunistic access. It consists of finding a spatial and temporal white space in the spectrum, to dynamically allocate a secondary transmission, without affecting the primary one [3].

In this case, modulation classification could be very useful to estimate the parameters of the primary transmission and, thus, to set those of the secondary one, such that the interference produced on the primary transmission can be kept to a non-harmful level [4].

Moreover, the transmission equipment, able to work in a dynamic spectrum scenario, requires a receiver which has to adapt itself to the transmitted signal, without knowing *a priori* any physical layer parameter [3]. It is necessary, therefore, a proper module providing a complete description of the radio environment, where the equipment is placed. Such module should be capable of extracting the following information from the received signal:

- Modulation scheme;
- Symbol frequency;
- Carrier frequency;
- Pulse shaping.

Modulation classification, thanks to its applicability to many fields, on both civil and military sector, has gained a relevant interest of the scientific community in the last years. In fact, several researches have been carried out to find reliable methods and algorithms for modulation classification [5, 6].

Most of them, however, support few modulation schemes or require some *a priori* information, such as the carrier frequency or the symbol rate.

Moreover, no papers have been found presenting an instrument prototype and reporting its characterization in a RF (Radio Frequency) environment.

In [7], a method for automatic digital modulation classification has been proposed, able to recognize the following modulation schemes:

- 2PSK (Phase Shift Keying), 4PSK, 8PSK;

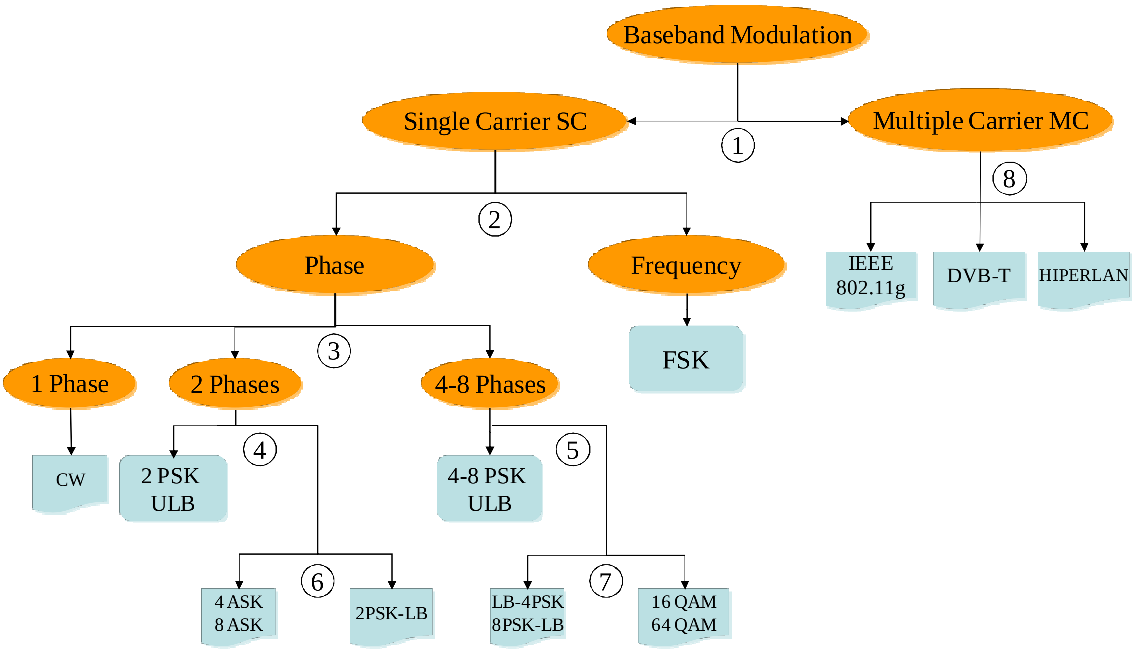


Fig. 1. Hierarchical tree structure of the method for the automatic modulation classification.

- 2FSK (Frequency Shift Keying), 4FSK, 8FSK;
- 16QAM (Quadrature Amplitude Modulation), 64QAM;
- 4ASK (Amplitude Shift Keying), 8ASK,
- several OFDM (Orthogonal Frequency Division Multiplexing) modulations with cyclic extension.

Then, in [8], the method has been improved, in order to support limited-bandwidth signals, which have not been considered in the previous work. A first characterization, carried out in MATLAB environment on simulated signals has been presented, too.

In this paper, the method [8] will be briefly recalled in Section 2. Then, in Section 3, the implementation of a digital modulation classifier prototype, based on the method [8], will be discussed. Finally, in Section 4, the results of an experimental validation phase, carried out in a RF environment, will be provided.

2. METHOD FOR AUTOMATIC MODULATION CLASSIFICATION

The method used for the realization of the prototype presents a hierarchical structure [8]. The classification is made by computing some features on the signal and testing one by one the features with some thresholds, found experimentally in a calibration phase. At each step of the classification, further information is estimated and added to the previous one, up to the leaf of the tree, where the result is found (Fig.1). Such structure shows good properties, as it allows recognizing with a wide range of modulations, even maintaining a low complexity. The classification problem, involving signals, which are very different each other, is in fact divided into small sub-problems.

The first step allows deciding between single carrier modulations or OFDM modulations. Here, the classification is based on a fourth order normality test [6, 8], operated on the signal samples. It has been demonstrated, in fact, that the OFDM signal, when the number of carriers grows up, tends to have a Gaussian distribution [9].

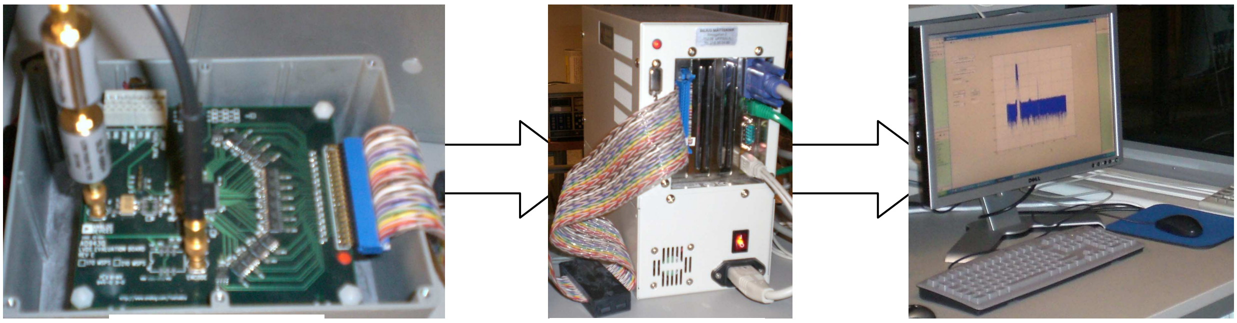
If the signal has been recognized as single carrier, a second step is carried out, in which an estimation of the instantaneous frequency, by means of the zero crossings, is obtained. Then, by looking at the sequence of the zero crossing time instants, the classification between signals with or without frequency modulation is achieved, as proposed in [10].

Going deep into the tree, at step 3, a decision on whether the signal has one, two or more of two phase levels is made, by evaluating the histogram of the phase hops in the signal. If just one phase is found, the signal is identified as not modulated at all and it is classified as Carrier Wave (CW).

At the steps 4 and 5, the amplitude modulation of the signal is tested, by computing an estimate of the power spectral density of the normalized amplitude of the complex envelope of the signal.

At steps 6 and 7, by looking at the standard deviation of the normalized amplitude of the complex envelope, the method allows selecting between M-ASK, with M>2 and limited-bandwidth 2PSK, and between M-PSK, with M>2 and QAM.

Finally, at step 8, if the signal has been recognized as OFDM, information about the symbol period and the duration of the cyclic extension are extracted from the signal autocorrelation and compared with those specified by the standards, to identify the specific OFDM modulation. In particular, three radio communication standards are currently recognized by the method: the IEEE 802.11g [11] and HIPERLAN (HIgh PErformance Radio LAN) [12] for WLAN (Wireless Local Area Network), and the European digital terrestrial TV (Digital Video Broadcasting – Terrestrial – DVB-T) [13].



AD9430 evaluation board

Frame grabber

PC

Fig. 2. Hardware architecture of the prototype.

3. PROTOTYPE OF THE AUTOMATIC DIGITAL MODULATION CLASSIFIER

Based on the method [8], briefly recalled in the previous section, a prototype of the automatic digital modulation classifier has been realized. The prototype has the hardware architecture shown in Fig.2. It is composed by a Personal Computer (PC), with the addition of an Analog Devices AD9430 Evaluation Board, which operates the analogue-to-digital conversion of the input signal and a frame grabber, which allows taking data from the digital interface of the converter and sharing them with a PC. The Analog Devices AD9430 is a 12-bit pipelined Analog-to-Digital (A/D) converter, with a maximum sampling frequency of 210 MSa/s, designed for wireless and wired broadband communication applications.

The software implementation of the prototype has been realized in C++ language under a Microsoft Windows operating system. On the top of the structure (Fig.3), the user commands are collected by a Graphical User Interface (GUI), based on the wxWidgets graphical library [13]. The software core is the modulation classification module, which implements the modulation classification method. It operates by using two *ad hoc* created libraries, which contain, respectively:

- DSP (Digital Signal Processing) functions, such as those realizing the FFT (Fast Fourier Transform) and the Hilbert Transform;
- statistical functions, such as mean and variance.

Other modules are the acquisition device driver and a database module (Signal DB), which allows storing the acquired signals in a non-volatile memory.

In addition, a TCP/IP server module has been added to the instrument, such that it can be controlled by remote by an external computer, located in the same network. The features exported by the TCP/IP server include the acquisition and the classification.

In Fig.4, a screenshot of the realized software is shown. Each row of the list is dedicated to a different acquired signal and, on the 6^{th} column, the identified modulation is reported.

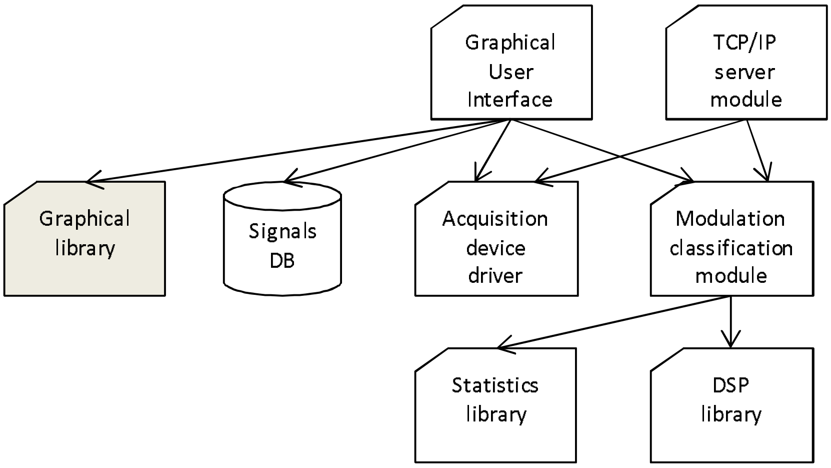
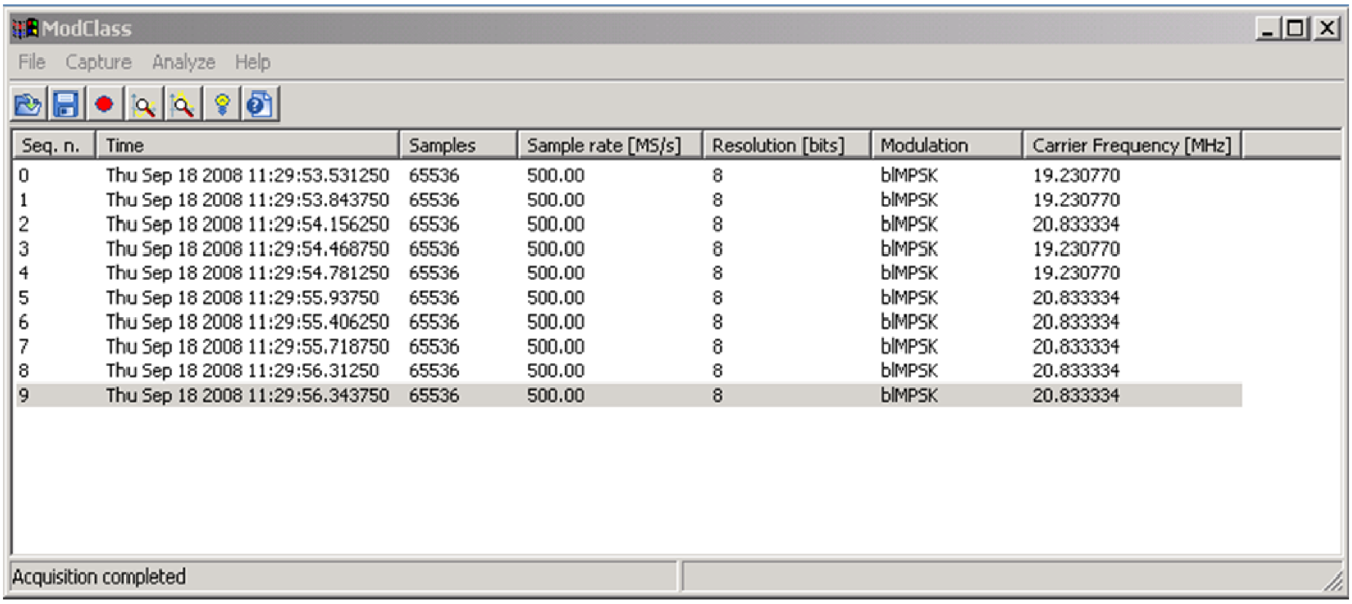


Fig. 3. Software modules of the prototype. All modules shown in white have been developed, while the graphical library has been taken from the wxWidgets open source project.

4. EXPERIMENTAL VALIDATION

In order to evaluate the digital modulation classifier, some tests have been carried out at the *Center for RF Measurement Technology* of the University of Gävle, Sweden. The measurement setup is shown in Fig.5. Modulated signals have been generated using a Rohde & Schwarz SMU200A vector signal generator. Then, the signals have been given to a Schaffner log-periodic CBL6112A transmitting antenna. A Rohde & Schwarz HE300 antenna has been used to capture the signal on the receiver side, and to give it to a down-converter, realized by the University of Gävle, which is in charge of reducing the frequency to an IF (Intermediate Frequency). A second SMU200A has been used to synchronize the receiving station by generating the local oscillator signal for the down-converter and the clock signal for the ADC on two different channels.



Seq. n.	Time	Samples	Sample rate [MS/s]	Resolution [bits]	Modulation	Carrier Frequency [MHz]
0	Thu Sep 18 2008 11:29:53.531250	65536	500.00	8	blMPSK	19.230770
1	Thu Sep 18 2008 11:29:53.843750	65536	500.00	8	blMPSK	19.230770
2	Thu Sep 18 2008 11:29:54.156250	65536	500.00	8	blMPSK	20.833334
3	Thu Sep 18 2008 11:29:54.468750	65536	500.00	8	blMPSK	19.230770
4	Thu Sep 18 2008 11:29:54.781250	65536	500.00	8	blMPSK	19.230770
5	Thu Sep 18 2008 11:29:55.93750	65536	500.00	8	blMPSK	20.833334
6	Thu Sep 18 2008 11:29:55.406250	65536	500.00	8	blMPSK	20.833334
7	Thu Sep 18 2008 11:29:55.718750	65536	500.00	8	blMPSK	20.833334
8	Thu Sep 18 2008 11:29:56.31250	65536	500.00	8	blMPSK	20.833334
9	Thu Sep 18 2008 11:29:56.343750	65536	500.00	8	blMPSK	20.833334

Fig. 4. Screenshot of the software GUI.

The test signals have been generated with frequencies ranging in the set {2,110; 2,115; 2,120; 2,125; 2,130} GHz, while the local oscillator frequency has been set to 2,100 GHz. In this way, during the tests, the IFs used were: 10, 20 and 30 MHz, respectively.

The ADC sampling clock has been fixed to 210 MHz, which is the maximum sampling rate available for the A/D converter, thus ensuring to take from 7 to 21 samples per carrier period.

The results of the characterization phase have been obtained under the conditions shown in Table 1. In particular, carrier frequency has been set to 2,120 GHz, local oscillator frequency to 2,100 GHz, symbol frequency to 2 MSymb/s, and sampling frequency to 210 MSa/s. During the generation of signals, a rectangular pulse shape has been used for Unlimited-Bandwidth PSK (UB-PSK) signals, a root raised cosine, with α parameter set to 0,35, for Limited-Bandwidth PSK (LB-PSK) and QAM modulated signals, while a Gaussian pulse with BT=0,30 has been used for FSK signals. For FSK modulations, a frequency deviation of 3 MHz has been used.

The amplitude level was set to 18 dBm, for PSK and FSK modulated signals, 16 dBm for 16QAM and 15 dBm for 64QAM.

For each type of modulation, 50 signals have been generated.

In Table 2, the matrix, containing the obtained results, is presented. Each row reports the generated signal type (indicated in the first column) and the percentages of identification of each considered modulation on the other columns. As an example, the UB-2PSK has been recognized properly as UB-2PSK, with a percentage of 84%; it has been recognized as LB-2PSK, with a percentage of 2% and as UB-MPSK, with a percentage of 14 %.

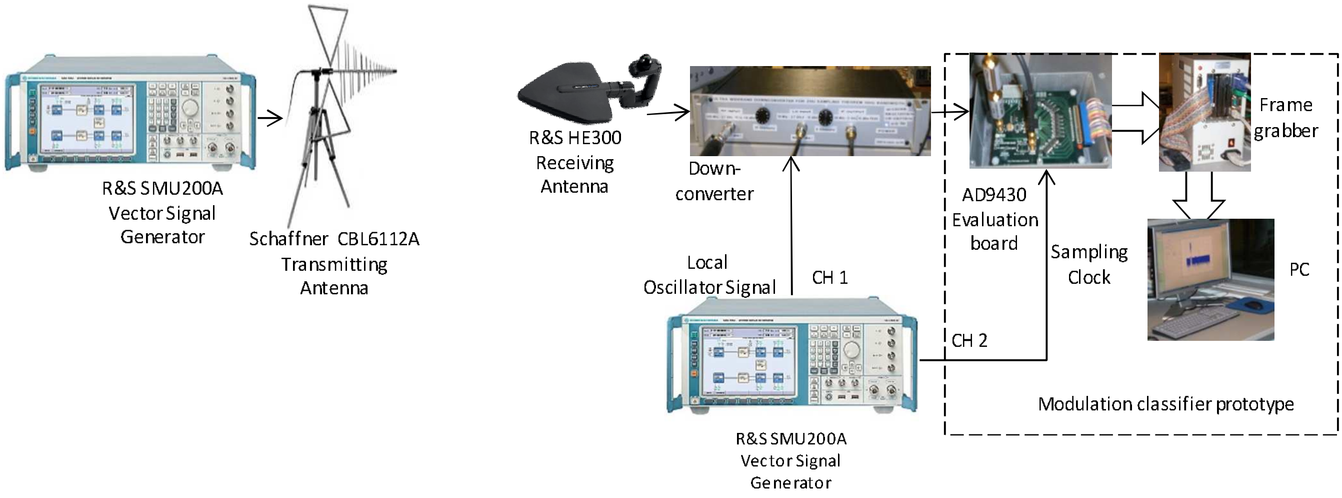


Fig. 5. Measurement setup for the classifier performance evaluation.

Table 1. Values of the parameters used during the first validation phase.

Parameter		Value
Carrier frequency		2120 MHz
Local oscillator frequency		2100 MHz
Symbol frequency		2 MSymb/s
Sampling frequency		210 MSa/s
Filter type	UB-PSK	Rectangular
	LB-PSK, QAM	Root cosine, α=0,35
	FSK	Gaussian, BT=0,30
FSK frequency deviation		3 MHz
Level	PSK, FSK	18 dBm
	QAM16	16 dBm
	QAM64	15 dBm

As it can be seen, all modulations were recognized with high percentages, with exception of the 4FSK. However, in this case, the estimation of the frequency hops has a poor resolution, due to the low ratio between the sampling frequency and the carrier frequency. In fact, there are only 5,25 samples between two zero crossing instants. As a consequence, the frequency hops are too low to be estimated. For the 2FSK signals, the IF oversampling ratio is the same, but the frequency hops are greater than in the previous case, since they have the same frequency deviation as 4FSK signals, but with half of frequency levels.

The results obtained are confirmed by the tests carried out, by changing the carrier frequency in the set {2,115; 2,120; 2,125} GHz, and letting the local oscillator frequency of the down-converter unchanged to 2,100 GHz, thus obtaining IF carrier frequency of 15, 20 and 25 MHz, respectively. (Fig.6). It can be seen that the classification percentage decreases for almost all modulations, when the carrier frequency increases. It can be explained by the ratio of the carrier frequency and the sampling frequency, which is too low to have a good estimation of the instantaneous frequency and the phase hops. This effect is worst in the case of the FSK, where it does not allow recognizing the modulation. Instead, in the case of PSK, it affects just the estimation of the number of levels of the modulation, which is well recognized as PSK.

CONCLUSIONS AND FURTHER WORK

In this paper, a prototype of an automatic digital modulation classifier is presented. It is a useful instrument to be used in the next generation communication systems based on a flexible and dynamic spectrum access. The hardware and software architecture of the instrument has been described, as well as the result of the validation phase, obtained in a radio environment, thanks to an international collaboration between the University of Sannio, Italy and the University of Gävle, Sweden. The test results, carried out for a wide number of digital modulations, commonly used in today’s communication systems, showed good performances in terms of classification percentages, even in a realistic scenario.

Further work is directed mainly to the addition of a software preprocessor to the automatic modulation classifier. Such preprocessor should complete the following tasks:

- To separate multiple signals eventually overlapped on the same frequency band;
- To compensate the distorting effects of the channel, mainly when the channel has a multipath behavior;
- To automatically adjust some parameters of the signal, such as the ratio between the IF carrier frequency and the sampling, in order to optimize the performances of the classifier.

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Table 2. The results obtained in the preliminary validation phase. Each row reports in the first cell the modulation type of the test signal and in the other cells, the percentages of identification of each modulation.

Test signal type	Modulation recognition percentages							
	LB-2PSK	LB-MPSK	UB-2PSK	UB-MPSK	FSK	QAM	ASK	CW
LB-2PSK	100	0	0	0	0	0	0	0
LB-4PSK	0	100	0	0	0	0	0	0
LB-8PSK	0	100	0	0	0	0	0	0
UB-2PSK	2	0	84	14	0	0	0	0
UB-4PSK	0	0	62	38	0	0	0	0
UB-8PSK	0	0	0	100	0	0	0	0
2FSK	0	0	0	0	100	0	0	0
4FSK	0	0	0	0	10	0	0	90
16QAM	0	0	0	0	0	100	0	0
64QAM	0	0	0	0	0	100	0	0

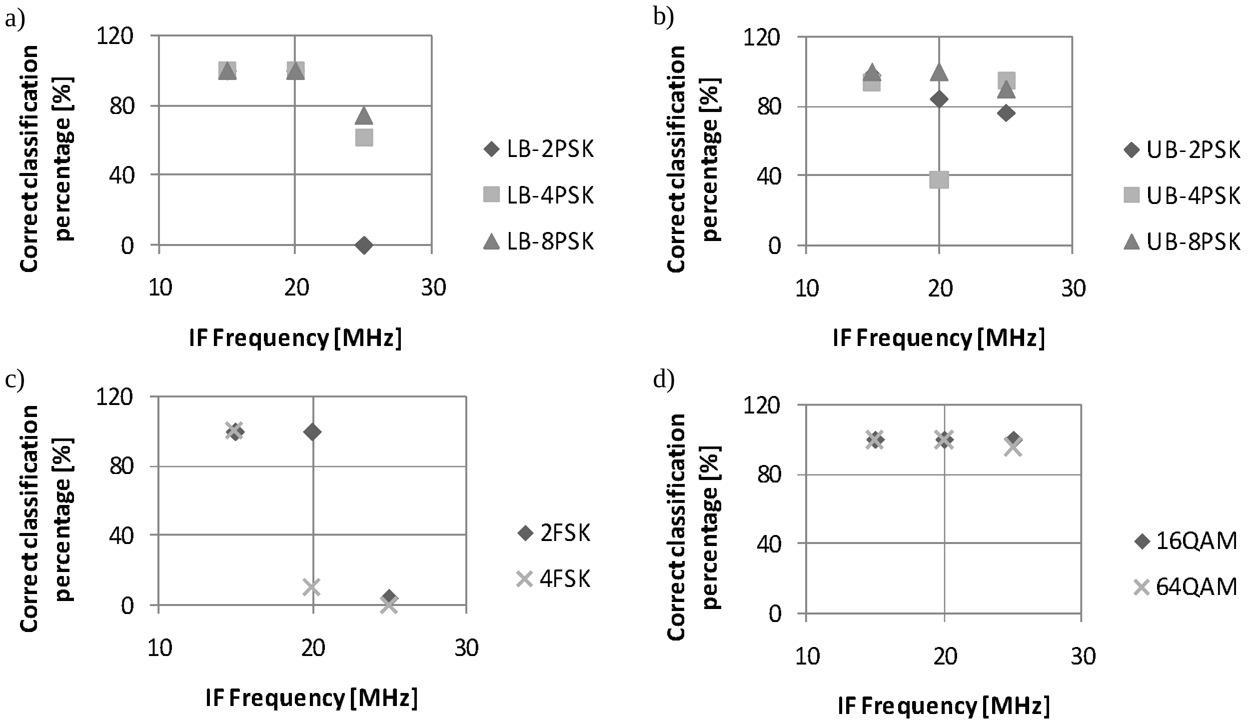

Fig. 6. Classification percentage obtained during the experimental validation, versus the IF carrier frequency for (a) LB-PSK signals, (b) UB-PSK signals, (c) FSK signals, and (d) QAM signals.

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