Technologies for VHF/UHF Signal Processing in Tactical Reconnaissance Systems

Uwe Matthies and Dr. Thomas Wolf
PROCITEC GmbH, Rastatter Straße 41, 75179 Pforzheim, Germany

Abstract **— The discussion about modulation classification versus modem recognition in tactical reconnaissance systems leads to a combination result to integrate both signal processing functions into one system concept. Together with highly integrated COTS hardware platforms compact monitoring and analysis solution can be reached. FPGA technology is used for performance critical real time applications.**

Keywords **— signal analysis, modulation classification, modem recognition**

I. Introduction

The interception of signals within the VUHF frequency range does not only have specific requirements on the sensor systems, but also poses a big challenge on the signal processing solutions. The decisive factors, which need to be met by the signal processing unit, are: the reliable detection of the relevant signals, the efficient and unerring analysis of the signal characteristics as well as in terms of the performance optimized algorithms. Best performance, absolute reliability and fitted for the mobile and semi-mobile use under difficult conditions are the requirements on the hardware components. Some of these challenges are related to the specific operational requirements of tactical mobile interception systems.

An important aspect, especially when talking about tactical VUHF systems, which can be used for various intended uses, is the adaptability of the signal processing unit. Depending on the operational area, mission and signal scenario, different tasks need to be performed by the signal processing unit. Flexibility at the best possible rate by quick adjustment on new signals, e.g. of the detection, classification and demodulation algorithms, is mandatory.

This paper describes aspects of a COTS (commercial of the shelf) hardware approach, an appropriate tool chain for manual and knowledge based automatic processing, the combination of signal classification and modem recognition and the necessary multiple levels of signal processing.

II. Combination of Signal Classification and Modem Recognition

While discussing signal processing in tactical reconnaissance systems, a major interest is the advantage of the coexistence of classification of modulation types next to modem type recognition.

U. Matthies, u.matthies@procitec.de; T. Wolf, t.wolf@procitec.de; Tel +49-7231-15561-0.

Only this combination guarantees fast results and detailed information on the relevant signals of interest. In the field of automatic analysis for automation of signal reconnaissance these two main functional approaches need to be discussed. On the one hand there are solutions for tactical systems based on signal classification and on the other hand solutions are based on modem recognition. Mostly scientific discussions have the intention to point out which of these ways is the better one to process a signal automatically. But the advantages and disadvantages of both types depend on the operational conditions and are well known. As tactical reconnaissance systems should be powered by the best approach, the optimal solution is based on a dynamic combination of the two different approaches.

In this context signal classification is characterized as the determination of modulation parameters of known and unknown signals. These parameters are e.g. SNR, modulation scheme, bandwidth, symbol rate and modulation specific measurements like shift etc. Interception systems based on signal classification provide a fast overview on the communication situation in a mostly unknown environment: band allocation over a large bandwidth. As such systems are not able to produce (demodulate and decode) the signal content an analysis of the signal in a more detailed way is not possible. The signal classification e.g. only indicates that there is a certain number of PSK modulations on air, but not whether these are modems relevant for reconnaissance or only amateur transmissions.

On the other hand the modem recognition allows for determination of all modem parameters. This includes modulation and coding. Advanced modem recognitions check the signal against a knowledge base and provide the required parameters to extract the actual signal content. This is known as “signal production”. Depending on the special signal type such recognitions may sometimes take time. Upon modem recognition, relevant signals can be processed (decoded) in real time. Surveillance and reconnaissance with modem recognition systems provide relevant steps for information superiority.

As it depends on the specific operational requirements up to date system approaches for signal interception should incorporate both practices: signal classification and modem recognition. This allows the system users to decide in relation to the tactical relevance, whether they want to concentrate on e.g. 100 parallel PSK emissions or on a smaller number of more relevant special modem types, in order to detect the military relevant emissions. The quality of the results of the combination depends on the implemented cooperation of signal classification and modem recognition.

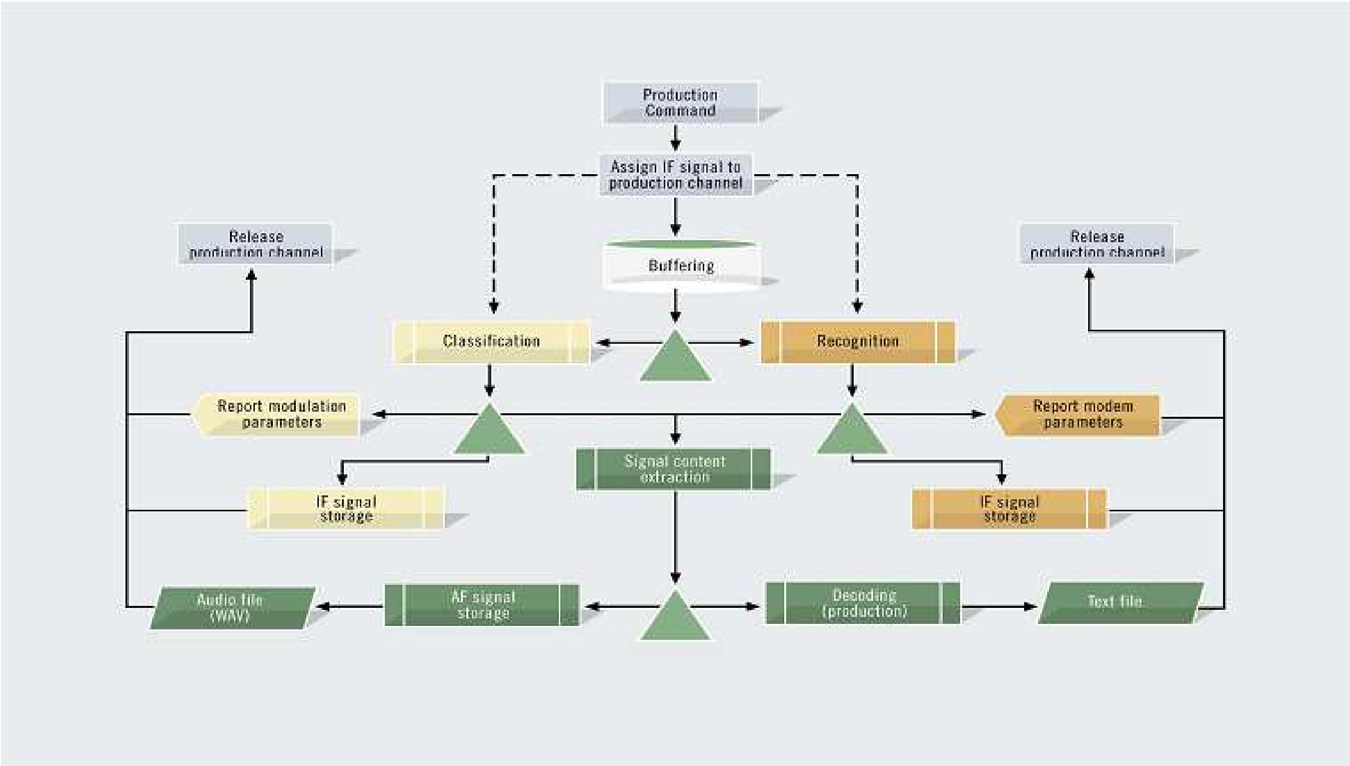

Fig. 1. Combination of signal classification and modem recognition

This structure does not depend on a frequency range. It can be used in HF and VHF / UHF frequency ranges. Signal processing systems for reconnaissance tasks should realize the following signal relevant functions: signal detection, signal classification, modem recognition, demodulation, decoding and signal recording. They allow the implementation of a process chain with multiple result levels.

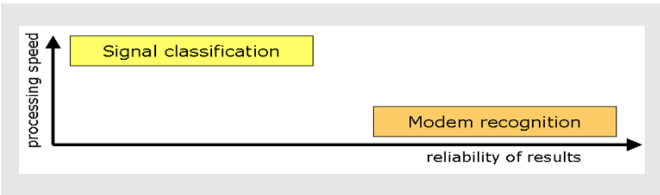

Fig. 2. The goal is to have reliable results in a short time

III. Multilevel Architecture for Detailed and Partial Results

As one of the main tasks is to filter the complete interesting frequency range down to the so called "signals of interest" a multilevel process is needed. Signal processing in a tactical system needs to have these very essential features: the set-up, the design, and the architecture have to be multi-level. This means, the process chain can be divided into adequate levels. Each level needs to be functional, receive incoming data and supply reasonable, utilizable partial results. Each of these results is crucial for the evaluation, especially for those emitters, whose signals can not be fully analyzed or processed due to the complexity or bad conditions in terms of reception. Nevertheless, in these cases, results of the single levels can provide valuable hints on the features of the signal.

The first filtering step is the detection of signal energy and the segmentation into single emissions. After this a first classification step can be added. This classification step does not result into the same classification level for each emission – there are big differences in the emission types. Some emissions have a specific behavior concerning the time – frequency area, e.g. burst or TDMA signals. By knowing the exact measurement of the parameters' frequency and time only no further analysis functionality is needed.

Other signals do not show such behavior and need to be analyzed in a next step – in this case for demodulator parameters. So with each step the number of unknown signals will be reduced and also the number of signals to be analyzed in the next level. The last step is the modem recognition. With this step a production of the detected modem is possible to get the decoded text. The multilevel processing delivers specific results for each step, also in the case of incomplete processing.

Signal detection means searching for signals in the spectrum. The following information is gained by the signal detection

- Segmentation of signals
- Signal level
- Centre frequency
- A rough information on the bandwidth

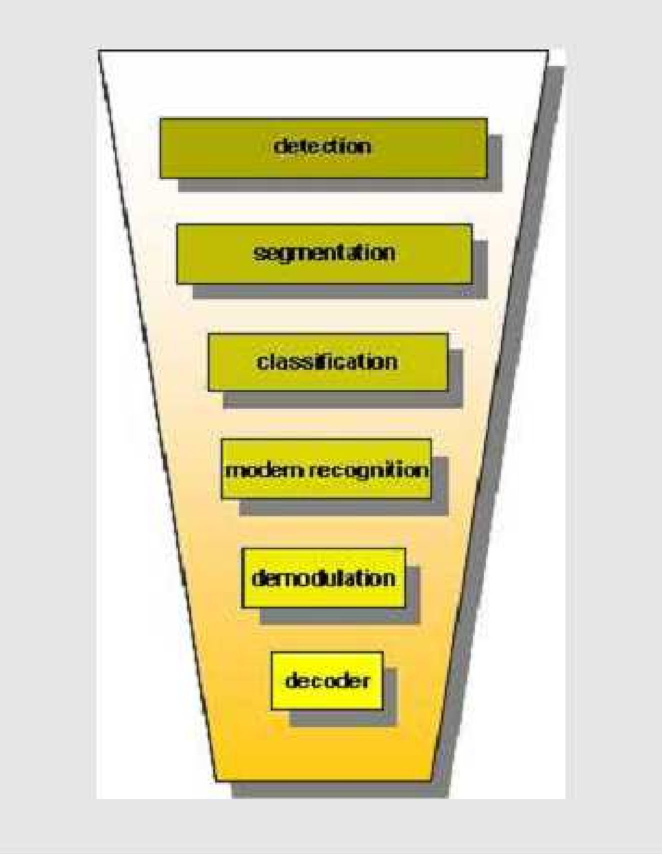

Fig. 3. Multilevel processing

An advantage of detecting signals by these certain attributes is the increase in performance and the reduction of data. This allows realizing a signal selective detection in the VUHF system. The classification unit identifies general signal characteristics such as:

- Exact bandwidth
- Modulation type
- Baud rate of digital modulated signals
- Operation mode of analogue modulated signals
- Centre frequency
- Shift frequency

The distinction between analogue modulated signals and digital modulated signals is important. The modulated speech signals, which can numerously be found in the VUHF range, have a certain importance. In order to be able to decide on the tactical relevance of these signals, they need to be made auditable.

The modulation unit separates the carrier frequency from the content. An efficient demodulation unit, which has widely configurable parameters, supplies the raw data both, for statistical evaluation as well as for the evaluation of its content by a following decoder unit. Depending on the modulation type, which needs to be demodulated, the exact carrier frequency or baud rate of a signal or both are necessary. On the one hand the demodulators need to be designed for each defined modulation type; on the other hand they need to be highly flexible in order to support the specific modulation types in wide range. Depending on the modulation type additional adaptive equalizers might be necessary. Primarily modulated signals require a pre-demodulation as well as a further process of recognition. Corresponding signals need to be processed via a demodulator which can be synchronized. Analogue modulated signals will be further processed via a separate process channel. This process needs to be carried out with as little time loss as possible which means in nearly real time, in order to follow up the audible receiver calibration. Initially, every process channel needs to be provided with a basis package of demodulator by reloading the software according to the mission requirements at the operational area these can be completed or exchanged fairly quickly and easily. Normally, the demodulation unit supplies the raw data and detects certain parameters of a modulation type such as:

- Exact carrier frequency
- Exact baud rate
- Modulation index
- Modulation degree
- Instantaneous frequency
- Instantaneous magnitude
- Instantaneous phase
- Quality information

The decoder unit needs to meet two major tasks: first, to eliminate the mechanisms for error correction which are necessary for transmission. The second important task is the exact analysis of the coding algorithm for the modem recognition process. The decoder unit needs to be equipped with a basic package of decoders and needs to offer the possibility of simple modification. In practice, emitters with easily modified standard coding algorithm are found more often. In order to adapt to a relevant signal scenario, an effective decoder developing tool – preferably in form of a meta-language, like the PROCITEC Decoder Description Language (DDL) - would be a good solution. In a separate work station, on the basis of bit stream analysis results, the decoders can be developed, tested and then taken over into the target system using a standardized file format.

The decoders are pure software solutions and act upon the already demodulated data stream. The requirements of the decoder units to the computing power of the signal processing platform are comparatively little. For example the decoder provides the following results:

- Identification of the signal emitter/receiver (e.g. call signs)
- Content of the transmission
- Information about the used frame
- Detection of the modem
- Changes in transmission state (like modulation type, bandwidth, frequency, …)
- Characteristics related to the protocol

The modem recognition uses the demodulation and the decoding unit in combination. The combination of the recognition of modulation type within the demodulation unit with the recognition of the coding algorithm within the decoding unit supplies a correct statement on the relevant emitter. Whereas a signal classification will determine a faded FSK-Signal as a signal with modulation ASK wrongly, the redundancy of the coding allows the modem recognition like the PROCITEC Automatic Production Channel (APC) to determine the modem correctly.

IV. Advanced COTS Approach for Enhanced Signal Processing Performance

Central requirements for the hardware arise from the mobility and the short reaction times of tactical systems, the high bandwidths of VUHF signals and the therefore necessary computing performance. Together with the minimization of the required space and power consumption this leads to advanced concepts for the hardware and software.

The typical well known COTS approach concentrates on the usage of standard processing platforms, like PC technology, whereas there are specific performance requirements that are not fulfilled by today's CPUs. FPGA (Field Programmable Gate Array) technologies provide the adequate possibilities concerning performance, power consumption, modularity and flexibility of the use. With FPGA technologies the goal of the modularization and the standardization of hardware components as well as software architecture can be achieved. The flexibility in usage of FPGAs can be compared with modern CPUs. Like compiled software for CPUs the special software packages for FPGAs allow functional changes or reprogramming within seconds. In this way FPGA becomes an advanced COTS approach.

The FPGAs which are available nowadays can be divided into several groups:

- Array of logic cells for general processing parts
- Free usable cells for signal processing with the central "multiply and accumulate = MAC"-architecture for all DSP parts like mixer, filter, down converter, …
- Internal and external RAM for storage of intermediate results and to buffer the incoming signals to "jump back" in the history of the signal
- Common on chip hardware parts like PowerPC´s to realize "normal software parts" together with the fast FPGA "coprocessor"
- Several external interfaces, e.g. high speed serial interconnects to other parts of the system

In the VUHF frequency range many modem types with a high bandwidth are available. Central point of the calculation of the needed processing power is the required sampling rate for the demodulation part. Within FPGAs the essential components of a demodulator, ideally adapted for interception tasks are realised: A buffer of several seconds for the incoming digital IF signal enables the demodulator to "go back" in the signal in time domain. This allows lossless demodulation starting with the first symbol. In addition a configurable multi channel, multi bandwidth digital down converter (DDC) with bandwidths of 25 kHz / 50 kHz / 200 kHz up to several MHz allows for adaptation to the relevant signal. Last but not least a bank of configurable demodulators (e.g. AM / FM or FSK / PSK) guarantees the flexible use of FPGA based demodulators. Demodulation processing can be adapted from a standard processing platform to FPGA. The system integration, i.e. the integration with other components into interception systems, is done by using FPGA-cards within well known standard PC hardware platforms. This results in a close relation between the standard processor software (responsible for controlling and decoding parts) and the fast FPGA processing (implementing the demodulation parts). This solution guarantees small size, low power consumption and very high data rates. The following figure gives an overview of an example system using FPGA processing and entitles the necessary components.

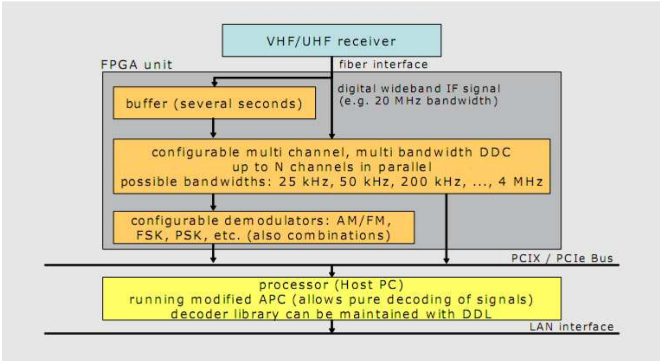

Fig. 4. FPGA environment

First part of the processing chain is the signal buffer. Here especially the I/O-bandwidth has to be taken into account. With a typical input bandwidth of 20 MHz a sampling rate of > 40 MS/s is needed. Even with 40 MS/s and an AD-Converter with 16 bit a data rate of 80 Mbytes/s has to be managed. Assuming 20 different channels for this example this results in a total bandwidth of about 1.7 GBytes/s. This is one limitation in the FPGA system.

The next step of the signal processing is a Digital Down Converter (DDC) for the selection of the signals of interest. Here a flexible multi channel solution with independent bandwidths per channel is needed. The limitation of logic cells makes it impossible to realize the DDC for each channel separately in the FPGA. This is why there is the need of integrating several DDC channels together. This can be realized without losing signal quality.

Each demodulator structure can only be used for one channel. Only "easy" demodulators like AM or FM can be realized in a similar integrated way like the DDC´s. There it is possible to realize the same number of demodulators as DDC channels are available. As more complex digital demodulator structures have more limitations, only a smaller pool of demodulators will be available to be used in all DDC channels in parallel / at the same time.

All channels in parallel decoding will run on standard PC CPUs. This is the optimal platform for decoding that allows changes in the decoder by the customer's specialists and independently from company's adaptations. Signal processing for the VUHF frequency range in tactical reconnaissance systems does not necessarily indicate the usage of inflexible DSPs. All essential functions can be run on a COTS platform combining the advantages of standard PC hardware platforms with FPGA technologies. This approach guarantees a flexible solution in processing from the first bit (buffer), optimal handling of the relevant signals (multichannel multi-bandwidth DDC), flexible demodulation (bank of demodulators) and adaptable decoding (changeable decoders running on standard CPUs). Depending on the operational aspects of the special tactical system the enhancement of signal processing performance based on FPGAs is an option to discuss but it's not a must.

V. Complete Tool Chain for Knowledge Based Approach

Also for an automatic processing system the ability of detailed manual signal analysis is mandatory. Familiar and preconfigured signal scenarios can be processed automatically; signals which are not entirely known can be processed semiautomatic, whereas unknown signals require manual processing. As mentioned above, the adaptability on new tasks and signal scenarios is important, especially when talking about tactical systems. Although the necessary tools are not part of the tactical system itself, in a supporting technical centre a complete process chain is needed with the possibility to work automatically, semiautomatic or manual. Signals which once were analyzed manually by the operators of the technical centre will now be analyzed automatically by the system.

The manual analysis environment consists of identical signal processing components as the automatic processing chain extended by specific analysis functions. The manual analysis environment also has to be provided with the identical input signal data as in the case of automatically processed live signals. In cases of interception of signals that are not known to the automatic processes like modulation classification and modem recognition, a more detailed manual technical analysis of these signals is necessary. To support this VUHF systems should incorporate recording solutions for broadband (e.g. 10 MHz) and narrowband (e.g. 25 kHz) signals. Together with the recording additional operational information is needed - in minimum frequency and time information. The information about the recording environment is needed, too: e.g. the trigger event for the recording start and the trigger event for the stop.

Starting from the manual technical analysis a seamless integration of "the way back" into the system is needed. If a certain signal was not automatically processed but analyzed in the manual analysis, the results have to be added to the existing knowledge base of the system. Universal demodulators and changeable decoders, e.g. defined by usage of a Decoder Description Language, allow the enhancement of the systems' knowledge base by the user himself.

At the end as a result the complete process chain provides a clear description of the signals as well as the content and if possible the network relations. For this purpose, normally, the signal processing unit of a tactical system consists of:

- Signal detection for recognition and evaluation of the signal energy in the spectrum
- Signal preparation of single signals for further processing concerning bandwidth, level and centre frequency.
- Signal classification for the detection of typical signal characteristics, such as type of modulation or operation mode for further processing by the production unit.
- Modem recognition for a more detailed information about the signal
- Knowledge base with description of well known and new analyzed modem types
- Demodulation and decoding for the production of the contents
- Adaptable decoders
- Recording of AF, IF, bits and symbol stream

The supporting technical centre needs

- Signal analysis software compatible with the recordings
- Software for the analysis of bit streams
- Decoder Adaptation tools
- Toolset for change of knowledge base

All steps of the manual or automatic signal processing chain are supported by modern software solutions like PROCITEC's SDA, BSP and PROCEED which form a complete and seamless toolkit. The technical centre has to be equipped with signal analysis software compatible to the system's recordings, software for the detailed analysis and measurement of bit streams and a platform for adapting the decoders and modem descriptions of the tactical system's signal processing unit. Based on this a knowledge based approach for automatic signal processing is available for the VUHF frequency range, too - it allows tactical systems to enhance their reconnaissance capability in parallel to operations.

References

[1] Roland Prösch, Technical Handbook for Radio Monitoring VHF/UHF, 2011

[2] Bernard Sklar, Digital Communications – Fundamentals and Applications, Prentice Hall, 2001

[3] PROCITEC GmbH, Reference Guide Decoder Description Language, 2011

[4] P. Vary, U. Heute, W. Hess, Digitale Sprachsignalverarbeitung, Teubner Stuttgart. 1998