W Band Multi Application Payload for Space and Multiplanetary Missions

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Abstract. The increasing demand for frequency locations with high bandwidth to satisfy the growing satellite communications applications made it necessary to explore higher and higher frequency ranges. W-band (75–110 GHz) can be considered as the new frontier of satellite communications.

Based on the experience gained by Oerlikon Contraves in the development and in the operation of a W band radar sensors operating at 95 GHz for Airport Surface Movement Control and Guidance and on W band point to point ground communication link modular "core" integrated modules based on MMIC technology are described on this paper. The main targets to reach for each "core" module are the minimisation of mass, volume and the modularity in order to have the possibility of use it in payloads that can be embarked on different platforms (nanosatellites, microsatellites, satellites, rovers on Moon and Mars. . . .) or used on ground for different applications including security.

The personalisation of the payload will be done by the antennas, the HPA and the baseband processing depending if the application will be a high rate, high speed communication link or a beacon for propagation measurement or a radar (traditional, SAR, interferometer. . . .)

1 General Information

The increasing demand for frequency locations with high bandwidth to satisfy the growing satellite communications applications made it necessary to explore higher and higher frequency ranges. Frequencies around 60 GHz cannot be utilized effectively due to atmospheric absorption, hence, the W-band (75–110 GHz) can be considered as the new frontier of satellite communications. The large bandwidth availability in W-band allows conceiving and proposing many advanced and innovative services that need high-volume data transfers without tight interactivity constraints for future scenarios.

The reduced wavelength will permit antennas and payloads with reduced volumes and weight doing the possibility of placing them on micro or nanosatellites platforms or on a knob of International Space Station (ISS). These are key payload features since the cost of a mission is closely related with the weight of the payload.

Pencil beam capability at reasonable antenna size will assure improved data security.

Considering that the main disadvantage of the use of W-band frequencies is the atmospheric attenuation, all its benefits could be fully exploited in space out of atmosphere or in interplanetary missions.

For which concern the communications, W band can be used for intersatellite links or for communications between a Lander or a station on the surface of the Moon (or Mars) and an orbiter, that could act as a data-relay node towards an Earth station (for example, the Deep Space Network).

Radars for small debris identification or for rendez-vous and docking operations could be envisaged

Due to the lack of atmosphere on the Moon, the use of millimetre (W band) or sub-millimetre bands of frequency could be the winning strategy for the development of high resolution interferometer radars with reduced mass and volume for the self guidance (instead of optics) of rovers operating on Moon surface or for the development of moon based radiometers for the analysis of atmosphere or for the completion of previous scientific missions (Planck, Herschel..).

W-band is recently considered as a "technological frontier"; thus representing the true challenge towards which the research community and the industry should concentrate their efforts.

2 "Core" Concept

For which concern possible applications relative to ground-satellite, satellite-ground communications, the characterisation of the channel together with some experimentation of the channel itself together with and in-orbit validation of W-band technology and space qualification processes must be considered mandatory before proposing a "commercial" mission operating in this band.

These applications are expected to provide the necessary elements towards the realization pre-operative multi application payload for space and interplanetary mission.

Concerning the hardware, it is important to mention here that since no existing space-qualified hardware has been reported yet, to fulfil the high power requirements and low response to cosmic radiations and space effects as required for GEO and LEO payloads, the research and development of such components is of a vital importance. This is actually the most important technological challenge on W-band frequencies. Actually, previous experience related to the development of platforms for scientific satellites, implied the necessity to anticipate a certain level of flexibility in defining the required characteristics, in which the details of the mission become defined more precisely during the project development (e.g. the detailed allocation of the band, permitted BER, transmission and reception power, the permitted redundancy, etc. . .). Since the characteristics of the on-board processing depend on such details in order to reduce the uncertainties in time schedule, it is necessary to follow a flexible approach that can be adapted according to the variation in requirements. This will offer a number of solutions that can be integrated together on one hardware platform although not defining the series of processing in a unique way. Obviously, the choice of a specific solution depends on the performance to be obtained using the system.

For this reason a multi application W band payload can be conceived composed by "core" integrated modules common to all and personalised in terms of antenna, power amplifier and signal processing depending on the application. The main targets to reach for the "core" front-ends are the minimisation of mass, volume and the modularity in order to have the possibility of use it in payloads that can be embarked on different platforms (nanosatellites, microsatellites, satellites, rovers on Moon and Mars. . . .)

Such constraints will imply a large use of Multifunctional Integrated MMIC on GaAs (MHEMT, PHEMT) reaching for these devices state of the art performances in terms of noise and power(100–200m W).

Other particular devices like MEMS switch could be used in case on such "core" module is required the control of the amplitude and the phase as in case of 3D Imaging radar for self guidance of small rovers on the moon also if, due to difficulties given by the small wavelength, sometimes is preferred move the beam mechanically or electromagnetically (PGB or Metamaterials) at antenna level.

If higher power are required as in GEO mission, HPA transmitters based on vacuum tubes shall be added to such core module. The kind of operation of such SSPA or HPA (CW, pulsed or digitally modulated) will be defined on the basis of the applications.

Other element that will personalize the payload are the baseband generation, the signal processing and the antenna depending if the application will be a high rate, high speed communication link or a beacon for propagation measurement or a radar.

Scope of this paper will be the identification of such "core" integrated modules derived from previous experience of Oerlikon Contraves to be used in different applications and missions space or ground based including security, proposing services, applications, integrated business opportunity able to merge two worlds – communications and navigation – that have been purposely apart for years.

3 Oerlikon Contraves Heritage

Oerlikon Contraves gained a lot of experience in the development and in the operation of a W band radar sensors operating at 95 GHz for Airport Surface Movement Control and Guidance.

The first prototype was installed in 2001 at the Frankfurt Airport and improved on 2003; a second one is installed at the Venice "Marco Polo" airport; presently they are operative and used as gap-filler of the main control radar. Other installations are foreseen within 2006.

The last configuration named SMART High Resolution Radar MK2 is shown in Fig. 1.

The main features of SMART HRR MK2 with respect to the previous one are:

- Klystron Based Transmitter
- Full Redundant TX/RX Chain
- No 'Active' Hardware Rotating
- Frequency agility
- Improved Maintenability Capability

Due to the frequency of operation, the main advantages of such radar are: reduced dimensions, simple installation, interference immunity, high resolution.

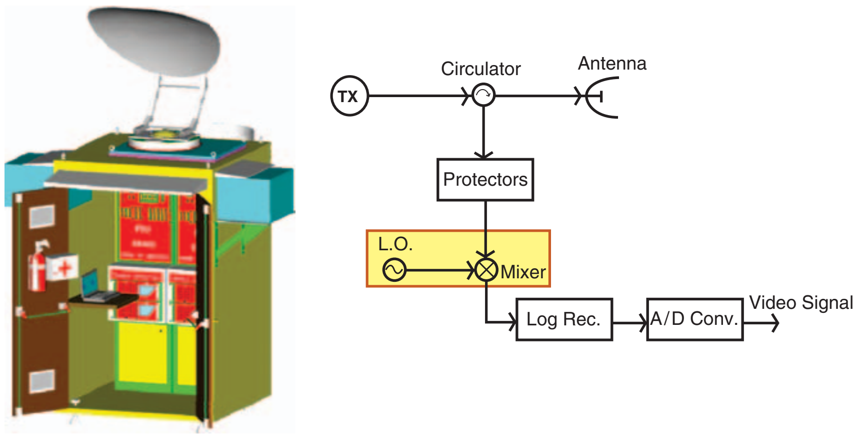

Fig. 1. High resolution rader MK2.

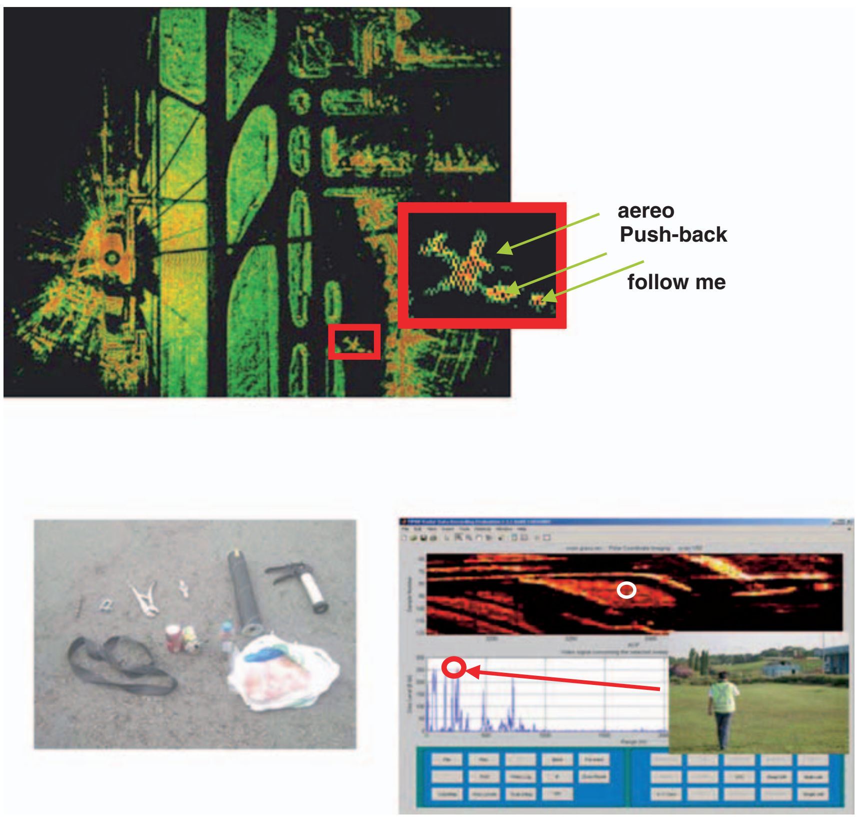

Fig. 2. High resolution rader MK2 test campaign.

This means that the radar can be used other than for **S**urface **M**ovement **S**urveillance (SMS) also for typical homeland security applications like:

Foreign **O**bjects Debris **D**etection (FOD)
Human **M**ovement **D**etection (HMD)

Typical returns from the field are shown in Fig. 2 for SMS, FOD and for HMD

Another field on which Oerlikon Contraves gained a lot of experience was in the development and test of a ground based W band point to point communication link. With this activity, some results relative to the atmospheric attenuation on ground have been found together with the demonstration of a FSK modulated communication link operating at 95 GHz.

Figure 3 shows the results of such experimentation.

Recently Oerlikon Contraves is active in the development and experimentation of a Limited Area W band FOD Warning Radar. The principle of working is shown in Fig. 4.

The radar is FMCW type and the adopted configuration for the prototype development is shown in Fig. 5.

Experimental views of the first prototype in operation are shown in Fig. 6.

In the space contest OCI participated to a lot of programs financed by ASI and ESA and is member of the "Moon base" activities.

In the contest of DAVID and WAVE programs OCI proposed for the respectively LEO and GEO high performance W band communication payloads a W/Ku Frequency conversion unit which scheme is shown in Fig. 7.

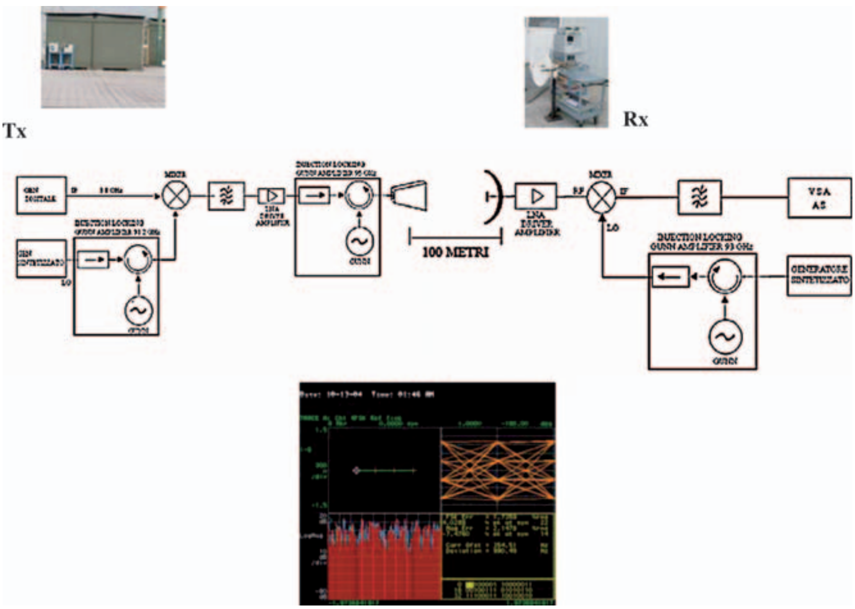

Fig. 3. FSK communication link.

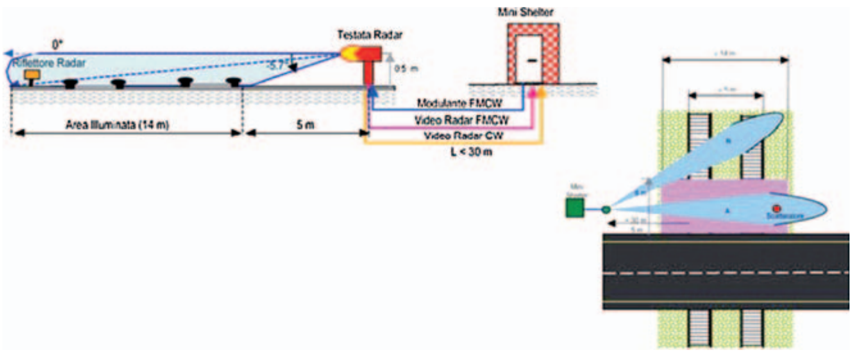

Fig. 4. Limited area W band FOD warning rader principle scheme.

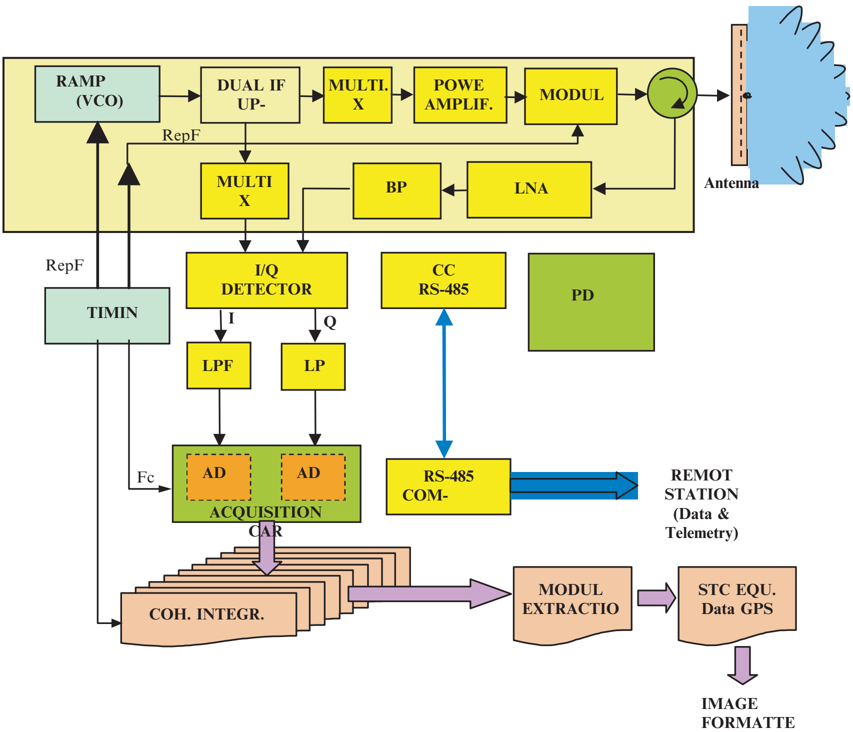

Fig. 5. FMCW rader functional diagram.

The system is considered fully redundant and an up/down conversion is foreseen for each channel. A traditional hybrid technology including low noise and medium power GaAs HEMT MMICs has been considered.

Fig. 6. FMCW rader testing results.

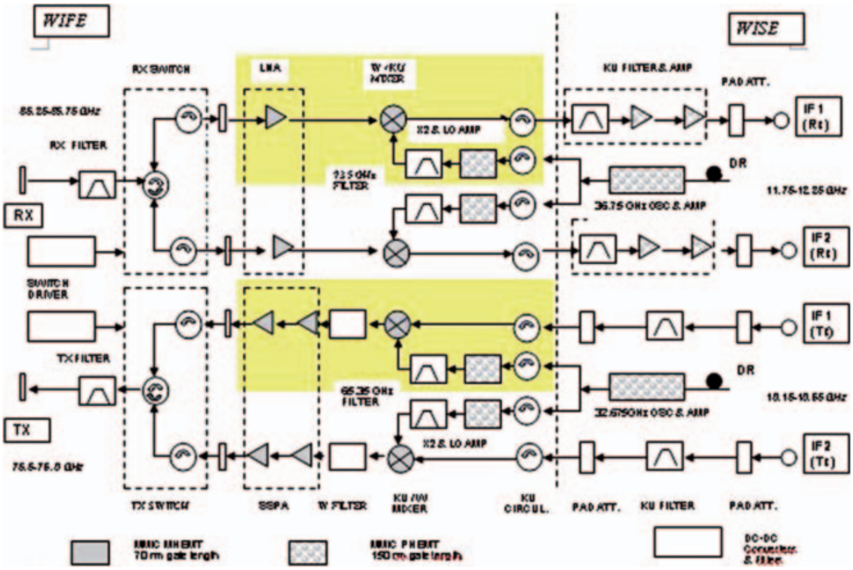

Fig. 7. DAVID principle diagram.

In order to get some additional information regarding the satellite to ground W band channel both for communication and for propagation(beacon), a mission with essential hardware mounted on a stratospheric vehicle (AEROWAVE) has been conceived.

The configuration of the AEROWAVE experiment is shown in Fig. 8.

Also if vacuum tubes, EIO, EIKA or TWT will be used for budget link reasons, monolithic medium power amplifies (MPA) have to be considered as drivers of the tubes itself.

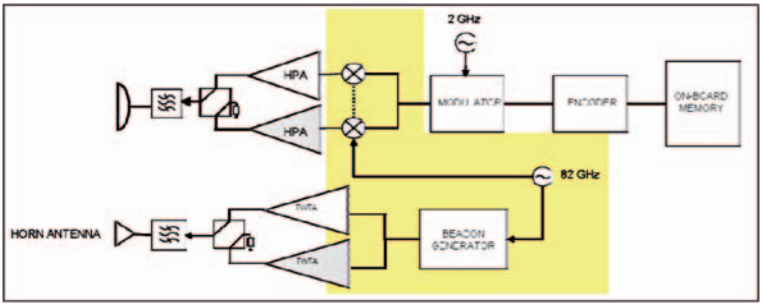

Fig. 8. Aerowave functional diagram.

4 Identification of "Core" Modules

In the block diagrams of the different systems experienced or studied by OCI (see Fig. 1, 5, 7, 8) have been highlighted some particular functional areas that have been studied in order to find the commonalities between them with the scope of finding a minimum number of "core" modules usable for any application.

The first step has been to find the state of the art of the technology in Europe for which concern the development of Low noise and Medium/High power MMIC amplifiers and Low noise MMIC oscillators operating in the W band. From this analysis has been found that in Europe only three foundries or research Institutes are active in this area:

- UMS(F): PH15 GaAs PHEMT 0,15 µm gate length for low noise and low power up to 77 GHz (automotive chipsets)
- OMMIC(F): D01MH GaAs MHEMT 0,130 µm gate length for low noise and low power up to 100 GHz
  D0071H E/D GaAs MHEMT 0,070 µm gate length for low noise and low power up to 160 GHz
- IAF(D): Fraunhofer Research Institute with public foundry GaAs MHEMT 0,070 µm gate length for low noise and low power up to 160 GHz
  GaAs PHEMT 0,150 µm gate length for medium power up to 110 GHz

Between the three IAF, seems to be the more advanced and completed offering both low noise and medium power amplifiers.

The best IAF available results are shown in Fig. 9 and Fig. 10 respectively for Low noise and for medium power MMICs

IAF is active also in the FMCW radar sensor and developed a complete chip shown in Fig. 11

Starting from this reality and working on the commonalities, four core modules (Figs. 12–15 and Tables 1–5) have been extracted in order to cover any need.

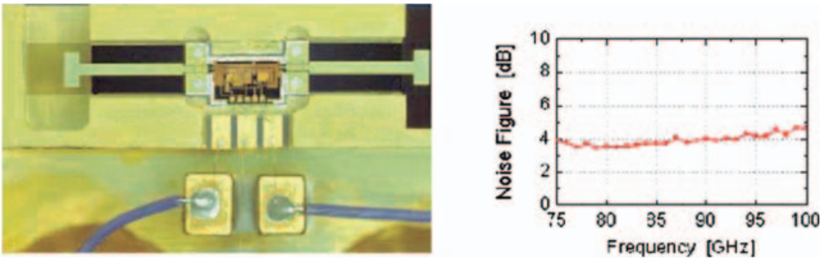

Fig. 9. IAF 94 GHz LNA.

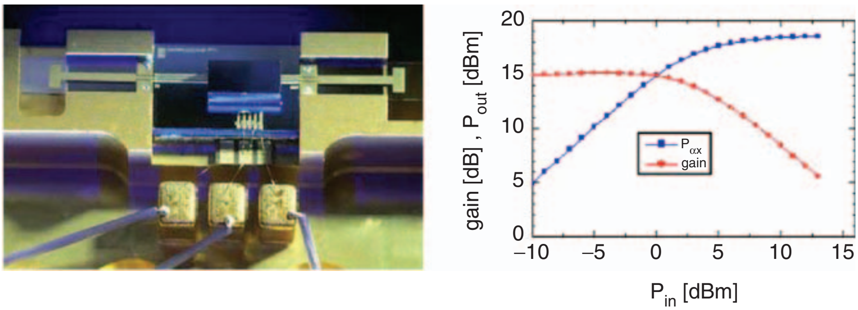

Fig. 10. IAF 94 GHz MPA.

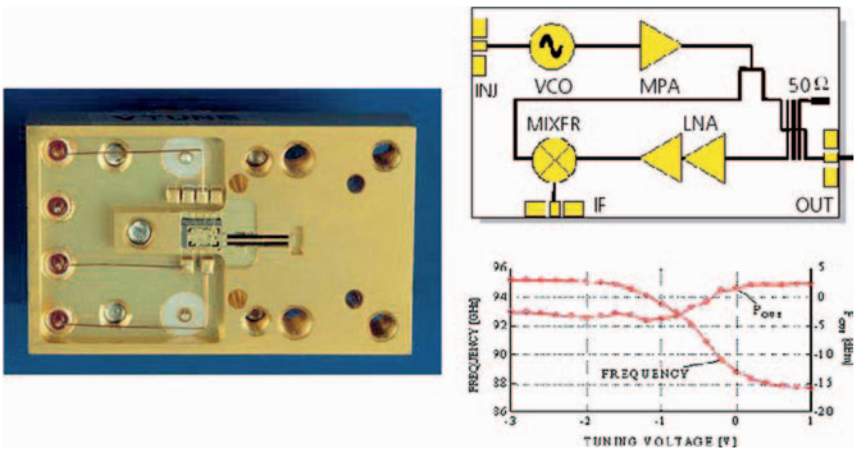

Fig. 11. IAF integrated FMCW.

UP CONVERTER CORE MODULE (UPC)

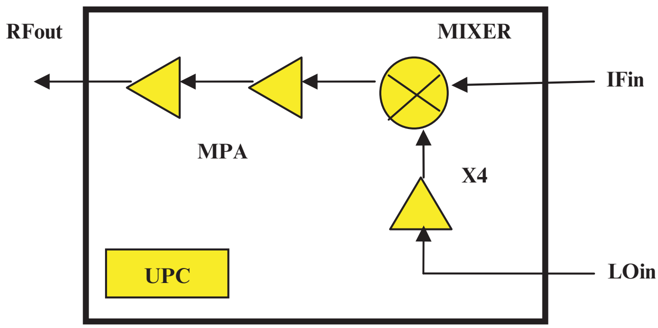

Fig. 12. UPC main characteristics.

DOWN CONVERTER CORE MODULE (DNC)

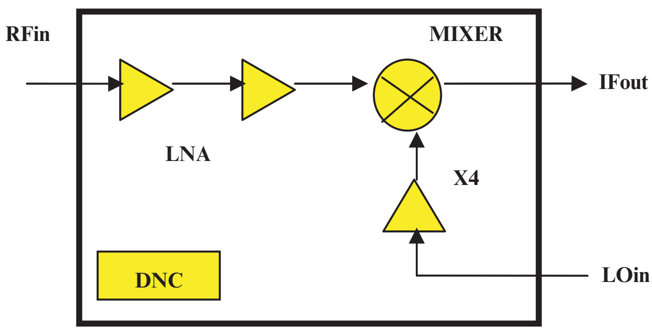

Fig. 13. UPC functional diagram.

MULTIPLIER CORE MODULE (MULT)

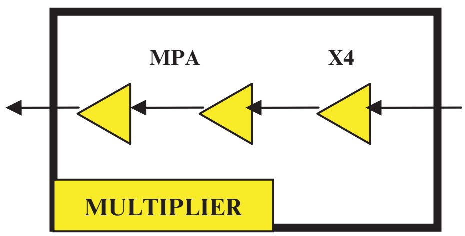

Fig. 14. MULT functional diagram.

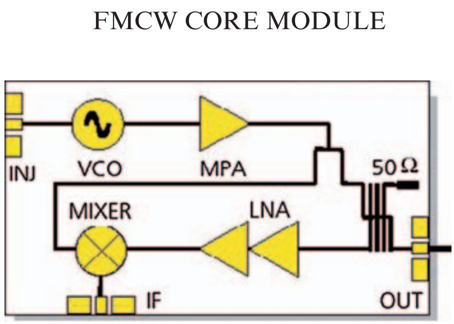

Fig. 15. FMCW functional scheme.

Table 1. UPC main characteristics.

UP Converter (UPC)		
IF in	2÷10,5 GHz	
RF out	75÷96 GHz	
LO in	18÷24 GHz	
RF out Power	> + 15 dBm	Integrated and with transition to WR10
IF-RF Gain	20 dB	

Table 2. DNC main characteristics.

Down Converter (DNC)		
RF in	75 ÷ 96 GHz	
LO in	18 ÷ 24 GHz	
IF out	1,5 ÷ 12,5 GHz	
NF	<4 dB	Integrated and with transition to WR10
RF-IF Gain	16 dB	

Table 3. MULT main characteristics.

Multiplier		
Fin	18÷24 GHz	
F out	73,5÷96 GHz	
Mult. factor	4	
Pout	>15 dBm	Integrated and with transition to WR10

Table 4. FMCW main characteristics.

		FMCW
Fout	94÷96 GHz	
Pout	> +6 dBm	Integrated and with transition to WR10
Tx/Rx isolation	>25 dB	
NF rx	< 10 dB	Integrated and with transition to WR10
Sweeping bandwidth	≤ 200 MHz	
L(f)	−70 dBc /Hz at 100 KHz	

Table 5. Frequency synthesizer main characteristics.

	Frequency Synthesizer
Fout	18000÷24000 MHz
F out/step	40 MHz or less
POUT	>27 dBm
L(f)	< −95 dBc /Hz at 1 KHz −105 dBc/Hz at 100 KHz
Switching time	< 100 nanosec

5 Use of "Core" Modules

Based on these modules an exercise has been done to demonstrate that replacing with these the highlighted parts of the schemes in Figs. 1, 5, 7, 8 is possible to rearrange all the applications just implemented by OCI and to cover all the future demands coming from space and or from homeland security on ground.

The LO in (TX) and LO in (RX) are generated by the same synthesiser switching between two frequencies (Figs. 16–19 and Tables 6–9).

Another application that can be implemented with the same modules is a radiometer operating in W band (see Fig. 20)with the characteristics shown in Table10.

6 Conclusions

Based on the Oerlikon Contraves heritage in the W band gained in about twenty years of activity in different fields a certain number of low mass, small dimensions, low consumption "core" modules have been identified and specified in order to cover all the known possible demands coming from radar sensors, communication links and radiometer.

A demonstration of this is given.

This approach will reduce the development costs of the hardware because all the efforts can be concentrated only in few items that can be used as part of a more complex puzzle.

The system architecture shall be focused on the use of such blocks and will be personalised depending on the application.

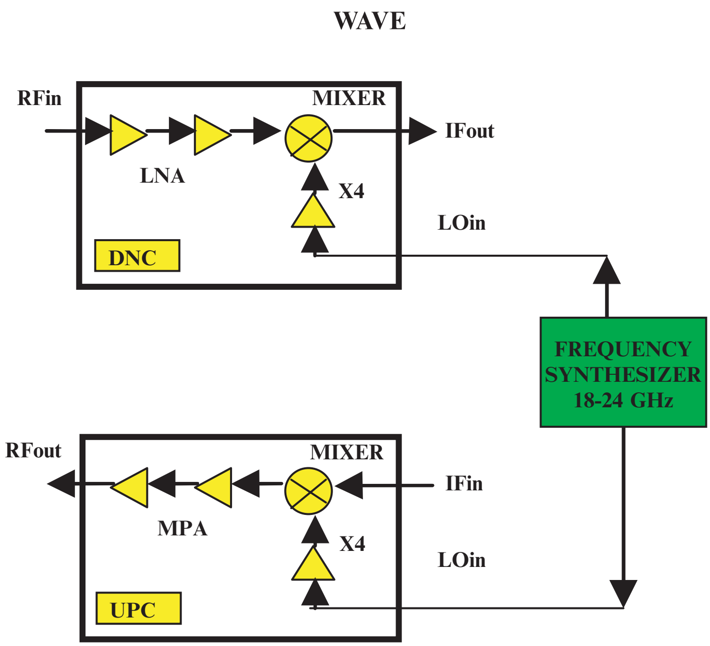

Fig. 16. Wave with core modules functional scheme.

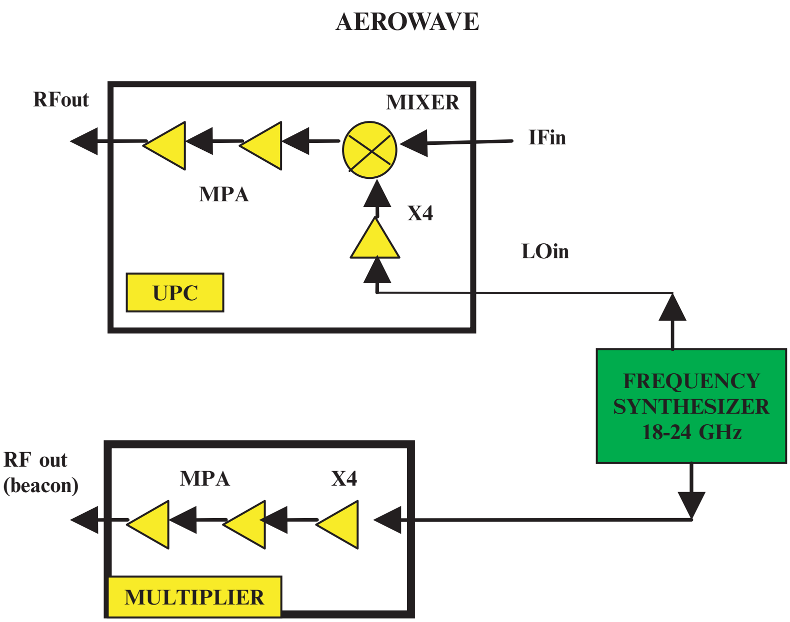

Fig. 17. Aerowave with core modules functional scheme.

SMART HRR MK2

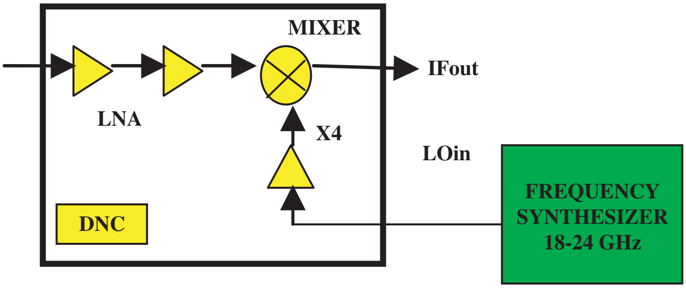

Fig. 18. Smart HRR MK2 with core modules functional scheme.

Limited Area W band FOD Warning Radar

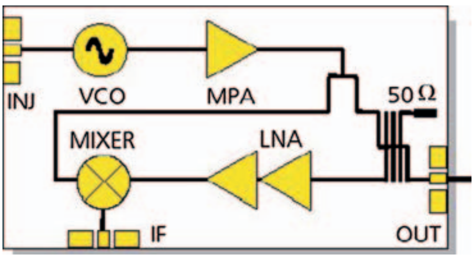

Fig. 19. FOD warning rader with core modulees functional scheme.

Table 6. Wave with core modules main characteristics.

	Wave
RFin (RX)	85500 ± 250 MHz
IF out (Rx)	12000 ± 250 MHz
IF in (TX)	10400 ± 250 MHz
RF out (TX)	75750 ± 250 MHz
POUT (TX)	>15 dBm
NF(Rx)	< 4 dB
LO in (RX)	18380 MHz
Loin (TX)	21540 MHz

Table 7. Wave with core modules main characteristics.

Aerowave		
	IF in (TX)	2000 MHz
	RF out (TX)	84000 MHz
	POUT (TX)	>15 dBm
	LO in (TX)	20500 MHz
	Loin (beacon)	20500 MHz
	RFout (beacon)	82000 MHz
	POUT(beacon)	>+15 dBm

Table 8. Smart HRR MK2 with core modules main characteristics.

	Smart MK2
RF in (RX)	94000–96000 MHz
IF out (RX)	1500 MHz
NF (RX)	<4 dB
LO in	23130–23630 MHz
Lo in step	40 MHz

Table 9. FOD warning rader with core modules functional characteristics.

	W band FOD warning radar
RF out (TX)	94000–96000 MHz
POUT (TX)	>+6 dBm
NF (RX)	<10 dB
VCO sweep BW	200 MHz

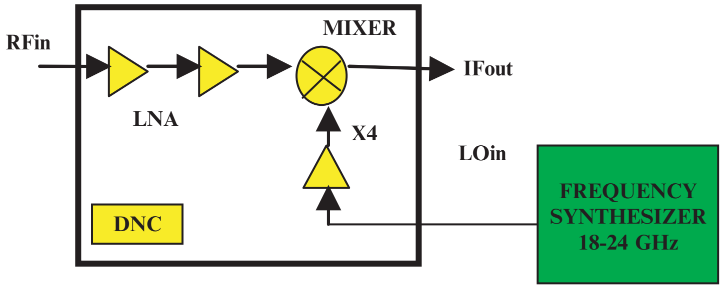

Fig. 20. W band radiometer with core modules functional scheme.

Table 10. W band radiometer with core modules main characteristics.

Radiometer		
	RF in (RX)	75000–96000 MHz
	IF out (RX)	0–250 MHz
	NF (RX)	<4 dB
	LO in	18750–24000 MHz

The use of such miniaturised modules will be fundamental for applications outside the atmosphere for the exploration of Moon and /or Mars.

In particular it can be possible to think to very miniaturised multifunctional payloads to be placed for example on a small rover moving on the Moon surface.

A shared compact hardware can be thought for the guidance of the rover and for communicating big amounts of data to a lunar base station ot to an or-biter rounding around the moon itself.