

A Rigorous Comparison of Microwave Profiling Radiometer Architectures: Compatibility with Future Instrument Demands

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Introduction

On January 27, 2006 Michael L. Exner from Radiometrics Corporation issued a relatively one-sided analysis about the advantages and disadvantages of the two leading radiometer concepts that are nowadays used for profiling radiometer architectures, the 'Frequency Agile Architecture' (FAA, MP-3000A radiometer) by Radiometrics and the 'Direct Detection Filterbank Architecture' (DDFA, RPG-HATPRO) implemented by RPG radiometers. In his somewhat incomplete analysis titled 'A Comparison of Leading Microwave Profiling Radiometer Architectures: Setting the Record Straight' M. Exner utters several statements that need further comments and corrections. The intention of this report is to add information on the subject to give the reader a more complete picture. In particular future instrument demands for ground based radiometers shall be discussed with respect to the capabilities of the two receiver architectures.

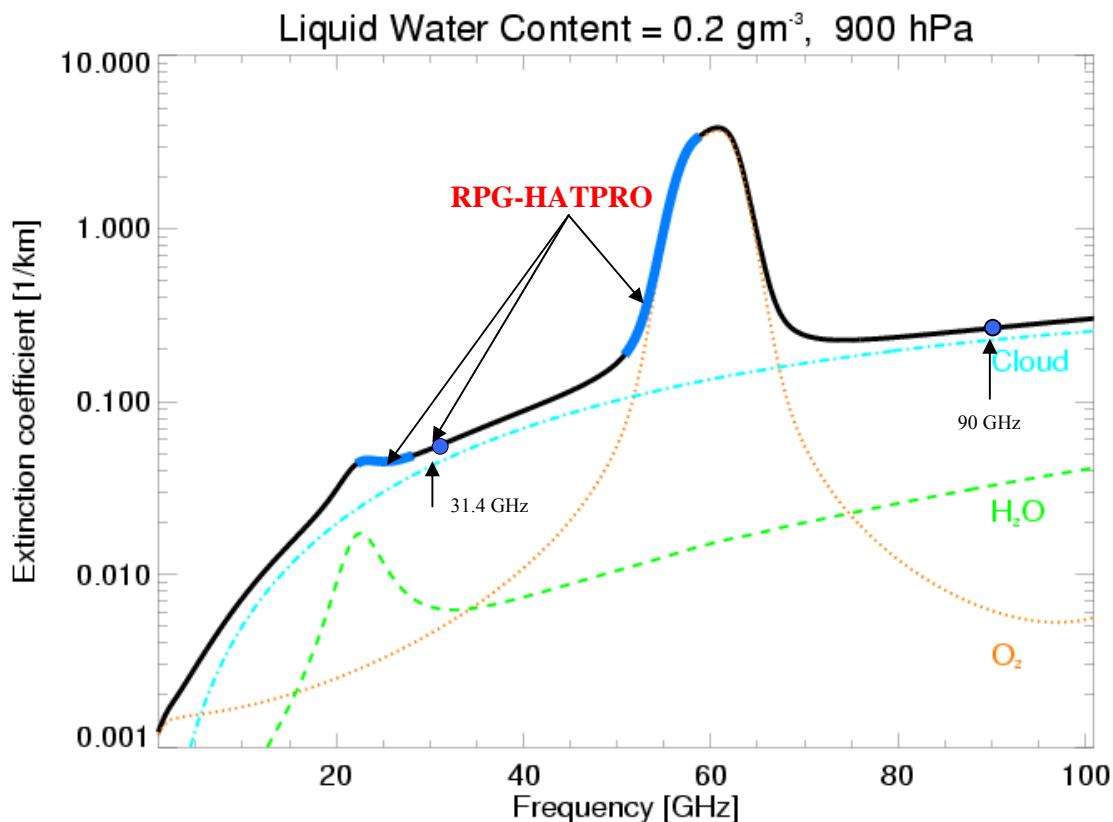


Fig.A: Atmospheric emission of liquid water, water vapour and oxygen. The frequency bands marked in blue are utilized by Radiometrics and RPG radiometers to derive LWP, IWV, Humidity and Temperature Profiles (full troposphere and boundary layer).

For the further discussion it is useful to briefly explain the method of microwave troposphere temperature and humidity profiling.

Atmospheric water vapour profile information is derived from frequency channels covering 6 GHz of the high frequency wing of the pressure broadened, relatively weak water vapour line (22-28 GHz). With a pressure broadening coefficient of about 3 MHz/hPa information between approx. 300 and 1000 hPa can be resolved with the spectral measurements. In the center of the oxygen absorption complex the atmosphere is optically thick and the measured radiation originates from regions close to the radiometer. For frequencies further away from the line center the atmosphere gets more transparent and the channels receive radiation which originates from regions more distant to the radiometer (see Fig.A). Due to the known mixing ratio and the temperature dependence of the absorption coefficient of oxygen, information about the vertical temperature distribution is contained in the channels spanning the 8 GHz of the low frequency side.

For a ground based radiometer pointing to zenith, well defined weighting function peaks for each frequency are observed (see Fig.2.2b). If the elevation angle is lowered, (and hence the atmospheric path is increased), the peaks shift to lower altitudes. This demonstrates the radiometer's superiority in the retrieval of the planetary boundary layer temperature.

The cloud liquid water contribution to the microwave signal increases roughly with the frequency squared. It depends on temperature and is proportional to the third power of the particle radius. Therefore measurements at two channels, one influenced mainly by the water vapor line and one in the 30 GHz window region lead to good estimates of LWP and IWV.

A theoretical analysis shows that the humidity profile information in the water vapour line can be well captured by acquiring 4 channels along the high frequency line wing plus one window channel (e.g. 31.4 GHz) for LWP detection. The determination of accurate temperature profiles requires at least 5 channels along the low frequency wing of the oxygen line.

Tunable single channel vs. multiple parallel channels

At first I want to briefly summarize the two different design concepts:

1. Frequency Agile Architecture (FAA)

The input signal F_s , after passing the feed horn and the noise injection section, is pre-amplified by a RF low noise amplifier and fed into a sub-harmonic mixer (see Fig.1). This mixer is controlled by a tuneable local oscillator (F_{LO}) and generates the two IF sidebands $F_{LO} - F_s$ (lower sideband LSB) and $F_s - F_{LO}$ (upper sideband USB) at its IF output port (this is called a double sideband down-converter). The IF signal is then further amplified, filtered, amplified and detected. A single DC video amplifier boosts the detector voltage into an AD converter for digital processing.

The most complex part of the 'Frequency Agile Architecture' is the tuneable local oscillator (TLO). It contains a base module that uses a reference oscillator signal at its input and generates a frequency stabilized output (a multiple of the reference oscillator signal) which can be set in frequency (PC controlled). The output frequency range of this synthesizer base module is typically around 3-5 GHz and has to be multiplied further up to the 25-30 GHz range needed for the temperature profiler's mixer LO input. These multiplier stages produce other harmonics in addition to the wanted output frequency range, so several filter sections have to 'clean' the frequency spectrum from these harmonics. Furthermore the multiplier stages need sufficient input power so that multiple amplifier stages are required to raise the signal level after each multiplication stage (see Fig.1). The FAA receiver concept is very old

and represents the technology of a radio or spectrum analyzer. Its major disadvantage is that only a single frequency channel can be observed at a time. For atmospheric profiling, the receiver has to step through the required 12 channels one after the other (8% duty cycle).

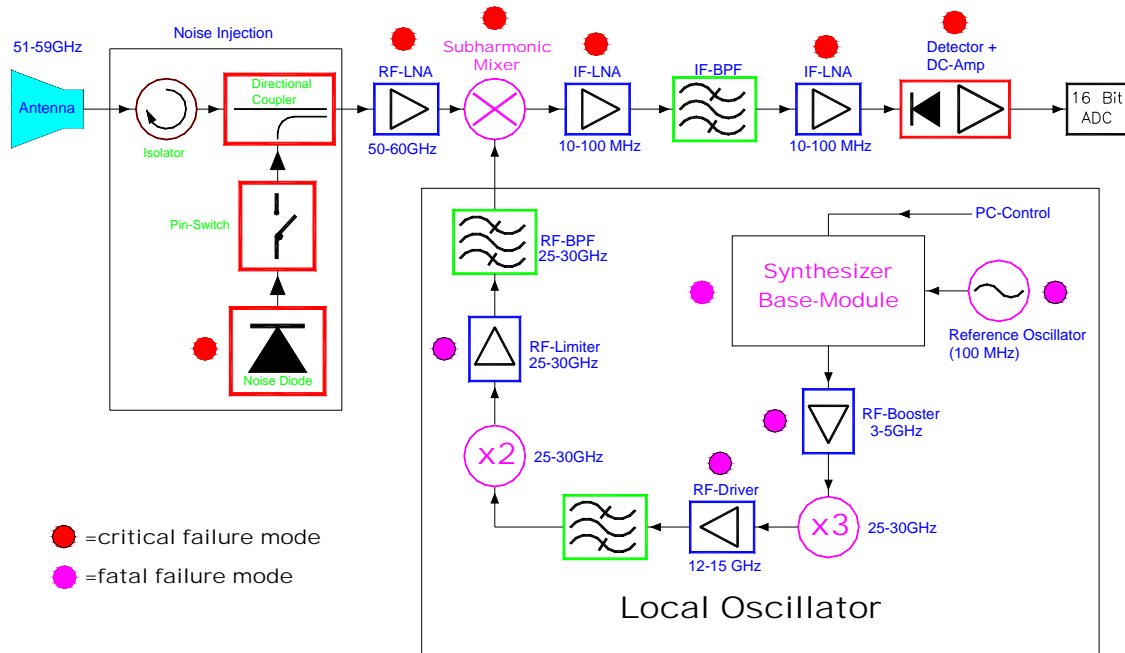


Fig.1: ‘Frequency Agile Architecture’ (FAA) 50-60 GHz receiver layout. The tunable local oscillator is a complex system of reference oscillator, synthesizer module, frequency multipliers, booster amplifiers and harmonics filters. Critical failure components (a failure of such a component leads to a failure of the temp. profiler) are marked with red dots, fatal failure components (a failure of such a component leads to a failure of both profilers) are marked with magenta dots.

2. Direct Detection Filterbank Architecture (DDFA)

Fig. 2 shows a schematic of the receiver system. At the receiver inputs a directional coupler allows for the injection of a precision noise signal generated by an on/off switching calibrated noise source. This noise signal is used to determine system non-linearities (four point method, described in section ‘Calibration’) and system noise temperature drifts during measurements. A low noise amplifier (LNA) boosts the input signal before it is split into 8 branches (only 7 are currently used). The splitters implement waveguide bandpass filters (BPF) with bandwidths and centre frequencies listed in table 1.

f_c [GHz]	22.24	23.04	23.84	25.44	26.24	27.84	31.40	51.26	52.28	53.86	54.94	56.66	57.30	58.00
b[MHz]	230	230	230	230	230	230	230	230	230	230	230	600	1000	2000

Table 1: Channel centre frequencies and corresponding bandwidths.

Each channel has its own detector diode. This allows for a **parallel detection and integration** of all channels which implies a fast scanning of the water vapour and oxygen lines (100% duty cycle). The detector outputs are amplified by an ultra low drift operational amplifier chain and multiplexed to a 16 bit AD converter.

The receivers are based on the direct detection technique without using mixers and local oscillators for signal down conversion. Instead the input signal is directly amplified, filtered and detected. This technology is based on state of the art MMIC low noise amplifiers (LNAs) which have become available throughout the last 6 years.

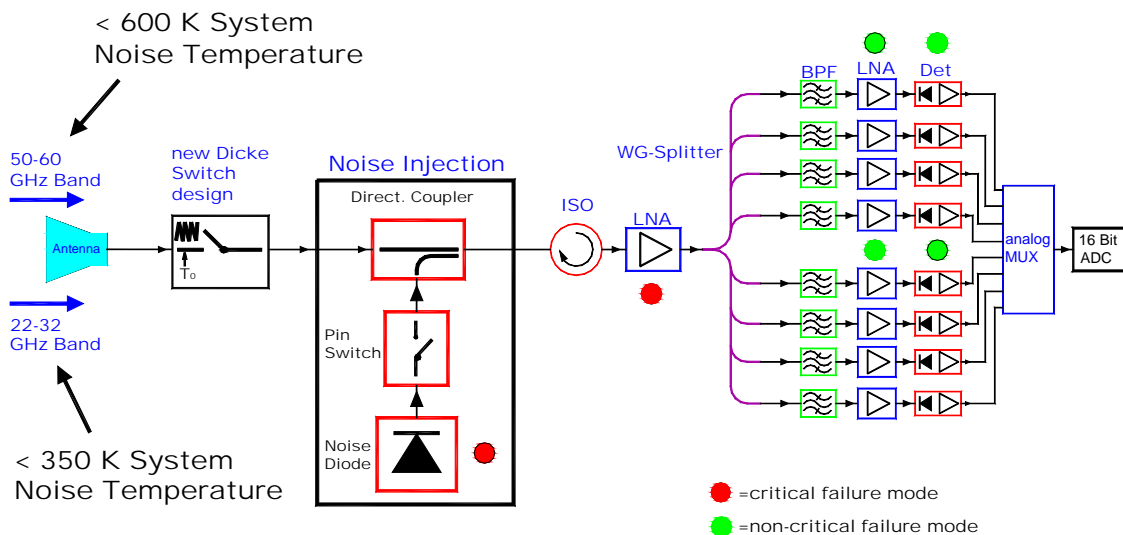


Fig.2: ‘Direct Detection Filterbank Architecture’ (DDFA) receiver layout. The signal is only amplified, split into 7 channels, filtered and all channels are detected in parallel. There is no local oscillator, mixer and IF amplifier chain. Critical failure components (a failure of such a component leads to a failure of the profiler) are marked with red dots, non-critical failure components (a failure of such a component leads to a failure of only a single channel) are marked with green dots.

Comments on M. Exner’s Statements

Statement 1: For an 8-channel receiver, the Filterbank Architecture requires a much higher parts count, resulting in much greater cost and complexity, and the reduced reliability inherent in a solution relying on higher parts count and complexity.

M. Exner has made this statement without a detailed analysis of the two designs and their components. In particular he does not mention the complex tuneable local oscillator in the FAA. By a direct comparison of Fig.1 and Fig.2 it becomes clear that the active components (only these are considered as critical in terms of reliability) parts count of the DDFA is not much higher than for the FAA, taking into account the tuneable local oscillator module with its various internal components. In a DDFA design we count 8 amplifiers and in a FAA design there are 6 (there are also drivers inside the Synthesizer Base Module).

It is true that the DDFA includes much more detector diodes (7) than the FFA design (1) but this is rather an advantage instead of a disadvantage for the following reason: The reliability of a system is usually (e.g. in space projects) analyzed by identifying the failure modes of the system. The system is split into its critical components and the failure of these components is then analyzed in terms of criticality. In Fig.1 and Fig.2 these critical components are marked with dots of different colours. A red dot characterizes a component as ‘critical’ which means that if this component fails, the whole profiler fails. A green dot marks a component as ‘non-critical’ which means that only a single channel fails in the case of the component failure. The worst failures are those labelled as ‘fatal’ (magenta dots). The DDFA design has no such components because it comprises two completely independent profilers. In contrary the FFA

design by Radiometrics uses a single tuneable local oscillator (TLO) to tune both profilers. Therefore, if a component in this TLO fails, both profilers are out of function.

By comparison of the FAA and DDFA designs it follows that **the DDFA design is much less critical (and therefore more reliable) than the FAA design**: There are 6 ‘critical’ components in the FAA but only 2 in the DDFA, there are at least 5 ‘fatal’ components in the FAA but none in the DDFA. Instead the DDFA contains 14 ‘non-critical’ active components that would only lead to a loss of a single channel when one of them fails. The profiler can still be used when a single channel fails because the DDFA design with its 7 channels on the water vapour line and 7 channels on the oxygen line is over-sampling the spectral lines. This means that there are more channels than independent spectral information. Even the MP-3000A with its 4000 possible frequency channels uses only 5 channels on the water vapour line. This is reasonable because by increasing the number of channels there is no increase of information. More channels are simply higher correlated among each other. Therefore the 7 detector diodes of the DDFA design offer redundancy while there is no redundancy at all in the FAA design (no backup if a component fails).

M. Exner’s argument of ‘much greater cost’ for the DDFA is not realistic and ignores the state of the art in MMIC technology and micro-machining. RPG produces all parts (except for semiconductors and power supplies) in-house and uses high precision milling machines and lathes. As an example, Fig.3 shows the temperature profiler’s 7-way splitter including all 7 bandpass filters (BPF). The device is machined within 3 hours to a precision of 2 μm . This mechanical precision sets the BPF’s centre frequency to a precision of < 1.0 MHz which can be further tuned mechanically.

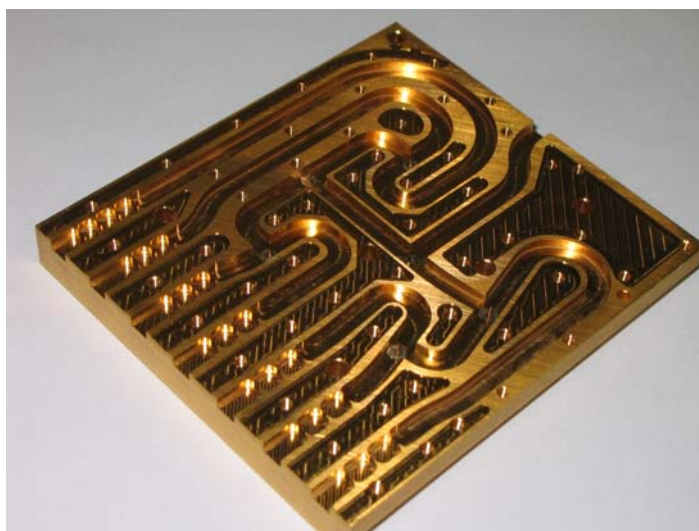


Fig.3: 7-way splitter including all BPFs.

Three years ago the price for Radiometrics’ dual profiler MP-3000 was around 350.000 US\$ while the price for the RPG-HATPRO was only 145.000 US\$. How can this extreme difference be explained when the FAA design is claimed to be so much less complex and costly compared to the DDFA design? In the meantime Radiometrics has lowered prices significantly (without changing the radiometer design significantly) but the MP-3000 is still more expensive than the RPG-HATPRO.

Another quality issue is the **electromagnetic interference** (both, sensitivity to and active generation of interference signals) of both Architectures. It is quite obvious from comparing Fig.1 and Fig.2 that the DDFA cannot be sensitive to external interference caused by strong radio transmission signals (< 100 MHz), mobile phone transmitters, wireless LAN etc.

because it does not use a down-conversion to a low frequency IF band (no mixer!). The humidity profiler in the DDFA cuts off all frequencies < 18 GHz and the temperature profiler's cut off is below 48 GHz. Therefore the DDFA is immune to a huge number of possible external interference signals which the FFA is not. This is one of the major motivations for building direct detection systems. A heterodyne receiver as used by Radiometrics MP-3000 can be disturbed in operation by low frequency jamming interference signals as has been reported from sites where strong transmitters are present. Furthermore the TP/WVP-3000 is not a real passive instrument. Its high power tuneable local oscillator (TLO) significantly leaks out of the instrument by passing the mixer and feed horn to the outside world. This was seen in microwave radiometer inter-comparison campaigns like LAUNCH (Lindenberg / Germany, Sept. – Oct. 2005). The MP-3000 was deployed next to a RPG-HATPRO and produced strong interference signals in the RF signal bands. Fig.4a shows an example of a HATPRO's 26.2 GHz channel water vapour line time series with lots of spikes on it. After the MP-3000 was turned off, the interference signals vanished (Fig.4b).

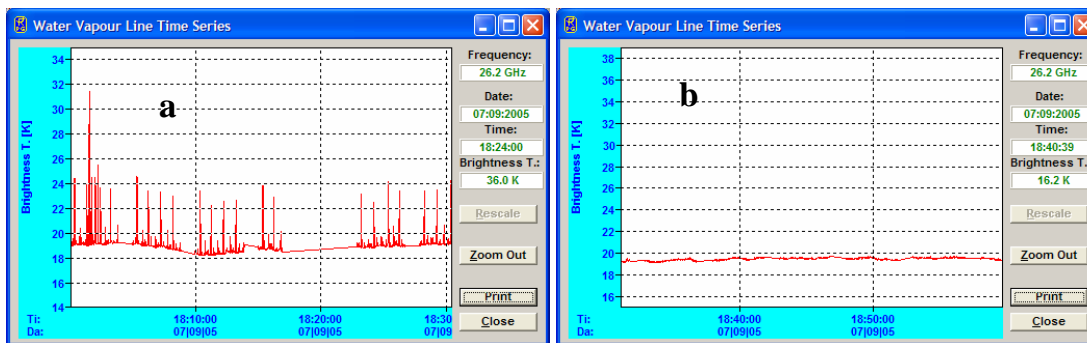


Fig.4a,b: Possible RF interference caused by the tuneable synthesizer of the FFA design.

The DDFA does not incorporate any strong oscillators and can be considered as **purely passive**. The explanation for the FFA RF-interference is the following: The FFA sweeps its tuneable oscillator right to the centre of the reception bands as indicated in Fig.5.

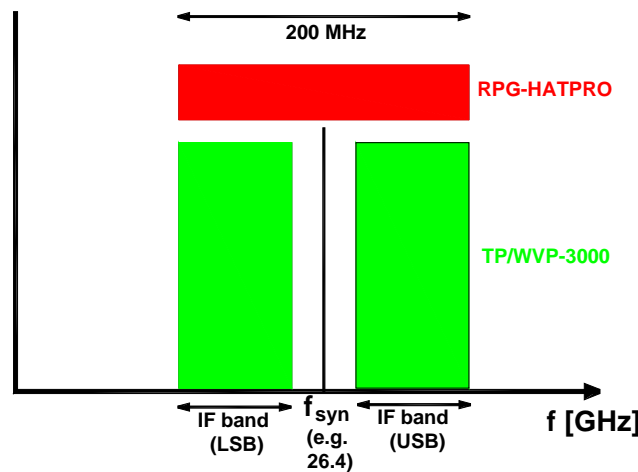


Fig.5: Double sideband frequency scheme of the FFA.

The two sidebands of the receiver are left and right of the strong synthesizer signal and the IF BPF (10-100 MHz) cuts out the reception band's centre. That is why the FFA is not sensitive

to its own oscillator. But other instruments that observe the full reception band will of course 'see' the strong oscillator emission in the centre of the band.

Statement 2: *The only theoretical advantage of the Filterbank Architecture is the shorter observation cycle time.*

This is not the only advantage of that architecture (what does 'only theoretical' mean in this context?) but one of the most valuable ones. The measurement duty cycle of each DDFA channel is close to 100% (parallel detection) while the duty cycle of each FFA channel is very poor (less than 10%) because the TLO scans the spectral lines (water vapour and oxygen) sequentially and not in parallel as the DDFA does. The duty cycle determines the integration times of the system. An absolute calibration of an FFA takes typically 30 minutes while it needs only 2 minutes for the DDFA. This also is valid for all other calibrations like automatic gain and noise calibrations. Even worse, the signal to noise ratio during the measurement phase is deteriorated by a factor of 4 compared to the DDFA design simply due to less integration time / channel (the noise level is proportional to $1/\sqrt{T}$ when T is the integration time). This is consistent with inter-comparison data from both types of instruments.

The biggest advantage of shorter integration time becomes obvious for the boundary layer temperature profiling technique. For the boundary layer temperature profiles (up to 1500 m altitude) the vertical resolution of the profiles can be improved from 200m (measured in zenith observations) to 50m (!) by scanning the atmosphere in elevation instead of only performing zenith observations. In particular low level inversions can ONLY be resolved satisfactorily well by this method. Fig.6a,b illustrates the need of very low noise level for the boundary layer temperature profiling technique. The brightness temperature (T_B) resolution required for a reasonably accurate resolution of the inversion is 0.1K RMS which is achieved by the DDFA in 30 seconds / angle so that a full scan takes 3 minutes. The FFA would need more than 10 times as long for this measurement precision (more than 35 minutes!) which is not realistic in practice. Thus the FFA receivers are not capable of measuring accurately enough in this mode to achieve the high vertical profile resolution.

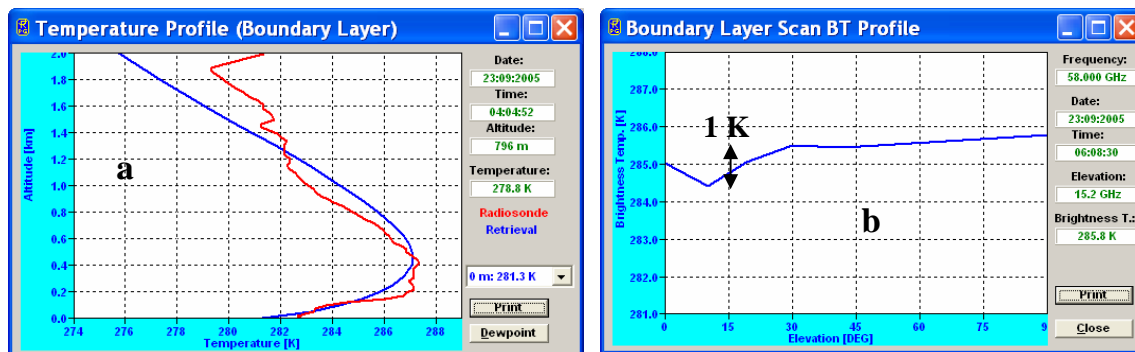


Fig.6a,b: *Low level temperature inversion (a) and associated brightness temperature elevation scan (b). The T_B variation in (b) is only 1 K @58 GHz for the full elevation scan (5° to 90°).*

Another important application of fast scanning and short integration cycles is the measurement of 2-D humidity fields. When the DDFA radiometer is equipped with an optional azimuth positioner, it is capable of performing a full 2-D sky scan (measuring the humidity field) within 5 minutes. The sampling time in this mode is 0.6 seconds, so the radiometer is producing 400 measurement samples during this scan. Full sky imaging is extremely useful for current and future instruments. In particular the 2-D distribution of humidity is of great interest. Humidity variations of up to 20% have been observed in a single

full sky observation. With the slow scanning capabilities of the FFA these measurements appear to be quite difficult, if not impossible.

The analysis of cloud structure and cloud variability also requires an LWP sampling rate in the order of 1 second and is not offered by the FFA.

M. Exner's statement '*Thus, the Frequency Agile Architecture provides a far better solution in nearly all ground-based applications*' neglects these interesting and important applications.

1/f Noise Suppression

Radiometrics claims to be able to reduce the 1/f receiver noise better than other system designers who are all using noise injection, Dicke switching and so on. Their method is not explained and remains to be somewhat obscure. **Fact is that all methods for noise suppression work equally well for the FFA and for the DDFA.** They do not depend on whether a system is sequentially scanning or measuring in parallel. The calibration front ends in Fig.1 and Fig.2 are almost identical except for the additional Dicke switch system in the DDFA which replaces the normally used ambient temperature target and can be switched within a few milliseconds (instead of moving the mirror to the ambient target). With the Dicke switch added to the receivers the DDFA is able to perform full automatic calibration cycles without encountering any target. The radiometer always keeps pointing to the scene. Also the DDFA uses noise injection techniques in order to suppress 1/f noise which works quite efficiently.

Channel Centre Frequency Determination

In order to determine the centre frequency of a double sideband mixer response in the Frequency Agile Architecture (see Fig.5) it is not sufficient to simply measure the frequency stability of the local oscillator. When M. Exner states the stability of the master oscillator to be 2ppm (44 kHz @ 22 GHz and 118 kHz @ 59 GHz) he assumes that this is the precision of the bandpass centre frequency. But this is not the case because the FAA is performing a **double sideband** measurement and the mixer response is never the same in both sidebands. This can be seen from Fig.7 which shows a typical mixer conversion as a function of frequency. Conversion loss changes of about 1 dB/GHz (a factor of 1.25 / GHz or 1.05 / 200 MHz) are quite common. This implies that the two sidebands in Fig.5 might differ in amplitude by 5% which changes the centre frequency of the total bandpass (lower + upper sideband) by up to 10 MHz. Due to M. Exner this results in a T_B error of more than 1 K. The frequency precision of the master oscillator only reflects the stability of the centre frequency shift. The shift itself does not change much (because of the oscillator stability) but it can be significantly high! The centre frequency shifts caused by the different sideband responses (see Fig.8) can vary from channel to channel and are hard to measure. Actually they are much more difficult to measure than the single sideband bandpass characteristics of the Direct Detection Filterbank Architecture RF filters which can be adjusted to better than 1 MHz by precision machining and post-tuning. We have thus shown in detail that the centre frequency definition of a DDFA bandpass is not at all worse than the centre frequency precision of the FAA. Mixer measurements (in particular double sideband) are more complicated than direct detection measurements.

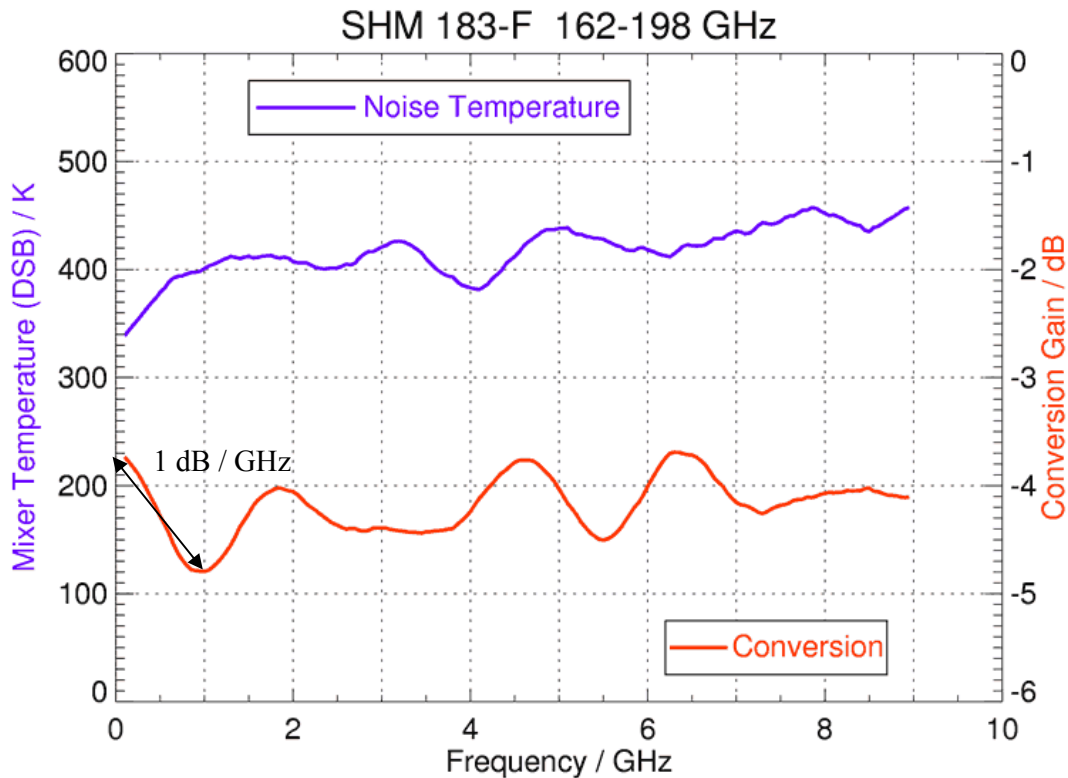


Fig.7: The conversion loss of a mixer is frequency dependent (red curve). This implies that the mixer response in the upper and lower sideband (in a double sideband measurement) is not necessarily the same.

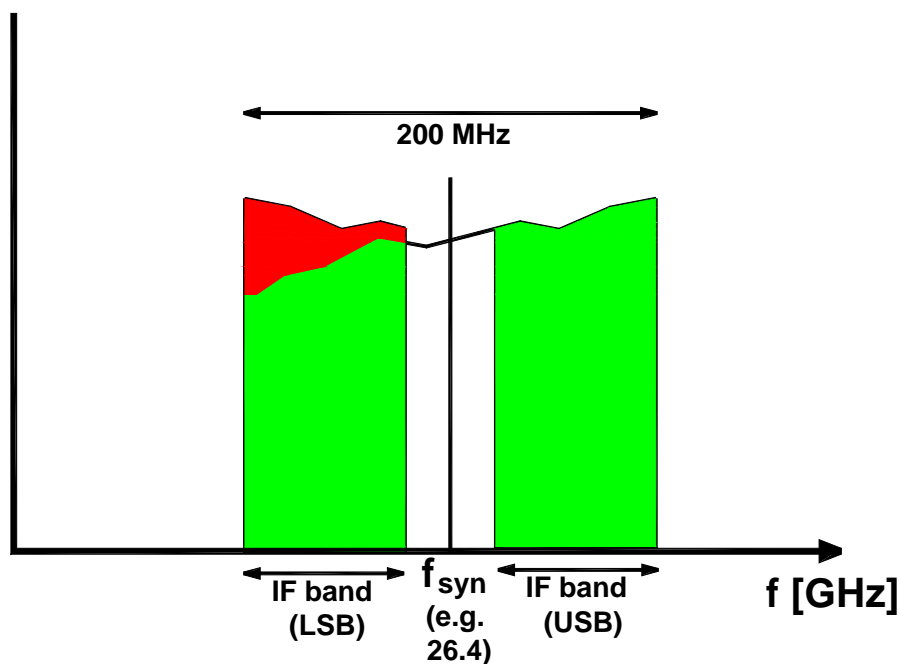


Fig.8: Sideband imbalance caused by the frequency dependence of mixer conversion. The ratio of the red area to the green area is a measure for the centre frequency shift.

In addition, the RF-LNA (low noise amplifier) at the receiver input has not exactly the same gain in the two sidebands. Therefore even more sideband imbalance may occur in the FFA design. Since the DDFA allows for the direct measurement and tuning of each individual bandpass - including the amplifiers' gain variations - it is possible to compensate these effects. Due to the single bandpass used in the FFA IF-chain, an individual bandpass correction is not feasible.

Channel Bandwidth Determination

Statement: *'It is far less complex and less expensive to manufacture and calibrate a bandpass filter operating in the 10-500 MHz range than to obtain the same bandwidth in a filter with a center frequency of 60 GHz. At 60 GHz, the required ratio of bandwidth to centre frequency is less than 1%, an extremely demanding requirement for mm wave mechanical filters.'*

This statement does not reflect the capabilities of modern micro-machining and the mechanical precision that is achievable. As mentioned above RPG machines a 7 way splitter including all 7 bandpass filters for the 50-60 GHz profiler in 3 hours. These filters can be produced up to 200 GHz with relative bandwidths of down to 0.3%. This is not 'extremely demanding' because resonant waveguide filters are the ideal filter type for narrow relative bandwidth. These filters are inherently high-Q devices because there is no lossy dielectric material involved. The gold plated filters are filled with air. In contrary the low frequency BPFs are usually filled with dielectric materials that might change with time by absorption of humidity or other aging effects. The bandpass characteristics of the DDFA RF-filters are extremely long term stable because the temperature stabilized filters contain no materials that might change in performance. The argument of higher cost for these filters is irrelevant because the RF-filters of the DDFA are small and can be integrated in a single package. There are no SMA connectors or cables involved in the design, which makes the whole receiver extremely stable (after transportation of the radiometer, an absolute calibration with liquid nitrogen is not required!). In sharp contrast the low frequency IF amplifier and filter chain of the FAA has to use SMA connectors and RF cables which imply long term instabilities. As a consequence the FAA has to be calibrated much more often than the DDFA.

Channel Spectral Symmetry

Statement: *'If the passband shape is not symmetrical about the center, it has the effect of biasing the observation to favour frequencies above or below the nominal center frequency'*

Due to the non-symmetrical mixer response in the two sidebands, as shown in Fig.8 the Frequency Agile Architecture itself does not produce symmetrical passband shapes. The non-symmetry is caused by the details of the mixer design and is hard to predict. Furthermore the non-symmetry effects are frequency dependent and vary for different channels. The FAA therefore cannot claim to produce highly symmetric bandpasses about the nominal centre frequencies. The conclusion is that **the real centre frequencies of the FAA deviate at least as much from the nominal centre frequencies as of the DDFA**. While we can easily measure the precise spectral shape of the single sideband bandpasses of the DDFA (by using a spectrum analyzer), the non-symmetric mixer response in the two sidebands of the FFA is much harder to be measured. The mixer folds the two sidebands into a single IF band and one needs a precision calibrated monochromatic source in the RF-band to calibrate the sideband imbalance. It is questionable that Radiometrics performs these complicated calibrations in order to correct the real centre frequencies. M. Exner's statement *'In fact, the Frequency Agile*

Architecture requires no tuning at all to set the channel center frequency, bandwidth and spectral symmetry.’ neglects non-symmetric sideband responses in a double sideband system.

Radio Frequency Interference

Statement: *’Thus, if Radio Frequency Interference (RFI) is encountered, it is a relatively simple matter to chose different observation frequencies to avoid RFI. No hardware change is required. In contrast, the Filterbank Architecture is “hardwired” to a limited set of frequencies that cannot be changed without complicated factory rework.’*”

‘Relatively simple matter’ in practice means to change the complete set of retrieval algorithms (the coefficient matrices that invert brightness temperature observations to produce profiles of atmospheric temperature and moisture). When changing a frequency, the radiometer has to be re-calibrated and the retrievals have to be replaced by new ones because the original retrievals included the frequency that has been replaced due to RFI. As mentioned above, RPG’s DDFA over-samples the water vapour line (7 channels, Radiometrics uses 5 channels) and oxygen line (also 7 channels). If there is an RFI present at a certain frequency, the strategy is to simply omit that channel and create a new set of retrievals without that channel. The radiometer does not have to be re-calibrated. Thus the effort (create new retrievals) for solving the RFI problem is the same in the FAA and DDFA approaches.

A comparable problem of RFI is the HFI (High Frequency Interference) in the down-converted band. This interference occurs at the intermediate frequencies (IF), e.g. 10-500 MHz. The FFA is not immune to this interference because it down-converts the RF signals to an IF frequency band right into this highly populated band (e.g. radio transmitters, etc.). This can make a deployment of the FAA problematic at sites with high power transmitters (e.g. mountains). This has been confirmed by various users. The DDFA is not sensitive to this interference type, because it only operates in the RF-bands.

Operational Flexibility

Statement: *’Compared to the fixed tuned, limited channels inherent in a Filterbank Architecture, the Frequency Agile Architecture offers much greater observation flexibility.’*

The DDFA was designed for profiling the earth’s atmosphere with highest efficiency and accuracy that is possible with a ground based instrument. About a decade ago, atmospheric science researchers optimized the frequency sets (and the number of frequencies) for observations of the oxygen line and water vapour line with respect to profiling water vapour and temperature of the atmosphere. The details can be found in:

J. Güldner, D. Spänkuch, 2001: ‘Remote sensing of the thermodynamic state of the atmospheric boundary layer by ground-based microwave radiometry’, J. Atmos. Oceanic Technol., 18, 925-933.

Since then, profiling radiometers (also Radiometrics’) are using these optimized frequency sets. We already discussed in detail the advantages of a fast sampling to meet future demands on ground based instruments and the higher accuracy of boundary layer temperature observation, which is only possible due to the short integration times of the DDFA. Switching to the FAA concept would mean to give up the more effective data acquisition of the DDFA just to gain the possibility of simulating other radiometers with different frequencies for comparison. It simply depends on the customer’s preferences. Some may want to monitor the atmospheric parameters as effective and accurate as possible, others may want to play around

with frequency shifting for radiometer inter-comparison. Our DDFA design is focussing on the first group of researchers.

Urban Legends Debunked

Statement1: *‘The use of a single mixer and local oscillator in the Frequency Agile Architecture eliminates the need for dozens of other more expensive components required in the Filterbank Architecture.’*

We already discussed that the parts counts of the FAA and DDFA are not extremely different. M. Exner conceals the high complexity of the tuneable oscillator, that has to cover a wide relative bandwidth (30%) without the slightest spurious harmonic getting out of the oscillator (a lot of filtering is required). We have analyzed the criticality of both designs and found, that the FAA comprises more ‘critical’ and ‘fatal critical’ components due to missing redundancy in the concept.

Again, when the DDFA components are said to be so much more expensive, why then is the FFA not cheaper than the DDFA?

Statement2: *‘..., the channel center frequency, bandwidth and symmetry achievable with the Frequency Agile Architecture is far superior to the mechanically tuned Filterbank Architecture.’*

We have already shown that this is not true. The belief that the high tuneable oscillator frequency precision is also the center frequency precision of the profiler is just an illusion, due to the non-symmetric mixer sideband conversion losses and RF-amplifier gain variations across the channel bandpass.

Statement3: *‘The fact is, the one VHF IF Bandpass filter required in the Frequency Agile Architecture costs less than 5% of all the mm wave filters required in the Filterbank Architecture.’*

How does M. Exner know about RPGs production costs for RF filters? He certainly knows the cost of the VHF IF-BPF. Maybe, if one buys single RF-filters, this can be quite expensive. But that is not the approach in the DDFA. Instead, RPG machines all these filters integrated into a single block, which is extremely effective and compact. RPG can produce the 7-splitter + 7 BPF block for about the same price as a VHF filter would cost. The production costs strongly depend on whether the manufacturer has the right tools for this production or has to buy everything from other suppliers. Since RPG manufactures these receivers all in-house, the various parts are perfectly matched together without the need for connectors or cables.

Statement4: *‘There is no evidence whatsoever that cell phones interfere with Radiometrics radiometers’*

It might be true that so far there is no evidence of cell phone interference with Radiometrics radiometers. **But there is definitely evidence that strong radio transmitters can interfere with Radiometrics radiometers based on the FAA concept and that Radiometrics radiometers can disturb other instrumentation operating on the same frequency bands.**

Statement5: *‘Wider bandwidth for upper V band channels is apparently needed in the case of the Filterbank Architecture to help overcome its higher 1/f limited noise.’*

The DDFA does effectively suppress 1/f noise with its noise injection technique. This is illustrated in Fig.9. The Allan variance plot shows clearly that there is no 1/f noise contribution up to 1000 seconds integration time. Actually the comparison of measurement noise between the two Architectures has resulted in a comparable noise amplitude for a 1

second sampling rate of the DDFA and a 12 seconds sampling rate of the FAA, as one would expect from the radiometer formula.

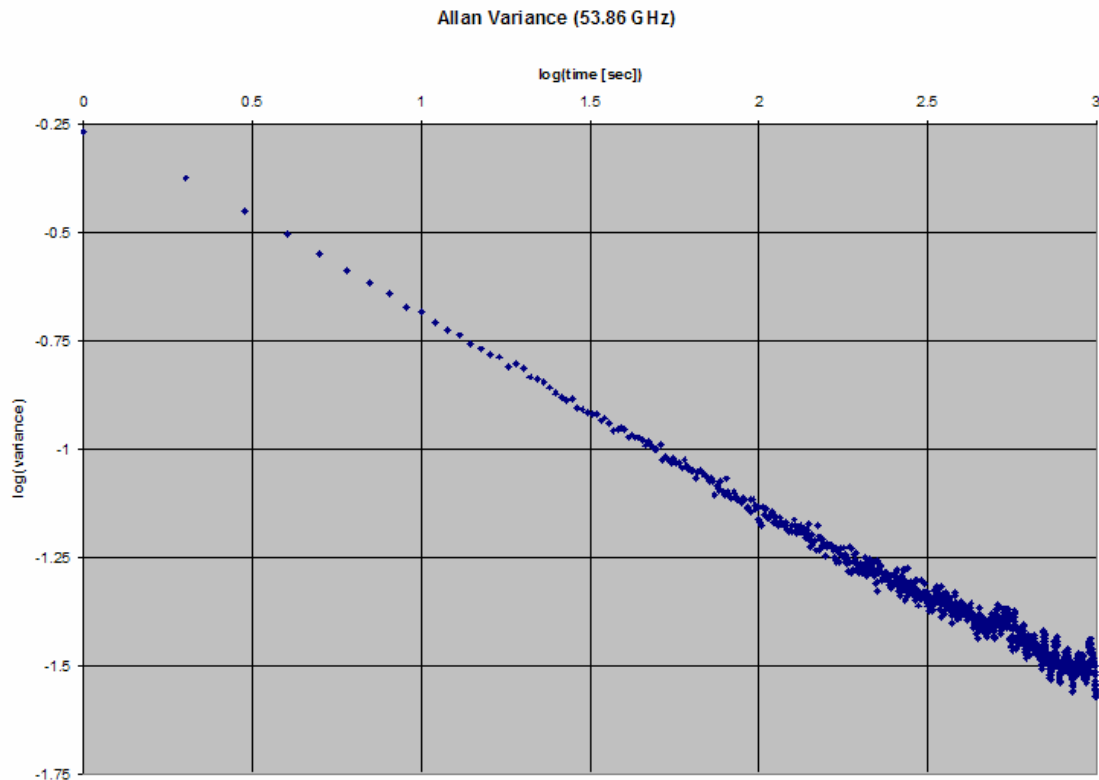


Fig.9: Allan variance plot of the 52.86 GHz DDFA channel. The measurement reveals that the noise injection method removes all 1/f noise contributions effectively. The noise level drops down at least to integration times of 1000 seconds!

Statement6: ‘For virtually all ground-based microwave radiometer applications, the Frequency Agile Architecture patented by Radiometrics provides higher performance at lower cost compared to Filterbank Architecture.’

In this report we have shown in detail that there are important applications (e.g. high vertical resolution in the boundary layer, cloud structure analysis, 2-D humidity field scanning, etc.) that can only be handled with a fast sampling of atmospheric brightness temperature measurements. We do not see why the FAA shall provide higher performance than the DDFA in all other applications like full troposphere temperature profiling or humidity profiling, IWV measurements etc. Real measurement comparisons have shown very similar performance for both architectures.

Summary

Major performance differences between Radiometrics MP-3000A and the RPG-HATPRO dual profilers:

Topic	MP-3000A	RPG-HATPRO
Sampling Rate	10 seconds	1 second
Antenna beam resolution	6° (Hum. Profiler), 2.5°	3.5° (Hum. Profiler), 1.8°

	(Temp. Profiler)	(Temp. Profiler)
Full Sky Mapping Capability	No	Yes (5 min. duration)
Boundary Layer Temperature resolution	200 m	50 m
Boundary Layer Temperature accuracy	0.5 K RMS	0.25 K RMS
Liquid water profiling technique (*)	neural network	PARCWAPT expert system
Seasonal retrieval support	No	Yes
Time for absolute calibration	30-60 minutes	2 minutes
Absolute calibration interval	6 month and after transportation	6 month
Dicke switch calibration standard	No	Yes
Long term TB drift	0.5 K / year	0.2 K / year
Receiver Technology	FAA	DDFA
Channels	4000, serial scanning	14, fixed, parallel scanning
Channels for profiling	5 (Hum. Prof), 7(Temp. Prof)	7 (Hum. Prof), 7(Temp. Prof)
Radiometric Noise [10 sec. integration time]	0.2 K RMS	0.06 K RMS
Thermal receiver stability	0.5 K	0.03 K
Dew Blower Heater system (prevents formation of liquid water on microwave window under fog conditions)	No	Yes
Elevation scanning for IR radiometer	No	Yes
Maximum number of IR channels	1	2
Channel centre frequency accuracy	10 MHz	0.5 MHz
Internal file backup system (1 GByte capacity flash)	No	Yes
Measurement without external PC possible (Auto-Run)	No	Yes
Level 0 data availability (raw data)	No	Yes
Frequency extension possible (Master / Slave radiometers)	No	Yes
Data cable, max. length	copper, 30 m	fiber optics, 1400 m
Serial data speed	9.600 Baud	115.000 Baud
Spurious signal emission (not purely passive instrument)	Yes	No
Immunity to HF interference (Radio Transmitters, TV etc.)	No	Yes

(*): see separate report