Implementation Feasibility Considerations for a Hyperspectral Microwave Sensor

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BLUF

- Q: Is a hyperspectral microwave sounder feasible?
- YES, it is technologically feasible/practical to build a hyperspectral microwave sounder that can provide dozens, 100s, or possibly even 1000s of channels
- HOWEVER, the resource limits of the spacecraft and/or overall system will force you to make performance tradeoffs

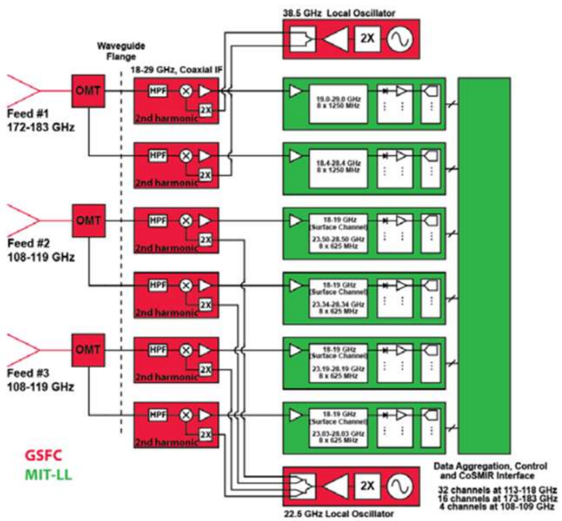
A note on what qualifies as "hyperspectral"

- The definition of what qualifies as "hyperspectral" is not universal
- Compare with non-hyperspectral ATMS
  - 5 humidity sounding channels
  - 6 temperature sounding channels
  - Some channels have multiple passbands → adds info or improves signal-to-noise
- Example: "HyMAS" airborne hyperspectral sounder concept (52 channels) from ~2015
  - 8 humidity sounding channels
  - 9 temperature sounding channels
  - Does this "qualify" as being "hyperspectral" in 2021 or a future-LEO timeframe?
  - In any case, it is a very useful point design for reference when we consider designs with 100s of channels

Example: Analog Hyperspectral MW Sounder

HyMAS airborne concept

Overall block diagram

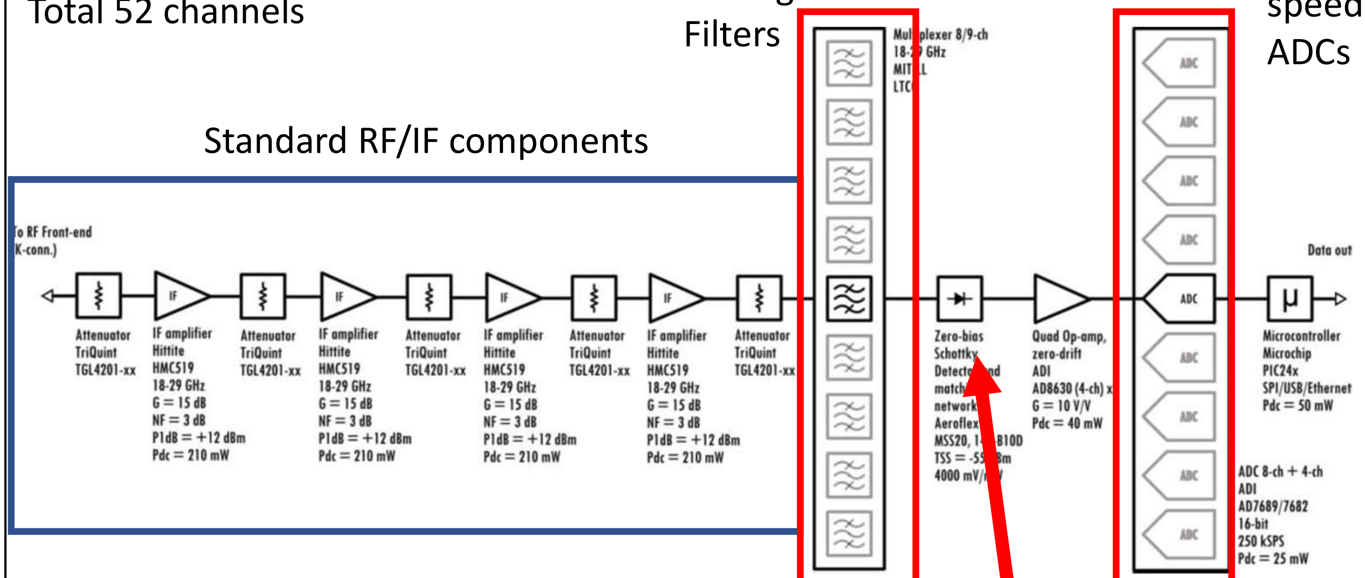


Zoomed IF section (1 of 6)
8-9 channels each
Total 52 channels

Standard RF/IF components

Multiple Analog Filters

Low speed ADCs



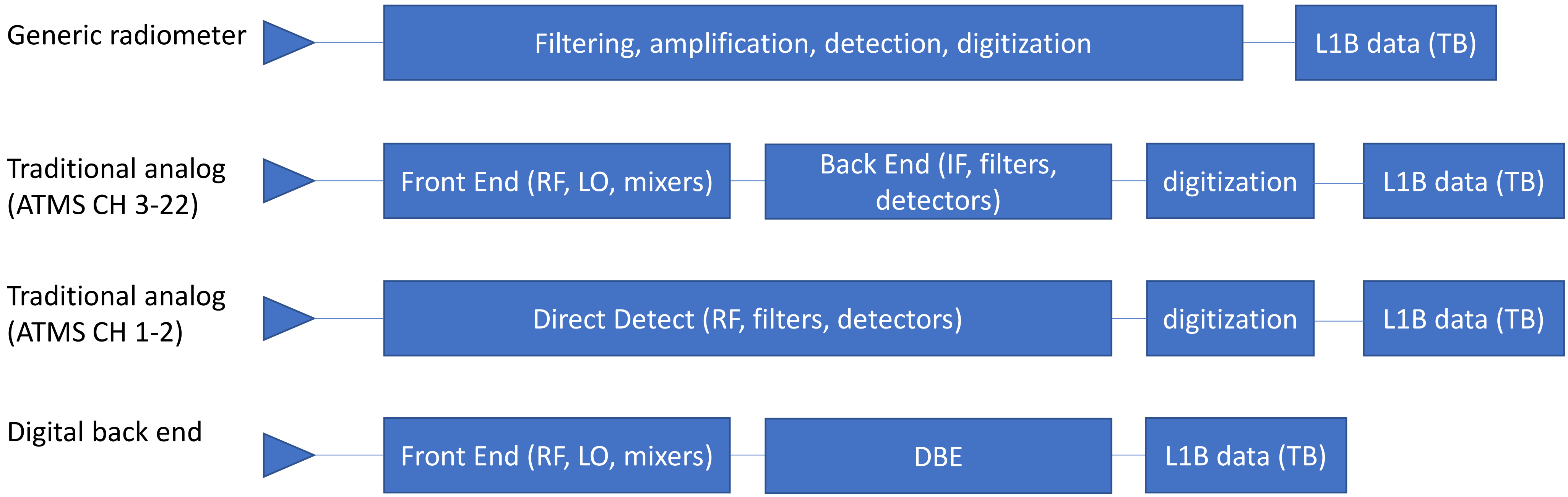
Analog Detector

52 copies of certain components → larger SWaP unless very low-loss components are available

Implementation/Performance Considerations

a) Total bandwidth, bandwidth for each band, MHz per channel, A/D speed & number of bits;
b) Narrower channels → finer vertical resolution→ degraded NEDT → larger error
c) More channels = more data & more computation →on-board or on-ground? →Downlink capacity (instantaneous, orbit average), duty cycle, ground station coverage, latency
d) # bands, # antennas, spatial resolution ←→ aperture size, overall package size, antenna bandwidth tradeoffs when combining bands
e) Spatial resolution → orbit altitude → global coverage → # sats → intercalibration requirements (instantaneous & over program life)
f) Size of package/antennas → on-board cal target? → cal design (examples: ATMS, TROPICS, pseudo-correlation, etc) → many trades

Digital vs. Analog HyMS Topologies



Digital Back-Ends (DBE)

- DBE capabilities keep increasing (fast)
- Space-qualified options already exist and more expected (<5 years)
- Digital designs for HyMS have huge advantages vs. analog designs
  - Flexibility, smaller size & weight vs. analog equivalent
  - More stable calibration; new options for inter-calibration
  - Possibility of also doing RFI detection
- In the future-LEO timeframe, HyMS will be based on DBE designs
- But, digital designs also generate challenges
  - Larger data volume & rates
  - Need for intercalibration (applies to all short-lived sats, not unique to HyMS)
  - Typical DBE will require significant power & thermal accommodation (extra 10s to 100s of watts of power and waste heat)
- You can always scale back to fit resources, but performance must also scale back (# channels, bandwidths, NEDT, etc)
- While the hardware exists to build a HyMS, end-to-end testing has yet to be done with real-world hyperspectral observations → risk reduction needed

A note about RFI detection using DBEs

- DBEs can definitely be used for RFI detection in addition to Hyperspectral sounding, but…
  - DBE resources are finite
  - RFI detection (especially for 5G) requires more sophisticated computation that just doing sounding alone
  - So, a DBE of a given capacity that does both simultaneously will need to sacrifice some sounding capability in order to additionally perform the RFI detection
  - And, the data volume increase per MHz is larger when adding RFI capability than when adding Hyperspectral capability alone
- The SMAP DBE works well, but
  - the nature of RFI in SMAP's band is different (easier to detect)
  - SMAP's algorithm is way more tolerant of RFI than NWP (12K vs. 0.1K)
  - HyMS bandwidths are 100x larger than SMAP's
  - HyMS will require more computation to try to detect RFI and data volumes will be large
  - We should not expect SMAP-like RFI detection performance for 5G –type RFI
  - 5G RFI detection algorithms is still low TRL; another ripe area for risk reduction…and we could do that at the same time as end-to-end testing of a hyperspectral concept; kill 2 birds with 1.5 stones