ADVANCED INSTRUMENTS:

NEW TECHNOLOGY AND CONCEPTS FOR RADIOMETERS

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ABSTRACT

Advanced microwave components now enable considerably smaller and lighter radiometers to be built for spaceborne systems than hitherto. Likewise, extensive but light antenna structures are underway and large aperture systems, e.g. for L-band soil moisture sensing, rapidly become viable. Correlation radiometers, featuring fast digital correlators, find use in synthetic aperture radiometers achieving good ground resolution and imaging capability through digital processing, as well as in polarimetric radiometers measuring the full set of Stokes parameters. Finally, digital radiometers with sub-harmonic sampling have become possible due to the rapid developments within digital technology. There is a bright future for microwave radiometers!

INTRODUCTION

Instruments can be advanced in different senses. A conceptually classic instrument may be improved using advanced technology in order to reduce resource demands (power, weight, bulk) - and this is highly important for everybody within the radiometer community in these times of "smaller and cheaper": the chance of launching a mission increases with decreasing weight and power figures! Or an instrument can be advanced in the sense that it is based on new advanced concepts or designs. Oftentimes an advanced design is intimately linked with advances in technology, closing the loop back to the previous point. In the following examples are given concerning both classes of instruments.

ADVANCED TECHNOLOGY IN SCANNERS

For three decades we have now seen a variety of imaging microwave radiometer systems in space. An interesting topic is always - and especially so for spaceborne instruments - the trade-off between instrument capabilities and resource (power, weight) demands.

The famous SMMR launched in 1978 represents technology of the 70'es. It had 10 radiometers spanning the frequency range from 6.6 GHz to 37 GHz. The receivers had a weight of 30 Kg and consumed 65 W of power, i.e. 3 Kg & 6.5 W per receiver on average. The radiometers were constructed using individual waveguide components joined together using sections of waveguide. The 80'es saw the development of the SSM/I series of multifrequency, imaging radiometers. The same technology was used, now featuring 3 Kg & 5 W per receiver. A dramatic change happened during the 90'es where MMIC technology became practical even at microwave frequencies. The JASON radiometer system serves the frequencies 18.2, 23.8, and 34 GHz, and features individual receiver units about 9 x 6 x 3 cm in size, with a weight of 400 g and a power consumption of 2 W. A unit includes everything from Dicke switch to A/D converter. TRW has designed and built these MMIC radiometers. Recent developments for a next generation JASON-like instrument saves additional resources by combining several receivers into one package: a 3-radiometer Dicke system (18.7, 21, and 34 GHz) is integrated into one unit about 8 x 10 x 2.5 cm with a weight of 550 g and consuming 4 W. This unit is developed by Quinstar Technologies under JPL contract, see Fig. 1. Again, everything from Dicke switches to A/D converters are included.

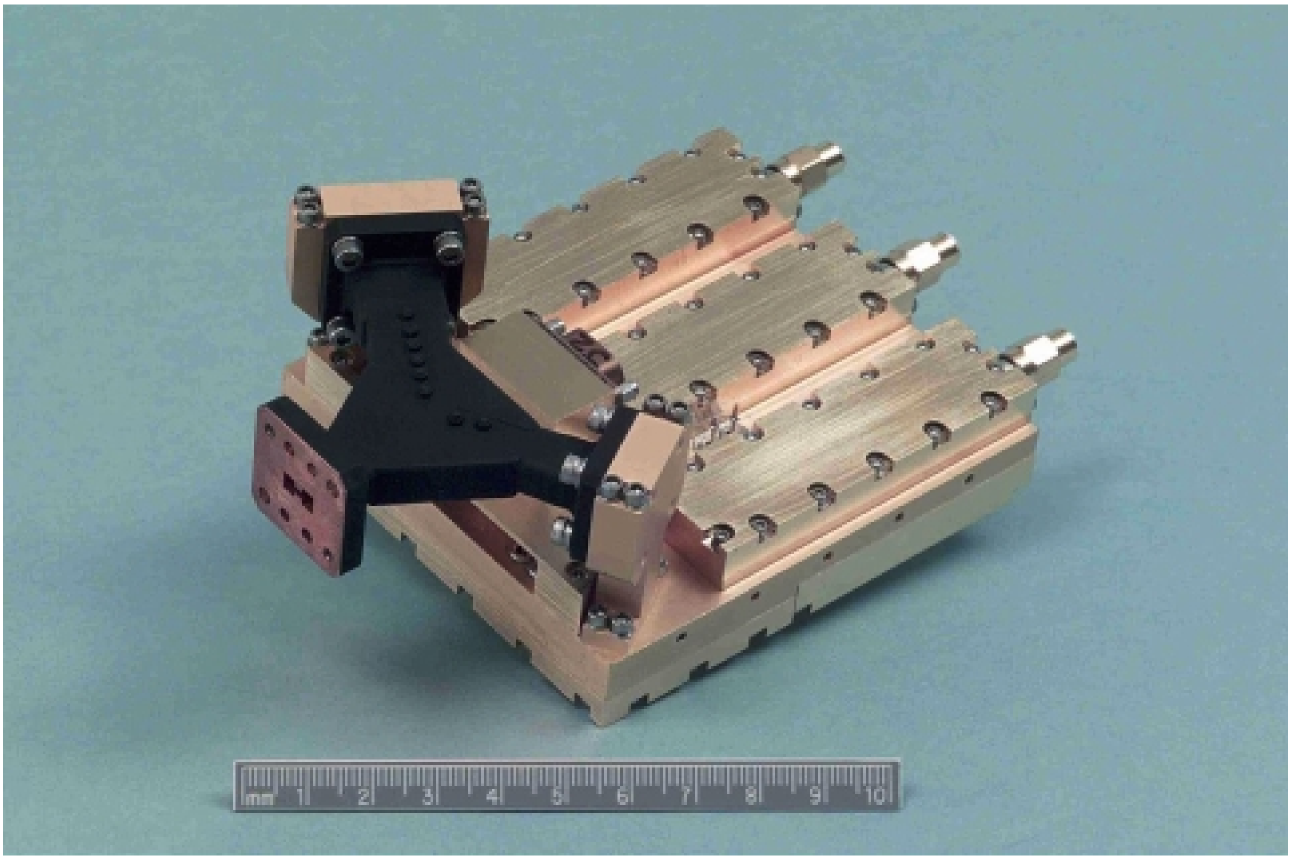

Fig. 1: 3-frequency MMIC radiometer by JPL / Quinstar Technologies

Another important resource driver is the antenna reflector. Low weight structures have been built, and it is known that a 2 m carbon fiber composite dish weighing 12 Kg has been launched into space. Similarly, a 3 m dish for a future ocean mission has been designed with a weight of 21 Kg. It seems like a present rule-of-thumb, concerning the weight of solid, high frequency reflectors, states a weight around 3 to 4 Kg per square meter.

A complete radiometer system of course includes several other units than what have been discussed above. Anyway, significant reductions in resource demands over the years can be noted. TMI (a version of SSM/I having additional 11 GHz channels) features 5 dual polarization channels (10 radiometers) spanning frequencies from 11 to 86 GHz with a weight of 54 Kg and a power consumption of 64 W. A recent design for a GPM (Global Precipitation Mission) radiometer system, having practically the same frequencies and antenna size as TMI, calls for 33 Kg and 30 W.

PUSHBROOM RADIOMETERS

The 1980'es saw the development of the pushbroom concept in order to achieve imaging capabilities without having moving (mechanical scan) structures. This is especially important in space and at the low end of the microwave spectrum where antenna apertures become overwhelmingly large for any decent ground resolution, cf. L-band radiometry for sea salinity / soil moisture sensing. The two challenging technology issues was: the many radiometers (could be more than 100), and the large antenna structures supporting apertures up to the 30 m range. The many receivers were never considered a showstopper as MMIC were being developed at the time, and later developments as described above have indeed confirmed that attitude. The huge antenna structure was a problem! But substantial developments have taken place, and now there is no doubt about the feasibility (but the price tag may still be high). A 12 m mesh antenna, having a weight of 85 Kg and being able to serve an L-band radiometer, has been flown in space. A 90 m upgrade has been designed. A communication satellite having two 19 x 17 m antennas has been designed and the antennas demonstrated. A 14 m inflatable parabolic reflector antenna has been built and successfully deployed in space. In parallel herewith a 27 x 36 m inflatable torus reflector antenna, directly intended for pushbroom applications, has been designed. The weight is 211 Kg.

CORRELATION RADIOMETERS

Beginning in the 80'es, and very much enhanced in the 90'es, correlation radiometers have been a hot issue. A correlation radiometer is basically 2 identical radiometers that, in addition to measuring the usual brightness temperature signals presented to their inputs, also measures the correlation between these input signals, see Fig. 2. The applications of such radiometers are in two different subject areas: synthetic aperture radiometers (where a large solid antenna reflector is traded for a lighter structure with many small antenna elements; each antenna element output is cross correlated with all others, and image formation is done by digital processing), and polarimetric radiometers (where the full Stokes vector is found by measuring the vertical and horizontal fields and the complex correlation between these). This of course presents some new requirements to the radiometers, and coherent operation, like in a SAR receiver, must be ensured: phase must be preserved through the receivers, and the 2 parallel channels must exhibit similar amplitude and phase characteristics. An obvious example is, that super-heterodyne systems must use one common local oscillator.

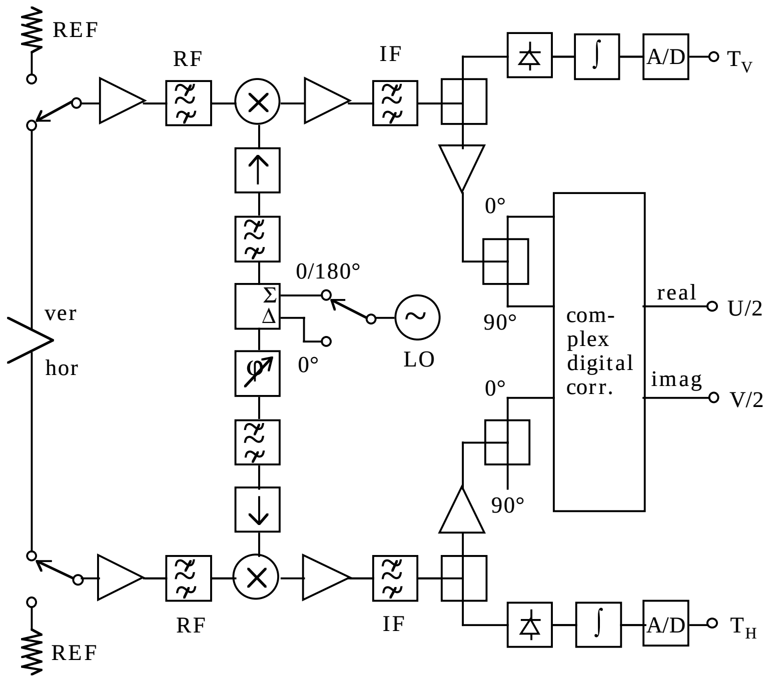

Fig. 2: Typical correlation radiometer

Analog correlators are possible and have been used, but digital systems are playing the major role nowadays. A typical microwave correlation radiometer system will feature traditional down-conversion using a mixer and a local oscillator. Typical radiometer bandwidths ranging from a few 10's of MHz to several hundreds of MHz can be handled by present day A/D converter systems. In some applications only one-bit conversion is needed and the process is relatively easy to handle, but also multibit applications are readily handled by off-the-shelf components like for example 8 bit converters having 1.6 GHz bandwidth.

DIGITAL RADIOMETER WITH SUB-HARMONIC SAMPLING

The availability of fast converters, and the fact that Nyquist states a sampling rate twice the bandwidth (and not twice the highest frequency), opens a new avenue within radiometer design: digital radiometers featuring sub-harmonic sampling. This way, L-band radiometers have been designed and built. No analog down-conversion takes place, the A/D converter directly samples the L-band signal around 1.4 GHz, the sampling rate being typically around 60 MHz in order to properly sample the typically 27 MHz band of an L-band radiometer. The requirement to the A/D conversion unit is of course that the input band encompass the microwave frequency and that the sampling time jitter is compatible with the input frequency (and not just the sampling frequency). The salient features of such a digital radiometer are: flexibility, stability, less microwave hardware, potentially smaller and less power. Flexibility comes from the fact that provided some oversampling of the input band, the analog filters can be relaxed (simpler design, smaller, cheaper) and further filtering be carried out digitally. This could then be adaptive bearing in mind the interference problems that must be foreseen at some frequencies (like L-band). By proper design digital circuitry are inherently more stable than analog circuitry. Less microwave hardware is evident as no local oscillator and mixers are needed. Properly designed and integrated digital hardware is typically smaller and lighter than normal microwave hardware (here excluding the relatively expensive MMIC technology). So far, no power is saved: although the local oscillator is often quite power consuming, so are generally fast digital chips. But the development concerning reduced volume and power consumption is dramatic for digital hardware.

SYNTHETIC APERTURE RADIOMETERS

As an alternative to pushbroom systems (devised to solve the problem with imagers and large apertures at for example L-band) the synthetic aperture radiometer, also known as the two-dimensional interferometric radiometer, is a viable option. In this concept a large antenna is substituted by a number of small antenna elements properly distributed within the aperture. Each element has its own radiometer, and the outputs of all possible pairs of radiometers are cross-correlated to find the visibility function, which is the Fourier transform of the brightness temperature scene being observed. Large antennas are traded for many receivers and very many correlators, which comes out favorably with today's technology.

Fig. 3 illustrates a 1.4 GHz system with 73 antenna elements and radiometers on three 4.5 m long arms. In the central unit 2628 correlators are found. The system acts as a radio camera, and as the satellite moves forward, a wide swath is covered – without mechanical movement. The ground resolution is comparable to that associated with a filled aperture having a radius equal to an arm length, in this case around 50 km from an 800 km orbit. Less structure, hence weight, is evident, and the arms are easily folded for integration with a modest sized launcher. An instrument like this, known as SMOS, is presently being developed by ESA as their second Earth Explorer Opportunity Mission to be launched in 2006.

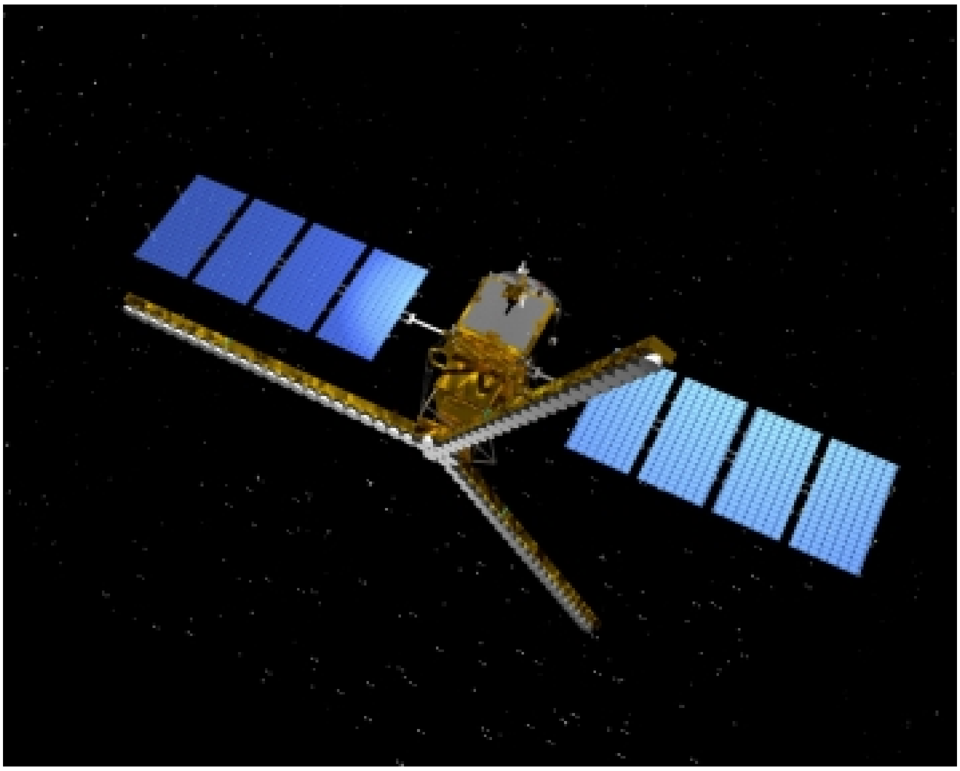

Fig. 3: Synthetic Aperture Radiometer System