



Memo 57

SKA system definition and costing : a first approach

S. Horiuchi, A. Chippendale, P.Hall
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Abstract. Despite the existence of several antenna concepts for the SKA much of the instrument's top-level design can be described in terms that are common to all concepts. This is not surprising of course since a great deal of the design process centres on transporting and processing common information volumes and rates derived from prescribed fields-of-view, observing bandwidths etc. In this short paper we outline a first attempt at a top-level description, and at estimating the basic performance and cost of putative arrays. The first version of the estimation tool is directed mainly at engineers but as the package is refined the tools should prove useful to a wider group. Most importantly, the system definition process has already provided a framework for continuing system design and development, principally via task forces within the SKA International Engineering Working Group.

1. Introduction

The present study, which is a work in progress, attempts to standardize SKA system definition and costing as much as possible. It owes much to the authors of SKA whitepapers (ISPO Concept Whitepapers, 2002, 2003) since it is essentially a synthesis of the strongest elements of the system designs and analyses therein. The publication of these whitepapers, detailing complete concepts for the instrument, was an important milestone in focusing discussion on key SKA science, engineering and economic issues. Whilst the whitepapers contributed much to the understanding of SKA challenges, the differences between various adopted design assumptions, costing models and performance metrics made comparison of results difficult. This work aims to make direct comparisons easier.

Cost is particularly important in current SKA discussions and an assumption in our work is that the overall cost of the SKA can be described as illustrated in Figure 1. This superposition model does not fully map the coupling between branches but, at this early stage of the project, it should nevertheless yield a much-improved estimate of the instrument cost. The parallel paths also fit well to the natural divisions of expertise and resources currently available. The work described in this short paper is concerned with the "component model" path of Figure 1.

Whilst one can imagine very complex approaches to system design and estimation, our work focuses on building up descriptions of the SKA from an elementary signal path using common sub-systems. The tools developed have already been used to give a total cost estimate of a generic small paraboloid concept (similar to the US LNSD proposal) for the SKA. Continuing efforts will refine the simple initial model used,

and extend the work to other concepts. Current versions of the description and estimation tools are available on the Web (Horiuchi, 2004); this paper gives some background to their development.

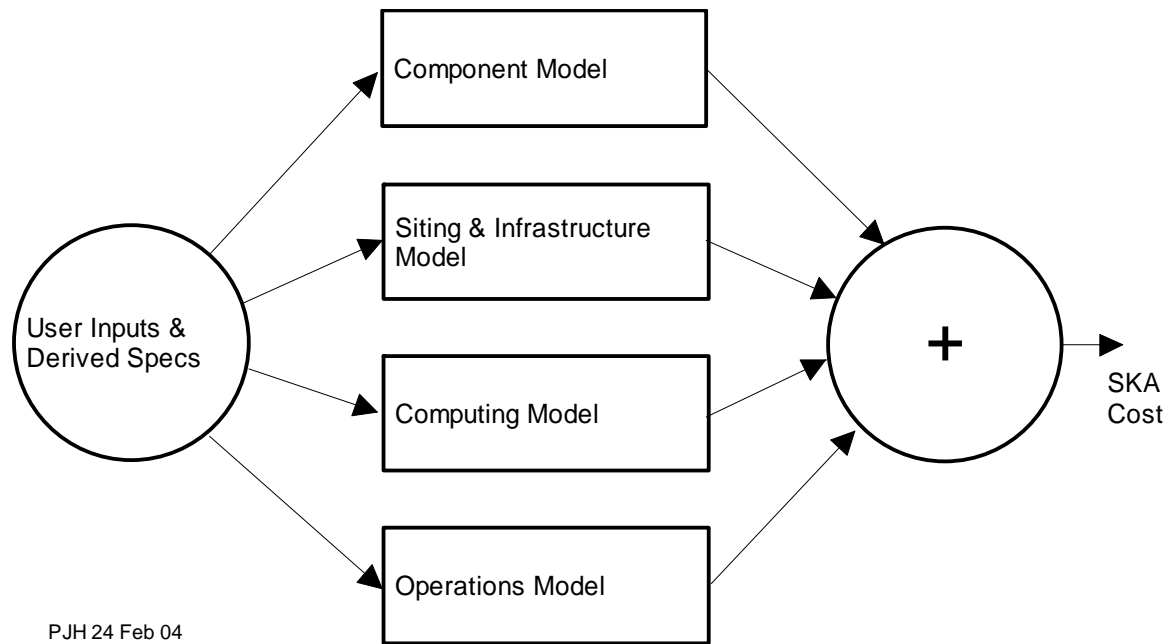


Figure 1. A simple costing model for the SKA.

2. The Signal Path

We define an elemental signal path that applies to all SKA concepts and that localizes, as far as possible, concept-specific descriptions. Figure 2 shows the model used, together with the grouping of major components within sub-systems. Concept-specific definitions are contained within the antenna sub-system, with the other blocks being equally applicable to, say, an aperture plane array, or a dish with a focal plane array. In some concepts some blocks are “straight-through” paths – there is no RF beam-forming in the present LNSD concept, for example. Similarly, not all concepts invoke sophisticated station-level signal processing; in the implementation adopted it is a simple matter to specify more extensive central processing in lieu of the highly distributed architecture.

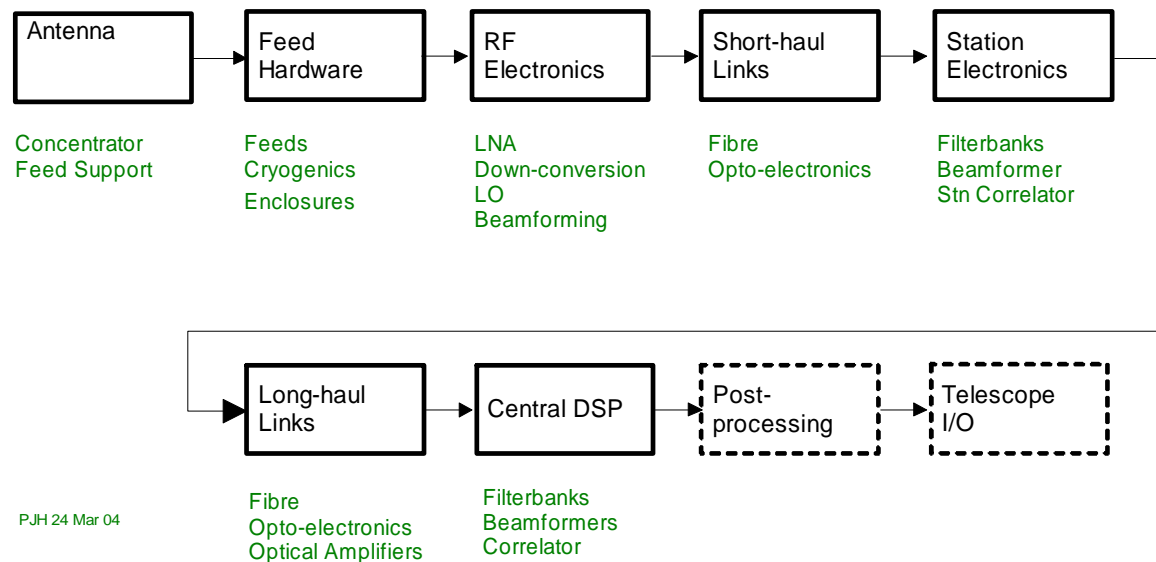


Figure 2. A system model for the SKA showing sub-systems and major components of the component model in Figure 1. Although the component model computes performance and costs only to the output of the central DSP stages, the two subsequent boxes (part of the SKA computing model) are shown for completeness.

In general, Figure 2 shows the signal flow in the smallest “unit” of the SKA, namely from:

- One polarization receptor in one observing band;
- One feed;
- One RF beam (where RF beam-forming is done);
- One antenna (or patch of phased array tiles);
- One unit signal transmission and processing bandwidth;
- One SKA station; and
- One distance regime of the SKA.

Our overall approach is to reduce, as early as possible in the signal chain, the SKA design challenge to one of a more generic data transport and processing problem. By describing a given SKA concept and configuration from key input data (e.g. operating frequency range, observing bandwidths, total field-of-view, distribution of collecting area, etc), we build up a detailed model of the telescope, allowing us to produce, for example, a cost estimate based on a count of major components and assumed unit costs.

We also recognize the need to include hybrid, or composite, SKA concepts in the modelling. The most obvious hybrid is one where separate high and low-frequency antennas are used, and where optimum signal distribution and processing is done within each frequency domain. Again, we take the simplest approach of building up a picture of the telescope from elemental paths. Figure 3 illustrates a two-band hybrid SKA, where T1 and T2 are different antenna technologies. This example also shows our approach to describing the distribution of collecting area in the telescope. The

adoption of fixed distance regimes simplifies computation of quantities (such as optical fibre lengths) by utilizing mean parameters for each region. Whilst the number of area divisions is flexible, Figure 3 shows a four-regime model. A simplified approach is taken to specifying the correlator, wherein the cost is assumed to be a function of the number of correlated entities (antennas, stations, ...) and the data rate per input. Internal correlator complexity and cost are described by models involving the required signal routing complexity and the rate of multiply-accumulate operations.

We recognized early the virtues of maintaining a descriptive formalism in models such as those shown in Figures 2 and 3. Apart from global descriptors of the telescope taken directly from, or derived immediately from, user inputs, sub-systems derive their inputs from the preceding sub-system and pass their outputs to the subsequent one. This, and related precautions, allows easy “object-oriented” system description. For reporting purposes, intermediate results (e.g. number of particular components within a sub-system) are retained in a central database.

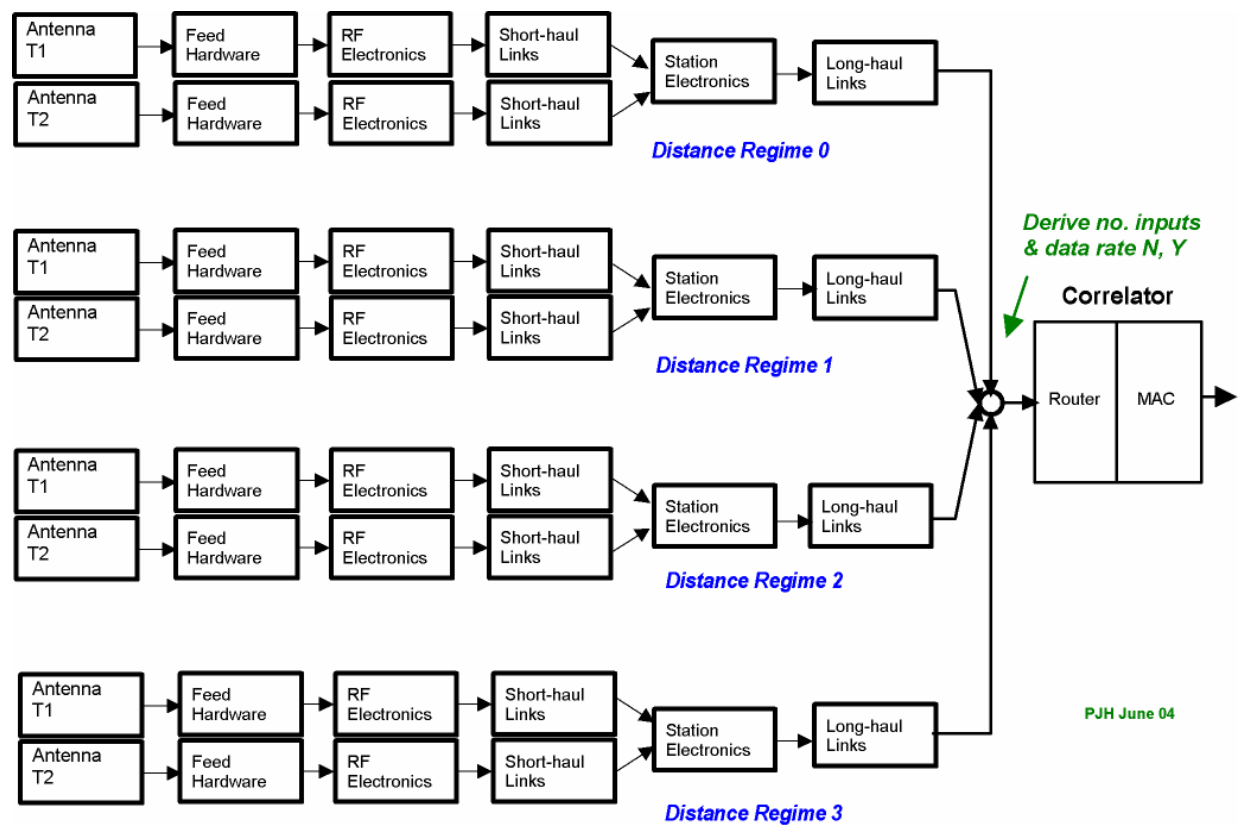


Figure 3. Example of an SKA design based on two antenna technologies (T1 and T2) and evaluated on the basis of four area distribution regimes.

While the descriptions can accommodate many concepts and physical realizations it is interesting to look at block diagrams for some of the possible arrangements. For example, Figure 4 shows a fairly general diagram applicable to e.g. an SKA using small dishes and focal plane arrays (to give multiple fields-of-view). The antennas are grouped into stations, at least outside the central 5 km diameter core region. A central FX correlator is used but much of the frequency domain processing, including achromatic station beam-forming and RFI excision, is done at the station prior to long-haul signal transmission.

3. Software Tools

Previous attempts at SKA performance and cost estimation [e.g. Weinreb and D'addario 2001, Hall et al., 2002, Bunton 2003] have used spreadsheet approaches. As the sophistication of the modelling increases, the maintainability and readability of spreadsheets suffer, as does the ability to incorporate computation units into program structures (loops etc.) We sought a more elegant and maintainable approach but recognized that, with the limited man-power available, there is presently no capacity to support individual users in a distributed software arrangement.

While several approaches are no doubt feasible, we settled on a web-based tool employing an HTML user interface, a compute engine based on the PHP scripting language and a data storage structure using a MySQL database. This allows engineers and others to easily specify a system, see the assumptions underlying the assumed system definition, and receive either brief or complex cost and performance reports.

As mentioned, an up-to-date version of the software can be viewed and run via the Web (Horiuchi, 2004). The program is constructed to perform computation for each distance regime as an inner loop and for each antenna technology as an outer loop. The program structure allows it to be modified and extended easily permitting, for example, investigation of cost and performance as a function of particular variables. As well as the present tabular and list reports, graphical outputs will shortly be implemented to better illustrate dependence in these investigations.

Figure 5 shows the web-form interface of the current program for a generic LNSD concept. The input page allows the user to modify default parameters such as the SKA sensitivity specification ($A_{\text{eff}}/T_{\text{sys}}$), the dish diameter (D), and the number of stations (N_{st}). Some other key parameters (e.g. the number of observed polarizations) are pre-set based on the SKA science requirements (Jones, 2004) but expert users will eventually be able to change these assumptions in later versions of the software.

An example of a top-level cost breakdown based on the parameters from Figure 5 is shown in Figure 6. Another program option generates a much more detailed report of all intermediate cost and performance parameters used throughout the computations; an example of this report format is shown in Figure 7. Note that costs are expressed in 2004 US dollars but, as in the SKA concept whitepapers, key component performances are extrapolated to 2010.

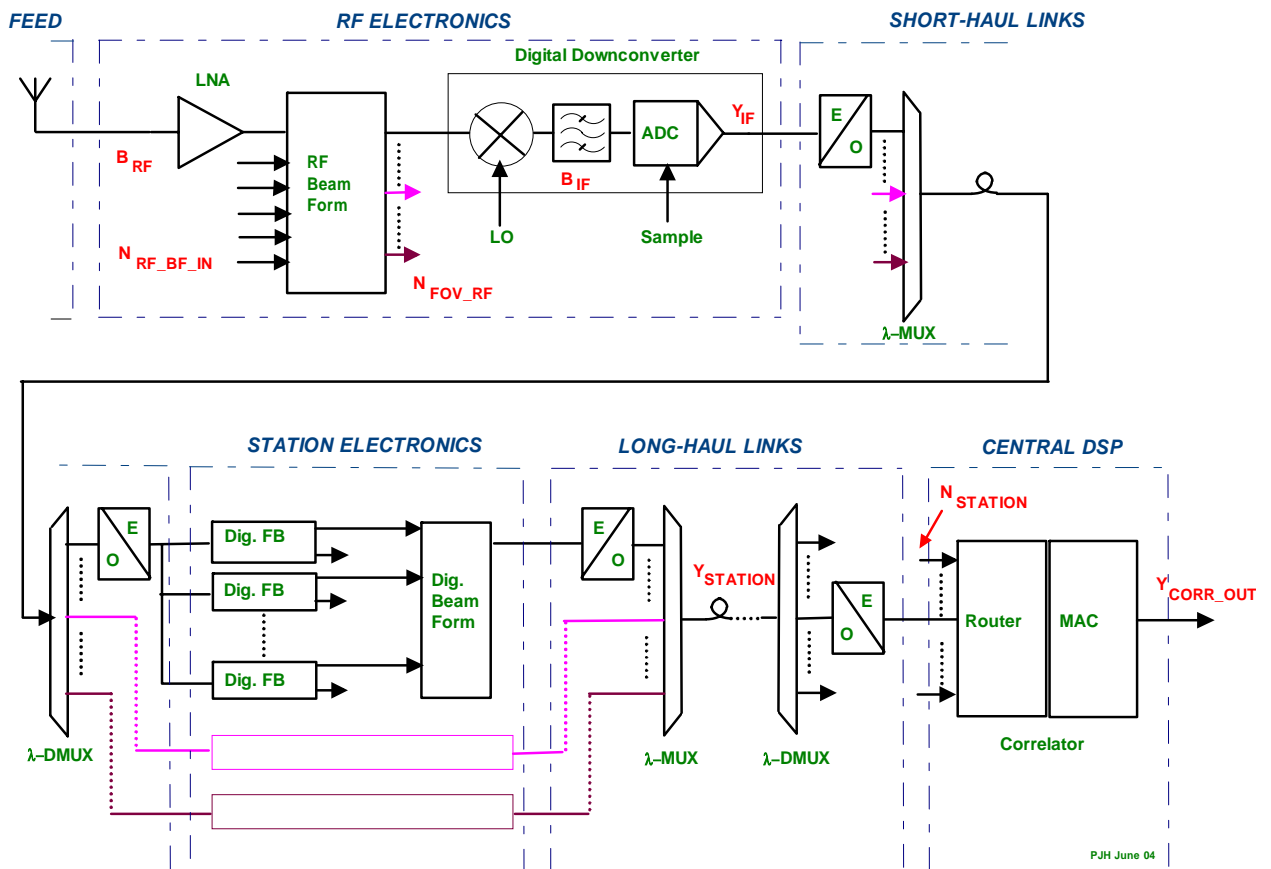


Figure 4. A view of the SKA system. In this example RF beam-forming is used to produce a number of fields-of-view (N_{FOV_RF}) from multiple ($N_{RF_BF_IN}$) feeds; the signals at a data rate Y_{IF} from each FOV are then transported and processed separately. Data are encoded and decoded via the electrical-optical (E-O) and inverse interfaces. Transport within stations and on long-haul links is via wavelength-multiplexed optical fibres (via λ -MUX and DMUX blocks). Data rates ($Y_{STATION}$) from each of the $N_{STATION}$ SKA stations are typically 1 Tb/s, and the correlator output rate (Y_{CORR_OUT}) is similar in some applications.

SKA Cost/Performance Simulator - LNAD

http://astronomy.swin.edu.au/~shoriuch/SKAcostsim/index_c.html

SKA Cost/Pe...ion Results SKA Cost/Pe...tor - LNAD SKA Cost/Pe...tor - LNSD Welcome to ...e Simulator

SKA Cost/Performance Simulator - LNSD technology

Parameter	Definition	Quantity	UNIT
Aeff/Tsys	SKA sensitivity metric	<input type="text" value="20000"/>	m ² /K
f_spec	Frequency at which A/T is specified	<input type="text" value="1.4"/>	GHz
f_max	Maximum observing frequency	<input type="text" value="34.0"/>	GHz
D	Diameter of dish	<input type="text" value="12"/>	m
Dst	Diameter of station	<input type="text" value="84"/>	m
Nst	Number of station	<input type="text" value="300"/>	none
B_rf	RF bandwidth for a single pol from a single feed	<input type="text" value="10.0"/>	GHz
IF_per_rf	Number of obs IFs per RF band	<input type="text" value="1"/>	none

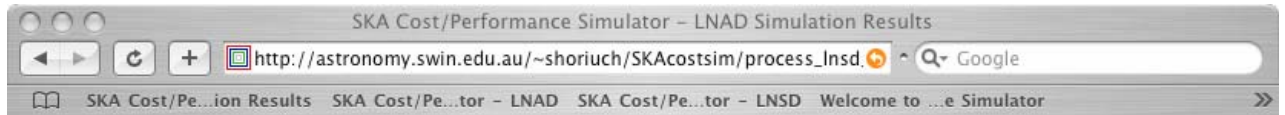
Distance from the center	Fraction of collecting area (total=1)	No. of RF FOV	Total FOV (deg ²)
0 - 5 km	<input type="text" value="0.50"/>	<input type="text" value="1"/>	<input type="text" value="1"/>
5 - 50 km	<input type="text" value="0.25"/>	<input type="text" value="1"/>	<input type="text" value="0.8"/>
50 - 250 km	<input type="text" value="0.125"/>	<input type="text" value="1"/>	<input type="text" value="0.4"/>
250 - 3000 km	<input type="text" value="0.125"/>	<input type="text" value="1"/>	<input type="text" value="0.1"/>

T_lna_phy [Physical temperature of LNA]: 20K 80K 300K(uncooled)

Q_if [Quantisation levels at digital IF]: 1-bit 2-bit 4-bit 8-bit

Q_corr_in [Quantisation levels at correlator Input]: 1-bit 2-bit 4-bit 8-bit 16-bit 32-bit

Figure 5. Web input interface for the generic LNSD version of the SKA cost and performance calculator.



LNSD Technology

Calculated Global Performance is as follows:

System temperature for $T_{lna_phys} = 20[K]$ is $14[K]$

Computed/Region	0 (0- 5 km)	1 (5 - 50 km)	2 (50 - 250 km)	3 (250 - 3000 km)	Total
Effective collecting area (km ²)	0.14	0.07	0.035	0.035	0.28
Number of stations	150	75	38	38	300
Number of antennas	1754	877	439	439	3509

Subsystem-Region Cost Breakdown and Total Cost (USD, M)

Subsystem/Region	0 (0- 5 km)	1 (5 - 50 km)	2 (50 - 250 km)	3 (250 - 3000 km)	Total (USD, M)
Antenna	303.2	151.6	75.8	75.8	606.3
Feed	77.2	38.6	19.3	19.3	154.4
RF Electronics	21.1	10.5	5.3	5.3	42.1
Short-haul Links	2.6	1.3	0.6	0.6	5.1
Station Electronics	4.4	2.1	0.9	0.8	8.2
Long-haul Links	18.4	16.5	14.7	39.1	88.7
Central DSP	-	-	-	-	49.3
Total (USD, M)	426.8	220.6	116.6	140.9	954.2

Figure 6. Example of top-level cost breakdown output of the SKA cost/performance calculator (for default parameters shown in Figure 5).

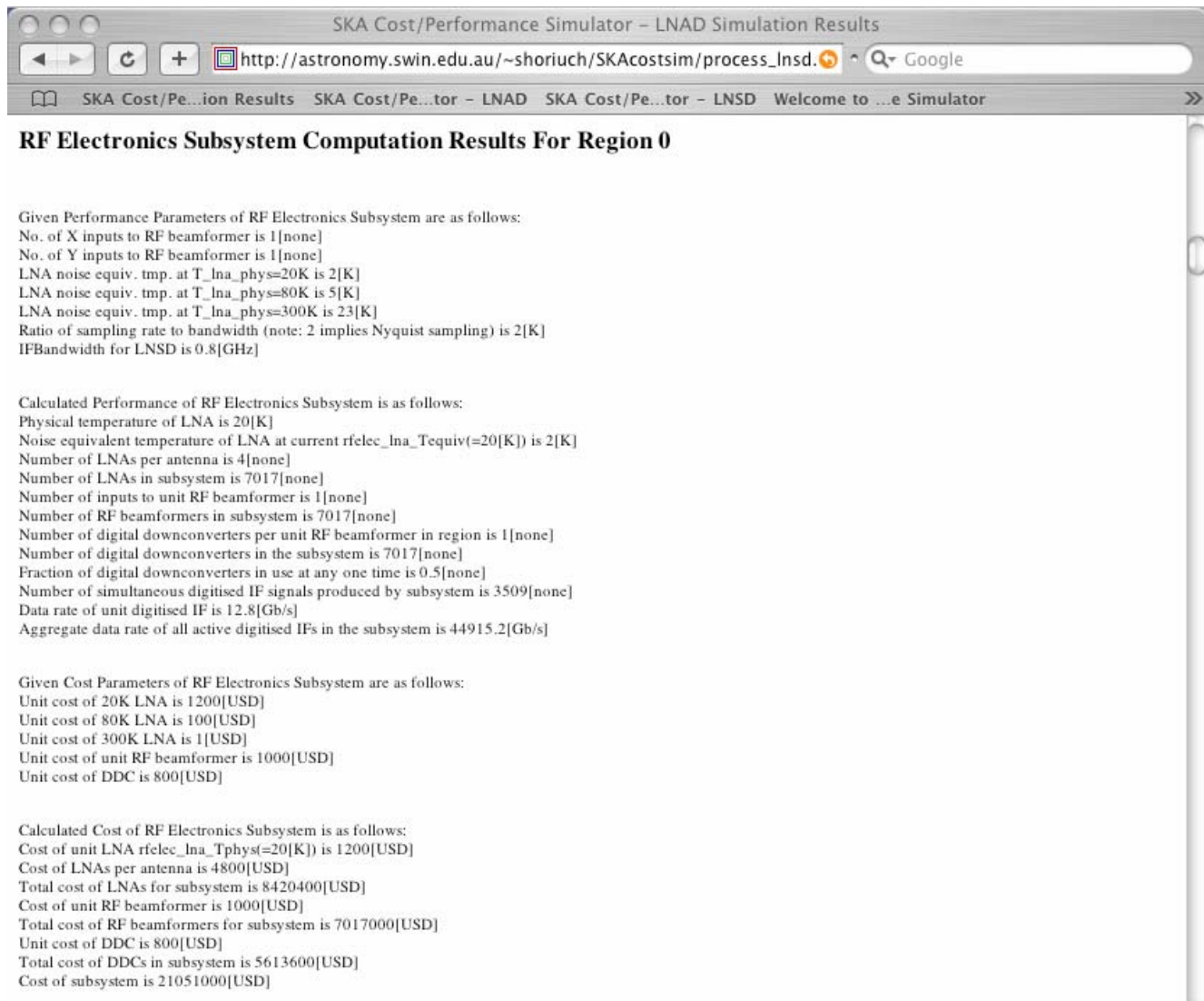


Figure 7. A more detailed report from the calculator relating, in this case, to the RF electronics sub-system.

4. Conclusion

A simple framework for describing and costing SKA concepts has been described. More international development efforts by engineering and simulation groups will ensure that the new software is a useful tool in selecting SKA technologies and in estimating project costs. Studies now in progress by task forces within the Engineering Working Group are aimed at producing, by the end of 2005, comprehensive descriptions of SKA sub-systems. These descriptions will incorporate enhanced sub-system models and updated costings; this information will be incorporated into the next generation of estimation software. We also recognize the need to begin a wider costing exercise, incorporating all the branches shown in Figure 1. This phase could usefully incorporate the knowledge of specialists from outside the SKA community, including infrastructure planners and financial experts.

5. Acknowledgements

The authors thank Dr John Bunton for early discussions relating to SKA system description and other colleagues for their continuing co-operation in expanding the initial work.

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