A SMART ACTIVE POWER COMBINER ARCHITECTURE FOR OPTIMUM GAIN AND G/T OF LARGE RECONFIGURABLE ARRAY ANTENNAS

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1. Introduction

Reconfigurable, active array antennas are attractive for a variety of applications in the military and aerospace area where high G/T figures are often required in combination with beamforming or beamsteering capabilities. Such antennas can be realized as direct radiating arrays or array-fed reflector antennas and comprise a passive radiator system, active electronic chains for the implementation of amplitude- and phase-settings, and a uniform power combiner for the final signal summation.

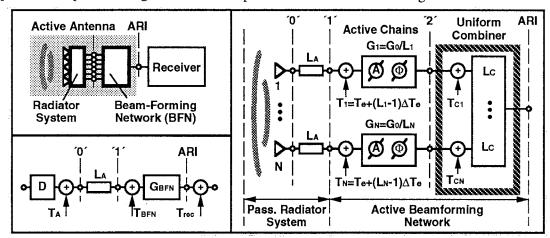


Fig. 1 General configuration of a reconfigurable, active array antenna for reception

As shown earlier [1-3] gain, system noise temperature and G/T of such antennas can be described by a fairly general antenna model (Fig.1) which comprises a N-element radiator system described by the directivity D and the internal losses L_A , and an active BFN composed of N identical active chains with a common maximum gain G_0 and individual, setting dependent gains, phases and noise temperatures $G_n = G_0/L_n$, ϕ_n and $T_n = T_e + (L_n - 1)\Delta T_e$. As vital part of the BFN, the uniform power combiner is described by its overall insertion loss L_C and a noise source T_{Cn} per chain which cover divider/ohmic losses, and internally generated noise, respectively. At the antenna-receiver-interface (ARI), the antenna is connected to a receiver with the input noise temperature T_{rec} . Based on this model the antenna gain at the ARI, the system noise temperature at the interface '0', and G/T of the antenna-receiver chain can be formulated [1-3] as

$$G = (D/L_A) G_0 (N/L_C) (G_W/N)$$
 with
$$(G_W/N) = (1/N) \sum_{n=1}^{N} (1/L_n)$$
 (1a,b)

$$T_{sys,0} = T_{sys,min} + (N/G_W)[L_A \Delta T_e + \Delta T_{sys,C}] \quad \text{with} \quad T_{sys,min} = T_A + (L_A-1)T_0 + L_A T_e \quad (2a,b)$$

$$\Delta T_{\text{sys,C}} = (L_A/G_0) (T_C + (L_C/N)T_{\text{rec}}) \text{ with } T_C = (1/N) \sum_{n=1}^{N} T_{C,n}$$
 (2c,d)

and
$$(G/T) = D/T_{svs,0}$$
 (3)

wherein $(1/L_n)$ denotes the applied amplitude weights, the practical approximation $\Delta T_e \ll T_e$ has been used and the impact of the actual amplitude setting is given by the actual directivity D and the general

parameter G_W/N which drives both gain and noise performances.

As shown by the eqs. the uniform power combiner causes a <u>setting independent</u> degradation (scaling) of the antenna gain via its normalized insertion loss L_C/N and a setting dependent degradation of system noise temperature and G/T via $\Delta T_{sys,C}$ (i.e L_C/N and the effective combiner noise temperature T_C). This implies that the power combiner can be a critical, performance limiting element, especially, if mm-wave frequencies and large element numbers are addressed, and integrated technology (MIC, MMIC) is desired to replace low loss but massive, bulky and complex waveguide types [3]. The usual solution to this problem is to increase the gain of the active chains via additional amplifier stages which implies, however, increased stability problems, complexity, mass, power consumption and heat dissipation and reaches a limit in case of large arrays, highly tapered amplitude distributions and platforms with limited resources (e.g. spaceborne carriers). Here, smart active combiners using a minimum number of low noise amplifiers (LNAs) to maintain high gain and G/T figures can be an interesting alternative because of their significantly smaller resource requirements. Below, such a smart architecture called 'dual stage smart active' (DSSA) combiner is proposed and analyzed in comparison to a conventional passive and a 'brute force' active (BFA) combiner representing the worst and best case performance limits. Then, the combiner impact on the antenna performance is illustrated via the representative example of a low sidelobe direct radiating array which permits a direct comparison with previouly published results [3].

2. Combiner Architectures and Performances

The three considered combiner architectures are summarized in Fig. 2 which indicates the conventional passive combiner as the basic building block of both active configurations.

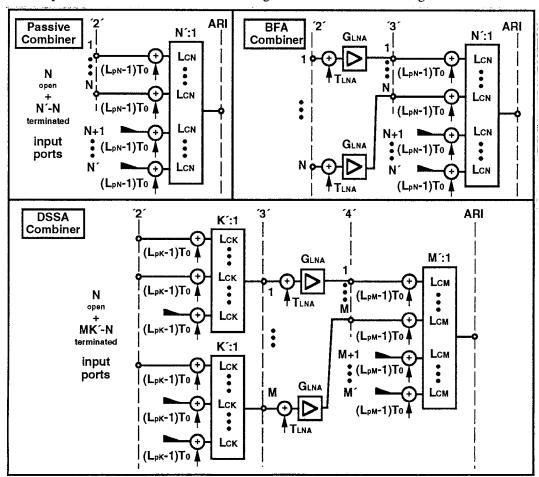


Fig. 2 Considered passive and active combiner architectures

Internally, the <u>passive combiner</u> is composed of a n-layer cascade of 2:1 combiner sub-units with an individual (ohmic) path loss L_{p0} leading to a maximum of $N'=2^n$ available input ports, an overall path loss $L_{pN}=L_{p0}^{\ n}$ and overall noise sources $T_{Cn}=(L_{pN}-1)T_0$ representing the internally generated thermal

noise per path. For N<> 2^n , the N:1 combiner is equivalent to a N':1 combiner with N'-N terminated input ports whereby T_C does not depend on the actual layer where the termination takes place. The <u>BFA combiner</u> is the simple combination of a passive combiner and LNAs located at all combiner inputs which reduce the combiner losses by the LNA gain (G_{LNA}) and establish the LNA noise temperature (T_{LNA}) as the dominant factor for T_C . This approach is widely equivalent to an increase of the active chain amplification and delivers the best noise performance but requires the largest number of LNAs (N). As a compromise between noise performance and effort, the <u>DSSA combiner</u> comprises passive (K':1)-combiners followed by LNAs and a further passive (M:1)-combiner which provides a combiner loss equivalent to the BFA type but permits to balance a significantly lower number of LNAs (about N/K' instead of N) against a somewhat reduced noise performance.

The individual parameters L_C/N and T_C of all three architectures can be derived by assuming equal RF power levels P_{IN} and equal input noise temperatures T_{IN} at all combiner input ports, calculating the RF output power P_{OUT} and the output noise temperature T_{OUT} and using

$$(L_C/N) = P_{IN}/P_{OUT}$$
 and $T_C = (L_C/N) T_{OUT} - T_{IN}$ (4a,b)

The corresponding mathematical formulations are summarized in Tab. 1 whereas simulation results for $L_{p0} = 1.5 \text{ dB}$, $G_{LNA} = 20 \text{ dB}$, $T_{LNA} = 400 \text{ K}$ and a wide range of input numbers are shown in Fig. 3.

	Lc/N	Тс	No. of LNAs
Passive Combiner	N L _{PN}	(<u>N</u> L _{PN} -1)To	0
BFA Combiner	N Lpn GLNA	$T_{LNA} + (\frac{N'}{N}L_{pN}-1)\frac{T_0}{G_{LNA}}$	N
DSSA Combiner	$\frac{N'}{N} \frac{L_{pN}}{G_{LNA}}$ $N' = M'K', L_{pN} = L_{pK} L_{pM}$	$\left(\frac{N^{\star}}{N}L_{pK}-1\right)T_{0} + \frac{N^{\star}}{N}L_{pK}\left(T_{LNA} + \left(\frac{M}{M}L_{pM}-1\right)\frac{T_{0}}{G_{LNA}}\right)$ $N^{\star} = MK$	M≈N/K′

Tab. 1 General mathematical formulation for the individual combiner parameters

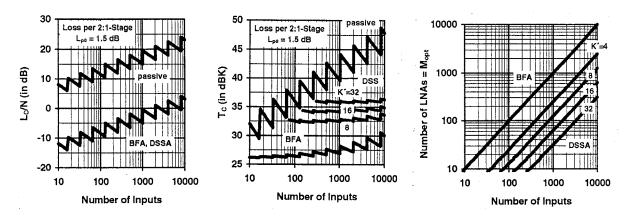
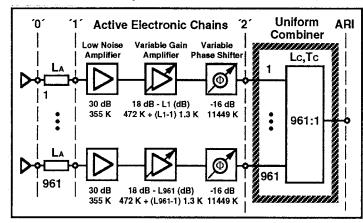


Fig. 3 Simulation results for the individual combiner parameters

With increasing number of inputs, L_C/N and T_C increase for all three combiner types because of the increasing path losses and their thermal noise whereby local minima occur for all $N=2^n$ because of the N'/N or N*/N terms in Tab. 1. As mentioned before, the LNA gain equally improves L_C/N for the BFA and DSSA configuration, wheras it almost eliminates the passive combiner impact on T_C in the BFA case (T_C is about T_{LNA}). For the DSSA, the formula in Tab. 1 implies a minimum of T_C , if N*=MK' is about N indicating that the optimum figure for M (M_{opt}) is the closest integer number which is larger or equal N/K'. Here, K' is selected first according to given limits for LNA numbers and T_C and then the corresponding M_{opt} is determined. The effect of this optimization is visible in Fig. 3 where M_{opt} is used showing that the optimization ensures 'flat' T_C curves (N*/N is always close to the optimum) and that the selection of K' determines both the reduction of the required LNA numbers and the level of T_C which approaches the BFA-case for small K'-figures.

3. Combiner Impact on Antenna Performance: a Low Sidelobe Direct Radiating Array Example

As an illustrative example, a spaceborne agile beam antenna realized as a direct radiating array with a 21 λ square aperture, 0.7 λ element spacing, N = 961 elements (N'= 1024), and L_A = 1.5 dB is considered (Fig. 4) which uses electronic chains composed of LNAs, variable gain amplifiers and variable phase shifters leading to the overall parameters $T_e = 365.7$ K, $\Delta T_e = 0.18$ K and $G_0 = 32$ dB. For the uniform combiner, all 3 discussed combiner types are investigated using the parameters $L_{p0} = 1.5$ dB, $G_{LNA} = 20$ dB and $T_{LNA} = 400$ K which lead to $L_C/N = 15.3$ dB, $T_C = 9645$ K and $L_C/N = -4.7$ dB, $T_C = 497$ K for the passive and the BFA combiner, respectively. For the DSSA combiner K' = 32 has been selected leading to $M_{opt} = 31$ (i.e. 31 LNAs are needed), $L_C/N = -4.7$ dB and $T_C = 3822$ K.



The antenna uses a lin-lin Taylor-n amplitude taper to obtain sidelobe ratios of 13 - 35 dB which correspond to an antenna directivity at the 3 dB-points (D_{EOC}) of 34.7 - 32.9 dBi. Gain, system noise temperature and G/T for this range of sidelobes are shown in Fig. 5 for an antenna temperature of $T_A = 280$ K (antenna beam pointed on dry land surfaces) and a receiver with a noise temperature of $T_{rec} = 1200$ K. Here, the gain figures of 49.9-41.1 dBi (pass.) and 69.9-61.1 dBi (act.) show

Fig. 4 Antenna configuration

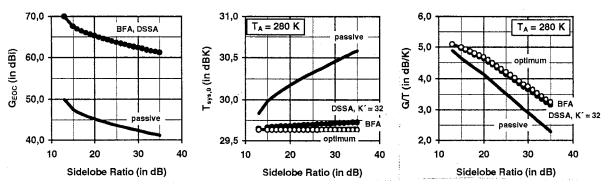


Fig. 5 Gain, system noise temperature and G/T of the antenna/receiver combination

the expected improvement given by the additional 20 dB LNA gain of the active combiner versions. The system noise temperatures of 29.8 - 30.6 dBK (pass.) and 29.7 dBK (act.) underline that both integrated active combiner architectures can provide equivalent overall noise performances which approach the optimum figure ($T_{\text{sys,min}}$) of 29.6 dBK and which compare well with corresponding waveguide types [3]. Hereby, the DSSA architectures includes only $\underline{31}$ instead of $\underline{961}$ LNAs i.e. it requires significantly less power for the same performance. The G/T is 5.1 - 3.1 dB/K for both active combiner versions with 5.1 - 3.2 dB/K being the theoretical optimum which is an improvement of up to 0.8 dB compared to the 4.9 - 2.3 dB/K of the passive combiner version that is important for space applications with small margins.

4. References

- [1] U.R. Kraft, D. U. E. Blaschke, Gain- and G/T-Considerations on Spaceborne Active Receive Antennas, Proc. of 1997 IEEE Int. Symp. on Antennas and Propagation, Montréal, Canada, 1997, pp. 2468-2471
- [2] U.R. Kraft, Gain and G/T-Variation of Active Multifeed Reflector Antennas and Phased Arrays with Steerable Beamwidth (in German), Proc. of ITG Conference on Antennas (ITG Fachbericht 149), Munich, Germany, 1998, pp. 73-78
- [3] U.R. Kraft, Gain and G/T of Reconfigurable Active Receive Antennas A Parametric Approach, Proc. of 1999 IEEE Int. Symp. on Antennas and Propagation, Orlando, USA, 1999, pp. 2250-2253