High Reliability Light Weight Multi-mission Amplifier System

Susumu Kitazume[1(✉)], Yosuke Takahara[1], Chihiro Hayashi[1], and Rowan Gilmore[2]

[1] JEPICO Corporation, Shinjuku Front Tower, 2-21-1, Kita-Shinjuku Shinjuku-ku, Tokyo 169-0074, Japan
{Kitazume,y_takahara,c_hayashi}@jepico.co.jp

[2] EMSolutions, 55 Curzon Street, Tennyson QLD 4105, Australia
Rowan.gilmore@emsolutions.com.au

Abstract. In support of a future ocean broadband projects, a Ka-band mobile satellite communications platform is proposed. To establish a high speed communications link, a high reliability and high power light weight RF amplifier is a key component of the subsystem. The Ka-band High Reliability Light Weight Multi Mission Amplifier system now under development is presented with the technical design and results of ongoing hardware testing. The purpose of this study is to demonstrate that the high reliability of a combined solid state multi-mission power amplifier consisting of many MMIC amplifiers.

Keywords: Ocean broadband · Multi-mission light weight amplifier system · Ka-band · MMIC · High reliability

1 Introduction

As part of continual research in the oceans and seas surrounding Japan, Autonomous Surface Vehicles (ASVs) are proposed to operate at points beyond the horizon and far from land based communication links. To provide high speed communication between these ASV, related research vessels and the land-based research facility, a Ka-band satellite uplink is proposed. Due to the remote nature of ASVs, the RF power amplifier within the communication subsystem will require high reliability and performance that is similar to that commonly needed for satellites.

Currently, Monolithic Microwave Integrated Circuit (MMIC) power amplifiers using GaAs or GaN FET technologies are used in a typical Solid State Power Amplifier (SSPA) for microwave and submillimeter wave applications. In order to realize high power outputs, amplifiers using these solid state elements are required to combine the output power of numerous devices. For the Wideband Internetworking engineering test and Demonstration Satellite (WINDS), the National Institute of Information and Communications Technology (NICT) in Japan developed a SSPA for the Ka-band Broadband Mobile Earth Station. This SSPA combined eight GaAs MMIC devices in parallel to generate 25 W of output power. However, current requirements demand more efficiency light weight and higher output power from amplifiers than the recent technology allows in order to provide a high data rate communication satellite system.

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Additionally, high reliability with a long Mean Time Between Failure (MTBF) is required in order to meet the requirement for continual satellite communications from remote ASVs, even when operated far away from land-based communication links. It is required high reliability and light weight because using remote access operation.

2 Redundant Configurations

Generally, for a reliable microwave amplification system, a fully redundant backup unit is employed. A fully redundant configuration with a redundant backup unit similar to that currently commonly used is shown in Fig. 1. Power Amplifier 1 (AMP-1) is used under normal operation, but upon failure of AMP-1, Power Amplifier 2 (AMP-2) enters normal operation mode by toggling of both the switches RF(IN) and RF(OUT).

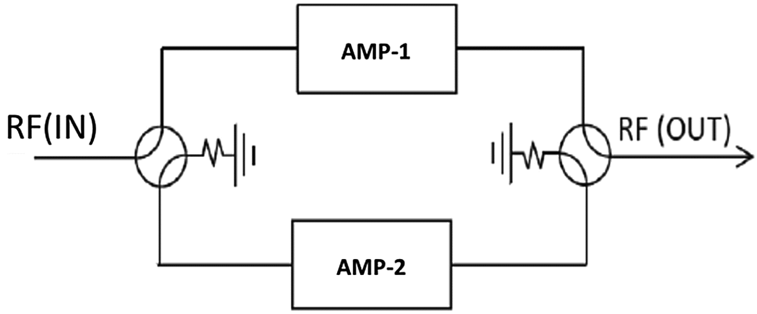


Fig. 1. 100% redundant systems (Normal redundant configuration)

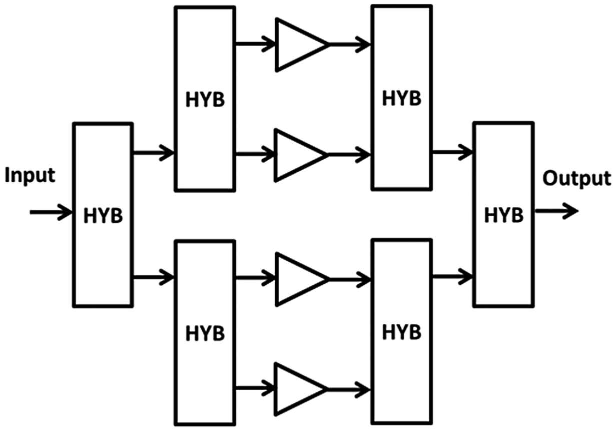


Fig. 2. An example of a power combiner without redundant

A common method to generate higher power output from a SSPA is to use a power combiner to merge several individual MMIC devices. As the output power of each MMIC device is much smaller than the desired output, around 2 or 3 W each as compared to the final output power of 20 to 30 W. For example, four parallel 2 W MMIC amplifiers are required to generate 10 W of output power as shown in Fig. 2. An example of a power combiner with 50% redundant system is shown in Fig. 3. In this case, 33% of amplifiers are not operated during normal operation. Thus the usable output power of this system, in normal operation, is just 2/3 of total system capability.

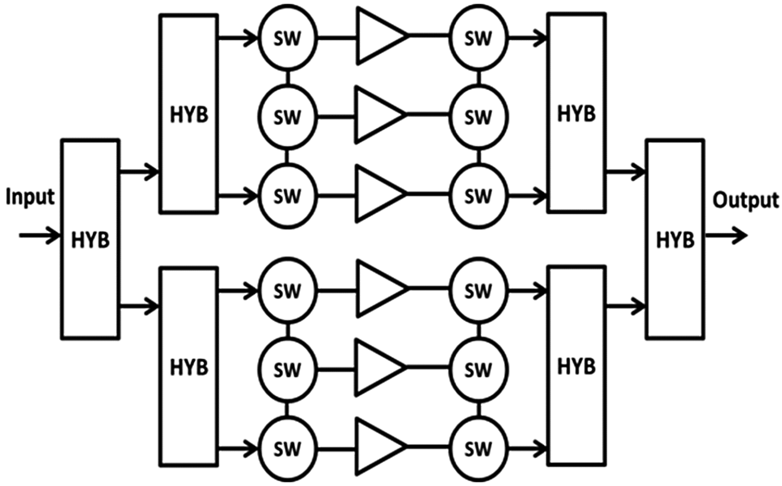


Fig. 3. An example of a power combiner with 50% redundancy.

3 Features of this Multi-mission Light Weight Amplifier System

In order to achieve a highly reliable configuration for microwave amplification operating at a higher output power, both power combining and redundant technology are required. A redundant configuration of 100% or 50% is commonly used. In the case of a 50% redundant configuration, for every two operational channels a redundant channel is not in use during normal operations (no failures). Thus, fully one third of the total system capacity is not used, and implies that this one third can be considered to be superfluous during normal operations. In order to reduce this occurrence within the Multi Mission Light weight Amplifier System (MMLAS) design, all equipment – including redundant parts – are used during all modes of operation. In the other words, all equipment for primary and redundant channels should be active in both cases of normal and failure operation. We are proposing this MMLAS for Ka-band Satellite Communications between ASVs or ocean-going research vessels and a satellite relay system.

This MMLAS is configured to operate all channels – both primary and redundant – during operation, resulting in 150% output power as compared to a 50% redundant system with the same available source capacity. In the event of the failure of an MMIC amplifier, it will be disconnected individually from the amplifier system and the system will still operate normally.

It means that total weight of this amplifier required to get 100% amplification is just 2/3 of weight in case of 50% redundant system. And we can say that the required weight is just half, in case of 100% redundant system.

When a failure occurs within the MMIC amplifier system there is an imbalance of power entering the combiner. This requires that power balancing technology be applied to the system in order to keep the power amplifier operating normally. In order to correct the imbalance of MMIC amplifier output power entering the combiner circuit in the case of failure, a bias control circuit for MMIC amplifier was designed. This involves the adjusting the phase of the MMIC amplifier output port and is effective to resolve unbalanced input power to combiner circuits, thus maintaining a reasonable total output power from the solid state power amplifier.

Alternatively, there is several method of resolving unbalanced input power from MMIC amplifier to combiner circuits are investigated and are evaluated. In order to confirm the basic performance how to adjust the output power of MMIC amplifier, a bread board model of one portion of this MMLAS is used, such as bias control of MMIC amplifier and phase control circuits between output of MMIC amplifier and power combiner circuits.

4 Multi Mission Light Weight Amplifier System (MMLAS)

The block diagram of the proposed MMLAS is shown in Fig. 4. Feature of this MMLAS is as follows. In the case of normal operation without any failures, all output power from the amplifiers is combined to generate the maximum possible output power of this amplifier system.

However, when a failure occurs on any one channel within the combiner, the active circuit is changed to the operation as same as redundant system operation.

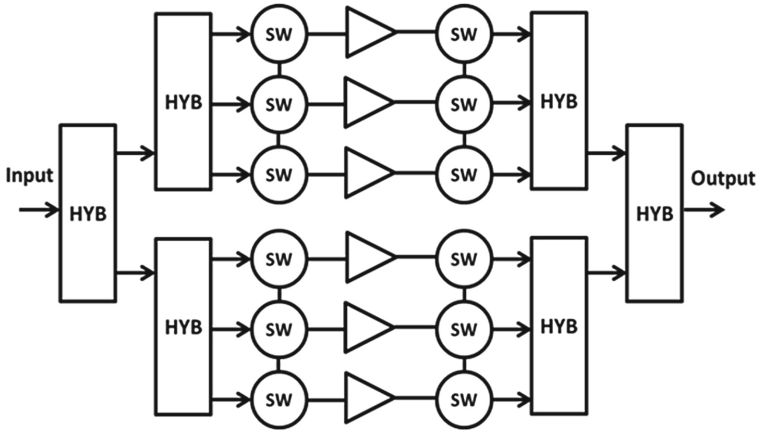
In other words, the proposed MMLAS, in the case of no MMIC failures, operates with all amplifier system equipment operating at 100%. In the case of a failure occurring, the amplifier system is operates the same as are 50% redundant system circuit without any weight increase.

5 Block Diagram of Tested Design

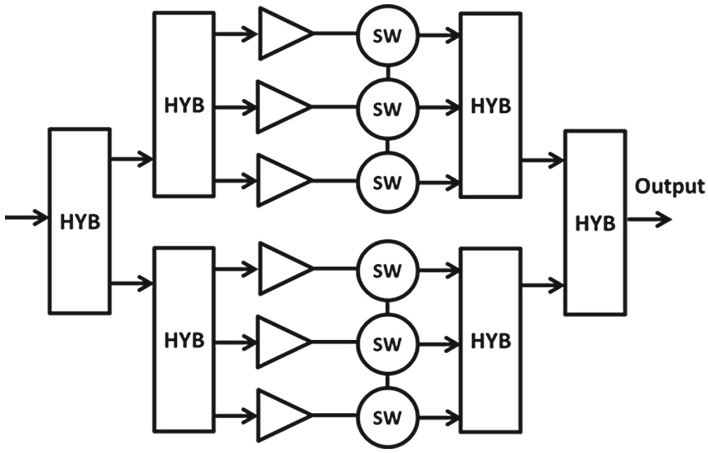
Symbolic block diagram of MMLAS is shown in Fig. 4, Case-B. A more detailed block diagram of the MMLAS with switch operation is shown in Fig. 5, which was used for our trial purpose.

6 Case Study of Circuit Operation in the Case of Key Operation

One of key technical issues for the MMLAS is how to combine output powers where the value of individual MMIC amplifiers has changed or where the ratio between two routes of individual MMIC amplifiers has changed. The output power at key points within the power combiner of the Multi-mission Amplifier was studied (see Fig. 5) and



Case A : Modified from Fig. 3



Case B : No input Switch (SW) required

Fig. 4. Symbolic block diagram of a MMLAS with combiner

the results are shown in Table 1. This test uses a unit test case in which the output power from each MMIC amplifier is 1 W.

From this case study, we can see that only one combiner hybrid (Hyb-1) requires adjustment of the input power value to compensate for a single route failure occurring within each channel A and B. We believe that it is enough to consider the case of one route failure for the analysis of this system, although this failure can occur in either or both of the channels. This is the key point which should be reviewed for further study to practically implement this design: how to reasonably operate Hyb-1 in order to combine the two unbalanced input power channels into one output without loss. This will need to be shown experimentally.

Table 1. Power unbalance estimation in the case of normal and failure

Location	Hyb-1		Hyb-2				Hyb-3		Hyb-4		Hyb-5	
	A	B	C	D	C`	E`	E	F	G	H	G`	H`
Normal	3	3	2	1	–	–	2	1	1	1	1	1
Failure (A)	2	3	–	–	2	–	2	1	1	1	1	1
Failure (B)	3	2	2	1	–	2	–	–	1	1	1	1
Failure (A&B)	2	2	–	–	2	2	–	–	1	1	1	1

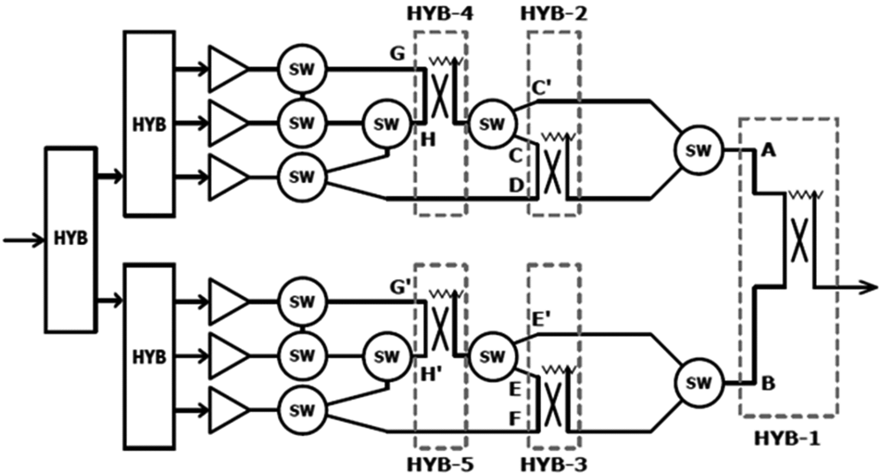


Fig. 5. Block diagram of high reliable MMLAS using combiner

One possibly means to adjust the unbalanced combiner input power is to adjust the bias control for supplying MMIC amplifier devices. To recover the output power back to the original values, bias control for MMIC Amplifier device presents the most reasonable and simplest method.

7 Howe to Operate Output Switch Circuit

Output switch circuit is shown in Fig. 6 as below. In case of normal operation, all three output terminals have equal output power. In the case of failure, where any one of the three amplifiers has failed, the circuit is adjusted such that the output of the two remaining MMIC amplifiers is maximized, with the failed MMIC device having no output.

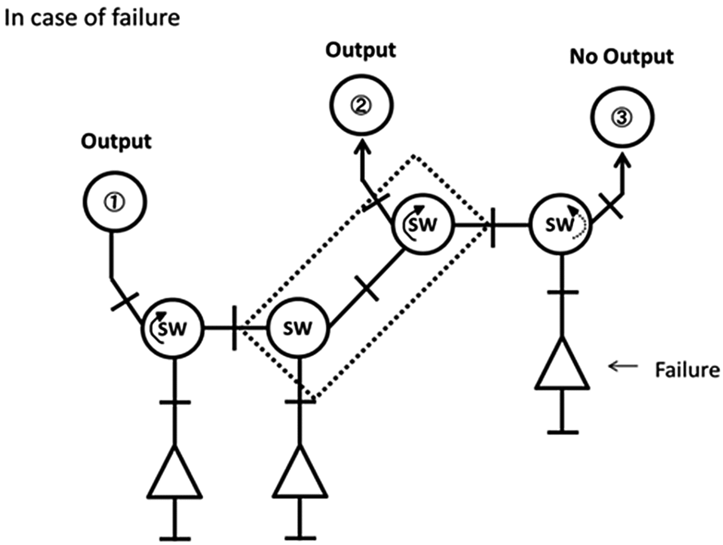


Fig. 6. Output switch circuit operation

8 Test Result

According to the results of the study defined above we have defined how to operate the final combiner hybrid (Hyb-1) within in the proposed amplifier system. This operation should work to combine the two unbalanced input powers at the output of the hybrid only a negligible loss. This is a key point which should be studied to take this idea into practice. The results of the experimental study which compared several circuit conditions is shown in Fig. 7 and Table 2. This test compares the combined input unbalanced power vs measured final output power and calculated values.

Table 2. Input vs output power of typical combiner, measured vs calculated value

Case	Pa [W]	Pb [W]	Tp [W]	MDV [dB]	CV [dB]	Delta [dB]
1	3.0	3.0	6.0	0	0	0
2	2.8	3.0	5.8	−0.15	−0.15	0.00
3	2.3	3.0	5.8	−0.54	−0.15	−0.39
4	2.0	3.0	5.0	−0.88	−0.79	−0.09
5	1.5	3.0	4.5	−1.41	−1.25	−0.16
6	1.0	3.0	4.0	−2.10	−1.76	−0.34

MDV – Measured Degraded Value.
CV – Calculated Value - CV = 10 log(Tp/Tp0); Tp0 = 6 W.
Delta – Difference between MDV and CV – Delta = MDV-CV.
Most probable case of failure happened in this amplifier should be case-4.

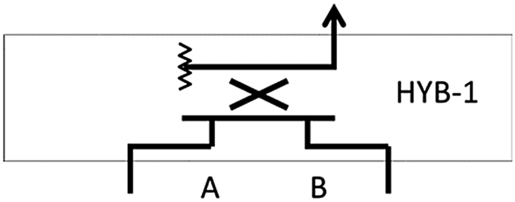


Fig. 7. Hybrid-1

9 Conclusions and Acknowledgement

In conclusion, in support of future ocean broadband projects that require continual, high bandwidth communications to the mainland, we are trying to develop an effective, high power and light weight high reliability MMLAS. Total weight of power amplifier is about half compared with 100% redundant system. Key to this technology is how to combine the unbalanced output power of MMIC amplifiers without any additional loss of power. Proposed is the bias control for MMIC amplifiers and/or phase control for MMIC amplifiers by phase shifter. The bias control of MMIC device is simple way to adjust unbalanced output power in order to adjust the output power to meet required value of combined power. In order to further clarify the test results, investigation into this system will continue. In order to make the test result clear in theoretical, we continue further study.

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