HIGH OUTPUT PORT ISOLATION AND LOW INTERMODULATION DISTORTION MULTI-PORT-AMPLIFIER

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ABSTRACT

The multi-port-amplifier (MPA) is an innovative on-board power amplifier for multi-beam mobile satellite communications because it enables the efficient use of DC power and the flexible allocation of RF power. It is important for the multi-beam mobile satellite communications system using the MPA to reduce the signal interference in the adjacent beam overlap area and to reduce intermodulation distortion (IMD) caused by multi-carrier amplification. In an MPA, high output port isolation and low IMD are achieved by a novel combination of high power amplifier (HPA) arrangement and a de-multiplexer/multiplexer configuration. This paper proposes an arrangement method of HPAs, which are the components of the MPA, to improve the isolation among the output ports without affecting the output power. An MPA configuration to reduce IMD is also proposed.

1. INTRODUCTION

Nippon Telegraph and Telephone (NTT) has proposed a unique multi-port-amplifier (MPA), which enables the efficient use of DC power and flexible RF power allocation, for use as an on-board high power amplifier in a multi-beam satellite communications system [1]-[3]. NTT has already developed and evaluated an on-board S-band 100W MPA for the ETS-VI satellite, scheduled to be launched in 1993 [4], [5]. Our study has been aimed at the further development of a large-scale MPA system.

Low isolation among beams causes signal interference in adjacent beam overlap areas in a multi-beam satellite communications system. Furthermore, co-amplification of the multi-carrier signals used in such systems produces intermodulation distortion (IMD), which results in degradation of transmission characteristics. Therefore, it is important to maximize beam isolation and to minimize IMD in the MPA system.

This paper proposes a new MPA configuration to improve the isolation among the output ports and to reduce IMD.

2. CONFIGURATION AND OPERATION PRINCIPLE OF MPA

An MPA is composed of a power divider, a power combiner and \( n = 2^r \) HPAs, and has \( m \) input and output ports. The power divider and the power combiner are composed of 90° hybrid networks. With this configuration, it is possible to terminate the unused input and output ports and to remove unnecessary hybrids in the case when \( m < n \) [1].

The power divider distributes an input signal to all HPAs in equal amplitude at specified 90° phase intervals determined by the connection relationship between the hybrid networks. The amplified signal is phase-combined by the power combiner and output to the output port which corresponds to the input port. If any deviation exists in the HPA characteristics, part of the signal is leaked to isolated ports, which results in isolation degradation.

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When multiple signals are input to the MPA, IMD is produced as a result of the nonlinear transfer characteristics of the HPAs. Since the relative phases of the signals from different input ports are different at the HPA input terminal, the relative phases of IMD produced by the HPAs are different. Therefore, the output of phase-combined IMD depends on which ports the multiple signals are input to [1], [2], [6].

3. NEW MPA CONFIGURATION TO ACHIEVE HIGH OUTPUT PORT ISOLATION AND LOW IMD

Figure 1 shows a proposed MPA configuration to achieve both high output port isolation and low IMD. The optimum HPA arrangement enables high output port isolation of the MPA without affecting the MPA output power. The de-multiplexer/multiplexer configuration enables low IMD in the amplification of multi-carrier signals.

4. HIGH OUTPUT PORT ISOLATION MPA
4.1 HPA ARRANGEMENT ALGORITHM TO IMPROVE ISOLATION

The isolation among the output ports is greatly improved by a proper HPA arrangement in an MPA configuration where the number of input or output ports \( m \) and the number of HPAs \( n \) is \( m \leq n/2 \). One of the two first-stage hybrid output terminals in the power combiner is terminated in the case when \( m \leq n/2 \). High isolation among output ports is realized by the HPA arrangement, which causes the leakage power to be absorbed into terminations whenever a signal is input to any of the MPA's input ports.

The absorption power at the termination dummy depends on the difference between the characteristics of two HPAs. The proposed method of arranging the HPAs to improve the isolation is based on the introduction of a new factor, named a unlike factor, in all of the HPA characteristics. The unlike factor between the \( i \)-th and \( j \)-th HPA characteristics is defined by

\[ K_{ij} = |\hat{A}_i - \hat{A}_j|^2 \]
where $A_i$ is the $i$-th HPA characteristics [7]. Through the use of this factor, which can be obtained with very little calculation, the optimum HPA arrangement to maximize the isolation can be directly obtained as follows. The $n(n-1)/2$ values of $K_{ij}$ are first calculated among $n$ HPAs. The two HPAs which give the maximum $K_{ij}$ are selected from among the $n$ HPAs and are connected to one hybrid of the power combiner. Next the two HPAs which give the maximum $K_{ij}$ (except for the two already selected) are selected from among the remaining $(n-2)$ HPAs and are connected to another hybrid of the power combiner. All HPAs are selected and connected in the same manner. The flowchart of the HPA arrangement method is shown in Fig. 2. When an MPA is composed in accordance with this proposed method, much of the unwanted power due to the deviation in HPA characteristics is absorbed in the termination dummies and the leakage power is decreased. The proposed MPA configuration does not decrease the MPA output power because the MPA output power does not depend on the HPA arrangement order.

### 4.2 ISOLATION IMPROVEMENT BY APPLYING HPA ARRANGEMENT METHOD

Two MPAs, each having four input and output ports ($m=4$), and eight HPAs ($n=8$), were composed. One was composed by using the proposed HPA arrangement method, and the other was composed by arranging the HPAs in order of their gain values. Figure 3 shows a comparison of the input-output characteristics and the isolation characteristics of the two MPAs. Experimental results confirm that the MPA output power is not affected by the new HPA arrangement and that this arrangement is effective in maximizing the isolation among the output ports.

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Fig. 2 The proposed algorithm of HPA arrangement method to maximize the isolation

Fig. 3 Input-output characteristics and isolation characteristics of an experimental MPA to which the HPA arrangement method was applied
It should also be emphasized that the isolation among the output ports is improved over a wide input range, even though the HPA arrangement order is determined by using the HPA characteristics at only one input level.

5. LOW IMD MPA
5.1 IMD DEPENDENCE ON CHANNEL ALLOCATION

The output of phase-combined IMD product, which is produced as a result of multiple-signal amplification at the nonlinear HPAs, depends on which ports the multiple signals are input to. All signals are co-amplified at the HPA stage without any dependency on the MPA signal inputs. However, the IMD products are dispersed to all the output ports [2] when multi-carrier signals are distributed to all the MPA's input ports. The number of IMD products in a particular communication channel depends on the channel allocation of the multi-carrier signals. Optimizing the channel allocation can decrease the number of IMD products at a particular communication channel. Figure 4 shows the calculated number of \( f_a + f_b - f_c \) type third-order IMD products for the following three cases; (a) all signals are input to one port of the MPA, (b) about one-fifth of all signals are input to each port of the MPA and allocated channels are concentrated, and (c) about one-fifth of all signals are input to each port of the MPA and channels are optimally allocated. It is the channel allocation method used in case (c) in which the channel allocation is optimized by repeating the exchange of a pair of communication channels [8]. These channel allocations are shown in Fig. 5. In all cases, the total number of signals is 27, the frequency separation between adjacent channels is the same, and the MPA has five input and output ports. The number of \( f_a + f_b - f_c \) type third-order IMD products, which are produced by any combination of three signals among all of the signals, are obtained by counting the IMD products falling into the same channel frequency at a specified output port.

The number of third-order IMD products falling into each channel is decreased when multi-carrier signals are distributed to all input ports of the MPA, and it can be further decreased by means of optimum channel allocation in a distributed signal input case. In case (c), the number of IMD products at the center channel is decreased by about one-seventh in comparison with case (a).

![Diagram](image)

**Fig. 4** Calculated number of \( f_a + f_b - f_c \) type third-order IMD products falling into each channel

**Table 1** Comparison of IMD at a center channel in several channel allocations of 27 carriers

<table>
<thead>
<tr>
<th>Allocation</th>
<th>Number of ( f_a + f_b - f_c ) type IM3</th>
<th>Analysis Relative Value</th>
<th>Measurement Relative Level of IM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case (a)</td>
<td>241</td>
<td>0dB</td>
<td>0dB</td>
</tr>
<tr>
<td>Case (b)</td>
<td>88</td>
<td>-4.4dB</td>
<td>-6.0dB</td>
</tr>
<tr>
<td>Case (c)</td>
<td>35</td>
<td>-8.4dB</td>
<td>-8.8dB</td>
</tr>
</tbody>
</table>
5.2 IMD and BER Characteristics in Several Channel Allocations

Table 1 shows the comparison of IMD at the center channel between analysis and measurement in several channel allocations of 27 carriers. Figure 6 shows the measured BER characteristics at the center channel under multi-carrier transmission. In these measurements, the multi-carrier input conditions are the same as those shown in Fig. 5. In measuring BER characteristics, the center channel signal was modulated and other signals were set to CW. The MPA used in the experiment has five input and output ports and is composed of eight HPAs. The fewer the number of IMD products falling into the communication channel is, the better the measured BER characteristics are. It is clear that the BER characteristics are greatly improved by optimizing the channel allocation in the MPA.
5.3 IMD IMPROVEMENT IN THE NEW MPA CONFIGURATION

IMD is worst at a center channel when multi-carrier signals are concentrated on one beam. This worst-case condition can not be avoided in a conventional MPA configuration. However, in the newly-proposed MPA configuration, shown in Fig.1, IMD is improved even in the event multi-carrier signals are concentrated on one beam. In this configuration, the input de-multiplexer divides a communication band into four sub-bands, and the output multiplexer combines the four sub-bands into a communication band. This makes it possible to distribute concentrated signals to several ports and consequently to reduce the influence of IMD. Experimental results also indicate that, in this MPA configuration, the influence of IMD can be further reduced by means of optimum channel allocation through ground station control.

6. CONCLUSIONS

This paper has proposed a new MPA configuration to improve isolation among its output ports and to reduce IMD. It was confirmed by experiments that, by applying the proposed HPA arrangement method, the isolation of the MPA could be greatly improved over a wide input range without affecting the MPA output power. It was also shown that the number of IMD products was decreased and BER characteristics were improved in this configuration even if multi-carrier signals were concentrated on one beam.

The proposed technologies will contribute significantly to the enhancement of traffic capacity and signal quality in multi-beam mobile satellite communications.

REFERENCES