

Frequency Allocation Method for Intermodulation Interference Reduction in Multibeam Wireless Communication

○Masayoshi TANAKA, Nihon University, College of Industrial Technology

1 Introduction

Multibeam communications systems that cover their service area with multiple spot beams can obtain high antenna gain and can consequently reduce transmitting power and increase receiving power. Such systems are very effective for mobile communications or for multimedia access networks in which small, economical terminals are indispensable. Frequency reuse is also available to save limited resources.

Beamforming and phased array type multibeam communication systems are one of the promising candidates ⁽¹⁾. However, since a large number of carriers are used in this system, mutual interference occurs due to the non-linear characteristics of the transmitter, and then the communication performance deteriorates.

To solve the issue, we propose an interference reduction method that controls the beam directions of interference waves to be different from those of communication waves. We explain the method and show its effectiveness in reducing the interference and the power consumption of the system.

2 Outline of multibeam communications

2.1 Configuration and remaining issues

In contrast to single beam communication that covers the service area with a single beam, multibeam communication that covers with multiple beams as shown in Fig. 1 can increase the received power, use small terminals and reuse the frequency. It has the feature that it can accommodate many users using a limited frequency band.

Figures 2 and 3 show examples of system configurations that implement this method. An individual transmission system with a transmitter for each beam, and a system that shares the power amplifier (HPA) with communication waves of other beams by applying phase array technology. The latter shares the HPA between the beams, and has the advantage that the transmission power can be used effectively even if communication traffic

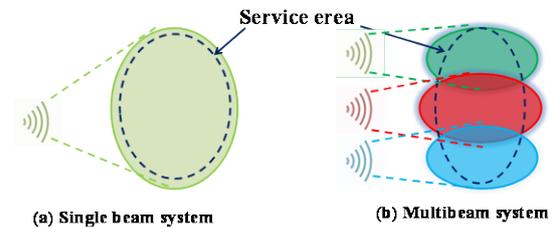


Fig.1 Single and multibeam communication systems.

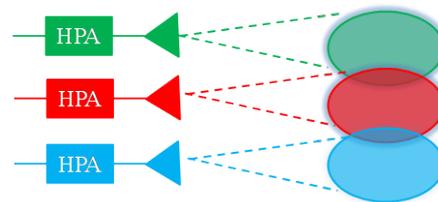


Fig. 2 Configuration of multibeam system with separate transmitters.

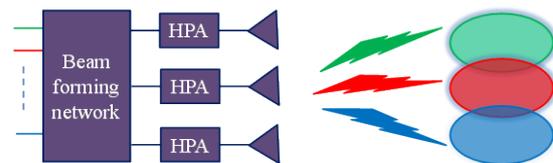


Fig. 3 Configuration of multibeam system with beam forming and phased array technology.

is imbalanced between the beams⁽¹⁾. Intermodulation distortion occurs due to the nonlinear characteristics, causing interference to the communication wave, resulting in degradation of communication performance.

2.2 Relationship between nonlinear characteristics of HPA and power efficiency

Figure 4 shows the relationship between typical HPA operating points and power efficiency. Near the saturation region, mutual interference (intermodulation:IM) based on nonlinear characteristics occurs. In order to avoid IM, when the output power P_{out} is lowered (output back off) and operated in a region with good linearity, there is a problem that the power efficiency decreases.

If interference based on nonlinear characteristics can be removed, operation near the

saturation region becomes possible, power efficiency is improved, and low power consumption can be expected.

2.3 Intermodulation in HPA

Each HPA is required to operate as near the saturation region as possible to raise efficiency. However, nonlinearity occurs there. Higher order intermodulation (IM) products are generated by this nonlinearity and affect the signals nearby in the frequency domain. In general, the dominant IM product is the third-order IM (IM3). There are two types of IM3, $F_a+F_b-F_c$ and $2F_a-F_b$. The former becomes dominant when the total number of carriers is large. Therefore, the main focus is placed on the $F_a+F_b-F_c$ type of IM3 in this paper.

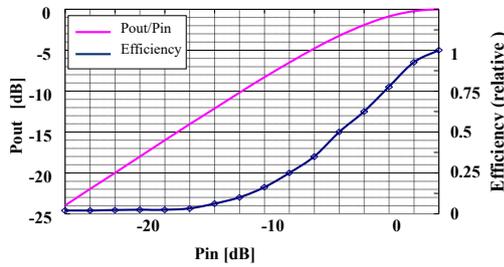


Fig. 4 Characteristics of high power amplifier (HPA).

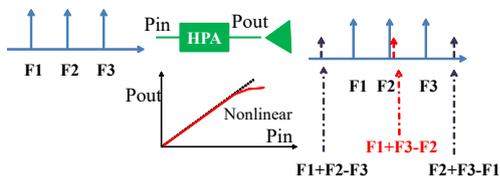


Fig. 5 Third order intermodulation IM3 generation mechanism.

2.4 Relationship between HPA input power and IM3 level

The level of IM3 is proportional to the cube of the input level P_{in} . Therefore, as shown in Fig. 6, IM3 increases by 3 dB when the input is increased by 1 dB. The operating point of HPA is determined by the allowable interference level.

3 Principle of interference reduction method in phased array type multibeam system

3.1 Communication beam direction

Figure 7 shows the configuration of a two-dimensional planar phased array antenna. K

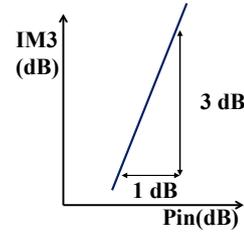


Fig. 6 Relationship between P_{in} and IM3 level.

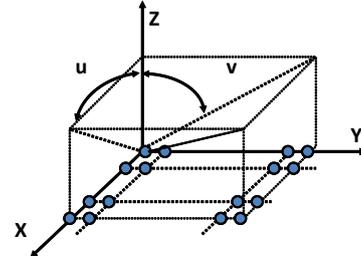


Fig. 7 Rectangular planar array geometry.

and L antenna elements are arranged at equal intervals along a square grid. The beam pattern (array factor) $F(u, v)_{i,m}$ for the m -th signal in beam i , $S(i,m)$ is given by the following equation⁽²⁾. Where u and v are the angles from the Z -axis, λ is the wavelength, $\kappa = 2\pi/\lambda$, d is the distance between elements and $A(i, m)_k e^{j(k\alpha(i,m))}$, $B(i, m)_\ell e^{j(\ell\beta(i,m))}$ are the complex weights.

$$F(u, v)_{i,m} = \left(\sum_{k=0}^{K-1} A(i, m)_k e^{j(k\kappa d \sin u + k\alpha(i,m))} \right) \quad (1)$$

$$\left(\sum_{\ell=0}^{L-1} B(i, m)_\ell e^{j(\ell\kappa d \sin v + \ell\beta(i,m))} \right)$$

The direction of the beam pattern can be changed by changing the values of α and β in Eq.(1).

The input voltage of $HPA_{k,\ell}$ is given by the following equation⁽¹⁾. Where $\omega_{i,m}$ and $\theta_{i,m}$ are the frequency and phase of the communication wave.

$$V_{k,\ell}(i, m) = A(i, m)_k \cdot \exp j[k\alpha(i, m)] \quad (2)$$

$$B(i, m)_\ell \cdot \exp j[\ell\beta(i, m)] \exp(j\omega_{i,m}t + \theta_{i,m})$$

3.2 IM3 beam direction

We define the three carriers as applied to beam- i_1 , i_2 , and i_3 as ω_{i_1} , ω_{i_2} , and ω_{i_3} , respectively.

The IM3 element, $im3_{k,\ell}$ with a frequency of $\omega_{i,IM3} = \omega_{i_1,m_1} + \omega_{i_2,m_2} - \omega_{i_3,m_3}$ is expressed by the following equation⁽¹⁾,

$$im3_{k,\ell} = D \cdot V_{k,\ell}(i_1, m_1) \cdot V_{k,\ell}(i_2, m_2) \cdot V_{k,\ell}(i_3, m_3) \quad (3)$$

Here, D is constant and is determined by the third order nonlinearity of $\text{HPA}_{k, \ell}$.

The IM3 output from the phased array system is expressed in the following equation from Eqs. (1) and (3).

Here $\alpha(i_1, m_1)$, $\beta(i_1, m_1)$, $\alpha(i_2, m_2)$, $\beta(i_2, m_2)$, $\alpha(i_3, m_3)$, $\beta(i_3, m_3)$ are the phase weights of ω_{i_1, m_1} , ω_{i_2, m_2} , and ω_{i_3, m_3} , respectively.

$$F(u, v)_{IM3} = D \cdot \left\{ \sum_{k=0}^{K-1} A_{IM3,k} \exp(jkcd \sin u + k\alpha_{IM3}) \right\} \cdot \left\{ \sum_{\ell=0}^{L-1} B_{IM3,\ell} \exp(jk\ell d \sin v + \ell\beta_{IM3}) \right\}$$

$$\alpha_{IM3} = \alpha(i_1, m_1) + \alpha(i_2, m_2) - \alpha(i_3, m_3) \quad (4)$$

$$\beta_{IM3} = \beta(i_1, m_1) + \beta(i_2, m_2) - \beta(i_3, m_3)$$

The beam direction of IM3 is determined by the following values, $\alpha(i_1, m_1)$, $\beta(i_1, m_1)$, $\alpha(i_2, m_2)$, $\beta(i_2, m_2)$, $\alpha(i_3, m_3)$, $\beta(i_3, m_3)$.

3.3 Radiation direction control of IM3 in 2D Phased array system

The beam direction of the communication wave is determined by the phase weights α and β input to each antenna element. On the other hand, the direction of IM3 is determined by the phase weights α and β of the three waves concerned, as shown in Eq. (4).

Interference can be removed by selecting frequency allocation so that the communication wave and IM3 are radiated in different directions.

Figure 8 shows an example of controlling the communication wave and IM3 to radiate in different directions. IM3, $F1 + F3 - F2 (= F2)$ is radiated in the direction different from the beam of communication wave $F2$ and no interference occurs.

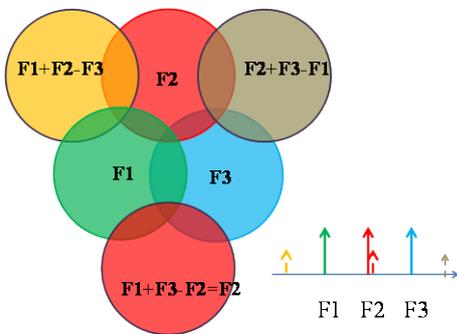


Fig. 8 An example of frequency allocation avoiding interference between communication wave $F2$ and $F1+F3-F2$ (red colored beam).

4 Multibeam arrangement and frequency reuse

The studied multi-beam arrangement is shown in Fig. 9. This system covers the service area with 10 beams, assigns 10 channels (ch) to each beam, and accommodates 100 channels (ch) as a whole. Ten beams were classified into three as follows.

Group 1(blue): Beams 1, 6, and 8,

Group 2(red): Beams 3, 5, and 10,

Group 3(green): Beams 2, 4, 7, and 9

In this system, the same frequency is used in the same group. A total of 30 carriers can accommodate 100 channels.

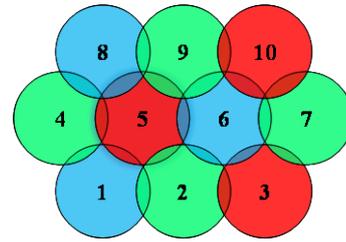


Fig. 9 Layout of multiple beams employing frequency reuse.

5 Frequency allocation control method for reducing interference

(a) Sequential allocation (without frequency allocation control)

Figure 10 shows the interference distribution and frequency assignment when carrier frequencies are assigned sequentially from group 1 to group 3. The maximum number of interferences is 2,245 waves/channel.

(b) Frequency allocation control

Figure 11 shows the interference distribution and frequency assignment when the frequency allocation assigned to each beam is controlled so that the interference generation is reduced. Compared with Fig. 10, the maximum number of interferences is reduced to 872 waves/channel.

(c) Frequency allocation control with empty slots

We examined the case where empty frequency slots were inserted between carriers. Figure 12 shows the interference distribution and frequency allocation when a total of 10 empty slots are inserted and the allocation control is performed so that interference generation is reduced. The maximum number of interferences is 649

waves/channel and the occurrence of interference is further reduced compared to Fig. 11.

6 Evaluation of frequency allocation control method

We evaluate the effect of the frequency allocation control method for reducing the IM3 interference.

Table 1 shows the amount of interference reduction and its effect. It can be seen that the occurrence of interference is reduced by 4.1 dB by applying the control method (b). Furthermore, the interference in (c) is further reduced than in (b), an improvement of 5.4 dB compared to (a).

As shown in Chapter 2, the HPA operating point is determined by the allowable interference level. As shown in Fig. 6, the HPA input level in dB and the IM3 level in dB have a 1: 3 relationship. Therefore, the operating point of the HPA can be brought close to the efficient saturation region by 1.4 or 1.8 dB, and the power efficiency of the HPA is improved. As a result, the proposed method is useful for reducing the power consumption of the system.

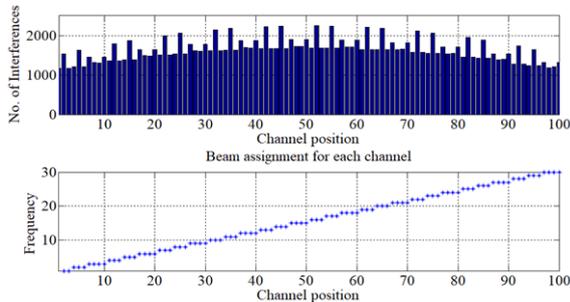


Fig. 10 Channel allocation and interference distribution when frequencies are assigned sequentially.

Table 1 Effect of IM3 interference reduction control.

Frequency allocation	Max. number of IM3/ch	Interference level (dB)	HPA input level (dB)
(a) Sequential	2,245	0	0
(b) IM3 reduction control (30 slots)	872	-4.1	+1.4
(c) IM3 reduction control (40 slots)	649	-5.4	+1.8

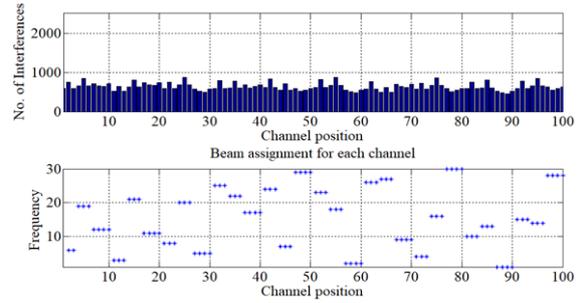


Fig. 11 Channel allocation and interference distribution after reduction control. (30 slots)

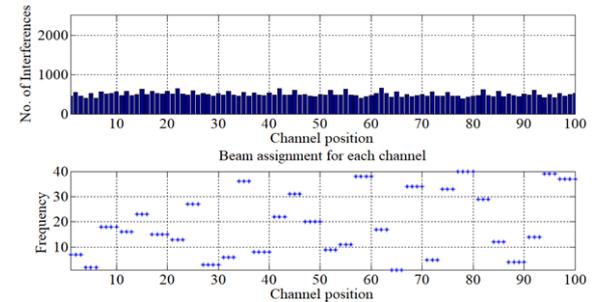


Fig. 12 Channel allocation and interference distribution after employing IM3 reduction control with 10 empty slots. (total number of slot: 40)

7 Summary

In a multi-beam communication system using a phased array technology, a frequency allocation method to reduce intermodulation distortion caused by common amplification of multiple carriers was investigated.

The radiation direction of interference waves based on intermodulation distortion is determined by the phase relationship of the three waves in this system. Using this principle, we proposed a control method that radiates the communication waves and the interference waves to different beams. It was shown that the proposed method can reduce the amount of interference by about 4 or 5 dB. As a result, the HPA can be operated at a power-efficient operating point and the proposed method is effective in reducing power consumption.

References

[1] Masayoshi TANAKA and Hideaki MASAKI, Multibeam Mobile Satellite Communication Payload with Beam-forming Network, AIAA 2007-3179, 25th AIAA International Communications Satellite Systems Conference, 2007.
 [2] J. Litva and T. Lo, "Chapter 2", Digital Beamforming in Wireless Communications, Artech House, 1996