Payload System Tradeoffs for Mobile Communications Satellites

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ABSTRACT

This paper describes system level trade-offs carried out during M-SAT design activities. These trade-offs relate to the use of low level beam forming, flexible power and spectrum distribution and selection of the number of beams to cover the service area. It is shown that antenna performance can be improved by sharing horns between beams using a low level BFN and that greatly increased power utilization is possible using a hybrid matrix concept to share power between beams.

INTRODUCTION

Since 1980, Spar Aerospace Limited has been engaged, under contract to the Department of Communication and to the Department of Industry, Science and Technology Canada, in a study and design of a payload for a mobile communication satellite. This paper describes some of the trade-offs carried out during the design of the payuload.

REQUIREMENTS

The design requires the complete coverage of Canada and the United States including Alaska, Hawaii and Puerto Rico. The minimum aggregate EIRP (AEIRP) is to exceed 54 dBW. Frequency reuse capability is required between the east and the west areas demanding a minimum of four beams across the continent. Capability of adapting to changing traffic patterns is also a requirement. As a minimum the capability should allow power to be moved between the two eastern beams and between the two western beams though not between the east and the west.

SYSTEM TRADE-OFFS

The system trade-offs described here include the following:

1. Number of beams covering the continent.
2. Frequency reuse capability.
3. Low level beam forming for improved antenna performance.
4. Capability of changing the allocation of power and spectrum between beams to match the evolving traffic pattern.

NUMBER OF BEAMS

Configurations have been evaluated for 10 beams, 8 beams and 4 beams covering Canada and the United States not counting Alaska, Hawaii and Puerto Rico, which require additional beam(s) in all cases. The 10 beam and 8 beam configurations consisted of 5 and 4 circular beams over Canada and an equal number of slightly elongated beams over the United States. The 4 beam configuration has elongated beams each of which covers part of Canada and part of the United States.

The advantage of fewer beams is the reduction of spacecraft hardware associated with each beam and the possibility of using a smaller L-Band reflector. The advantage of more beams is the increased antenna gain and resulting increased EIRP and in the case of the 10 beam configuration, the increased frequency reuse capability.

FREQUENCY REUSE

Frequency reuse patterns are well known and are characterized by the number of frequency segments required (one per beam) so that the beams are sufficiently far apart and the frequency segments can be reused. For the triangular beam format, the frequency segments can number 4, 7, 9 or higher for a symmetric reuse pattern. For a square beam format, the number can be 4, 9 or higher. Since the North American continent favoured a square beam format, the choice was between 4 and 9 segments of frequency. The 4 and 9 segment plans require every other beam and every third beam to use the same frequency respectively.

To have frequency reuse in every other beam requires that, not only must the first sidelobe be suppressed but also that the main lobe of the nearest alternate beam must not extend into the designated reuse region. This demands very narrow beams formed using large reflectors and results in a large gain difference between the peak of the beam and the edge of the coverage area. This causes a large difference in carrier power through the reverse transponder and an increased demand for feeder link power.

These problems are eased by reusing the spectrum only in every third beam. This allows use of a smaller antenna diameter and reduced feeder link transmitter power. There is a small impact on the antenna gain with the smaller antenna as the system is sized on the antenna gain at the cross over point between beams rather than the peak antenna gain.

FLEXIBLE POWER DISTRIBUTION

In a multibeam environment, the traffic in each beam may not be known at the time the payload is designed, and in addition some changes in traffic distribution can be expected during the life of the spacecraft. If fixed power is assigned to each beam, then it should be matched to the expected traffic in each beam. Preferably, flexibility of power distribution should be built into the payload so that the capability can be matched to the traffic as the traffic evolves. A simplified block diagram of a transponder with fixed power per beam is shown in Figure 1.

The disadvantage of fixed power assignment can be seen from Figure 2. The maximum power utilization factor is shown as a function of the traffic fraction serviced by a fully powered beam for three cases; two beams with two equal power pools, four beams with four equal power pools, and ten beams with ten equal power pools. The power utilization factor is defined as the total power radiated by all beams as a fraction of the total power available in all beams. This can be determined by looking only at the performance of one amplifier in one beam. That is, the power utilization factor is given by the power radiated by one beam as a fraction of the total power available in all beams divided by the fraction of the traffic carried by that beam. The same utilization factor is obtained by considering beams which are not fully loaded. Also, power pools may be unequal as is the case if the beam powers are taylored to the expected traffic distribution. The utilization faction will be on the appropriate line in the case of a fully loaded amplifier and below the line for one not fully loaded but the same utilization factor will be obtained no matter which amplifier is considered.

As the traffic builds up, there will be a point at which even the lightly loaded beams reach full power and the power utilization factor will reach unity. However, in the meantime, traffic has been rejected in the heavily loaded beams.

A design approach is to interconnect the amplifiers for a number of beams by means of a hybrid matrix network[1] which combines the separate power pools into a single power pool and allows any beam to dip into the pool for the number of carriers present at each instant of time. The hybrid matrix consists of a network of 3 dB hybrids connected so that a binary number of input and output ports exist. The configuration for a 4 X 4 (4 input and 4 output ports) hybrid matrix is shown in Figure 3. An input hybrid matrix is placed before the amplifiers which takes the signal at each input port and divides it equally between all amplifiers. An output hybrid matrix is placed after the amplifiers which collects the signal from all amplifiers and directs it to the corresponding output port. In this way, every signal extracts an equal amount of power from all amplifiers in the hybrid matrix power amplifier. A simplified block diagram of the transponder is given in Figure 4 showing the location of the input and output hybrid matrix. In this way for example, four beams with four power pools can be converted to a single power pool by connecting all beams to the hybrid matrix network.

FLEXIBLE FREQUENCY DISTRIBUTION

In order to make use of the power flexibility, as provided by the hybrid matrix, it is necessary to have a corresponding amount of spectrum flexibility.

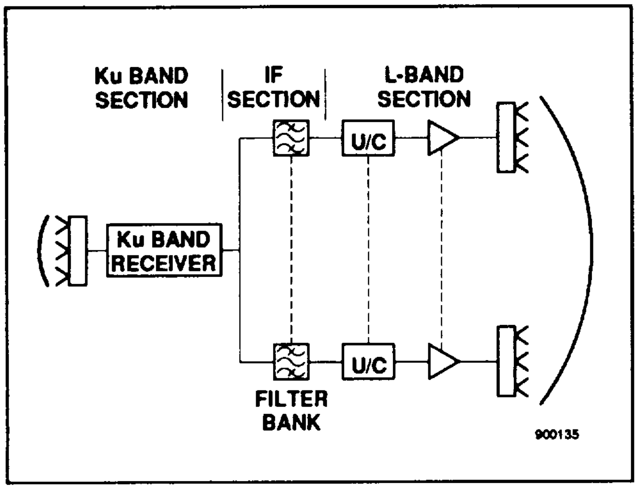

Fig. 1. Forward repeater with fixed power per beam

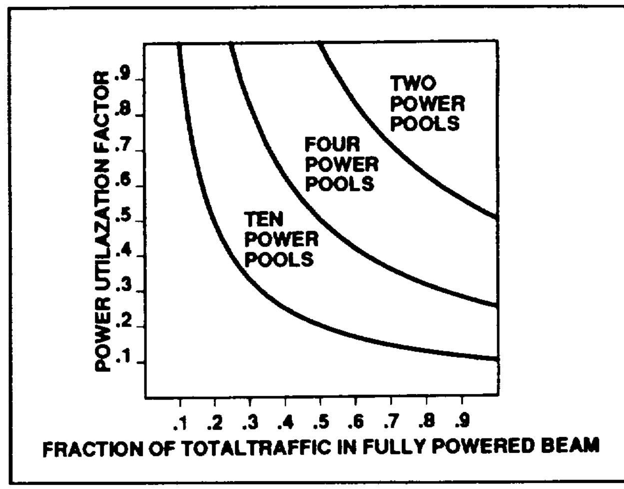

Fig. 2. Maximum power utilization curves for 2, 4 and 10 pools of power

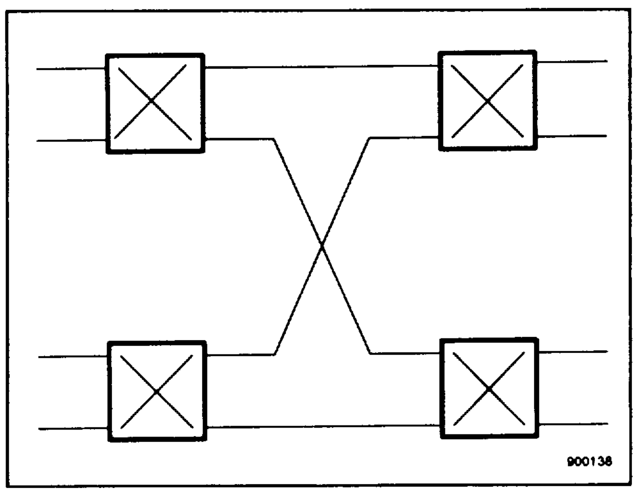

Fig. 3. Block diagram of a 4X4 hybrid matrix

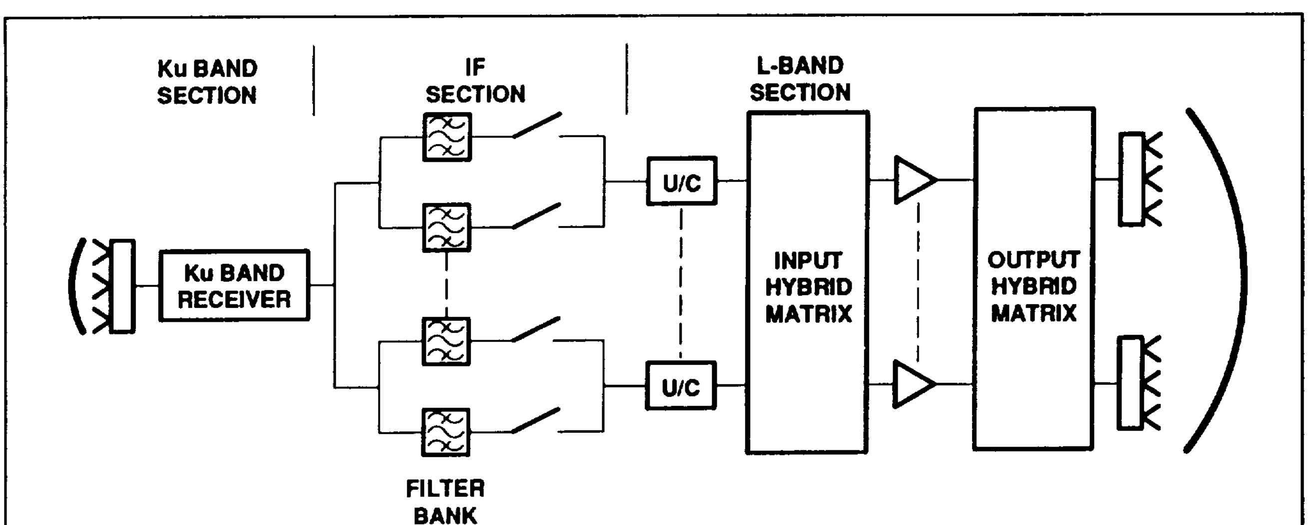

Fig. 4. Forward repeater with flexible power and spectrum distribution

Table 1. Comparison between filter bank and filter switch matrix approach to spectrum flexibility

	Filter switch matrix	Filter bank
Total bandwidth (MHz)	29	29
Filter bandwidth (MHz)	0.5 - 2.0	3.5
Switches per filter	3 to 5	one
Several filters connectable to one beam	yes	yes
Several beams connectable to one filter	yes	yes
Number of filters	40 per use	8 per beam

This is provided in a stepwise fashion by switching filters rather than in a continuous fashion as provided for power with the hybrid matrix. There are two ways of implementing the filter switching as shown in Figures 5and 6, namely a filter switch matrix approach and a filter bank approach.

The filter switch matrix approach connects the filters permanently to the feeder link and connects them to the desired beam by means of switches. A full 29 MHz of filters is provided for each frequency use and connected to the feeder link for transmission to the ground.

The filter bank approach provides a full 29 MHz of filters permanently connected to each beam and these are connected or disconnected as desired.

The filter bank approach tends to have more filtering and less switching whereas the filter switch matrix approach tends to have less filtering and more switching. However, to minimize the number of filters in the filter bank approach, the filter bandwidth is increased. A summary comparison between the two approachs is given in Table 1.

Table 2. Comparison of shared and un-shared horn approaches

	Un-shared horns	Shared horns
Reflector size (m)	5X6	5X5
Edge of coverage gain	Ref.	+1 dB
Peak to edge gain delta	5-6 dB	2.5-3 dB
Reuse isolation	Ref.	+2-3 dB

LOW LEVEL BEAM FORMING

To provide good overlap between beams, it is necesary to share horns between beams, that is to use the same horn as part of the horn cluster for adjacent beams. Because of the loss in the beam forming network, the network is placed before the final power amplifiers (or after the initial LNA's on the receive side) with one amplifier used for each radiating element. This is shown in simplified form in Figure 7. The advantage of sharing horns in this way is a higher antenna gain at the cross-over point between beams and a lower gain variation across the beam compared to un-shared horns. An additional advantage is the reduction of sidelobes in the reuse region. The disadvantage with shared horns is that the antenna and the transponder are intermingled and the performance of each can not be separately evaluated. Table 2 summarizes the performance obtained for M-SAT with both shared and un-shared horn approachs.

REFERENCES

1. **Egami and Kawai.** May 1987. An Adaptive Multiple Beam System Concept. IEEE Journal on Selected Areas in Communications, SAC5, pp. 630-636.

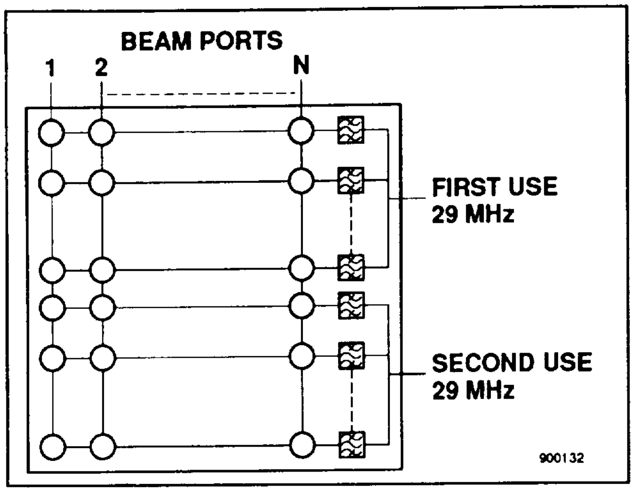

Fig. 5. Filter switch matrix configuration

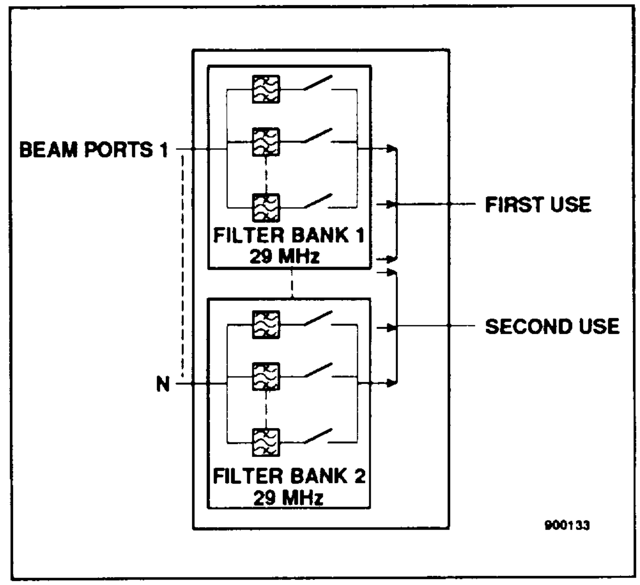

Fig. 6. Filter bank configuration

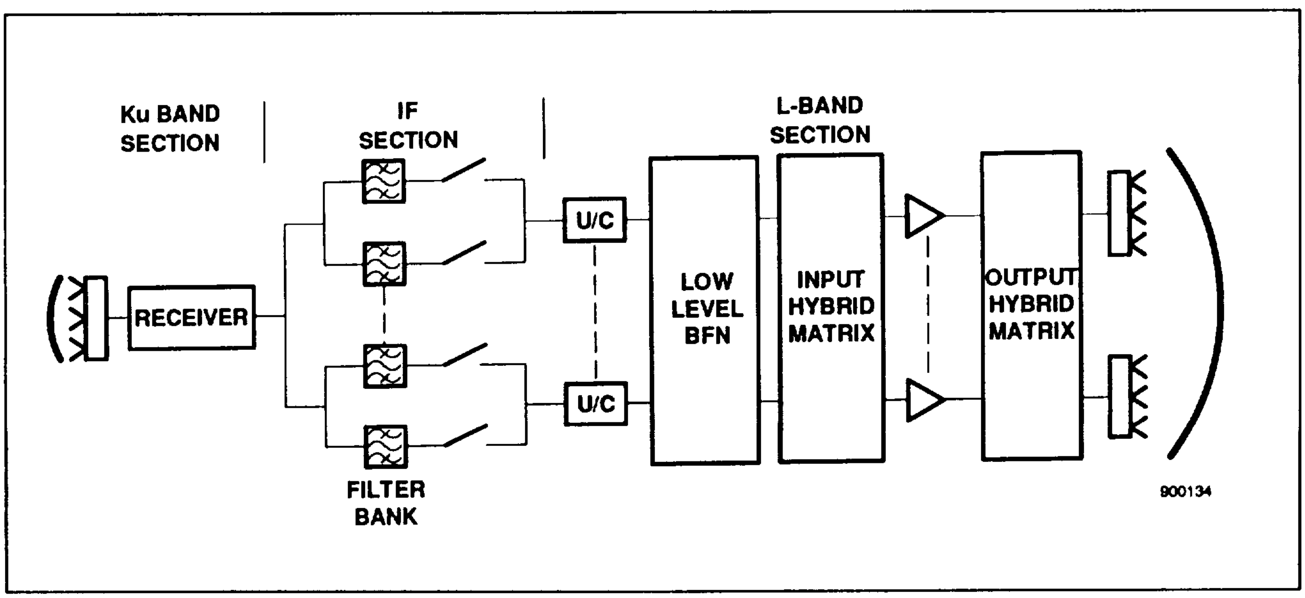

Fig. 7. Forward repeater with low level beam forming and flexible power and spectrum distribution