Ka-Band Multiplexer With Multiple Input and Output Ports

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ABSTRACT

Aiming at the development of Ka-band HTS satellite and the application of microwave technology, a new type of Ka-band OMUX with three input ports and five output ports is presented. The whole design process is combined with network model synthesis, field path equivalent hybrid model, pattern matching method and EM tools. The design procedures are included in this paper. The optimized dimensions and the simulated results are presented. Due to the use of hybrid equivalent circuit model of sleeveless multiplexer, unnecessary full-wave EM simulation is avoided, design efficiency is greatly accelerated, and simulation performance of OMUX is guaranteed to meet design indexes.

KEYWORDS

OMUX, Network Model, Equivalent Circuit, EM Simulation.

INTRODUCTION

The output multiplexer is the basic product on the spacecraft payload and is an
important part of the satellite transponder system. It is typically used in the high-power portion of the satellite payload to achieve high-power combining functions whose performance directly affects the communication quality of the repeater channel[1]. In recent years, with the rapid development of the satellite industry, the increasingly tight communication frequency resources have promoted the development of HTS satellites, which have many advantages such as multi-spot beam, frequency reuse, and superior anti-interference performance. As satellite bandwidth continues to expand globally, Ka-band technology and applications have attracted more attention, especially for HTS satellites that use multiple beams, which typically require a more flexible payload design. In the Ka-band multi-beam payload system, the multi-input and multi-output multiplexer can arbitrarily synthesize and output multiple narrow-band signals output by different multi-channel signal decomposers (DeMUX). Compared with the traditional output multiplexer, the multi-input and multi-output multiplexer has many advantages such as product sensitivity, small size, light weight, high isolation, flexible use of power amplifiers for different channels, flexible output combination, and the like. There are many design difficulties in circuit synthesis, design optimization, and structural arrangement. For now, the best system-level solution to the difficulty of designing such an output multiplexer is to connect different multiplexers through the branch connection channels.

Figure 1. Partial system block diagram of Ka-Band HTS satellite transponder.

Figure 1 shows the block diagram of part of the ka-band HTS satellite repeater system. Such a system has many advantages, such as allocating larger amplification
power to busy signal areas in different periods of busy information, and improving the working bandwidth of signal in busy areas. In the back end of the system output multiplexer part, in order to reduce the mutual influence between different channels to increase the passband isolation, the traditional method needs to increase the isolator, which makes the output multiplexer increase in volume and increase the design complexity. The proposed multi-input multi-output multiplexer of Ka frequency band can remove isolators by means of circuit synthesis, structure optimization and other means, and still ensure the required isolation index between the passes, thus reducing the volume and structure complexity of the output multiplexer.

![Functional block diagram of output multiplexer with three input ports and five output ports.](image)

In Figure 2, the three-input and five-out output multiplexers consist of a 3-channel DEMUX and two dual-channel DEMUXs. The composite signal is input through the A, B, and C ports, and then split into 7 beams through the CH1 to CH7 channel filters. The beam passing through the CH1 channel filter is recombined with the beam from the CH5 channel filter, and the composite signal of the two beams is output from the common port of the OMUX. The beams passing through the CH3 and CH6 channel filters are also recombined and output from the common port.

In recent years, the design technology of multiplexers has been rapidly developed. The latest OMUX design methodology has been described in [2]–[6]. A hybrid equivalent circuit model (HECM) for NSOMUX design is proposed in [6]. This article
combines the field-pass hybrid equivalent model and EM tools to design and quickly optimize the output multiplexer.

MULTIPLEXER DESIGN PROCEDURE

NETWORK MODEL SYNTHESIS AND COUPLING MATRIX INITIAL OPTIMIZATION

Figure 3 shows the network model of the OMUX for three input ports and five output ports. It consists of three DeMUXs, including seven bandpass filters (channels) and two common output ports. CH1 and CH5, CH 3 and CH6 are combined and output. The symbol "T-J" denotes the waveguide T-junction. Different from the traditional T-junction, the manifold iris is combined into the T-junction, and the first resonator of channel filter coupled to manifold is presented by a section of waveguide transmission line. The remainder reduced-order filter is represented by a modified coupling matrix, and the "C" represents a circuit-based. The theoretical network model of the waveguide transmission line, CH1 to CH7 is represented as a reduced-order filter, and the calculation formula of the reduced-order coupling matrix has a specific formula in[6]. "B" indicates that the waveguide-bend. In this design, T-junction is analyzed by pattern matching techniques.

Figure 3. Network model of output multiplexer with three input ports and five output ports.
It is worth noting that the initial coupling matrix of each channel filter is synthesized using a single-port network model and the filter function is determined to meet the required performance specifications. Before the coupling matrix is brought into the network model, it is necessary to carry out simulation optimization of the entire network circuit level, and make necessary adjustments to the coupling matrix to obtain the rough optimization initial value.

**DEMUX DESIGN**

This 0MUX can be seen as a triplexer and some channels of two duplexers combined output. The article chooses to design DeMUX first, then consider the merge problem, and try to reduce the unnecessary optimization process. The design of DeMUX in the article uses a hybrid equivalent circuit model of a sleeveless multiplexer, strictly following the design steps proposed in[6] to improve design efficiency. Figure 4 shows the 3D model of the designed 3 channel DeMUX and its performance characteristics.

Figure 4. (a) 3-D model view of a 3 channel multiplexer. (b) Performance characteristics of a 3 channel multiplexer.
The single DeMUX is designed quickly and accurately using HECM in step B, and the combined output port design needs to be considered next. In the network model, CH1 and CH5, CH3 and CH6 are output merged, but the phase change and discontinuity of waveguide transmission line and waveguide bend in OMUX Common Port will have a malignant impact on filter performance of merged channel. Therefore, it is necessary to optimize EM for waveguide transmission line and waveguide bend in OMUX Common Port, and fine-tune the coupling matrix of the remainder reduced-order filter of the combined channel to achieve good return loss. The specific design is as follows:

All EM models (not adjusted in DeMUX) except the merged channel remainder reduced-order filter in DeMUX are saved as sub-circuits, and full-field simulation is performed to save the simulation results.

Calculate the S-parameters of the merged channel filter, extract its coupling matrix, and store it as a two-port network model.

According to the structural layout restrictions, the appropriate waveguide bend, a certain length of the waveguide transmission line and the ET/HT output port are selected to form the EM initial model of the OMUX Common Port.

The sub-circuit saved in the first step, the two-port network saved in the second step, and the EM initial model of the OMUX Common Port in the third step are connected to form hybrid equivalent circuit model, and the performance index optimization conditions are set in the simulation tool. The coupling matrix and EM model were initially optimized quickly.

The optimized EM model is saved, and the optimized reduced order filter coupling matrix is gradually replaced by the EM structure to obtain the complete EM model of OMUX.

**3-D MODEL AND SIMULATION RESULTS**

The OMUX designed in this paper uses a rectangular waveguide resonator to implement a single-channel filter. The rectangular waveguides are all built on the WR51 waveguide, the T-J of the DeMUX selects the HT structure, and the OMUX combined output port selects the ET structure and the Mited bend. The manifold iris
has a thickness of 3.2 mm and a chamfer of 1.6 mm. The performance of the single channel filter is shown in Table I. A three-dimensional model view of the final OMUX with connected channels is shown in Figure 5:

| CH# | Filter Function | Bandwidths (MHz) |
|-----|-----------------|------------------|
| CH1 | 5               | 19650-19750      |
| CH2 | 5               | 19875-20075      |
| CH3 | 4               | 20200-20300      |
| CH4 | 4               | 19100-19300      |
| CH5 | 5               | 19450-19550      |
| CH6 | 4               | 20400-20500      |
| CH7 | 5               | 20700-20900      |
Figure 5. 3-D model view of Ka-band multiplexer with three input ports and five output ports

The manifold dimensions are listed in Table II. The simulated performance is shown in Figure 6.

**TABLE II. MANIFOLD DIMENSIONS FOR THE KA-BAND MULTIPLEXER WITH THREE INPUT PORTS AND FIVE OUTPUT PORTS.**

| L#  | Length(mm) | L#  | Length(mm) |
|-----|------------|-----|------------|
| L0  | 10.000     | L9  | 16.181     |
| L1  | 21.193     | L10 | 5.068      |
| L2  | 16.195     | L11 | 4.463      |
| L3  | 10.000     | L12 | 3.712      |
| L4  | 16.587     | L13 | 4.250      |
| L5  | 15.287     | L14 | 2.638      |
| L6  | 13.804     | L15 | 2.445      |
| L7  | 10.000     | L16 | 2.531      |
| L8  | 18.026     | L17 | 1.898      |
Through the simulated performance obtained by EM simulation, it can be seen that the performance of the Ka-band multiplexer with three input ports and five output ports designed by the above steps fully meets the requirements of the index.

CONCLUSION

This paper designs a Ka-band multiplexer with multiple input ports, output ports and connected channels. The detailed process of synthesis, design and optimization of the whole network model is expounded, and the physical dimensions of the partial parameters, the final 3D model and the full-wave simulation results are given. In the design process, the hybrid equivalent circuit model of the sleeveless multiplexer is used, which greatly improves the design efficiency while maintaining good precision. It avoids the time consuming of unnecessary full electromagnetic simulation and greatly shortens the design cycle.
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