A NEW MILLIMETER-WAVE BAND-SPLITTING FILTER USING FIGURE-8 HYBRIDS

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This paper describes the structure and 3-dB coupling characteristics of a newly developed "figure-8 hybrid" operated in a circular TE_{01} mode, the experimental results for a band-splitting filter using the present hybrids and its application to the branching filter system for the millimeter-wave communication system.

Band-splitting filter using the figure-8 hybrids

The TE_{01} mode circular waveguide hybrid is the most suitable component for the band-splitting filter for the guided-wave communication system at millimeter wavelengths, because such a filter can easily be connected to the long distance transmission line operated in the circular TE_{01} mode, is of low loss and can be fabricated at high accuracy. There are only two hybrids in this category, namely the figure-8 hybrid[1,2] and a Michelson interferometer type hybrid[3,4], at present. The figure-8 hybrid is much smaller in size than the Michelson one, because the waveguide diameter of the former is one fifth to one tenth of that of the latter.

The figure-8 hybrid consists of two parallel TE_{01} mode circular waveguides having the same diameter, coupled to each other by a number of small holes in the common wall. The coupling is made by the axial magnetic field. Figure 1 shows a gold-plated experimental model in the 75 GHz band of the band-splitting filter composed of two figure-8 hybrids and two cutoff high-pass filters. In Fig. 2, where the 3-dB coupling characteristics of the hybrid are shown, it is found that the experimental results are well coincident with the theoretical prediction, if it is considered that the heat loss and the mode conversion loss are included in the measured plots.

Figure 3 indicates the measured characteristics of the band-splitting filter in the 75 GHz band. The branching losses are, on an average, 0.8 to 1.1 dB in the lower band of 60 to 70 GHz and 0.7 to 0.9 dB in the upper band of 70 to 85 GHz. The upper limit of the operating frequency range can be extended to 90 GHz or more, though experiments have not been made over 85 GHz. The theoretically estimated losses are 0.6 dB or less in 50, 75 and 100 GHz bands where the specific bandwidth of 40 percent, the ratio of the overall bandwidth to the cutoff frequency of the cutoff filter, is divided into two parts. Such broad-band properties have been obtained from two ideas introduced to design the hybrids:

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first, to make the lengths of two hybrids differ from each other (see Fig. 3) and, second, to select the waveguide diameter and the shape and size of the coupling hole in order to make the variation of the coupling coefficient with the frequency as small as possible. Sharp cutoff effects and low reflection characteristics in the pass band of the high-pass filter have been obtained by the unconventional cosine-cubed cutoff filter.[5]

Application of the figure-8 filters to the branching system

A four stage hierarchical branching system for the repeater station is tentatively planned,[1] as shown in Fig. 4. The Michelson interferometer type filter is suitable for a first stage band-splitting filter because of the very wide specific bandwidth attainable to 100 percent or more. This filter requires too much space, however, because it works on quasi-optical principles. Moreover, it has a high loss of 1.2 dB, or twice the loss of the figure-8 band-splitting filter. Therefore, the figure-8 filter may be used effectively as a second stage band-splitting filter and a transmit-receive branching filter. A center-excited type filter,[6] a three-guide type filter[7] and a directional filter using ring resonators[8] have been developed in our laboratory as the last stage of a channel-dropping filter.

Recently, two all solid-state PCM-AM repeaters having a 46.5 GHz and a 47.2 GHz carriers have been built operating at a bit rate of 225.47 Mb/s using 4 GHz IF. To examine the feasibility of the repeaters, tests including the branching system, an 8.4-kilometer circular waveguide and delay distortion equalizers have been carried out.

A millimeter-wave branching filter system used for the experiments is shown schematically in Fig. 4. The figure-8 band-splitting filters with inner diameters of 10 and 11 millimeters have been utilized as the second stage and third stage branching filters. Figure 5 illustrates the typical overall transmission characteristics from channel 7 input to channel 7' output. The channel-dropping filters used are the three-guide type with two-resonator maximally flat response, a 3-dB bandwidth of 530 MHz and a band spacing of 420 or 550 MHz. The overall loss passing through eight stage filters was 11.8 dB at the midband of 46.5 GHz where the 11 millimeters diam. helix waveguide loss, 0.8 dB, was included. In future, the overall loss will be reduced to 7 dB by introducing optimum design method and decreasing heat losses, even when ten channel-dropping filters are connected in cascade.

The pulse response for 1010 pattern at 225 Megabauds shown in Fig. 6 gives good results; that is, the pulse echo level is under the observation limit of - 28 dB and undesired distortion in the waveforms has not been observed.

From the above experimental results, it is concluded that the figure-8 filter is very useful as a branching filter for the millimeter-wave communication system.

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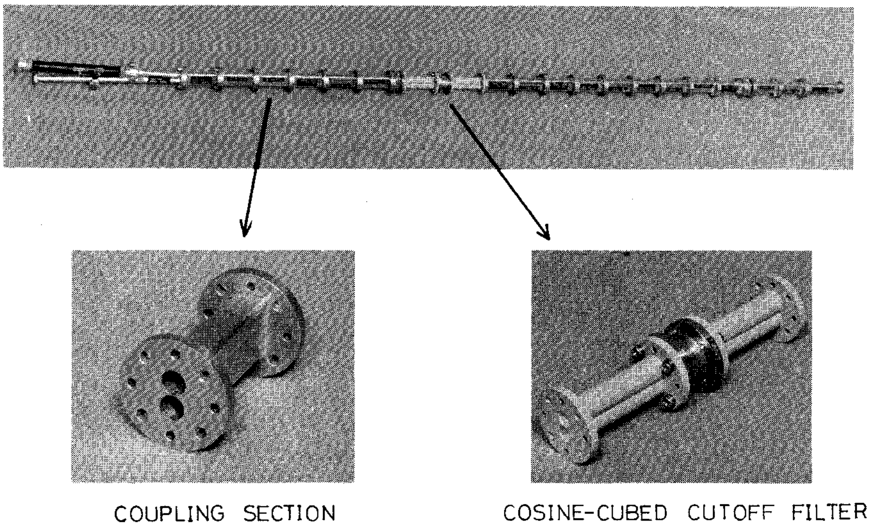

Fig. 1 Band-splitting filter for the 60 to 90 GHz band.

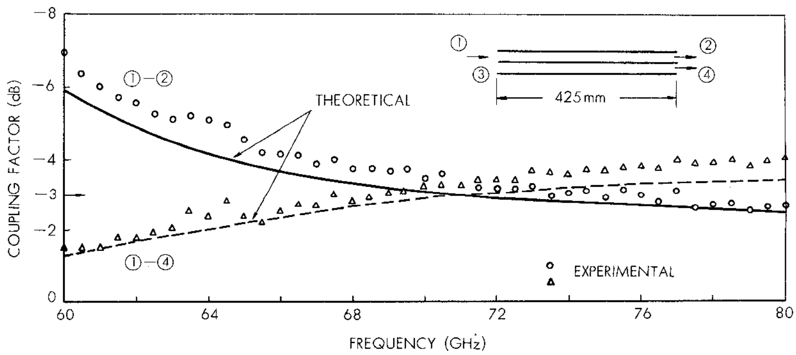

Fig. 2 3-dB coupling characteristics of a figure-8 hybrid.

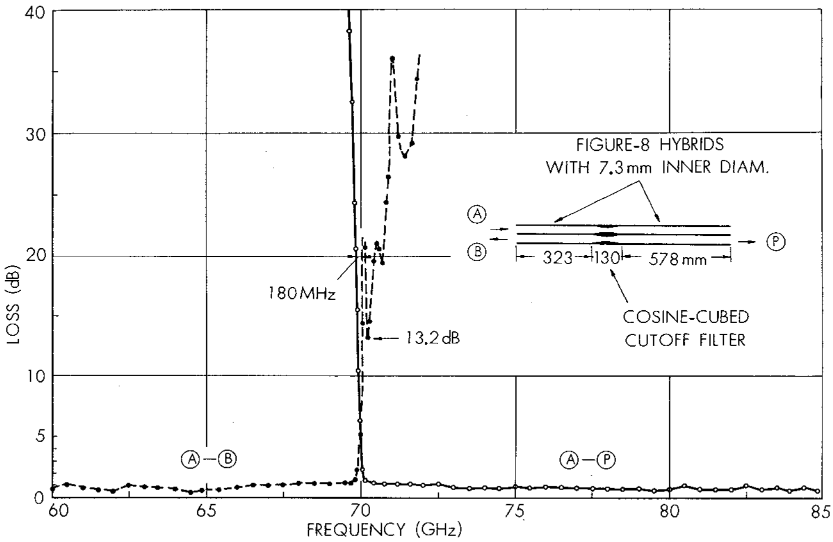

Fig. 3 Experimental results for a band-splitting filter.

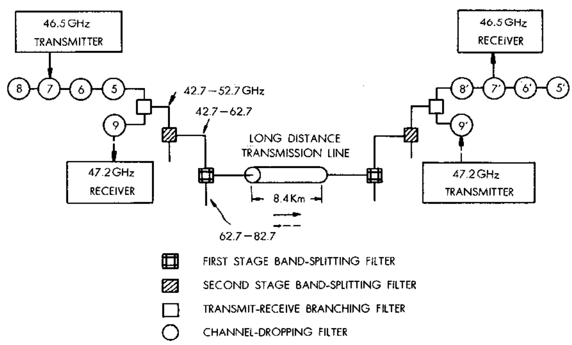

Fig. 4 Experimental branching system for the millimeter-wave communication system.

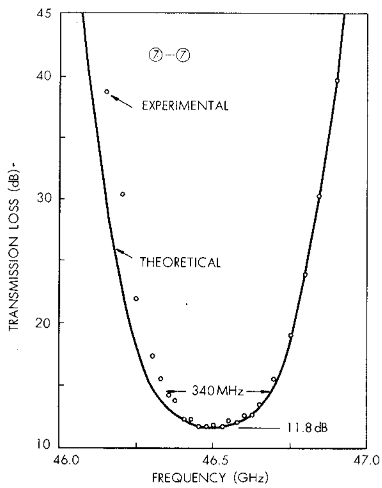

Fig. 5 Overall transmission characteristics of channel No. 7.

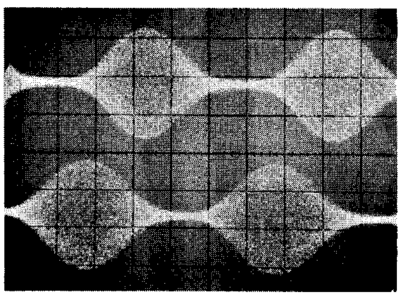

Fig. 6 Input and output pulse waveforms (upper and lower traces, respectively) in the branching system. Horizontal scale: 2 ns/div.