A Quasioptical Circuit Technology for Shortmillimeter-Wavelength Multiplexers

NOBUO NAKAJIMA AND RYUICHI WATANABE

Invited Paper

Abstract—**This paper describes constructions and electrical performances of shortmillimeter-wavelength quasioptical passive circuits using the Gaussian beam mode, i.e., beam mode launchers, polarization-independent beam splitters, circular polarization duplexers, filters, diplexers, and multiplexers. The diplexers were devised to handle wide bandwidths with fairly low loss and to have a sharp cutoff response so that they can be applied to telecommunications systems. Experiments on these components including frequency multiplexers and antenna feed systems were carried out in the 100-GHz band. It is shown that quasioptical circuits are particulary useful in reducing insertion loss of multiplexing systems for shortmillimeter wavelengths.**

I. Introduction

THE EXTENSION of the operating frequencies into millimeter waves, particulary those higher than 100 GHz, reveals the inadequacies of the dominant mode waveguide components. Losses increase rapidly; for example, at 100 GHz a loss of about 4 dB/m is not uncommon for a practical waveguide. Component size becomes so small that it is almost impossible to achieve the relative tolerances which are necessary to maintain the performance requirements.

Therefore, the need for alternatives is apparent. Open guided structures, i.e., quasioptical waveguides (Gaussian beam waveguide), groove guides, and dielectric waveguides, have already been proposed as alternatives and have been investigated both theoretically and experimentally. Of these, the Gaussian beam waveguide has the lowest insertion loss.

In early investigations of Gaussian beam waveguides, the main focus was on transmission lines [1]. However, due to recent advances in millimeter-wave satellite communications systems and radio astronomical equipment, Gaussian beam waveguides are recognized to be suitable in the construction of antenna feed systems. Several types of quasioptical components and feed systems have been developed in the microwave and millimeter-wave regions [2]–[9]. For example, Shindo *et al.* have developed a microwave multilayer dielectric filter for satellite communications antenna feed systems [2]. Goldsmith has developed an antenna feed system for radio-astronomy in the shortmillimeter-wave region [3]. Arnaud *et. al.* did the fundamental research on quasioptical filters in the millimeter-wave region [4]. These works show that the Gaussian beam waveguide also has the potential for realizing low loss passive circuits having various functions. However, to use quasioptical devices for more advanced applications, such as in frequency multiplexers for telecommunications systems, further investigation is required to improve the electrical performances. For example, maintaining fairly low insertion loss over a wide bandwidth and sharpening cutoff response.

This paper reviews the results of our work on quasioptical basic components, diplexers, and multiplexers in the shortmillimeter-wavelengths region. In Section II, the basic components, i.e., Gaussian beam mode launchers, polarization-independent beam splitters and circular polarization duplexers are presented. These devices are used to construct the diplexers described in Section III, where five types of diplexers are presented. Three of them are channel-dropping diplexers. The other two are band diplexers. In Section IV, a multiplexing system and an antenna feed system are described.

II. Basic Components

Dielectric plates, metal grids, lenses, mirrors, Fabry–Perot resonators, and horn launchers are mentioned as the basic components of quasioptical circuits. Dielectric plates and metal grids are used as directional couplers. Dielectric plates have a flatter response over wide bandwidths than metal grids. For example, the coupling loss of a hybrid made from fused quartz is within 3 ± 0.2 dB for octave bandwidths. However, to obtain a coupling loss greater than 10 dB, a metal grid is preferable. Mirrors and lenses are used for mode matching between the components. As the insertion loss of lenses is increased by surface reflection and absorption, mirrors, which have excellent reflectivity, are better for use.

The quasioptical devices mentioned above are well known and are already used in the aforementioned applications. In this section, four additional types of basic components having new functions are described.

A. *Gaussian Beam Mode Launcher [10]*

A Gaussian beam mode launcher is necessary in the application of beam guide circuits in shortmillimeter wavelengths. This is because active devices such as oscillators and detectors are still mounted in a single-mode wave-

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The authors are with the Yokosuka Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation, Yokosuka-shi 238-03, Japan.

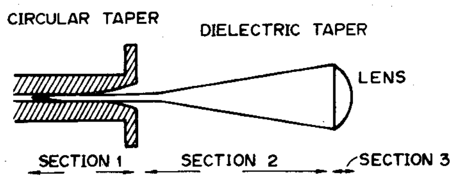


Fig. 1. Dielectric horn launcher.

guide. The insertion loss of a launcher should be kept low and the radiation pattern must closely coincide with the Gaussian mode.

A launcher is usually constructed using a conventional horn with a lens or metal mirror. In this case, there exists an intrinsic loss of about 0.5 dB caused by mismatching between the horn mode and beam mode. In addition, lens surface reflection causes about 0.2-dB insertion loss because the lens is usually made of plastics such as polyethylene (relative dielectric constant $\epsilon_r = 2.3$).

A corrugated horn is useful in reducing mismatch loss. A field distribution of a horn aperture, which is nearly equal to the zeroth-order Bessel function, is very close to the Gaussian distribution. The mismatch loss is less than 0.1 dB. However, the difficulty of making corrugated grooves grows relative to the increase in frequency.

The dielectric horn proposed here is well suited for a beam mode launcher in the shortmillimeter-waveguide region because it is easy to fabricate and, like the corrugated horn, the radiation pattern is very close to the Gaussian distribution.

Fig. 1 shows the structure of a dielectric horn launcher. The launcher is composed of three sections. The first section converts the circular waveguide mode (TE_{11}) to the dielectric waveguide mode (HE_{11}). The radius r_0 of the waveguide is limited by the following equation so that higher mode waves may not propagate in the dielectric waveguide:

$$2.4 \geq \frac{2\pi r_0}{\lambda} \sqrt{\epsilon_r - 1} \tag{1}$$

where λ is wavelength. The second section is a dielectric horn whose diameter is expanded to have a suitable aperture in order to match a horn mode with a Gaussian beam mode. The last section adjusts the phase front distribution of the horn to the radiated/received beam mode. Measured insertion loss of a fabricated launcher with a 3.8-mm beam radius and a 1.0-mm waveguide radius is 0.7 dB at 100 GHz. VSWR is less than 1.2.

B. *Polarization-Independent Beam Splitter* [11]

Since the transmission and reflection coefficients of the beam splitters usually used vary depending on the state of the incident wave polarization, they cannot be used for mutually orthogonal polarization application. The proposed beam splitter has polarization-independent characteristics.

This beam splitter consists of thin parallel metallic strips backed by a dielectric sheet, as shown in Fig. 2. The metallic strips are laid parallel to the plane of incidence. The incident wave is resolved into two mutually orthogonal polarizations, i.e., $E_{\parallel}$- and $E_{\perp}$-polarizations. The $E_{\perp}$-polarization transmission coefficient of the thin parallel metallic strips is smaller than that of the dielectric sheet. The $E_{\parallel}$-polarization transmission coefficient of the thin parallel metallic strips is larger than that of the dielectric sheet. By combining the dielectric sheet and the thin parallel metallic strips, polarization-dependent characteristics cancel each other out. In addition, wide-band characteristics can be obtained by optimizing the design parameters [11].

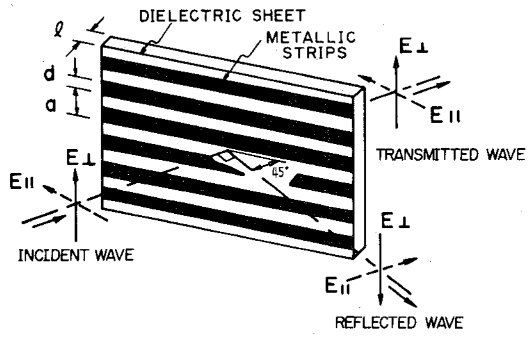


Fig. 2. Polarization-independent beam splitter.

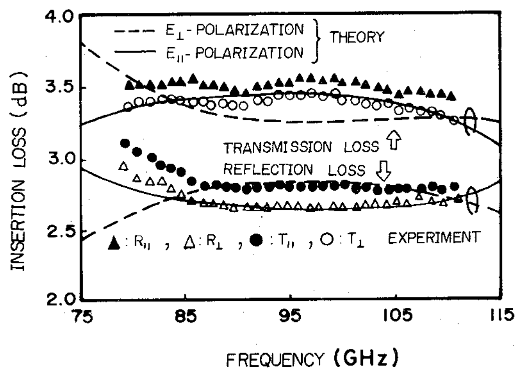


Fig. 3. Theoretical and measured frequency response of a polarization independent beam splitter.

A polarization-independent hybrid is composed of a fused quartz plate ($\epsilon_r = 3.8$) and metallic strips. Metallic strips are made by photolithographic etching of a 0.002-mm thick gold layer deposited on the fuzed quartz substrate by vacuum evaporation techiques. The design parameters l, d, and a are 0.44, 0.05, and 0.56 mm, respectively.

The frequency responses of the polarization-independent hybrid are shown in Fig. 3. The measured transmission and reflection coefficients for both $E_{\parallel}$- and $E_{\perp}$-polarizations are within 3.0 ± 0.5 dB in the 80- to 110-GHz bandwidth. The insertion losses for both polarizations are within 0.2 dB in the 80- to 110-GHz bandwidth.

C. *Circular Polarization Duplexer* [12]

Since a circular polarization duplexer separates the reflected wave of a filter from the incident beam, it is useful to construct Fabry–Perot diplexer and dielectric multilayer diplexer (see Section III-A). This circular polarization duplexer operates like a circulator.

A circular polarization duplexer consists of a polarization splitter and a quarter-wave plate. An overall view is shown in Fig. 4. The polarization splitter is made of a wire

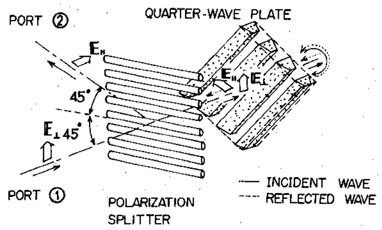


Fig. 4. Construction of a circular polarization duplexer.

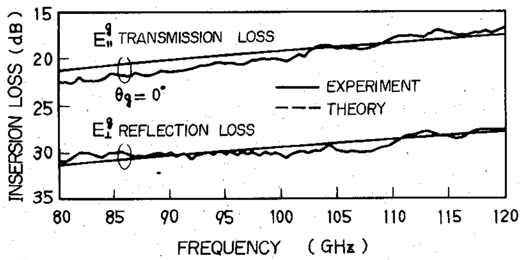


Fig. 5. Measured insertion loss of a polarizer.

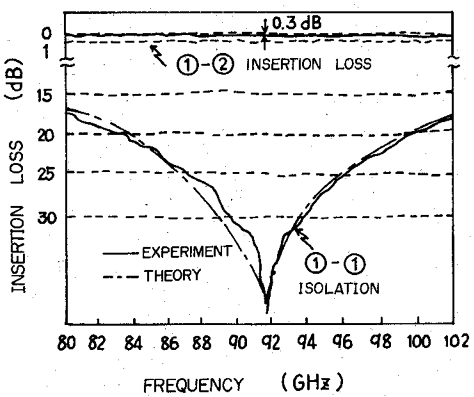


Fig. 6. Theoretical and measured frequency response of a circular polarization duplexer.

grid array. The quarter-wave plate is made of an artificial anisotropic dielectric medium which consists of spaced dielectric plates with tapered edges. Dielectric plates are arranged at an angle of 45 degrees with the electric vector of the incoming wave.

The incoming wave is resolved into two electric vectors, one with its electric field parallel to the plates and the other with its electric field normal to the plates. The wave whose electric vector is parallel to the dielectric plates emerges from the dielectric plates 90 degrees in advance of waves with the electric vector normal to the plates by designing thickness, width, and spacing of dielectric plates properly.

The operational principle is as follows. A $E_{\perp}$-polarized incident wave from port ① passes through the polarization splitter. The wave then passes through the quarter-wave plate and is converted to a circularly polarized wave. The circular polarization direction is reversed on the reflector. After passing back through the quarter-wave plate, the output wave is converted to a linear $E_{\parallel}$-polarized wave, which is completely reflected by the polarization splitter into port ②.

The diameter and spacing of a wire grid array which forms the polarization splitter are 0.08 and 0.35 mm, respectively. Measured amplitude separation between two orthogonal polarized waves and insertion loss are less than -17 dB (Fig. 5) and 0.1 dB, respectively. To get a low insertion loss and low VSWR over a wide bandwidth, the design parameters of the quarter-wave plates are optimized [12]. The thickness, width, and spacing of the dielectric plates are 1.34, 15.6, and 1.8 mm, respectively. The taper angle is 30 degrees.

Measured frequency response is shown in Fig. 6. Experimental results show that the insertion loss from port ① to port ② is 0.3 dB and relative bandwidth is 19 percent within the frequency bands where return loss is greater than 20 dB.

D. Filters

A filter with low insertion loss and sharp cutoff response is necessary for the application of diplexers in telecommunications.

Three kinds of filters are described in this section. All of these filters are used in the construction of diplexers.

Fabry–Perot Filter [13]: The Fabry–Perot filter is well known as a low-loss quasioptical bandpass filter. It is made of parallel spaced dielectric plates or metal grids in shortmillimeter wavelengths. To get high Q values, the flatness and parallelism of these plates are important. Thus the plates and grids are fixed with precisely machined spacers. Metal grids are made of thin copper sheets backed by dielectrics and are tensioned to get flat surfaces.

Fig. 7(a) shows the fabricated Fabry–Perot filter made of two resonators connected in cascade. Coupling losses of these plates are designed to be 13 dB (for inner one) and 4.6 dB (for outer one), to obtain a maximally flat response with a 3-dB bandwidth of 0.96 GHz. The grid is formed on 0.02-mm thick copper by photolithographic etching. The dielectric plate is 0.73-mm thick almina ceramic.

Pass through loss at resonant frequency is 0.3 dB in the 100-GHz band.

Dielectric Multilayer Filter [14]: Dielectric multilayer filter made of spaced dielectric plates has a very sharp cutoff response with a low insertion loss. This filter can be designed as either a low-pass or a bandpass filter. The design method is the same as that of the overmoded multilayer dielectric filter [15]. A large aperture radius is useful for reducing the diffraction loss, but it is difficult to manufacture large dielectric plates precisely. Therefore, the aperture diameter of the filter should be determined by evaluating the diffraction loss and the degradation of frequency response caused by the effect of dimensional tolerance due to the difficulty of manufacturing.

The 21-pole Tchebycheff filter having 100-GHz cutoff frequency is designed and fabricated using 22 fused quartz disks with 28-mm diameter and thickness of from 23 to 289 μm. The thickness of these disks is controlled within ± 3-μm tolerance. Insertion loss including diffraction loss is below 0.5 dB. The guard bandwidth (transition region where crosstalk exceeds 30 dB between two separated bands) is less than 1.2 GHz.

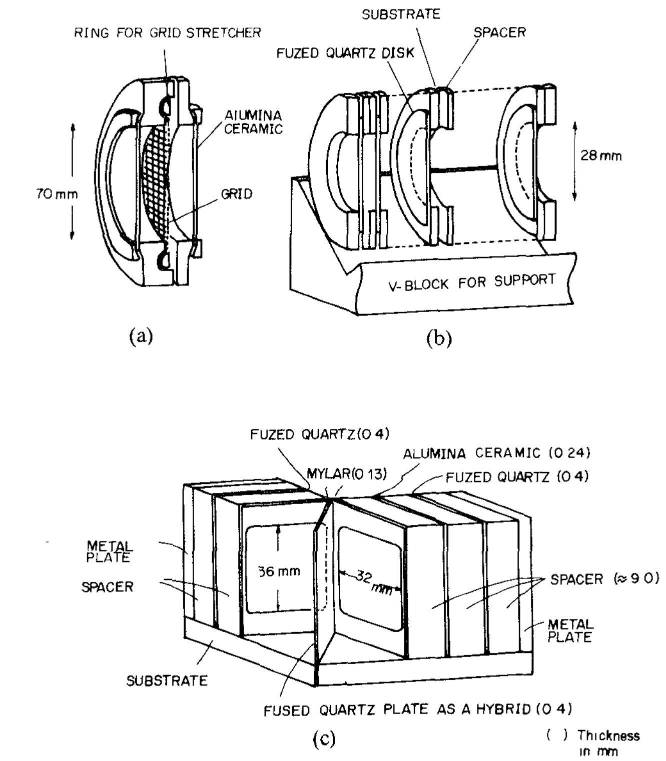


Fig. 7. Quasioptical filter. (a) Fabry–Perot type. (b) Dielectric multilayer type. (c) Hybrid–multilayer type.

TABLE I
TYPICAL CHARACTERISTICS OF FABRICATED FILTERS

	Fabry-Perot Type	Dielectric Multilayer Type	Hybrid-Multilayer Type
Frequency Response	2-pole Maximally Flat	22-pole Tchebycheff	5-pole Elliptic Function
Passband Width	1 GHz	25 GHz	5 GHz
Stopband Width	9 GHz	20 GHz	10 GHz
Insertion Loss	0 5 dB	0 5 dB	0 5 dB
Input Beamwaist Diameter	20 ~ 40mm	20 mm	20 mm

Hybrid-Multilayer Filter [*16*]*:* A sharp cutoff filter, named "hybrid-multilayer filter," whose frequency response is characterized by odd-order elliptic function, has been newly developed. This filter is composed of a hybrid and two shunt lines as shown in Fig. 7(c). Shunt lines are made of cascaded resonators and short circuited by metal plates. The hybrid is made of a fused quartz plate. The numbers of resonators in the two shunt lines differ by one. The resonant frequencies of all resonators are the same and are adjusted to the center frequency of the designed passband (or stopband). The difference of frequency response between the two shunt lines produces the filtering operation. The frequency response of the filter depends on the phase difference between waves that reflect from the two shunt lines. In phase waves are combined and transmitted to the output port. Out-of-phase waves are combined and reflected to the input port.

The design parameters of each resonator are determined by the exact synthesis method [16]. Both bandpass and bandstop responses can be obtained by almost the same design procedure. The frequency response is reversed by shifting the relative distance between the hybrid and both shunt lines by a quarter-wavelength. The total number of resonators coincides to the number of zeros in the passband (or poles in the stopband) response. Moreover, in the special case that passbandwidth is equal to the stopbandwidth, the total number of resonators is reduced to half that in the usual case.

Measured electrical performance of the fifth-order bandstop filter are shown in Table I along with the performances of other types of filters.

III. DIPLEXERS

In order to be applied in frequency multiplexers of telecommunications systems, diplexers are required to have not only a low insertion loss but also wide-band characteristics so as to divide/combine many RF channels with 100~1000-MHz bandwidth over a wide frequency range. In addition, the interchannel crosstalk should be minimized to suppress interference.

Multiplexers are usually composed of two kinds of diplexers; channel diplexer and band diplexer. The overall frequency band is divided into two subbands with equal bandwidths by the band diplexer. Therefore, the band diplexer is required to have wide-band characteristics, low-loss, sharp cutoff response, and low interchannel interference. The channel diplexers are usually connected in tandem and separate each RF channel sequentially. Spurious resonances should be avoided over wide bandwidth as possible so as to divide many RF channels simultaneously. Frequency response is usually of the 2-pole maximally flat type or Tchebycheff type.

A. Channel Diplexer

Ring Diplexer: The quasioptical ring diplexer has advantage in low insertion loss, low VSWR, and simple construction. Because the conventional quasioptical ring resonator is large in order to reduce the diffraction loss, the spurious resonance interval is small. Therefore, the useful bandwidth has a relatively narrow range.

The proposed ring diplexer is devised to minimize size without increasing diffraction loss so as to obtain a wide operational bandwidth with low insertion loss. By using triangular shaped resonators, a wide resonance frequency interval is obtained. Fig. 8 shows the structure of the proposed diplexer. Two resonators are cascaded to obtain the 2-pole maximally flat response. Mirror curvature is designed to satisfy the confocal condition. The beam waist radius of the resonant mode is 1.2λ (λ: wavelength) and the circumferential length of each ring is 10λ. The mirror aperture is more than 1.5 w (w is beam diameter). Thus the diffraction loss is about 0.005 dB.

Mirrors are of brass and machined to form a section of a spheroidal surface by a lathe. Couplers are made of mica plates (outer) and a metal grid (inner). The metal grid is made by photolithographic etching.

Fig. 9 shows frequency responses of the through channel and the dropped channel port. No spurious resonance can be observed within the specified frequency range (107 ± 10

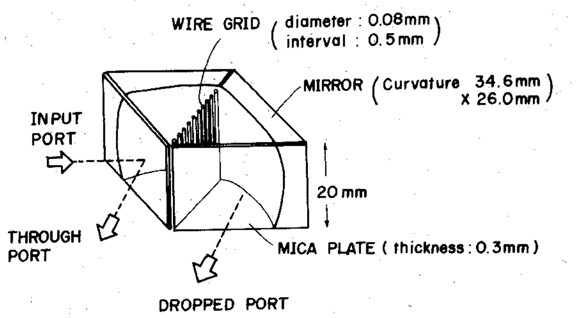


Fig. 8. Ring diplexer.

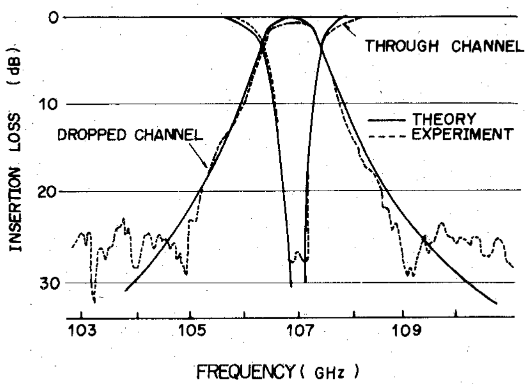


Fig. 9. Measured frequency responses of a ring diplexer.

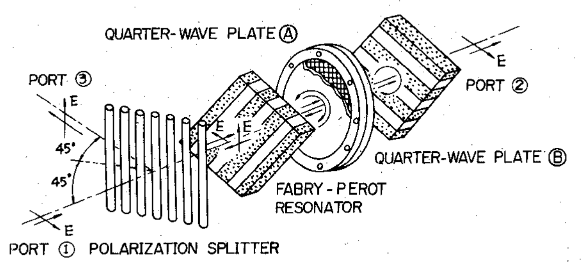


Fig. 10. Fabry–Perot diplexer.

GHz). The channel-dropping loss and the through-channel loss were 0.5 and 0.2 dB, respectively.

Fabry–Perot Diplexer [*13*]*:* A plane-parallel Fabry–Perot resonator working under oblique incidence can be used as a quasioptical diplexer [4]. However, it is difficult to get sharp cutoff response because walk-off loss increases with the increase in the number of resonators connected in cascade. To obtain a sharp cutoff diplexer with low insertion loss, a novel structure using a circular polarization duplexer, was developed.

The proposed diplexer consists of a two-resonator Fabry–Perot filter (Section II-D), a polarization splitter and two quarter-wave plates as shown in Fig. 10. Reflected waves (nonresonant frequency band) are separated from the input beam by the circular polarization duplexer (Section II-C). The transmitted beam is changed back to a linear polarization beam by the quarter-wave plate Ⓑ.

The measured frequency response of this diplexer is shown in Fig. 11. Measured channel-dropping loss was about 0.5 dB. Minimum through-channel loss was about 0.3 dB.

Periodic Diplexer [*18*]*:* The periodic diplexer is used to divide/combine the RF channels alternately. An overall view is shown in Fig. 12. It consists of quarter-wave plates, a polarization-independent hybrid (Section II-B), a polarizer and resonators.

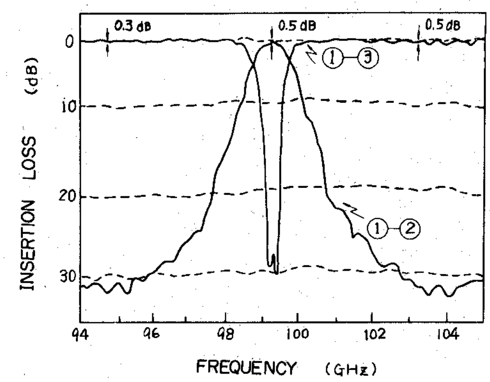


Fig. 11. Measured frequency response of a Fabry–Perot diplexer.

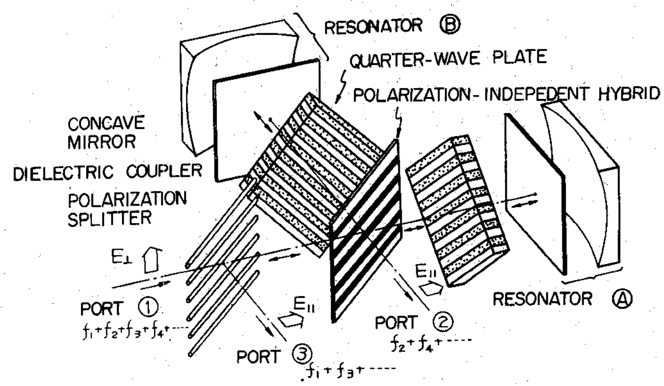


Fig. 12. Periodic diplexer.

Filtering principle is the same as that of the Michelson diplexer. However, this diplexer is easier to construct than the Michelson type diplexer because the number of applied resonators is half that of the Michelson type diplexer having same frequency response.

A linearly polarized incident beam from port ① passes through the polarization splitter. Then, it is divided into two beams with equal power by a polarization-independent hybrid. One beam, which passes through the polarization-independent hybrid, is transmitted to the resonator Ⓐ. The other beam, which is reflected at the polarization-independent hybrid, is transmitted to the resonator Ⓑ. These two Gaussian beams are converted into circularly polarized beams by quarter-wave plates, and reflected by the resonators Ⓐ and Ⓑ. The reflected circularly polarized beams are reconverted into linearly polarized beams by quarter-wave plates. These polarizations are perpendicular to that of the incident beam polarization. After these beams are brought together by the polarization independent hybrid, one beam, with even channel ($f_2+f_4+\cdots$) emerges at port ②. The other, with odd channel ($f_1+f_3+\cdots$), is reflected by the polarization splitter and emerges at port ③. Resonators are composed of dielectric sheets made of 0.72-mm thick alumina ceramic and 0.5-mm thick teflon, and mirrors, whose curvatures are 217 and 203 mm, respectively.

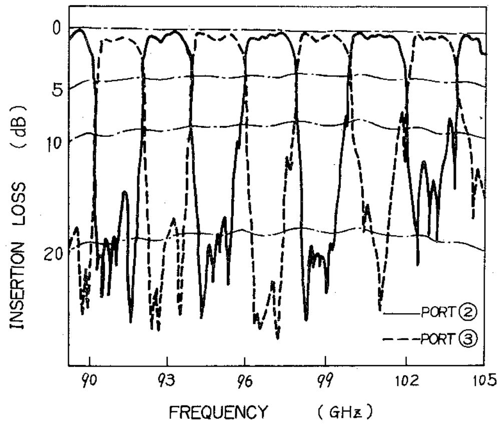


Fig. 13. Measured frequency response of a periodic diplexer.

The measured frequency response is shown in Fig. 13. Insertion loss is less than 1 dB.

B. Band Diplexer

Multilayer Dielectric Diplexer [14]: The basic operational principle is the same as that of the Fabry–Perot diplexer except that the Fabry–Perot resonator is replaced by the dielectric multilayer filter (Section II-D) in order to get a sharper cutoff response. The applicable bandwidth is mainly limited by the electrical performance of the quarter-wave plates.

Insertion loss of the wave transmitted through the filter, is always kept low because the polarization is completely recovered by placing the two quarter-wave plates perpendicular to each other as shown in Fig. 10. On the other hand, the insertion loss of the wave reflected from the filter increases with the increase in the axial ratio of the quarter-wave plate. Therefore, the quarter-wave plates are designed to perform best within the stopband of the filter.

Beam parameters (radius and position of beam waist) of the input and output beams are not generally in agreement with each other due to the diffraction effect. Thus mode mismatching occurs between the input and output beams of the filter. The optimum matching condition is derived by the Fourier transformation technique. In the fabricated diplexer, mismatching loss is reduced from 0.2 to 0.002 dB in the specified frequency band.

The measured frequency response is shown in Fig. 14. The cutoff frequency is 100.8 GHz. The guard bandwidth is 1.9 GHz. The transmission loss in lower and higher frequency bands (from 80.0 to 100.8 GHz and 100.8 to 120 GHz) is less than 1.0 and 0.5 dB, respectively.

Michelson Diplexer [19]: Like in the over-moded band diplexer [20], the Michelson type construction is suited for the quasioptical band diplexer, because the hybrid made of a dielectric plate, whose performance limits the applicable bandwidth, has a very flat response over a wide bandwidth. Although it is difficult to use the filter based on the waveguide cutoff behavior, the hybrid-multilayer filter (Section II-D) is effective in obtaining a wide bandwidth (≈one octave), sharp cutoff, and compact band diplexer.

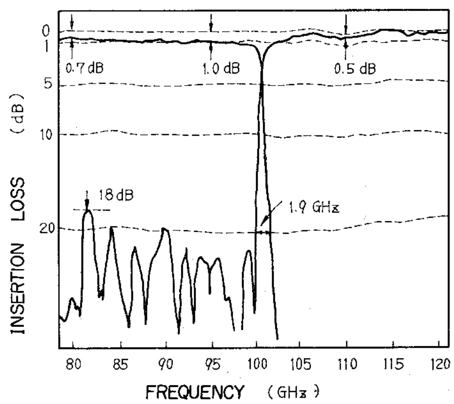


Fig. 14. Measured frequency response of a dielectric multilayer diplexer.

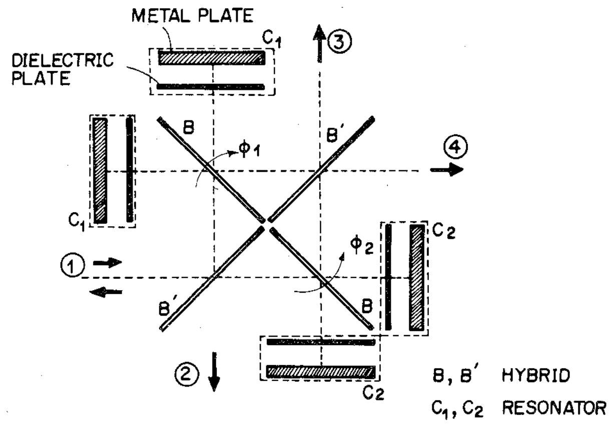


Fig. 15. Schematic diagram of a Michelson diplexer.

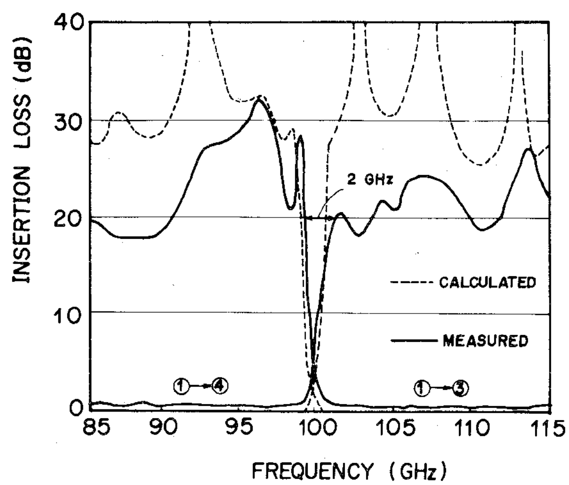


Fig. 16. Measured and theoretical frequency responses of a Michelson diplexer.

By making the passbandwidth and stopbandwidth equal, the total number of resonators is reduced by half as described in [16]. Frequency response of the fabricated diplexer is characterized by a fifth-order elliptic function with one resonator for each of the four shunt lines.

The structure of the proposed diplexer is simple as shown in Fig. 15. The hybrids are made of fused quartz plates. Resonators are made of alumina ceramic or mylar plates and are short circuited by metal plates. The thick-

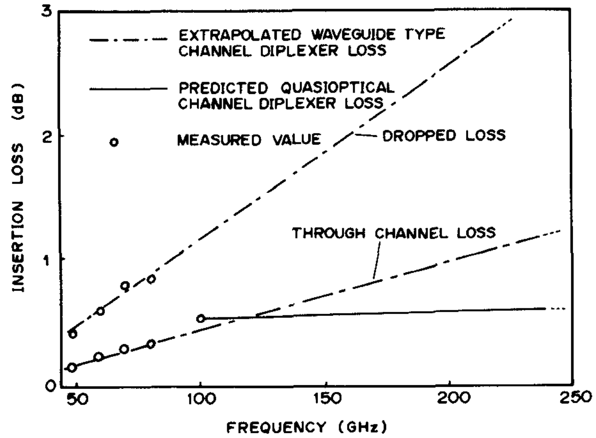


Fig. 17. Frequency dependence of the insertion loss of waveguide diplexer and quasioptical diplexer.

ness of each plate is the same as that of the periodic diplexer. Their resonant frequencies are adjusted to correspond with the cutoff frequency.

The parts which consist of hybrid B and two symmetrical resonators C/C' operate as all-pass circuits. All power entering from port ① is recovered either at port ③ or port ④ depending on the phase difference ($\phi_1-\phi_2$) between the two paths $B'-B-C_1-B-B'$ and $B'-B-C_2-B-B'$.

Fig. 16 shows the theoretical and experimental frequency responses. Measured insertion losses were 0.3–0.8 dB in both subbands. The guard-bandwidth was 2 GHz (1.5 GHz in theory). Crosstalks and the return loss were both under -20 dB (-30 dB in theory). These degradations are mainly due to the misalignment and can be reduced with the aid of tuning devices.

C. Loss Comparison Between Quasioptical Diplexer and Waveguide Diplexer

In the case of the waveguide diplexer, insertion loss is caused mainly by the conduction loss of the metallic wall. The conduction loss increases with the square root of frequency. In addition, the fabrication difficulty due to the decrease in the dimension also causes an increase in the insertion loss.

In the quasioptical diplexer, intrinsic losses (conduction loss and absorption loss of the dielectrics) account for an extremely small part of the insertion loss. Other loss factors, i.e., diffraction loss and mode-mismatching loss do not increase with frequency, thus it is expected that the insertion loss increase of the quasioptical diplexer will be very slow. The estimated insertion loss of the quasioptical diplexer increases in proportion to about fifth root of frequency. The frequency dependent characteristics for insertion loss are shown in Fig. 17 for both diplexer types.

IV. Application

A. Multiplexer

Overall insertion loss of a conventional waveguide multiplexer almost coincides with the sum of the insertion loss of each component. However, in the case of the quasioptical diplexer, there are additional losses due to mode mismatching caused by misalignment of the diplexers and by change in the field distribution according to frequency change. Therefore, to make the quasioptical multiplexer applicable to existing systems, it is necessary to confirm the overall loss experimentally.

Fig. 18 shows the fabricated multiplexer, composed of ring diplexers and a Michelson diplexer. The Gaussian beam is excited by a dielectric horn. Ring diplexers are connected in tandem with spheroidal mirrors of 50-mm focal length. Field distribution of output and input beams between the Michelson diplexer and ring diplexer is matched by a mirror of 80-mm focal length. Amplitude and phase distribution between incident wave and resonant mode of the diplexer is matched theoretically by Kogelnik's equation [21]. Every mirror aperture is 1.5 times larger than that of the beam diameter, thus the diffraction loss is negligible (0.01 dB). Positions and angles of each component (diplexer, mirror) can be arranged by tuning screws in order to adjust their optical axis to each other experimentally.

Fig. 20 shows the measured frequency responses excluding the insertion loss of the launcher. The measured loss is 1.5 to 2 times larger than predicted value. Assuming that the aberration and misalignment of the mirror cause this additional loss, the insertion loss increase is about 0.2 dB per one mirror. The relations of the number of RF channels to be divided/combined and the total insertion loss (Fig. 20) are estimated by the experimental results. It can be shown that the more the number of RF channels to be divided/combined increases, the more quasioptical diplexers are advantageous with regard to loss as compared with conventional waveguide diplexers. A more exact mode matching design and position tuning technique will further reduce the insertion loss. In addition, at frequencies higher than 100 GHz, it is thought that the insertion loss difference increases greatly as shown in Fig. 17.

B. Feed System

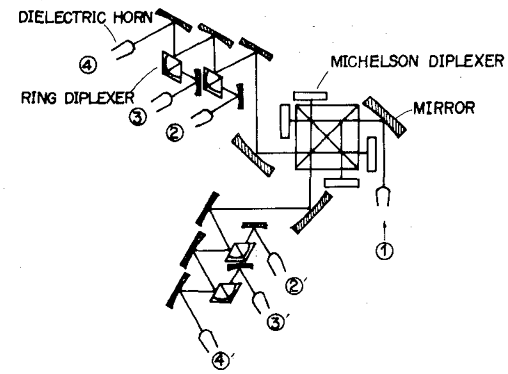
Applying quasioptical techniques is particularly effective in reducing antenna feed loss. Quasioptical feed is advantageous not only for reducing the dividing loss but for also reducing guided loss. They are the lowest among various guides in shortmillimeter wavelengths.

In addition, for a radioastronomical observation system, quasioptical components can isolate thermal conduction between the detector and the guide system by guiding the incident waves through the window on the cryostat wall.

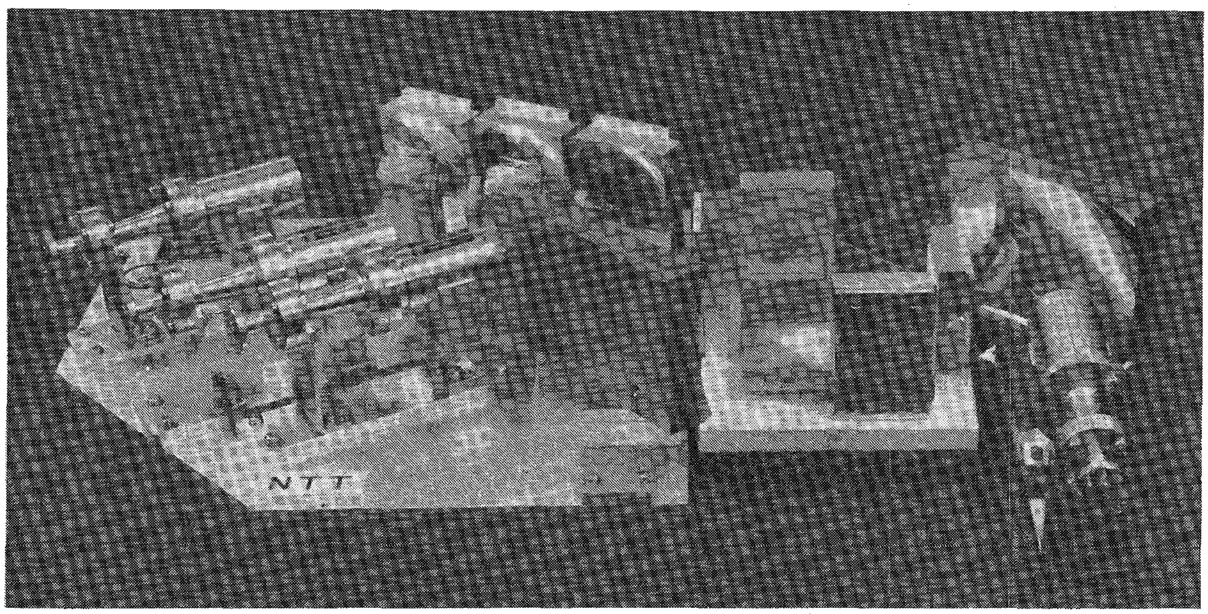
Fig. 21 shows the proposed feed and local injection system for 114 GHz using a Fabry–Perot diplexer. Sharp cutoff response is obtained by two resonators in order to suppress the interference of local noise.

A dielectric horn launcher with a 3.9-mm radius is installed within the cryostat and local oscillator. The input beam from the antenna and local oscillator, and the output beam to the cryostat are converged by a TPX lens.

Insertion loss from ports ① to ② is 2.5 dB, and that from ports ② to ③ is 3 dB. The insertion losses of each



(a)



(b)

Fig. 18. Construction of a multiplexer. (a) Schematic diagram. (b) Overall view.

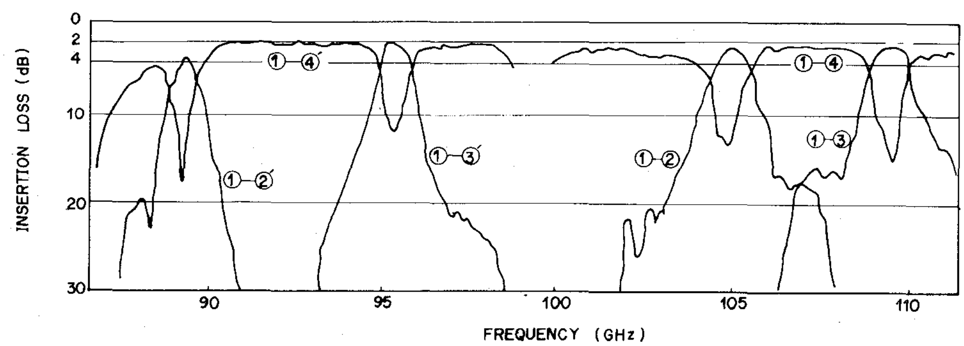


Fig. 19. Measured overall frequency response of a multiplexer.

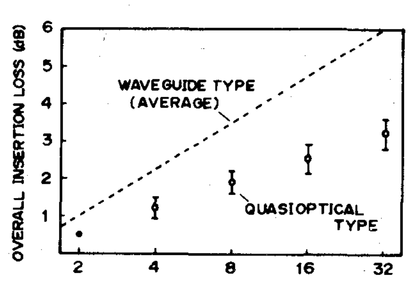


Fig. 20. Comparison of estimated overall insertion loss between waveguide multiplexer and quasioptical feed system (within dotted lines).

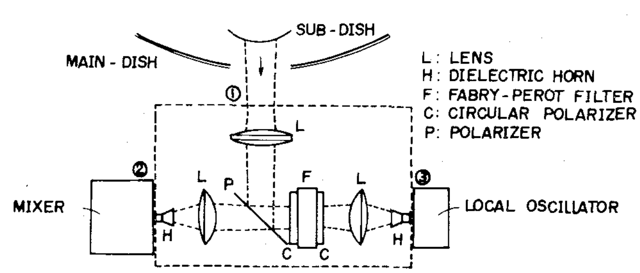


Fig. 21. Construction of a quasioptical feed system (within dotted lines).

lens and launcher are about 0.5 and 0.7 dB, respectively. If lenses are replaced by mirrors, the insertion loss may be more decreased. Isolation of local noise at the signal frequency is -30 dB.

Since the launcher aperture in the cryostat is so small ($\approx$wavelength), in order to minimize the thermal conduction from outside into the cryostat, the beam divergence becomes large (35°). Therefore, the surfaces of both sides of the lens are shaped to suppress the aberration or the excitation of higher order mode waves.

If this feed system were made by waveguides, the insertion loss would be $7\sim8$ dB in the 100-GHz band. The quasioptical technique is very effective in reducing loss for a feed system especially in the shortmillimeter wave region and above.

V. Conclusion

This paper reviews our research work on low-loss quasioptical basic components, diplexers, multiplexers, and feed systems using Gaussian beam waveguides in the shortmillimeter-wavelength region. They were newly developed for application in shortmillimeter-wavelength telecommunications systems. It is shown that quasioptical circuit technology using Gaussian beam mode is particularly effective in realizing a low-loss frequency multiplexer for frequencies higher than 100 GHz.

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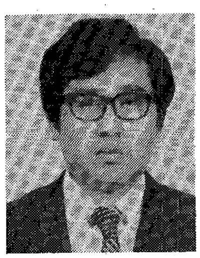
Nobuo Nakajima was born in Kiryu, Japan, on June 18, 1947. He received the B.S. and M.S. degrees in electrical engineering from Tohoku University, Sendai, Japan, in 1970 and 1972, respectively.

In 1972 he joined the Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation, Yokosuka-shi, Japan. From 1972 to 1979 he was concerned with research on filters and other components for millimeter- and submillimeter-wave transmission systems and is now working on the development of microwave antennas and diplexers.

He is a member of the Institute of Electronics and Communication Engineers of Japan.



Ryuichi Watanabe was born in Sapporo, Japan, on January 17, 1950. He received the B.S., M.S. and Ph.D. degrees in electronics engineering from Hokkaido University, Sapporo, Japan, in 1973, 1975, and 1981, respectively.

He joined the Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation, in 1975. From 1975 to 1979 he was engaged in research of quasioptical passive devices for shortmillimeter wavelength. Since 1979 he has been engaged in the research of optical devices such as multiplexers and switches for optical-fiber transmission systems.

Dr. Watanabe is a member of the Institute of Electronics and Communications Engineers of Japan.