TABLE I

Electrical Performance of 80-GHz Stabilized IMPATT Oscillator

Frequency	80.000	(GHz)
Power output	55	(mW)
Pushing figure	50	(kHz/mA)
Frequency stability*	-2.5×10^{-6}	($°C^{-1}$)
Power stability*	∓ 1	(dB/$\pm 20°C$)
External Q	10000	
Dc current	460	(mA)

*) Temperature range : 5 ~ 45°C

in a cavity-controlled mode where the oscillation frequency is almost the same as the resonant frequency of the reaction cavity. The "pushing figure" was minimum near 80 GHz. The electrical performance at 80 GHz is listed in Table I. The frequency stability of $\pm 5 \times 10^{-6}/\mp 20$ °C and 50 kHz/mA and power output of 55 mW have been obtained.

In a V-band IMPATT oscillator, nearly the same frequency stability has been obtained.

Acknowledgment

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References

[1] J. R. Ashley and C. B. Searles, "Microwave oscillator noise reduction by a transmission stabilizing cavity," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Noise*), vol. MTT-16, pp. 743–748, Sept. 1968.

[2] S. Nagano and H. Kondo, "Highly stabilized half-watt IMPATT oscillator," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Circuit Aspects of Avalanche-Diode and Transferred Electron Devices*), vol. MTT-18, pp. 885–890, Nov. 1970.

[3] Y. Ito, H. Komizo, and S. Sasagawa, "Cavity stabilized X-band Gunn oscillator," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Circuit Aspects of Avalanche-Diode and Transferred Electron Devices*), vol. MTT-18, pp. 890–897, Nov. 1970.

[4] N. D. Kenyon, "A circuit design for mm-wave IMPATT oscillators," presented at the IEEE G-MTT Int. Microwave Symp., Newport Beach, Calif., May 11–14, 1970.

[5] S. Nagano and S. Ohnaka, "A highly stabilized K_a-band Gunn oscillator," *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. MTT-20, pp. 174–176, Feb. 1972.

[6] D. C. Hanson and J. E. Rowe, "Microwave circuit characteristics of bulk GaAs oscillators," *IEEE Trans. Electron Devices* (*Second Special Issue on Semiconductor Bulk Effect and Transit-Time Devices*), vol. ED-14, pp. 469–476, Sept. 1967

Channel Multiplexing Network for a 20-GHz Radio-Relay Transmission System

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***Abstract*—The Nippon Telegraph and Telephone Public Corporation (NTT) plans to make a field test for the practical application of the 20-GHz radio-relay transmission system. This short paper describes channel multiplexing–demultiplexing networks fabricated for use in this test. Overall loss of the network constructed by three stages, namely, a Vertical–horizontal (V–H) polarizing filter, a transmit–receive filter, and a channel-dropping filter, is 5 dB, even though a 2-dB loss of a flexible waveguide is included.**

A radio-relay pulse-code-modulation transmission system in the 20-GHz band has been studied as a large-capacity communication system to prepare for an increase in transmission medium demands caused by new communication services, for instance, picture phone and data transmission [1], [2].

The Nippon Telegraph and Telephone Public Corporation (NTT) is going to make a field test for the practical application of a 20-GHz radio-relay communication system, called the 20G–400M system [2].

The trial link with two terminal stations will be installed over an 2.8-km route.

Fig. 1 shows the construction of the multiplexer–demultiplexer for the field test, of which specifications are shown as follows:

frequency band	17.7–21.0 GHz (overall band—3.2 GHz) and common use of both polarizations;
clock frequency	200 MBd (a bit rate of 400 Mb/s with 4-phase phase-shift keyed);
channel spacing	300 MHz;
guard band	500 MHz.

The multiplexer consists of one vertical–horizontal (V–H) polarizing filter, two transmit–receive filters, 20 channel-dropping filters, and BRF and BPF filters suppressing frequency crosstalk to received signals from transmitted signals [3], [4]. The common use of both polarized waves, that is, a V wave and an H wave, is adopted in order to use restricted frequency bands efficiently. However, heavy rainfall degrades the polarization isolation. This may make it necessary to stagger horizontally and vertically polarized channels. Operation of the trial test link will provide additional data on degradation of cross polarization by rainfall.

First, two orthogonal polarized waves are separated by a V–H polarizing filter. Next, the 17.7–21.0-GHz band is divided into two by the transmit–receive filter, resulting in four groups: A_V, A_H, B_V, and B_H, each having a bandwidth of 1.6 GHz. It is planned to achieve two-way transmission by a single antenna with A_V and A_H groups of lower frequencies in one direction and B_V and B_H groups of higher frequencies in the opposite direction.

A concentrated coupled type like the V–H polarizing filter, a circulator like the transmit–receive filter, and a ring-type filter like the channel-dropping filter are adopted, as described later.

The multiplexer occupies only $1055 \times 860 \times 200$ mm³ (box size) except for the V–H polarizing filter, which is set on back of the antenna mounted at the top of a pole [2]. The multiplexer is maintained at a low dry air pressure of 0.05 kg/cm² above atmospheric pressure.

The trial V–H polarizing filter is a concentrated coupled type, as shown in Fig. 2. One polarized wave is reflected by a plate and emerges to port 2 and the other is transduced from circular TE_{11} to rectangular TE_{10} by a taper-type mode transducer and emerges to port 3. The insertion loss is 0.16 dB for each polarized wave from port 1 to port 2 or 3.

The size of the inner circular waveguide, operated in a dominant TE_{11} mode, is 10.8 mm and the rectangular waveguide is WRJ-180 ($a = 12.954$ mm and $b = 6.477$ mm).

The polarization isolation is over 45 dB and each input VSWR is under 1.10 for the entire frequency range.

Since the frequency crosstalk is most strongly expected at the boundary channels, filters such as BPF and BRF, as well as the transmit–receive filter, must be provided to suppress this crosstalk. The two dominant interference paths, namely, to R_6 from T_5 in one station and to R_5 from T_6 in the next station, must be considered. Also, the crosstalk level must be suppressed to under 114 dB in order to realize required $D/U = -33$ dB when transmitted power, fading margin, section loss, and antenna gain are taken into consideration [2], [3].

There are two types of transmit–receive filters: one consists of two hybrids and two high-pass cutoff filters and the other uses a circulator. In the case of the cutoff-filter-type transmit–receive filter, the former crosstalk, namely, to R_6 from T_5, is sufficiently suppressed by the very sharp frequency response and high attenuation of the cutoff area, but the latter one is not sufficiently suppressed. On the other hand, for the circulator type, the two crosstalks must be suppressed by inserting some filters. In this test, the circulator type is adopted because it is smaller in size and lower in loss than the cutoff-filter type. Moreover, it is confirmed [3] that the crosstalks can be sufficiently suppressed by installing a receiving BPF with a five-cavity Butterworth response and a BRF with a two-cavity Butterworth response, as shown in Fig. 1. The former, with 400 MHz of 3-dB bandwidth, is composed of 6 inductive metal posts. The construction of the latter is the same as for the ring-type channel-dropping filter using the response of ports 1 and 2 as BRF.

The forward loss of the trial circulator (Fig. 3) is under 0.15 dB and the backward loss is over 35 dB for the entire band.

Fig. 4 shows the trial ring-type filter, which has been developed as a channel-dropping filter for the proposed millimeter-wave multiplexing network in the NTT [5], [6].

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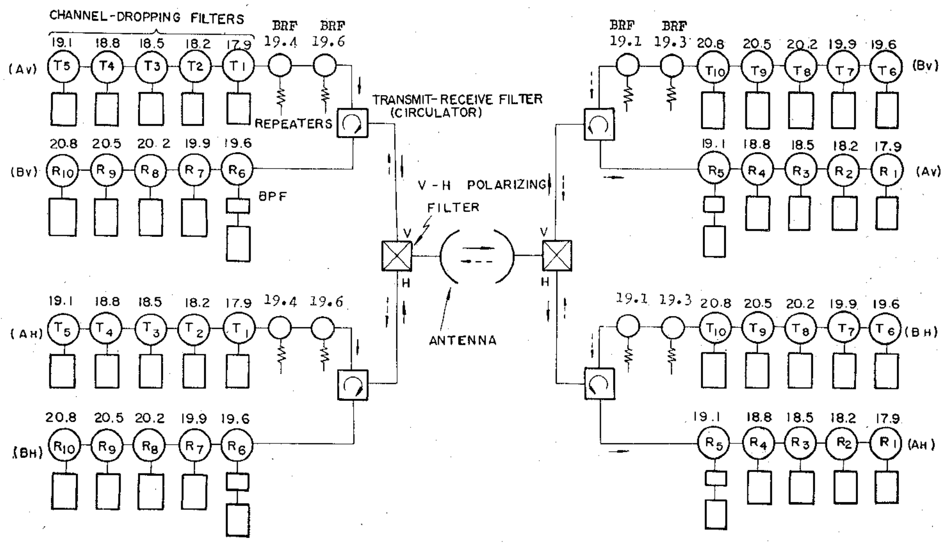
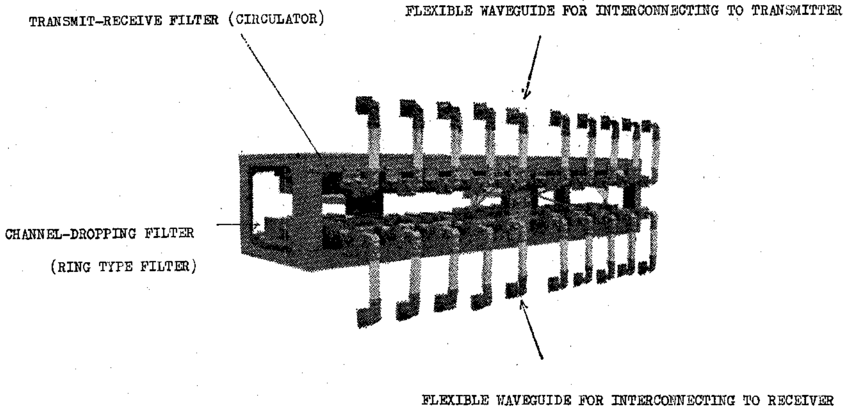


(a)



(b)

Fig. 1. (a) 20G-400M channel multiplexing network. (b) Overall view (a V–H polarizing filter and an antenna are set on the back side of this box).

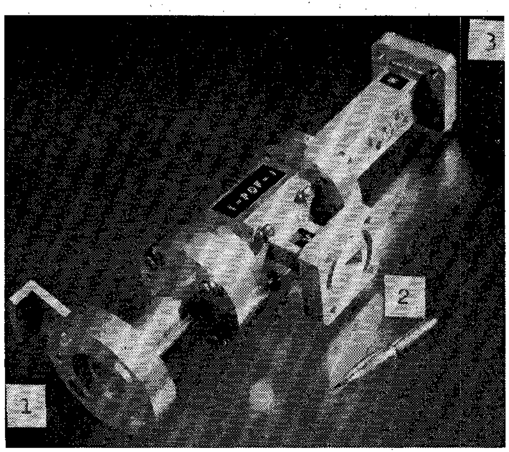


Fig. 2. Trial V–H polarizing filter.

The specifications for the channel-dropping filter are as follows:

frequency response	two-cavity Butterworth;
center frequency	as shown in Fig. 1;
3-dB bandwidth	300 MHz.

Two ring-shaped traveling-wave cavities are coupled to each other by a multihole coupler and to upper and lower waveguides by multi-slit couplers [6].

Gold is plated on the metal surfaces. A dielectric rod is inserted in each cavity in order to finely adjust the resonant frequency. The channel-dropping loss in ports 1–3 at the resonant frequency of 18.5 GHz is 0.22 dB, and the passband loss is under 0.1 dB.

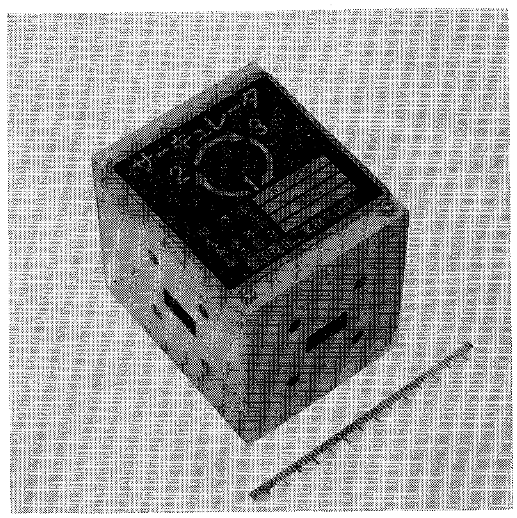


Fig. 3. Trial circulator-type transmit–receive filter

Fig. 5 represents the frequency responses of the main channel from T_7 to R_7 and the static frequency crosstalks from T_6 to R_7 and from T_8 to R_7, when transmit and receive multiplexers are interconnected by a circular waveguide with 10.8-mm inside diameter. The theoretical curves in Fig. 5 (a), obtained under the assumption that the channel-dropping filter is of an ideal two-cavity Butterworth type, are well coincident with the experimental results in Fig. 5(b). The overall loss for the center frequency of 19.9 GHz is 5.0 dB and is broken down in Table I.

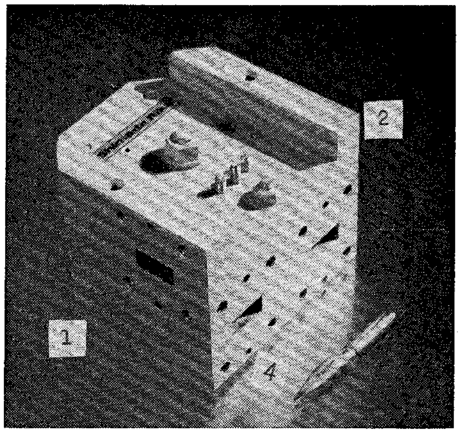
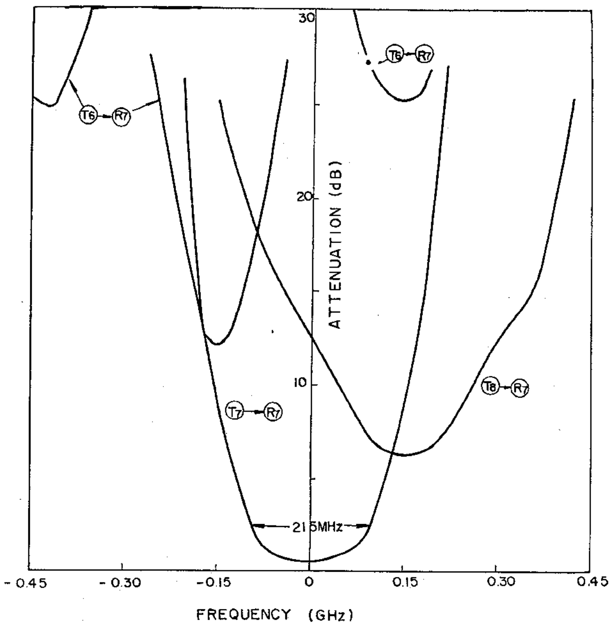
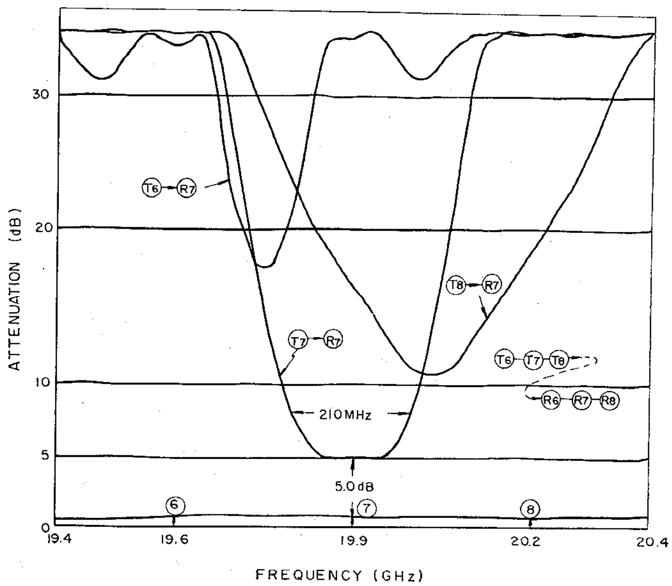


Fig. 4. Trial ring-type channel-dropping filter.



(a)



(b)

Fig. 5. Overall frequency response of the multiplexing networks where $f_0 = 19.9$ GHz. (a) Theoretical curves. (b) Experimental curves.

TABLE I

COMPONENTS OF MEASURED OVERALL LOSS

	MEASURED VALUE [a]	PREDICTED VALUE
OVERALL LOSS (dB)	5.0 dB	5.5 dB
V-H POLARIZING FILTER	0.16 X 2	0.20 X 2
TRANSMIT - RECIEVE FILTER	0.20 X 2	0.15 X 2
PRESSURE WINDOW	0.10 X 2	0.10 X 2
CHANNEL-DROPPING FILTER (FIVE CHANNELS IN CASCADE)	1.66	1.92
INTERCONNECTION WAVEGUIDES		
RECTANGULAR	0.40	0.60
FLEXIBLE	2.02	2.08

[a] When the center frequency is 19.9 GHz.

A large amount of flexibility for adjusting antenna direction and also for interconnecting to the repeater was included in the first time test. Therefore, the total length of the flexible waveguide extends to approximately 0.5 m for each transmit and receive side. In the future, it is promising that the overall loss will be reduced to within 4 dB of the first trial target because it will not be necessary for the flexible waveguide to be so long.

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REFERENCES

[1] L. C. Tillotson, "Use of frequencies above 10 GHz for common carrier application," *Bell Syst. Tech. J.*, vol. 48, no. 6, pp. 1563–1576, 1969.
[2] M. Takada, "On the digital radio relay system in millimeter wave region," Tech. Group Commun. Syst., Inst. Electron. Commun. Eng. Japan, Rep CS70-37, July 1970.
[3] I. Ohtomo *et al.*, "Overall transmission characteristics of a branching filter system for 20-GHz radio relay communication system," *Rev. Elec. Commun. Lab.*, vol. 20, nos. 1 and 2, pp. 53–70, Jan.–Feb. 1972.
[4] I. Ohtomo *et al.*, "Channel multiplexing network for a 20-GHz radio relay communication system," Tech. Group Microwaves, Inst. Electron. Commun. Japan, Rep. MW72-24, June 1972.
[5] J. Ohtomo and S. Shimada, "A channel-dropping filter using ring resonators for millimeter wave communication system," *Electron. Commun. Japan*, vol. 52-B, no. 5, pp. 57–66, 1969.
[6] I. Ohtomo *et al.*, "Ring-type channel-dropping filters for MM waveguide transmission systems," *Microwave J.*, pp. 35–40, Nov. 1972.

A Potential Theory Method for Covered Microstrip

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***Abstract*—Matrix methods [1] are used to analyze the properties of covered microstrip. The Green's function is calculated by a potential theory method assuming the TEM mode of propagation. Computed impedance values of covered microstrip agree closely with other experimental and theoretical data. The technique is a general one and can be used to treat multiple-layer and covered microstrip.**

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