MILLIMETRIC WAVEGUIDE LINE IN A CABLE TUNNEL

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ABSTRACT

An intra-city millimetric waveguide system, utilizing a cable tunnel, has been developed. This paper describes the development of waveguides for bends to make a meandering waveguide line with low loss and low waveform distortion. Field test results are also described.

INTRODUCTION

A millimetric waveguide system (W-40G), which is capable of transmitting about 300,000 telephone channels (both ways), utilizing the 43 to 87 GHz frequency band, has been developed under Electrical Communication Laboratories (ECL) auspices. In this system, waveguide line is placed in a 150mm bore welded steel conduit laid under roads.

In a large city, however, repeated new conduit construction becomes difficult, due to heavy vehicular traffic which would be blocked by such work. To cope with increasing transmission capacity requirements, a cable tunnel network is being constructed in large Japanese cities according to NTT's long term plan.

Waveguide line laid in a cable tuunel has higher loss than that laid in a conduit, because there are many more bends in a cable tunnel. System survey results, however, showed that an intra-city waveguide system in a cable tunnel (WT-40G) would be better than any other system to bring the entire W-40G capacity to the hearts of large cities, form the viewpoit of cost and tunnel space utilization[1].

The most important WT-40G system technical problems involve how to transmit millimeter-wave signals while suppressing loss increase and waveform distortion resulting from many bends. Special waveguides for sharp bends were investigated, and two types of mode filter and a 14mm bore flexible waveguide were developed for this purpose. This paper describes the characteristics of waveguides for bends, design of newly developed components and the results of the field test.

CABLE TUNNEL BEND CONDITIONS

Statistical bending conditions of an actual cable tunnel were investigated. Cable tunnels are calssified into open-cut tunnel, which is constructed by the open-cut method, or a shielded tunnel, which is constructed by the shield method. For shallow underground construction, an open-cut tunnel usually has about 20 bends/km, whose average angle is 40°. This is to avoid obstacles such as water, sewer or gas pipes. On the other hand, a shielded tunnel has about one bend/km. According to these results, a "Standard Cable Tunnel" was assumed having a hypothetical standard bend distribution. It is (Fig. 1 and Table 1) equally composed of open-cut and shielded tunnels. Using this Standard Cable Tunnel, it is possible to estimate total transmission characteristics on designing waveguide components for bends.

BEND USING A CORNER WAVEGUIDE

A corner waveguide is a miter elbow having a reflecting plane. Although it has been used for a long time, thorough investigation of its characteristics has not been carried out. Recent detailed measurements clarified the fine loss and spurious mode generation characteristics of a corner waveguide. By using these accurate data, it became possible to estimate correct transmission characteristics.

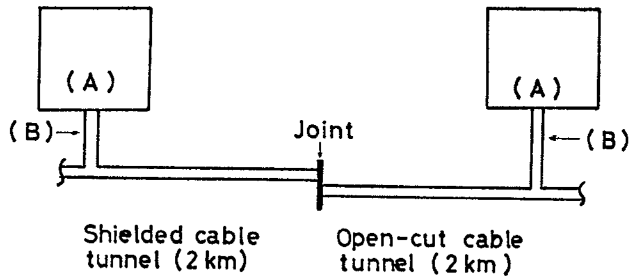

Figure 1. Standard Cable Tunnel
(A);Elevation to the repeater station
(B);Joint between telephone office and cable tunnel

Table 1. Arrengement of Standerd Cable Tunnel Bends

Section	Number of Bends
(A) & (B)	8 per telephone office
open-cut cable tunnel	20/km (average)
shielded cable tunnel	1/km(average)
joint between open-cut & shield cable tunnel	2

Figure 2 shows that the loss vs. frequency characteristics graph has many sharp peaks with a maximum of 0.1 dB. These loss peak patterns are confirmed by the fact that peaks agree well for one corner waveguide measurements and many(52) corner waveguides measurements.

When many corner waveguides are used in the line, two problems appear. First is the loss peaks described above, which make it necessary to apply an amplitude equalizer to the repeater. Second is the waveform dis-

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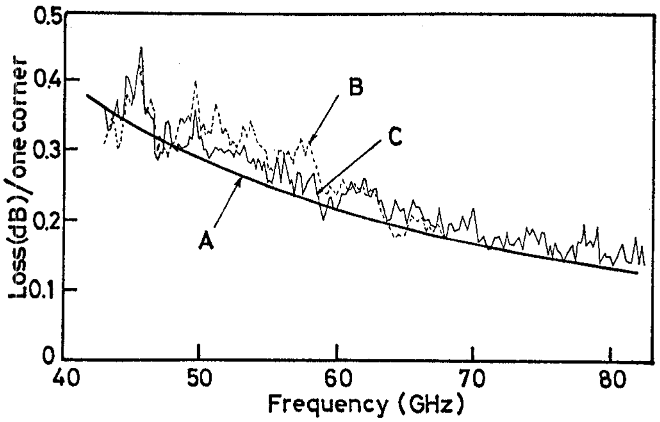


Figure 2. Measured TE_{01} Mode Loss in a Corner Waveguide
A;Calculted value by Marcatili[4]
B;Measured value on corner waveguide
C;Measured value on 52 corner waveguide

tortion noise caused by the mode conversion. This phenomenon causes high pitch ripples in the loss vs. frequency characteristics. In order to keep the distortion noise within a permitted value, application of mode filters for TEon modes is indispensable to the WT-40G system.

Recently, two types of mode filter for TEon modes were developed. One is the circular arc polygonal (CAP) filter[2] and the other is the phase inversion (PI) filter[3]. These mode filters were designed for the WT-40G system. The design method is based mainly on the distortion noise (S/N) of the entire line when corner waveguides are used with mode filters at the bends where using a corner waveguide is profitable. Figure 3 shows the characteristics of the developed CAP mode filter.

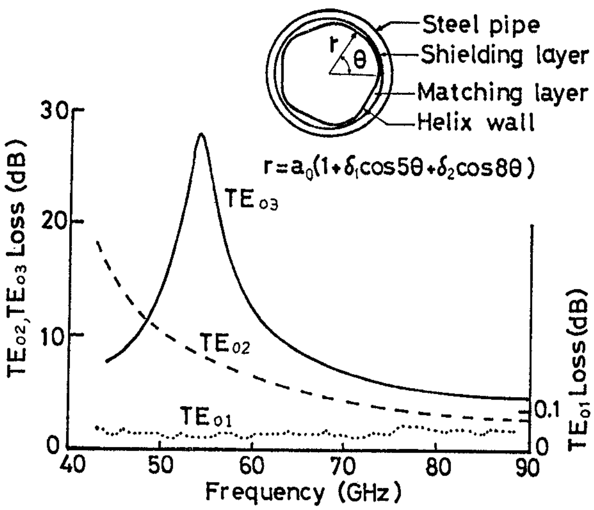


Figure 3. Measured TE_{on} Modes Loss in Circular Arc Polygonal Mode Filter

BEND USING A FLEXIBLE WAVEGUIDE

According to the investigation, the bend angle of a cable tunnel averages around 40°, and there are often complex shaped bends. For these bends, a small bore flexible waveguide is suitable in loss and smoothness of shape, because a corner waveguide applicable to these angles is a double corner waveguide which adds 0.8dB loss (45GHz). A shielded type helix waveguide is suitable for this purpose. The optimum bore is dependent on the radius of curvature, frequency band and wall structure of the waveguide.

Actual standard bending conditions and the Standard Cable Tunnel were taken into consideration. It was concluded that 14mm is the optimum bore for WT-40G system. Figure 4 describes the results obtained from the experimental equations when the radius of curvature is 1 meter. Finally, actual flexible waveguide loss is from about one half to one third of that of a double corner waveguide, when the angle is 45°, though it is 1.2 to 1.5 times that of a single corner waveguide for a 90° angle. Consequently, a flexible waveguide excells very much for small angle bend. To cope with various bending conditions, its unit lengths were determined to be 1.2 meter and 1.8 meter.

A tapered waveguide must be used to connect a 14mm bore flexible waveguide to a main 51mm bore waveguide. When 14-51 tapered waveguides are inserted into the waveguide line, TE_{02} mode resonance becomes a problem. It occurs because TE_{02} mode is a cut-off mode in the 14mm bore waveguide in lower than the 47.8 GHz frequency region. The resonance phenomenon was experimentally investigated and it was clarified that the distortion noise can be neglected if tapered waveguide TE_{02} mode generation is less than -35 dB.

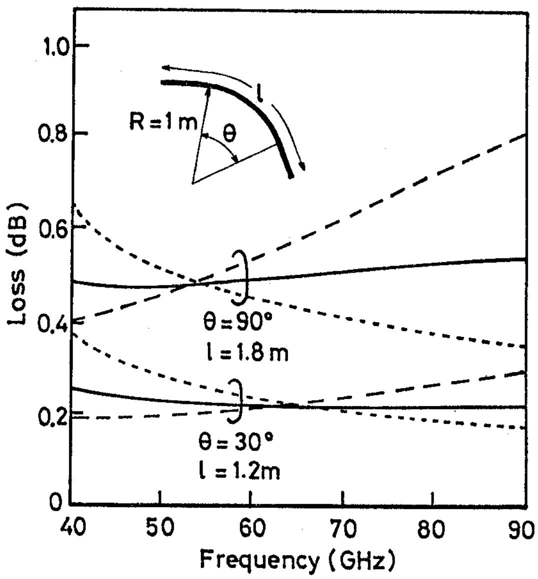


Figure 4. Flexible Waveguide Loss Determined by Experimental Equations
------- 12mm$^\phi$
——— 14mm$^\phi$
— — — — 16mm$^\phi$

FIELD TESTS

Field tests were carried out by constructing a 4km loop line in an actual cable tunnel centered on the Okubo Telephone Office in Tokyo. Tests have been continued which involve measurements of transmission characteristics, construction and maintenance methods, as well as characteristics stability.

The test line includes 60 sharp bends, as are shown in Table 2, in accordance with the conditions of the Standard Cable Tunnel.

Since the tunnel used for the tests is a shielded one, the open-cut tunnel was imitated by changing the laying level to form the bends artificially.

Figure 5 shows the loss measurement results. The dotted line shows the calculated loss which is determined by adding all the kinds of expected losses before construction. The calculated and measured losses are in good agreement, under 7% error. It should be mentioned that all types of waveguides were used just as designed. In paticular, any changes made in the flexible waveguide figure, due to construction problems, were small enough to maintain the designed loss. The broken line in Fig. 5 shows expected loss for 7 km repeater span, including 100 bends, under the same bending conditions. It indicates that a 7 km span is possible with a sufficient margin below the loss limit.

Figure 6 shows the results of loss ripple measurements. The dotted line shows the ripple standard deviation calculated by the matrix multiplication method. This result shows clearly that mode filters design and characteristics are satisfactory.

Figure 7 shows the resonance observed in the test line. Such small and sharp loss ripples as shown in Fig. 7, however, have little effect on the waveform distortion. Consequently, it is recognized that loss ripples due to resonance give satisfactory results by using preferable tapered waveguides.

Table 2. Numbers of Special waveguides used in the Field Test Line

Bends	Numbers	Kind of WG	Used Numbers
Bends by CWG	24	Single CWG	14
		Double CWG	10
		Mode Filters	15
Bends by FWG	36	1 2m FWG	27
		1 8m FWG	14
		Tapered WG	44

WG : Waveguide
CWG : Corner Waveguide
FWG : Flexible Waveguide

The numbers for bends by FWG and for used FWG or Tapered WG does not coincide, because there are adjacent bends and complex bends.

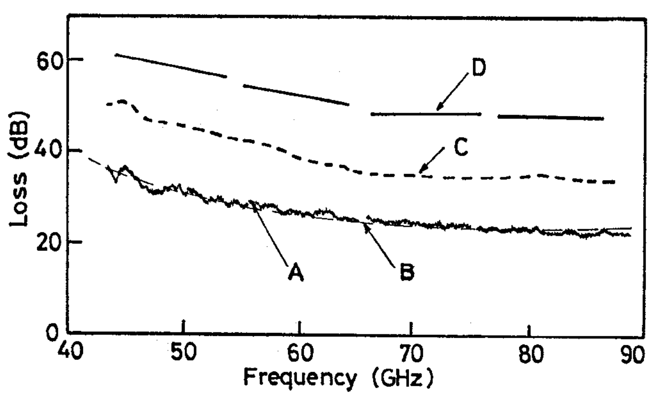


Figure 5. Field Test Line Loss Characteristics
A ; Measured loss (4 km, 60 bends)
B ; Calculated loss (4 km, 60 bends)
C ; Calculated loss (7 km, 100 bends)
D ; Loss limit for one repeater span

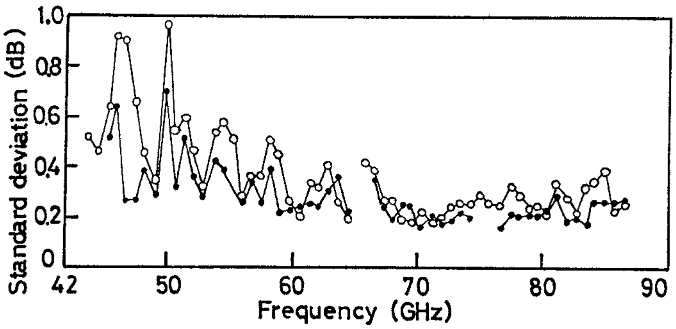
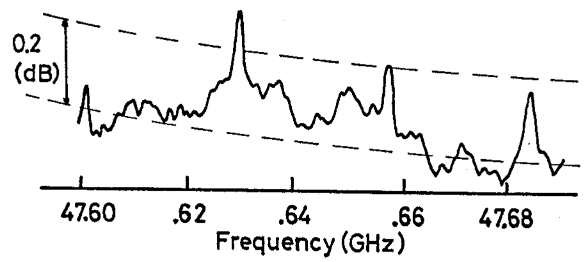


Figure 6. Field Test Line Loss Ripple Standard Deviation
• ; Measured value
o ; Calculated value



Figuer 7. Measured Loss Peaks due to Resonance

CONCLUSIONS

An intra-city waveguide system has been developed to bring the entire W-40G capacity to the hearts of large cities.

Two types of mode filters and 14mm bore flexible waveguide were developed in order to keep loss low and suppress waveform distortion. The statistical bending conditions of an actual cable tunnel were taken into consideration in designing these waveguides.

Field tests were carried out by constructing a 4 km line including 60 sharp bends. The test results show that the transmission characteristics agree with the expected results and conclude that 7 km repeater spacing, which covers most distances between telephone offices in large Japanese cities, is čertainly possible for the Standard Cable Tunnel conditions.

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