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NON-COSTLY LOCAL OSCILLATOR DISTRIBUTION IN PIPE

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13 December, 1982

CSIRO DIVISION OF RADIOPHYSICS

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The cheapest sort of transmission line is plain pipe. Therefore the advantages of commercial transmission line and fibre optics should be weighed carefully against the cost excess over pipe.

Special waveguide as used for the VLA is very costly and no longer in production. The principal alternatives are (i) various coaxial cables operated at lower frequencies where attenuation is favourable, followed by frequency multiplication and phase locked loops, and (ii) fibre optic transmission lines followed by corresponding terminal equipment at each antenna or station.

Local oscillator distribution at a microwave frequency simplifies the terminal electronic equipment at each antenna. Of course, X-band attenuation is substantial; on the other hand powerful stable oscillators are now available. The way is open to avoid distributing feeble signals that are ingeniously used to synchronize five or more independent remote oscillators. Frequency drift of the central oscillator is relatively benign compared with loss of synchronization.

Commercial X-band waveguide is by definition expensive. Pipe on the other hand is cheap. Butt joints are simple to make and multiple back-up runs can be contemplated.

A traditional objection to the use of long runs of circular waveguide is that the direction of polarization at exit is not parallel to the input direction. The remedy is to rotate the output coupler for maximum signal. As the dependence goes as cos θ, the adjustment is not critical. The polarization direction is not particularly time variable being essentially a function of position and shape of the pipe.

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Attenuation

For the TE11 mode in circular aluminium guide (Terman, p.263)

$$\alpha = 74.5\ a^{-3/2}(m^2-1)^{1/2}(m^{-1/2}+m^{3/2}/2.38) \quad \text{db/km} \tag{1}$$

where $m = \lambda_c/\lambda$ and a = pipe radius.

This formula applies to all modes. The critical wavelength λ_c is obtained as follows:

Mode	TE11	TM01	TE21	TE01	TM11
λ_c/a	3.413	2.613	2.057	1.640	1.640

Fig. 1 shows that at λ = 3 cm attenuation of 50 db/km may be expected in 3 cm diameter pipe.

Other modes

Guide wavelengths and critical wavelengths for the lowest modes may be read off from Figs. 2 to 4 for pipe diameters 3, 4 and 5 cm. These curves are calculated from

$$\lambda_g^{-2} = \lambda^{-2} - \lambda_c^{-2} \tag{2}$$

Oval pipe

If pipe is squeezed into an oval, the TE11 mode splits into e TE11 and o TE11 , "wanted" and "unwanted". As the tube is deformed the critical wavelength for the unwanted mode gets shorter and at a certain point propagation at the operating wavelength cuts off. Such a pipe would not be able to exhibit rotation of the plane of polarization or elliptical polarization and might be a suitable form for negotiating bends, twists or other special runs.

Phase tolerance

If a length L is subject to a change dL, then the phase length L' changes by dL' where

$$dL'/L = dL/L.$$

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If the pipe radius changes by da, then we can show by differentiating (2) that

$$dL'/L' = -d\lambda_g/\lambda_g = (\lambda_g/\lambda_c)^2\, da/a \qquad (3)$$

To a rough approximation it will be found that

$$dL'/L' \doteq 0.5\, da/a.$$

Temperature effect

Unlike coaxial transmission line, hollow pipe has a phase length that depends on transverse dimensions, as given by (3), and phase changes might therefore be produced by temperature changes. It does not necessarily follow that buried pipe expands and contracts with temperature; it may do what the soil does. However, as a worst case one can assume expansion as if the pipe were unconstrained.

Taking 15 cm as an upper limit for the 24-hour penetration depth in soil (J.G.R., 68, 2217, 1963) then a depth of 75 cm is 5 penetration depths and the amplitude reduction factor for the 24-hour temperature wave is exp(-5) = 0.0067. Thus a peak-to-peak surface temperature variation of 30°C (E.G. 0° to 30° in winter or 15° to 45° in summer from night to day) produces a variation of 0.2°C at a depth of 75 cm. The effect of thermal expansion with an expansion coefficient of 23×10^{-6} for aluminium, even if expansion can occur, is negligible.

Pressurization

Pressurization can change the phase length in two ways: the dielectric constant n is raised and the diameter of the guide is increased. For n we have, in the absence of water vapour,

$$n = 1 + 79\times10^{-6} P/T$$

where P is in millibars and T in kelvins. The fractional change per atmosphere is thus 270 parts per million. At a wavelength of 3 cm the phase change would be 3000° per atmosphere per kilometre. This significant effect applies also to coaxial transmission line. A pressure rise caused by temperature does not raise n.

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Expansion of diameter due to pressure is estimated as follows, assuming the pipe is free to expand unrestrained.

$$da/a = (a/tE)\,dP$$

where t is the wall thickness and E is Young's modulus. With a = 0.02 m, t = 0.001 m, we find da = 1 μm per atmosphere. The phase effect calculated from (3) is negligible by comparison with the effect of dielectric constant.

Practical considerations

Butt joints can be made in the field by force fitting adjoining pipes into a sleeve (Fig. 4). The pipe ends should be protected in handling with the same care given to electrical connectors but in the event of damage, a hand tool can remove a piece to leave a fresh end. Electrolytic corrosion is the same as for other transmission lines and needs attention according to local soil conditions. Standard procedures are to maintain the aluminium at a d.c. potential, to coat it in some way that is free from pinholes, to use a non-corroding alloy or to make the wall thickness great enough for the desired lifetime. With pressurization leakage is not important. Labor of laying transmission line is a significant part of the comparison between one kind of line and another.

Loss of energy by mode conversion can be avoided completely by use of small enough pipe. One saves on material cost but accepts higher attenuation. It is certain however that lower attenuation is obtainable with slightly over-size pipe that permits the TM01 mode to propagate. To go this way with confidence, it would be necessary to make comparative attenuation tests on two pipe sizes over say 100 metres. It would not be absolutely necessary to bury these pipe runs but if they were not buried, it would be desirable to immobilize them mechanically in some way such as by tensioning.

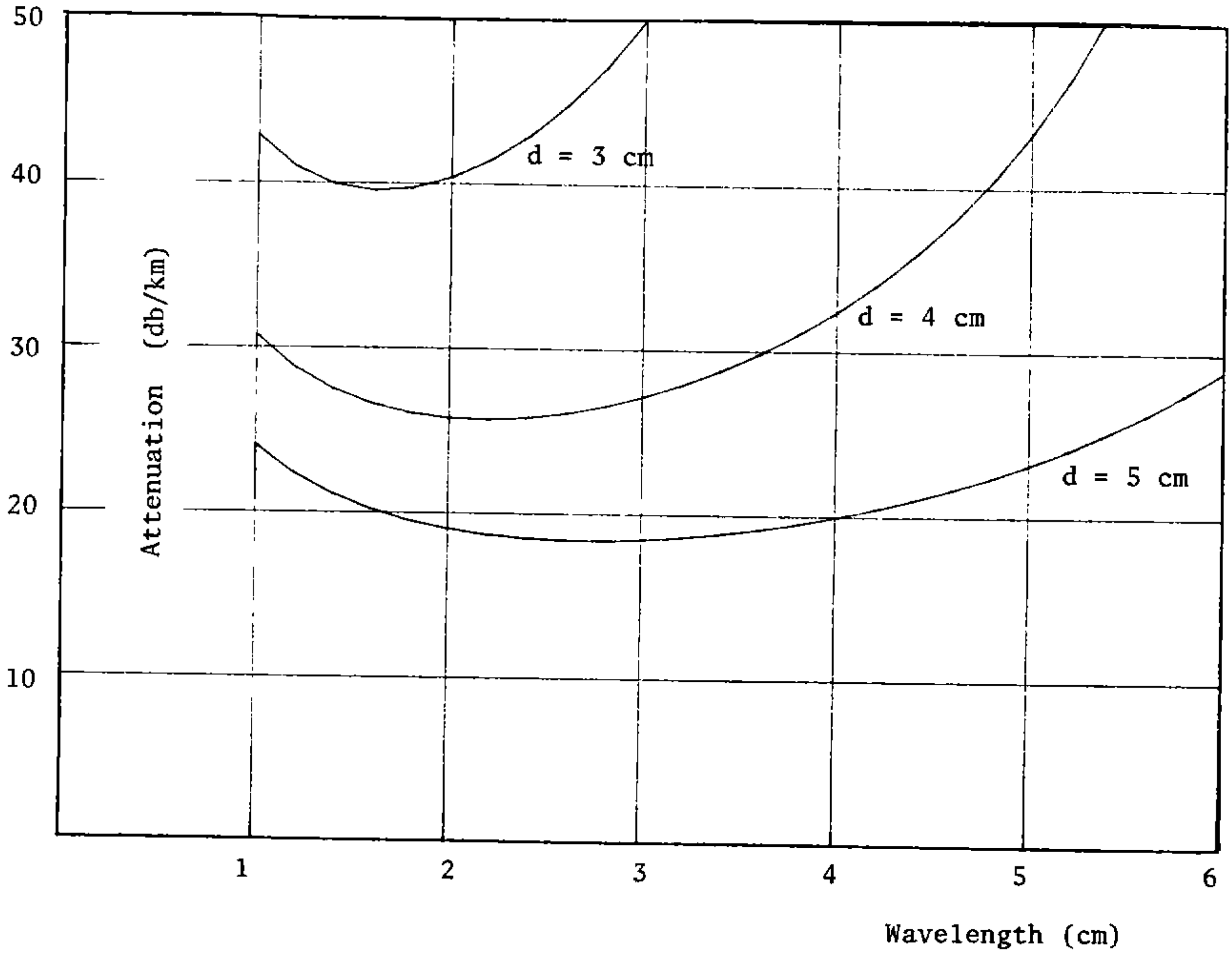


Fig. 1 Attenuation of TE11 mode in pipes of 3, 4 and 5 cm diameter.

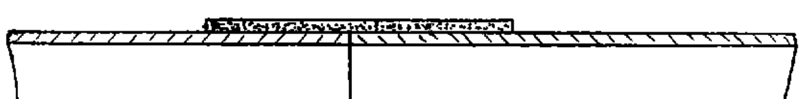


Fig. 4 Force-fit butt joint in pipe.

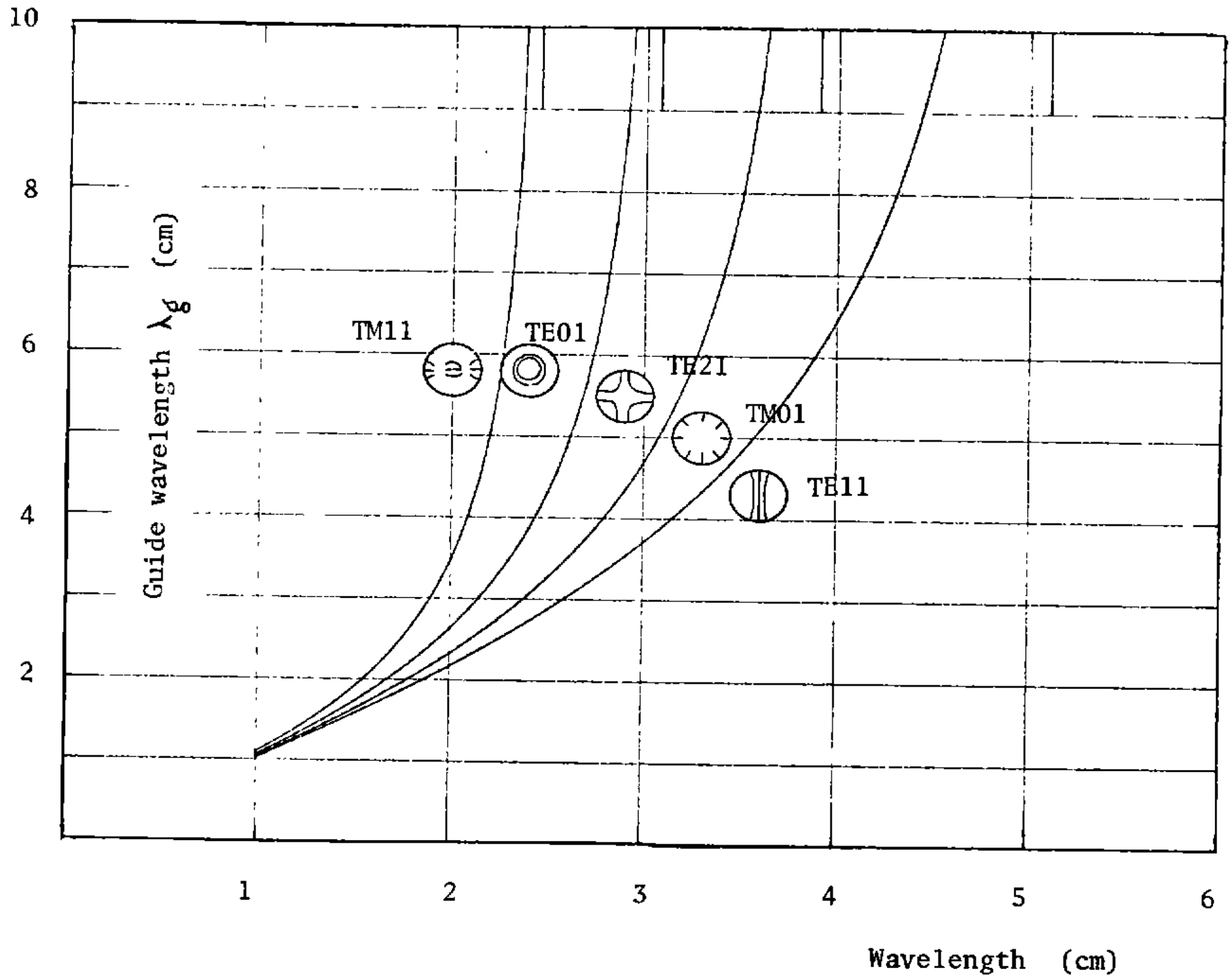
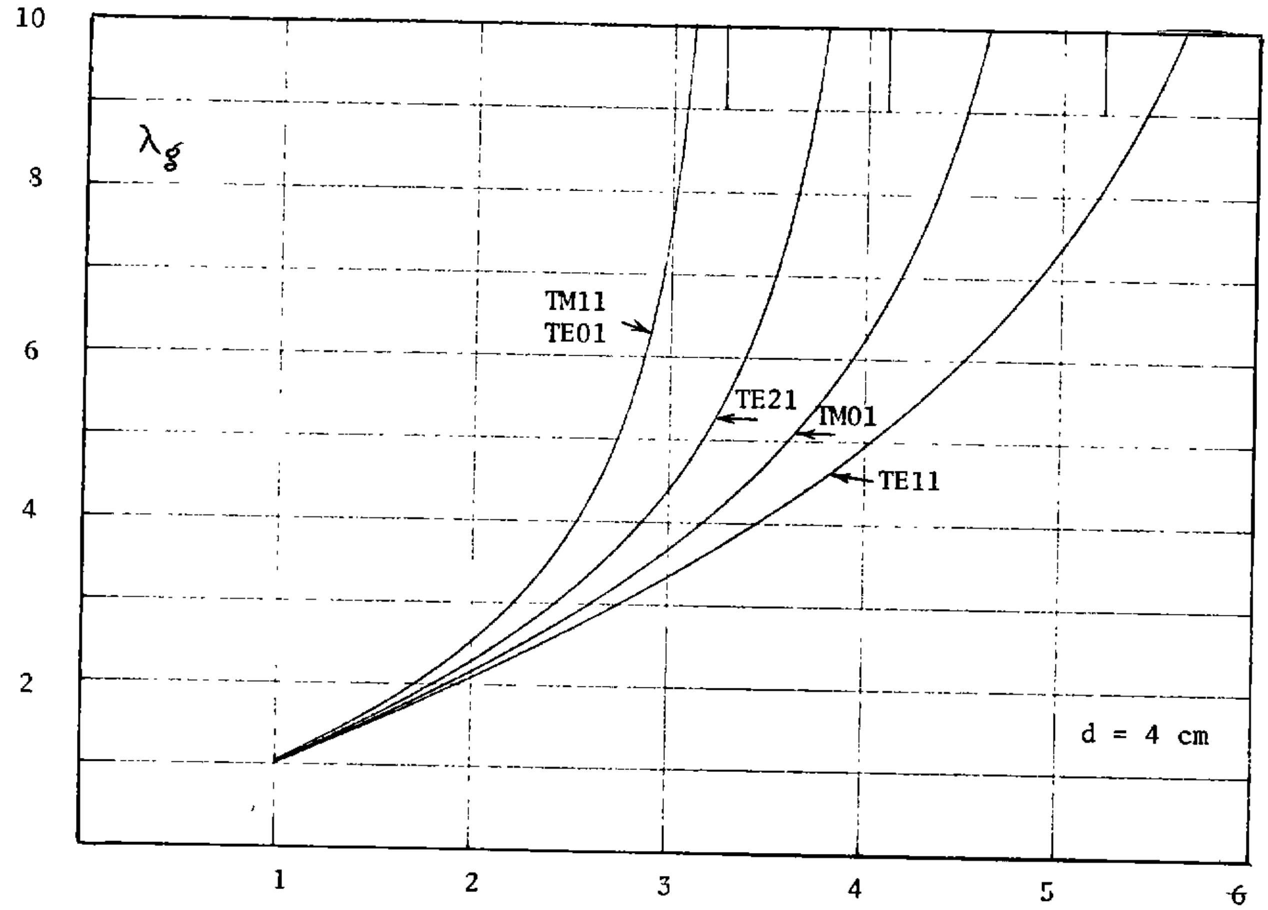
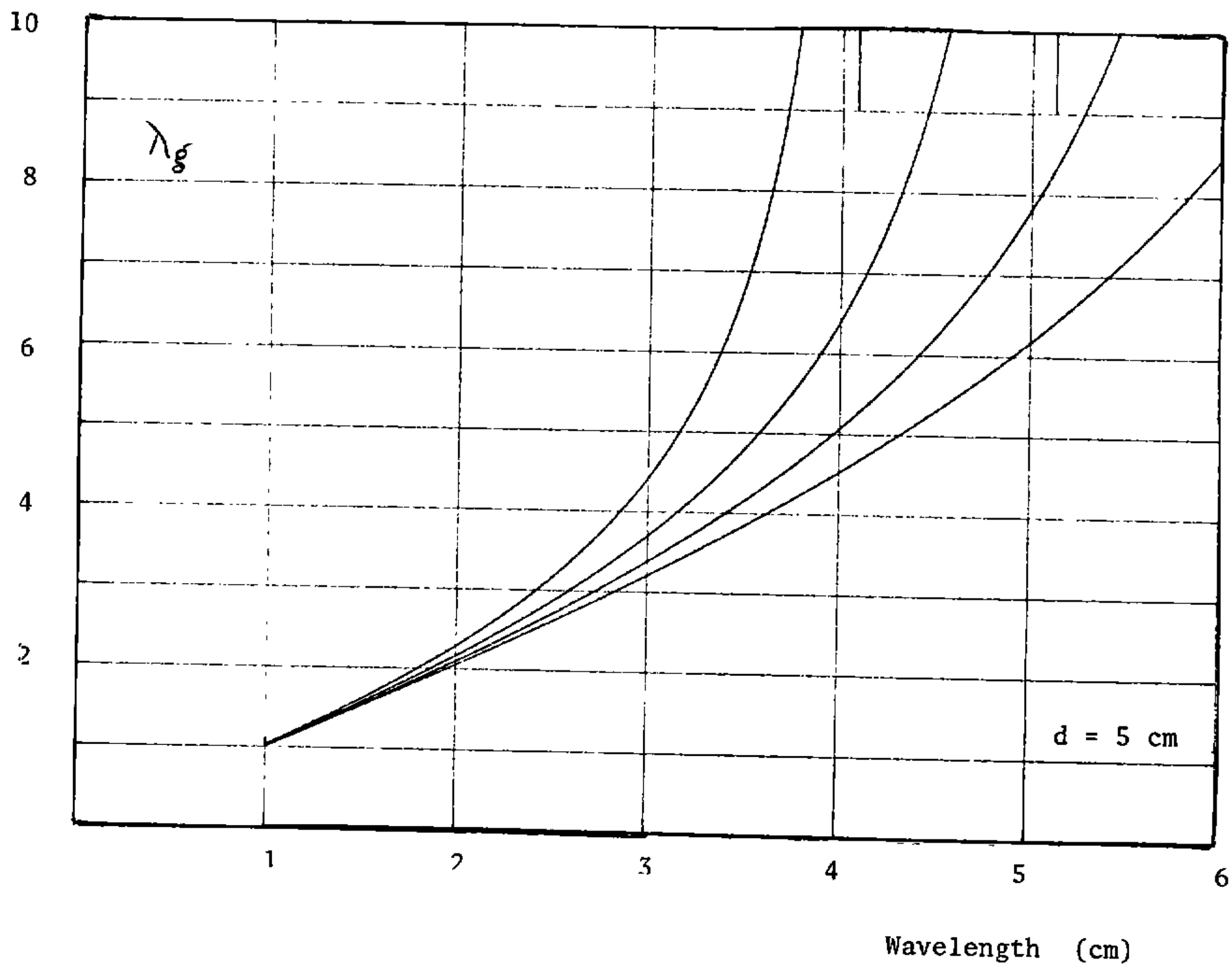


Fig. 2 Guide wavelength and critical wavelengths for 3 cm diameter pipe.





Figs. 3 & 4 Guide wavelengths and critical wavelengths for 4 and 5 cm diameter pipes.