In Fig.10 we show the frequency dependence of the modulation depth with and without shielding plane. The observed data were estimated by the procedure given in [8] using the experimental values for basic parameters. The solid lines in Fig.10 represents the theoretical curve which was calculated from Eq.(6) using the attenuation constant a estimated from experimental data. A good agreement between theory and experiment is obtained. In the absence of a shielding plane, the quasi-periodic structure originated from the velocity mismatch between the optical wave and the signal wave, as was predicted from Eq.(6), was clearly seen. This sort of periodic structure reflects the low-loss nature of the superconducting electrode. In the case of velocity matching with a shielding plane, the bandwidth is shown to be dramatically enhanced as predected by theory. The good agreement between theory and experiment also demonstrates the validity of both the theoretical model of Eq.(4) and the present experimental method. From this experiment we see that the $LiNbO_3$ optical modulator with a superconducting electrode can be operated as expected from theory.

IV. Conclusions

The performance of a traveling-wave type $LiNbO_3$ optical modulator with superconducting electrodes has been studied theoretically as well as experimentally. In the case of velocity matching between signal and optical waves using a shielding plane on top of the coplanar waveguide, numerical calculations of the attenuation constants of both superconducting and normal-conducting striplines indicate that the performance of the optical modulator is expected to be much superior to that using normal metals with respect to the figure of merit of bandwidth / driving-voltage.

We have carried out the experiment on the velocity-matched traveling-wave type $LiNbO_3$ optical modulator whose electrode is a superconductor (NbN), and demonstrated the microwave modulation characteristics as expected from theory. From this experiment using low Tc superconductors we can see the drastic improvement of the optical modulator performance by introducing superconducting electrodes. Studies on the resonant-type optical modulators with high Tc superconducting electrodes are in progress.

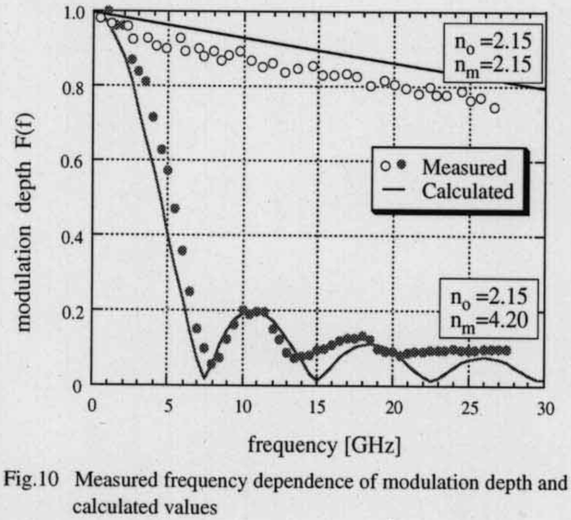

Fig.10 Measured frequency dependence of modulation depth and calculated values

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