VII. MICROWAVE AND MILLIMETER WAVE TECHNIQUES

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A. LOW-TEMPERATURE MILLIMETER WAVE RECEIVERS: LOW-BARRIER CRYOGENIC DIODES

Lance A. Glasser, Robert L. Kyhl

We have recently proposed a possibility for low-barrier height diodes: the n^+nn^+ diode. At cryogenic temperatures the carriers freeze out in the central n region to give a low barrier. A preliminary trial diode with a rather large dot size (50 μm) and a rather thick n region (7 μm) gives the vi curve shown in Fig. VII-1 taken from a curve tracer. The hysteresis shown presumably represents ionization of the frozen donors.
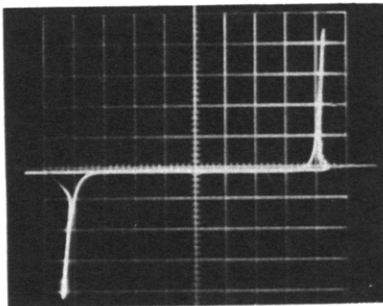

Fig. VII-1.
vi curve of n^+nn^+ diode at 4.2° K.
Scale: 10 μA/div, 50 mV/div.

The process is slow. It is possible to sweep through the break point in the vi curve more rapidly without showing hysteresis. Microwave measurements on this diode are not yet available.

There are similarities to the "cryosar," a bulk semiconductor device described in 1959.[1]

References

1. A. L. McWhorter and R. H. Rediker, Proc. IRE 47, 1207 (1959).

B. MULTIPLE MICROWAVE SOLID-STATE DEVICES

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1. Optimizing the Linearity of Multistage Amplifiers

One of the simplest configurations in which multiple active devices can be combined for high-power amplification is that of a multistage amplifier where each of the cascaded stages is a complete amplifier in itself and employs one negative-resistance device. The nonlinearity of the devices makes each of the stages nonlinear, and the gain compression of the complete amplifier is the product (or sum, if expressed in dB) of the gain compressions of individual stages. The gain compression of an individual stage depends upon the input power level, as well as the power gain of that stage. As the input power level of a stage goes on increasing for the successive stages in a cascade, it is clear that the gain of each individual stage should be so adjusted that the gain compression of the complete amplifier is not sensitively dependent upon a single stage. The advantages of such an adjustment are obvious: (i) none of the stages is underutilized so that the overall gain compression is minimum, and (ii) the reliability is improved because the overall gain compression is not a sensitive function of the operating conditions or deterioration of a single device.

An optimum distribution of the power gain and gain compression among the stages of an n-stage cascaded amplifier has been found to exist. This optimization can be carried out for a given negative-resistance device, at a given frequency, and for a given overall power gain and gain compression. The optimum distribution depends, of course, upon the nature of the nonlinearity of individual devices. For the purpose of present calculations, the devices are assumed to be IMPATT diodes, whose nonlinear behavior is conveniently modeled by using the nonlinear equivalent circuit proposed earlier.[1] A paper entitled "Design of Multi-Device Negative Resistance Amplifiers with Optimal Linearity" will appear in Proceedings of the Cornell Electrical Engineering Conference, August 1975.

2. Unified Theory of Injection Locking

Multiple active device oscillators may be classified in two groups depending upon the nature of the circuit: (i) oscillator combinations, in which each device is embedded in an individual oscillator and the oscillator outputs are combined; and (ii) device combinations, in which the devices are not associated with individual, identifiable, oscillator circuits but rather share a single resonant circuit. In the oscillator combination schemes of group (i) the individual oscillator outputs must be synchronized for satisfactory operation, and injection locking exists in successful circuits even when no explicit locking arrangement is apparent. This question does not arise in the case of

the oscillators of group (ii) where the interaction between the devices is much stronger, and the resulting phenomena such as frequency jumps are better described in terms of more complex processes than oscillator injection locking. A study of injection locking is essential, however, for the first group of combining schemes.

Present theories of injection locking fall into three classes according to the nature of the oscillator model: (i) van der Pol theory, in which the oscillator is modeled by a nonlinear differential equation that has oscillatory solutions, (ii) Adler theory, in which the nonlinear oscillator is modeled by a positive feedback circuit in which the phase of the feedback signal controls the oscillator frequency, and (iii) Kurokawa theory, in which the frequency of oscillation is determined by a resonant circuit including the nonlinear active device.

It appears feasible to unify the three models so that they may be viewed as complementary rather than as alternative representations. As a first step, a simple idealized oscillator is described in each of these three ways and the injection-locking behavior predicted by each theory is compared. The unified model will then be employed to study oscillator combination schemes.

References

1. M. S. Gupta, "Large-Signal Equivalent Circuit for IMPATT-Diode Characterization and Its Application to Amplifiers," IEEE Trans., Vol. MTT-21, No. 11, pp.689-694, November 1973.

C. PRESSURE BROADENING CALCULATIONS APPLIED TO MICROWAVE ABSORPTION OF OXYGEN AND WATER VAPOR IN THE ATMOSPHERE

Alan H. Barrett, Kai S. Lam

Results of calculations for oxygen self-broadening for rotational lines N = 1 to N = 11 were presented in Progress Report No. 115 (pp. 74-83). Numbers for O_2-O_2 linewidths (MHz/Torr) at T ≈ 300° K were found to compare favorably with existing experimental data. The case of N_2 broadening was then treated. This involved changing the values of parameters used in the O_2-O_2 interaction potential while retaining the same form of the expression

$$V = \left(Ae^{-ar} - \frac{C}{r^6}\right) + P_2(\cos\theta)\left(Aa_r e^{-ar} - \frac{Ca_a}{r^6}\right).$$

Since the most recent experimental data[1] indicated that the ratio of the N_2 to O_2

broadening effectiveness ≈ 0.93, we have attempted to vary parameters in V to achieve $\Delta\nu_{O_2-N_2}/\Delta\nu_{O_2-O_2} = 0.93$. We found that $\Delta\nu$ was quite insensitive to A and a (the short-range force constants) and the most convenient parameter to vary was C, since an almost linear relationship was obtained between $\Delta\nu$ and C.

To calculate the absorption coefficient in the atmosphere, matrix elements for N up to ~ 33 are required. The computation of these elements for large N would have involved a prohibitive amount of computer time. Examination of the explicitly calculated matrix subblock for N up to 11 revealed that regular patterns occurred for both diagonal and off-diagonal elements. In general the absolute values of off-diagonal elements decreased rapidly with increasing N; hence, an extrapolation procedure was adopted to determine elements for N > 11.

A diagonalization and inversion process of the 102×102 matrix (for $N = 1, 3, 5, \ldots,$ 33) was required for each set of values of temperature and pressure but not for each observing frequency. Preliminary results for absorption coefficients have been obtained in the $50 \rightarrow 70$ GHz band for $T = 300°K$, $P = 760$ Torr and $T = 210°K$, $P = 150$ Torr, corresponding respectively to ground level and the lowest layers of the tropopause. Comparison with results from noninterference theories using the Gross line shape and empirically determined parameters revealed that, with the present interference theory, the lines are much less well resolved because of overlapping effects.

Formulations for the H_2O absorption calculation have also been carried out. In the atmosphere, H_2O-N_2 and H_2O-O_2 interactions predominate, and for both of these cases we have chosen the interaction as dipole-quadrupole. The straight-line approximation has been used in computing the collision integral, since $\langle V_{d-q}\rangle_{\Omega_1} = \langle V_{d-q}\rangle_{\Omega_2} = 0$, where Ω_1 is the radiator orientation and Ω_2 is the perturber orientation. This procedure enabled the interaction operator to be written as an explicit function of v_o (impact velocity) and b (impact parameter) so that the thermal average and average over b of the interaction operator could be carried out analytically. The same procedure can also be used for dipole-dipole interactions such as occur for H_2O-H_2O. We found that

$$\Delta V_{d-q} \propto T^{-5/6}$$

$$\Delta V_{d-d} \propto T^{-1}.$$

Results for the matrix elements and absorption coefficients for H_2O will be presented in a future report.

References

1. M. J. Liebe, OT Report 75-00 (1975), U. S. Department of Commerce, Washington, D. C.

D. VERY LONG BASELINE INTERFEROMETRY: 6-cm OBSERVATIONS   JSEP
    OF RADIO GALAXIES OVER A 228-km BASELINE

Robert C. Walker, Kwok-Yung Lo, Bernard F. Burke

Recent aperture synthesis maps of extended extragalactic radio sources show structure down to scales of approximately 2 seconds of arc. These maps often show compact components, both within the extended regions of emission and at positions coincident with the associated optical objects. In particular, 5-GHz observations of Cygnus A showed,[1] in addition to the classic extended double structure, that there are compact components both within the main lobes and coincident with the optical nucleus. The nuclear source was unresolved and smaller than 1."5 arc while the outer compact components may have been just resolved, although the data are not conclusive. Similar phenomena have been observed in other radio galaxies. Kellermann and his co-workers[2] recently extended these results to much higher resolution at 7.8 GHz. They found structure in the central components of several radio galaxies on scales of a few times 0."001 arc. They also found the outer components to be resolved with fringe spacings of ~0."01 arc.

In June 1974, several extragalactic radio sources that show bright compact components in maps provided by observations with the One-Mile and 5-km telescopes of the Mullard Radio Astronomy Observatory in Cambridge[3-6] were observed at 5 GHz during a VLBI (Very Long Baseline Interferometry) experiment between the 140 ft (43 m) antenna of the National Radio Astronomy Observatory in Green Bank, West Virginia, and the 85 ft (26 m) antenna of the Naval Research Laboratory in Maryland Point, Maryland. In this experiment, we were joined by J. M. Moran, of the Smithsonian Astrophysical Observatory, and by K. J. Johnston, of the Naval Research Laboratory.

Since the frequency used in these observations was the same as that used in Cambridge, direct comparison of the fluxes of the compact features is possible. The relatively short baseline, approximately 228 km, gave a fringe spacing of ~0."05 arc, which is intermediate between the longest linked interferometers and most VLBI baselines. Hydrogen maser frequency standards at both stations and radiometers whose system temperatures were 85°K at NRAO and 150°K at NRL gave a 5σ detection limit of ~0.15 Jy. The data were recorded on the Mark II VLBI system and most of the data reduction was done with the standard programs at NRAO,[7] although an additional program that displays normalized correlation coefficients as a function of fringe rate and delay was used to search for weak sources and for multiple components within a single source. The correlated flux calibrations were based[1] on a total flux of 433 Jy for Cyg A and an overall scaling factor obtained from observations of sources (including 3C84 and   JSEP

BL Lac) which appear unresolved on this baseline.

The central sources in Cygnus A, 3C111, 3C109, 3C465, and 3C390.3 were observed. Table VII-1 gives the results. Column 1 lists the source, columns 2 and 3 the projected baseline components in millions of wavelengths, column 4 the normalized correlation coefficient, column 5 the correlated flux density, column 6 the Cambridge 5-GHz flux density of the central compact feature, and column 7 the ratio of the correlated flux density to the Cambridge flux density. No attempt was made to account for time variations or for different calibration schemes. The results are consistent with those of Kellermann et al.[2] at 7.8 GHz insofar as the central component in each galaxy is unresolved within the experimental errors.

Table VII-1.   Results of 6-cm VLBI experiment.

Source	u	v	A	S_c	S(CAMB)		γ
	($10^6\lambda$)			Jy	Jy		
Cygnus A	-3.3	1.3	.00021	.8	1.1	[1]	0.7
	-3.4	-1.0	.00024	1.0			0.9
	-1.9	-2.0	.00025	.9			0.8
3C111	-2.5	1.8	.00087	2.0	1.2-2.0	[8]	
	-3.7	0.5	.00083	1.8	(variable)		
	-3.4	-1.0	.00083	1.9			
	-1.6	-2.0	.00082	2.0			
3C109	-3.0	0.5	.00019	.4	.38	[4]	1.1
	-3.8	0.1	.00020	.4			1.1
	-3.0	-0.3	.00020	.4			1.1
3C390.3	-2.1	3.0	.00019	.4	.35	[5]	1.1
3C465	3.8	-2.1	.00013	.3	.29	[6]	1.0

Errors: $\Delta S_c \sim$ 15%, ΔS(CAMB) $\sim$ 13%, $\Delta\gamma \sim$ 20%.
References: [1] Hargrave and Ryle, [8] Fanaroff, [4] Branson, Elsmore, Pooley, and Ryle, [5] Harris, [6] Riley and Branson.

Most of the flux density from Cygnus A at 5 GHz comes from the large double lobe structure that extends approximately 100 kpc in both directions from the optical galaxy. We attempted to detect compact components within these lobes by searching in fringe rate and delay. The entire source was within the individual telescope beams, and any compact component would have appeared as a correlation, offset in fringe rate and

delay from the central source. No such correlations were detected to a 5σ sensitivity of approximately 0.25 Jy. This noise level is somewhat higher than that for isolated faint sources because Cygnus A significantly raises the system temperatures. If any compact structure of 0."5 arc size or smaller was present, its flux must have been a very small proportion ($\lesssim 1/1000$) of the total source flux. The brightness temperature of any such compact structure must have been less than 5×10^{6} °K. Any significant condensation, therefore, must have been larger than 75 pc, under the assumption that $H_O = 50$ km sec^{-1} Mpc^{-1}.

Our limit is consistent with the models for the various features in Cygnus A given by Hargrave and Ryle.[1] They suggested that all data available to them were consistent with resolution of all the outer compact components at a level of 1"-2" arc, corresponding to a scale size of from 1.5 to 3 kpc. The high correlated fluxes on the longer base-lines ($\lesssim 35$ km) were explained by a sharp cutoff (< 0."25 arc) at the outer edge of the south following component (feature D). For a more complete discussion of the models and of the physical implications, the reader is referred to their paper. While they found no need for compact subcomponents of high surface brightness to explain the available data, their allowable limits on such features are not as stringent as the present results.

The central source in Cygnus A lies very close to the line of symmetry defined by the most concentrated parts of the main lobes, and the brightest outer condensations subtend a relatively small angle (~1°) as seen from the center. Such a high degree of collimation has been used as support for an ejection hypothesis, in which the high luminosity is maintained by compact, energetic fragments, cast off from the central nucleus.[9] Such a model provides a plausible way of explaining the observed concentration of energetic particles in the outer lobes, but our failure to observe compact objects in the outer parts raises the question of why such energy sources are two or more orders of magnitude less luminous than the principal structures that they are maintaining.

References

1. P. J. Hargrave and M. Ryle, M.N. Roy. Astron. Soc. 166, 305 (1974).
2. K. I. Kellermann, B. G. Clark, A. E. Niell, and D. B. Shaffer, Astrophys. J. Letters 197, L113 (1975).
3. S. Mitton, Astrophys. Letters 6, 161 (1970).
4. N. J. B. A. Branson, B. Elsmore, G. G. Pooley, and M. Ryle, M.N. Roy. Astron. Soc. 156, 377 (1972).
5. A. Harris, M.N. Roy. Astron. Soc. 158, 1 (1972).
6. J. M. Riley and N. J. B. A. Branson, M.N. Roy. Astron. Soc. 164, 271 (1973).
7. B. G. Clark, Proc. IEEE 61, 1242 (1973).
8. B. L. Fanaroff, M.N. Roy. Astron. Soc. 166, 1P (1974).
9. G. R. Brubidge, Nature 216, 1287 (1967).