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SOLID-STATE LOCAL OSCILLATOR SOURCES FOR MILLIMETER AND SUBMILLIMETER WAVES IN EUROPA

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SUMMARY

This paper gives an overview of the European activities in developing solid-state local oscillator sources for high millimeter and submillimeter frequencies. Radio astronomy with ground based telescopes has conventionally been the driving force in this area. Projects funded by the European Space Agency and national space agencies aiming to spaceborne radio astronomy and remote sensing of the atmosphere have recently given more impetus for this research.

INTRODUCTION

The choice of local oscillators for low noise receivers above 100 GHz is restricted. Fundamental sources used most frequently are Gunn oscillators up to about 150 GHz, klystrons up to 200 GHz, carcinotrons up to 500 GHz and combinations of gas lasers at discrete frequencies above 150 GHz. Vacuum tube oscillators, such as klystrons and carcinotrons, are expensive, have short lifetime and need high voltage power supplies. Gas lasers are large in mechanical size and fragile. Therefore, there is a strong need of all-solid-state local oscillators also above 150 GHz. In recent years frequency multipliers based on a Schottky-varactor have become widely used as mm-wave local oscillators. A good overview of the European status in this field in 1987 is given in /1/.

Mainly defence budgets provide the funding for development of solid-state oscillators, such as Gunn and IMPATT, at around 100 GHz. Funding for development of novel devices for fundamental oscillators and of frequency multipliers for higher frequencies comes often from national science foundations or from the European Space Agency (ESA) and national space agencies. ESA has recently awarded a study contract "Development of critical detection technologies for spaceborne submillimeter heterodyne receivers" in which several companies, universities and research institutes are involved in Ireland, Sweden, the Netherlands, Great Britain, France, Italy and Finland. In this study Schottky multipliers and quantum well diode oscillators are being developed for submillimeter waves. The distant goal is ESA's cornerstone program FIRST (Far Infrared and Submillimeter Space Telescope) /2/, see Figure 1.

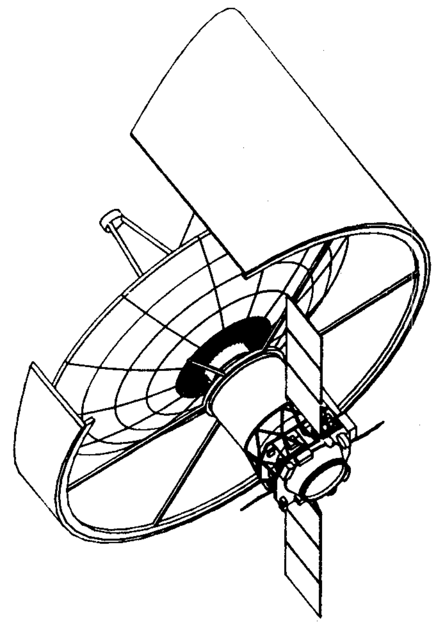

Figure 1. FIRST /1/.

FUNDAMENTAL SOURCES

The Gunn device is widely used in local oscillators both in military and civil applications at around 100 GHz because of its good noise properties. Therefore also European industry together with universities has a strong interest in developing both the Gunn devices and Gunn oscillators.

Work towards higher mm-wave efficiency from InP Gunn diodes has been reported from Thomson-CSF and University of Lille. /3,4/ and from GaAs Gunn diodes from GEC and Marconi /5/

Fundamental InP oscillators with dielectric resonator stabilization up to 94 GHz have been developed at Thomson-CSF /6/. Ondria at Marconi has designed second harmonic quartz microstrip Gunn oscillators using both InP and GaAs diodes /7/. Second harmonic oscillators for 100 GHz and beyond using waveguide mounts have been reported by Barth at AEG /8/, Jacobs and Vowinkel at University of Cologne /9/ and Rydberg and Kollberg at Chalmers University of Technology /10/. The highest frequencies from the second harmonic Gunn oscillators are about 150 GHz.

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The IMPATT oscillator is known to be noisier than Gunn /11/, but is usable for local oscillator purposes when the FM noise is reduced with phase locking and the AM noise far from the carrier is filtered effectively.

A strong effort has been devoted at AEG and University of Munich to develop improved IMPATT diodes for 100 GHz. Si-MBE has been used to make comparisons between single drift, double drift and quasi Read double drift Si IMPATT diodes. The latter was found to deliver the highest efficiency and the highest output power at 100 GHz /12/. From a monolithic Si IMPATT diode an output power of 1 mW was obtained at 76 GHz /13/, and the monolithic design has been extended into silicon mm-wave integrated circuits /14/.

A novel IMPATT device is the MITATT diode, utilizing a combination of tunnelling injection and impact ionisation at lower fields. The MITATT diode should exhibit better noise performance than the conventional IMPATT diode and oscillation capability up to the submm-wave region. In the first experiments with a Si/SiGe heterostructure MITATT diode, shown in Figure 2, a very low noise CW output of 25 mW was obtained at 103 GHz.

n^+	n	i	p	p^+
Si	Si	$Si_{0 6}Ge_{0 4}$	Si	Si
substrate	280 nm	10 nm	280 nm	240 nm

Figure 2. Layer sequence of Si/SiGe double drift MITATT diode for 100 GHz operation /15/.

Quantum well diodes (resonant tunnelling) based on GaAs heterostructures have been utilized in oscillator research at Chalmers University of Technology /16-18/. At 90 GHz 84 μW at 77 K and 60 μW at room temperature was obtained from a quantum well oscillator. At 176 GHz at room temperature 1 μW output power was measured.

At AEG the resonant tunnelling effect has been shown in a Si/SiGe heterostructure /19/. Millimeter wave oscillations in this device have not been reported.

When an extremely low noise SIS quasiparticle mixer /20/ is used in mm- or submm-astronomy observations, the local oscillator power needed is well below 1 μW. This low power is possible to create by using a long Josephson junction fluxon oscillator. First European experimental results and attempts to develop an integrated superconducting heterodyne receiver have been reported by Monaco et al. /21/ and Crete et al. /22/

FREQUENCY MULTIPLIERS

A Schottky varactor frequency multiplier is becoming a standard component in the local oscillator system of a radioastronomy receiver at frequencies from 150 to 500 GHz. The local oscillator power needed at 500 GHz by a Schottky mixer at room temperature is a few milliwatts and only a few hundreds of μW at 20 K. SIS mixers need only a few nanowatts at 100 GHz /20/ and the LO power requirement scales as the square of the frequency.

A European source for Schottky diodes is Farran Technology Ltd. Farran together with the Microelectronics Center of University of Cork is developing improved multiplier diodes up to 1000 GHz.

A frequency doubler is the simpliest and most effective multiplier. A tripler requires an idler circuit at the second harmonic frequency which complicates the design and reduces the efficiency. Higher order multipliers require more idler circuits and are therefore so complicated designs that their use is less frequent.

Using varactors from either Farran or University of Virginia several European radioastronomy receiver groups have developed multipliers for their mm-wave receivers. At Meudon observatory doublers for 80-190 GHz and triplers for 240-240 GHz range /23,24/ have been constructed. Maximum efficiencies from the doublers are about 20 % and maximum output power 12 mW.

A waveguide cavity is utilized as the idler circuit in the Meudon triplers, the same applies to the triplers designed at IRAM up to 250 GHz /25/. A coaxial resonator is used in the triplers designed at Chalmers University of Technology /26/.

The submillimeter range is reached by Woestenburg at NFRA Dwingeloo using a doubler from 345 to 690 GHz with 15 μW output power /27/ and by Zimmermann et al. at Radiometer-physics Meckenheim using a quintupler from 92 to 490 GHz /28/.

A systematic study of frequency multipliers of various orders has been carried out at Helsinki University of Technology since 1985. Several experimental multipliers have been designed using scaled model measurements and harmonic balance analysis in optimizing the waveguide mount for a given varactor. The highest efficiencies obtained experimentally are: 45 % from a doubler at 94 GHz output frequency /29/, 28 % from a tripler at 107 GHz /30/, 11 % from a quadrupler at 148 GHz and 4 % from a quintupler at 168 GHz /31/. All these efficiencies are better than those reported in literature before at the same or higher frequencies. Figure 3 shows the tripler for 100 GHz with a crossed waveguide mount and its efficiency as a function of the output frequency at various input power levels. Figure 4 shows the theoretical results from harmonic balance analysis. Frequency doublers have been constructed also for 183 and 230 GHz output frequencies with good efficiency and output power. Also comparisons of the efficiency of higher order multipliers and cascaded doubler have been carried out /31/. Currently frequency multipliers with output frequencies in the submillimeter region are studied.

The quantum well diode suits well to triplers and higher odd-order multipliers, because due to the symmetric property of the I-V characteristic even harmonics are not produced. Encouraging results with a tripler to 250 GHz have been reported from Chalmers University of Technology /18/.

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REFERENCES

/1/ FIRST, Far Infrared and Submillimeter Space Telescope, Assessment Study, ESA document SCI (83) 1, September 1983.

/2/ Proceedings of the workshop "Solid State Sources at Millimeter and Submillimeter Wavelengths", MTT-Chapter of the West Germany Section of the IEEE, Ulm, September 1987.

/3/ M.A. di Forte-Poisson, G. Colomer, C. Brylinski, J.P. Duchemin, F. Azan, J. Lacombe, "High power, high efficiency LP. MOCVD InP Gunn diodes for 94 GHz", Proc. of the 15th European Microwave Conference, Microwave Exhibitions and Publishers Ltd., pp. 177-182, 1985.

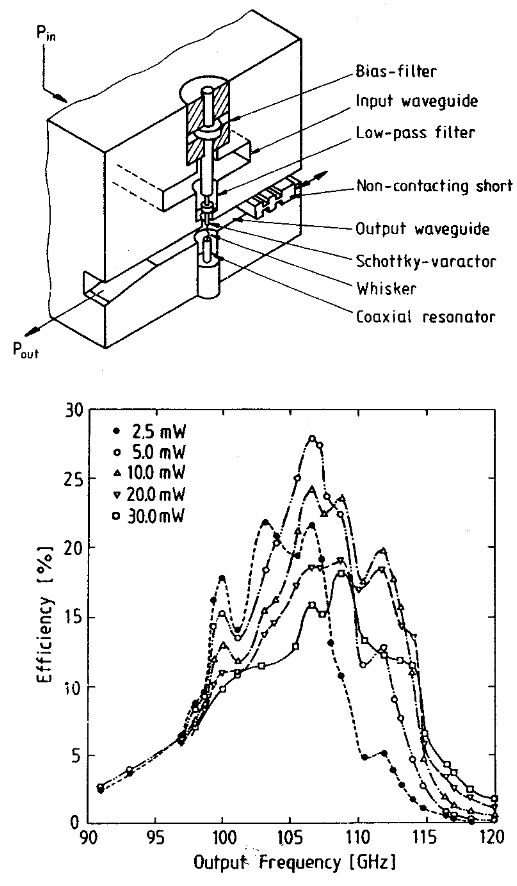

Figure 3. Crossed waveguide Schottky-varactor frequency tripler for 105 GHz and its efficiency /30/.

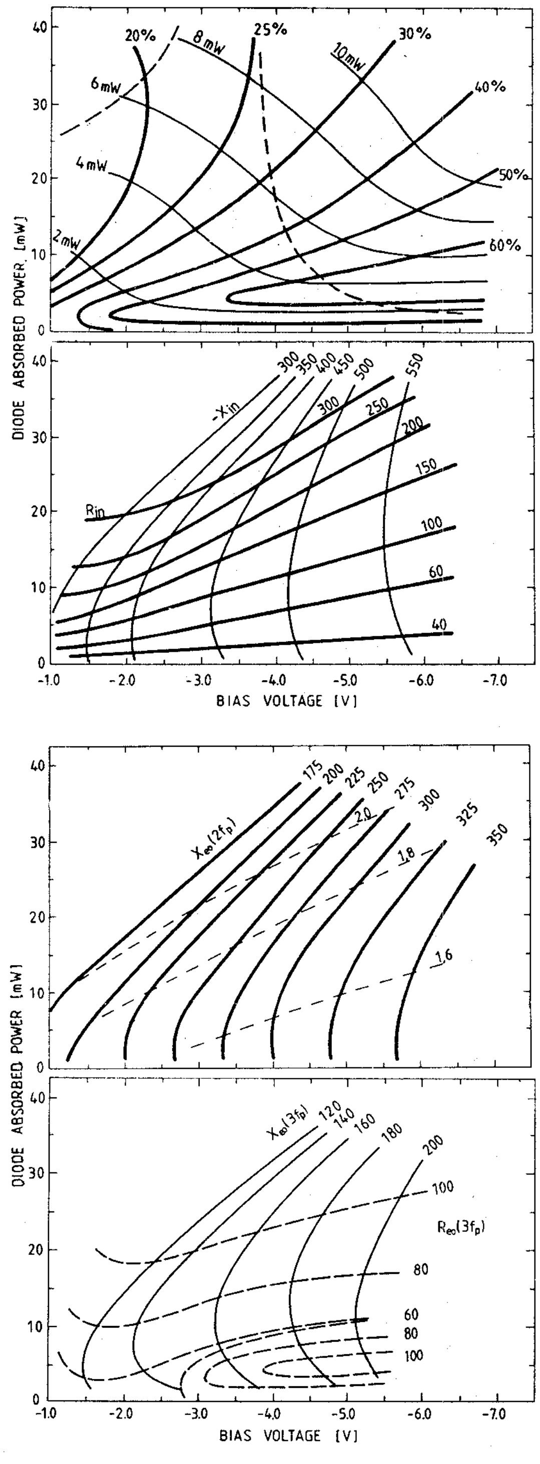

Figure 4. Theoretical results for a tripler from 35 to 105 GHz. Efficiency and output power, input impedance, optimum idler reactance and optimum output impedance /30/.

/4/ M.R. Friscourt, P.A. Rolland, J.P. Duchemin, J. Lacombe, "High power high efficiency millimeter wave TED's with reverse-biased heterojunction cathode contact", Proc. of the 15th European Microwave Conference, Microwave Exhibitions and Publishers Ltd., pp. 183-188, 1985.
/5/ J. Ondria, "Latest advances in mmW osillators", IEE Colloquim "Solid State Components for Radar" Digest, Paper no. 8, Savoy Place, London, England, Feb. 1988.
/6/ N. Mamodaly, F. Farzaneh, A. Bert, J. Obregon, P. Guillon,"A fundamental-mode InP Gunn dielectric resonator oscillator at 94 GHz", Proc. of the 15th European Microwave Conference, Microwave Exhibitions and Publishers Ltd., pp. 170-176, 1985.
/7/ J. Ondria, "Quartz microstrip radial disk fundamental and second harmonic mmW Gunn oscillators", Proc. of the 18th European Microwave Conference, Microwave Exhibitions and Publishers Ltd., pp. 351-363, 1988.
/8/ H. Barth, "Oberwellen-Oscillatoren zur Leistungserzeugung im Millimeterwellen Gebiet", Thesis for the degree of Doctor-Ingenieur at Technical University Hamburg-Harburg, West Germany, 1988.
/9/ K. Jacobs, B. Vowinkel, "Solid state mm-wave oscillators with large tuning range", 1987 IEEE MTT-S Digest, pp. 863-866, 1987.
/10/ A. Rydberg, E. Kollberg, "Wideband tunable 140 GHz second-harmonic InP-TEO oscillator", Electronic Lett., vol. 22, pp. 770-771, 1986.
/11/ G.A. Ediss, N.J. Keen, P. Zimmermann, "comparison of AM noise from a klystron and an IMPATT oscillator at around 90 GHz", IEEE Trans. Microwave Theory Tech., vol. MTT-30, pp. 2012-2013, 1982.
/12/ J.F. Luy, E. Kasper, W. Behr, "Semiconductor structures for 100 GHz Silicon IMPATT diodes", Proc. of the 17th European Microwave Conference, Microwave Exhibitions and Publishers Ltd., pp. 820-825, 1987.
/13/ J.F. Luy, K.M. Strohm, J. Buechler, "Silicon monolithic millimeter wave IMPATT oscillators", Proc. of the 18th European Microwave Conference, Microwave Exhibitions and Publishers Ltd., pp. 382-387, 1988.
/14/ J.F. Luy, J. Buechler, "90 GHz SIMMWIC (Silicon monolithic millimeter wave integrated circuit), to be published in the proc. of MIOP'89 Conference, 1989.
/15/ J.F. Luy, H. Jorke, H. Kibbel, A. Casel, E. Kasper, "Si/SiGe heterostructure MITATT diode", Electronics Lett., vol. 24, no. 22, pp. 1386-1387, 1988.
/16/ H. Grönqvist, A. Rydberg, H. Hjelmgren, H. Zirath, E. Kollberg, J. Söderström, T. Anderson, "A millimeter wave quantum well diode oscillator", Proc. of the 18th European Microwave Conference. Microwave Exhibitions and Publishers Ltd., pp. 370-375, 1988.
/17/ A. Rydberg, H. Grönqvist, E. Kollberg, "A theoretical and experimental investigation on millimeter-wave quantum well oscillators", Microwave and Optical Technology Lett., vol. 1, pp. 333-336, 1988.
/18/ A. Rydberg, H. Grönqvist, E. Kollberg, "Millimeter-wave quantum-well oscillators and multipliers", to be published in the proc. of MIOP'89 Conference, 1989.
/19/ E. Kasper, H. Dämbkes, J.F. Luy, "Very low temperature MBE process for SiGe and Si device structures", Tecnical Digest of IEDM 88, p. 558, 1988.
/20/ A.V. Räisänen, D.G. Crete, P.L. Richards, F.L. Lloyd, "A 100 GHz SIS quasiparticle mixer with 10 dB coupled gain", 1987 IEEE MTT-S Digest, pp. 929-930, 1987.
/21/ R. Monaco, S. Pagano, G. Costabile, "Josephson local oscillator for integrated radioastronomical receivers", Digest of the 13th Int. Conf. on Infrared and Millimeter Waves (ed. R.J. Temkin), SPIE, vol. 1039, pp. 73-74, 1988.
/22/ D.-G. Crete, P. Feautrier, M. Hanus, R. Monaco, P.J. Encrenaz, "Nb/AlO_x/Nb junctions for integrated superconducting heterodyne receiver", to be published in the Proc. of the 2nd Workshop on Stimulated Nonlinear Effects in Josephson Devices", World Scientific Corp., Singapore, 1989.
/23/ L. Pagani, G. Beaudin, M. Gheudin, A. Dechamps, and P. Encrenaz, "A 230 GHz low noise cooled receiver for radioastronomy applications", Proc. of the 15th European Microwave Conference, Microwave Exhibitions and Publishers Ltd., pp. 291-296, 1985.
/24/ L. Pagani, G. Ruffie, G. Beaudin, M. Gheudin, and A. Dechamps, "A low noise cryogenic receiver for spectroscopic applications in mm-wave radioastronomy at 230 GHz", Microwave Journal, vol. 29, no. 10, pp. 119-131, 1986.
/25/ R. Blundell, IRAM, private communication.
/26/ A. Rydberg, "Solid state local oscillators for millimeter-wave low noise mixers". Thesis for Doctor of Technology degree, Chalmers University of Technology, Technical Report no. 187, 1988.
/27/ E.E.M. Woestenburg, "Performance of a single ended Schottky diode mixer at 345 GHz as low noise mixer and frequency doubler for 690 GHz", Instrumentation for Submillimeter Spectroscopy (ed. Erik Kollberg), Proc. SPIE 598, pp. 60-64, 1985.
/28/ R. Zimmermann, P. Zimmermann, R. Zimmermann, "490 GHz solid state source with varactor quintupler", Digest of the 13th International Conference on Infrared and Millimeter Waves (ed. R.J. Temkin), SPIE, vol. 1039, pp. 77-78, 1988.
/29/ T.J. Tolmunen, A.V. Räisänen, "An efficient Schottky-varactor frequency multiplier at millimeter waves. Part I: Doubler", Int. J. of Infrared and Millimeter Waves, vol. 8, pp. 1313-1336, 1987.
/30/ T.J. Tolmunen, A.V. Räisänen, "An efficient Schottky-varactor frequency multiplier at millimeter waves. Part II: Tripler", Int. J. of Infrared and Millimeter Waves, vol. 8, pp. 1337-1353, 1987.
/31/ T. Tolmunen, A. Räisänen, M. Sironen, "Higher order frequency multipliers - a solution for mm- and submm-wave local oscillator signal generation", 1989 IEEE MTT-S Digest (this conference), 1989.