AD-A087 869 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH F/G 20/1
MAIN DEVELOPMENT DIRECTIONS OF SOLID-STATE MICROWAVE ELECTRONIC--ETC(U)
DEC 79 A SMOLINSKI
UNCLASSIFIED FTD-ID(RS)T-1628-79 NL

1 OF 1
ADA
087869

END
DATE
FILMED
9-80
DTIC

PHOTOGRAPH THIS SHEET

DTIC ACCESSION NUMBER: ADA087869

LEVEL

INVENTORY

FTD-ID(RS)T-1628-79

DOCUMENT IDENTIFICATION

**DISTRIBUTION STATEMENT A**
Approved for public release;
Distribution Unlimited

DISTRIBUTION STATEMENT

| ACCESSION FOR | | |
|---|---|---|
| NTIS | GRA&I | ☒ |
| DTIC | TAB | ☐ |
| UNANNOUNCED | | ☐ |
| JUSTIFICATION | | |
| BY | | |
| DISTRIBUTION / | | |
| AVAILABILITY CODES | | |
| DIST | AVAIL AND/OR SPECIAL | |
| A | | |

DISTRIBUTION STAMP

DTIC
S ELECTE D
AUG 15 1980
D

DATE ACCESSIONED

DATE RECEIVED IN DTIC

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDA-2

DTIC FORM OCT 79 70A

DOCUMENT PROCESSING SHEET

FTD-ID(RS)T-1628-79

# FOREIGN TECHNOLOGY DIVISION

## MAIN DEVELOPMENT DIRECTIONS OF SOLID-STATE MICROWAVE ELECTRONICS

By

Adam Smolinski

FTD -ID(RS)T-1628-79

# EDITED TRANSLATION

FTD-ID(RS)T-1628-79 19 December 1979

MICROFICHE NR: FTD-79-C-001636

MAIN DEVELOPMENT DIRECTIONS OF SOLID-STATE MICROWAVE ELECTRONICS

By: Adam Smolinski

English pages: 19

Source: Elektronika, Vol. 19, Nr. 1, 1978, pp. 2-7

Country of Origin: Poland
Translated by: MSgt B. Rudawskyj
Requester: FTD/TQFE
Approved for public release; distribution unlimited.

| | |
|---|---|
| THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION. | PREPARED BY: TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WP.AFB, OHIO. |

# MAIN DEVELOPMENT DIRECTIONS OF SOLID-STATE MICROWAVE ELECTRONICS*

Adam Smolinski

In the tradition of the National Conference on Solid-State Microwave Electronics we need to discuss development fundamentals of the preceding three years in this field.

I would like to tie in facts of more than three years ago, and say that MECS [microwave electronics] has reached a certain level of technical development where many technological design and measurement problems have been solved, thereby making possible production of solid-state components and solid-state systems suitable for use not only in an earth environment, but also in outer space. We can safely say that MECS components have made possible today's progress in communication satellites. We must, however, point out that the above mentioned development concerns mainly the decimeter and centimeter frequency bands. To cross into the area of shorter frequencies, up to and including the sub-millimeter band, will take yet a great amount of research, particularly by industry. It is known that these frequencies permit sending a greater amount of information for a more precise operation of equipment.

---

* Summary of an inauguration lecture at the IVth National Conference on Solid-State Microwave Electronics. Gdansk 17 Nov. 1977.

Aside from the direction of "frequency related" development, we also have the increase range of devices, expressed as "desideratum" of greater power and lower noise. Power that has been acquired with the help of semiconductors has approached the theoretical limit of material utilization (Fig. 1); however, in the case of medium-kilowatt power, we are reaching it only with the greatest difficulty and effort.

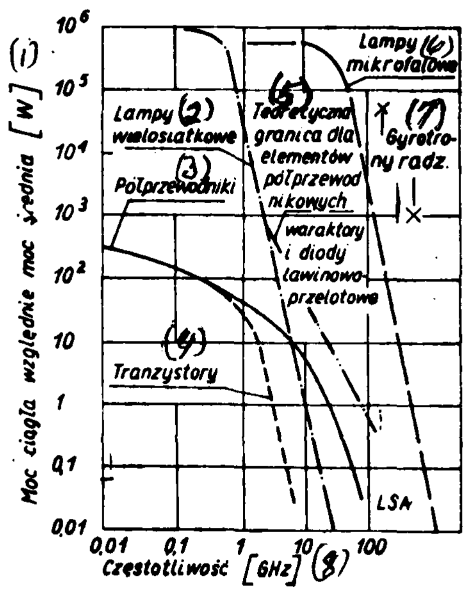


Fig. 1. Medium power produced via generators of different types in the microwave range.

KEY: (1) Continuous power relative to medium power; (2) Multigrid tubes; (3) Semiconductors; (4) Transistors; (5) Theoretical limit of semiconductor elements, varactors, and diodes; (6) Microwave tubes; (7) Gyrotron; (8) Frequency.

We will talk about specific progress in this area later. Here, rather, I would like to deal with the matter of gyratrons. These are tube-type generators incorporating the advantages of masers and klystrons, utilizing a strong relativistic electronic union to create oscillations in the centimeter and shorter, down to millimeter frequency bands, with medium power of several score and up to several hundred kilowatts in the millimeter frequency band [1, 2]. This unquestioned achievement could find application in radar and in plasma-type devices [3].

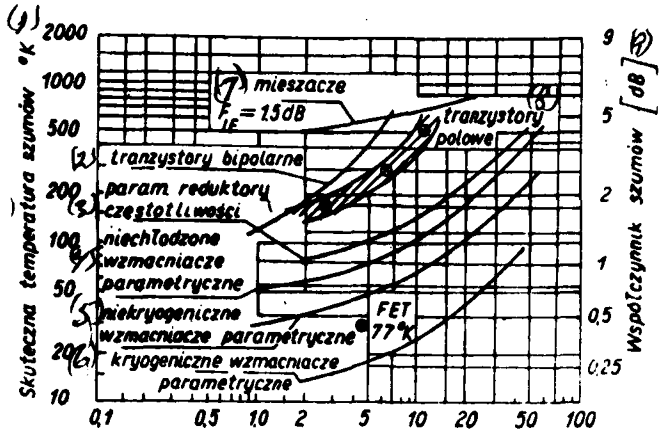


Fig. 2. Frequency related effective noise temperature of different types of semiconductors.

KEY: (1) Effective noise temperature; (2) Bipolar transistors; (3) Parametric frequency reducer; (4) Uncooled parameteric amplifiers; (5) Non-cryogenic parametric amplifiers; (6) Cryogenic parametric amplifiers; (7) Mixers; (8) Field transistors; (9) Noise coefficient.

Such great power reaching a gigawat of impulse power can be created with a cloud of monoenergized electrons in a waveguide actuated by intersecting fixed fields - magnetic and electrical. The electrons moving along a spiral are stopped by a screen and lose energy to the wave signal in the waveguide at a frequency greater than the frequency of the cyclotron. Gyratrons create radiation of the wave designated by the magnetic field, and not because of the resonant size of the magnetic cavity, thus permitting the attainment of very high power with comparatively small energy density.

Another method of achieving development in the microwave field in the millimeter wave band is through low noise elements. Here we must mention the new position of the semiconductor/superconductor diode known as super-Schottky. Working as a heterodyne detector at a temperature of liquid helium, it shows an effective noise temperature of 6K at 9 GHz (Fig. 2) [4]. On the other hand, in the millimeter wave band (200-325 GHz), we can note a different record, namely an effective temperature of 1320K [equivalent to the noise coefficient of 7.4 dB] and, equally, the cryogenic mixer in the 6.5 dB stratum and a bandwith of B = 20 MHz working in conjunction with Josephson effect and a 9 GHz medium frequency maser amplifier [5]. These type of circuits find application in radioastronomy, in the examination of atmospheric characteristics, and plasma, and lately in aircraft radiometers.

Both achievements mentioned greatly exceed known values of frequency-related effective noise temperatures of various types of semiconductors. This graph demonstrates via the quantitive method the achievement in the area of applied devices. Let us turn our attention now to the data on cryogenic parametric amplifiers which have replaced the maser as of a few years ago. Figure 3 shows how the noise decreased in cooled and uncooled parametric amplifiers in recent years. This process was brought forth by advancements in the sphere of materials and instrument technology.

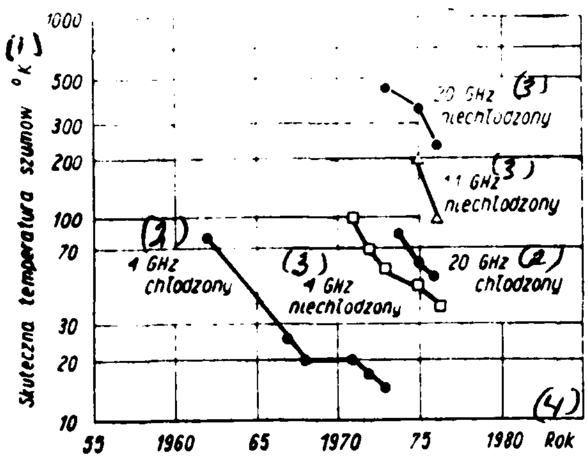


Fig. 3.

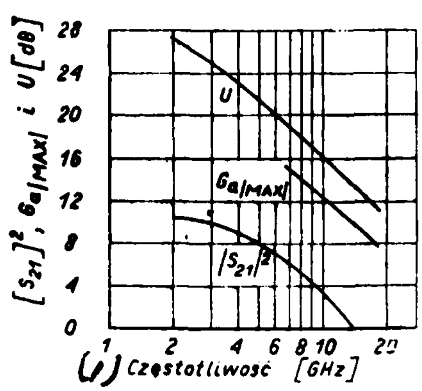


Fig. 4.

Fig. 3. Effective noise temperature of parametric amplifiers.
KEY: (1) Effective noise temperature; (2) Uncooled; (3) Cooled; (4) Year.

Fig. 4. Maximal unilateral amplification and $|S_{21}|2$ of a typical gallium-arsenide field transistor with 1 μm gate.
KEY: (1) Frequancy.

These advancements were most evident in field-effect transistors made of gallium-arsenide, which today have become reliable devices that can be mass produced for use in many applications [6]. First essential application of these transistors is in the area of low noise amplification. Transistors with a 0.5 μm and even a 0.25 μm gate are beginning to come into universal use. In the laboratories gates even with 0.15 μmduration have been created permitting the broadening of the wide-band area above 20 GHz (for example up to 26 GHz with a 6.6 dB noise coefficient and 5.6 dB amplification). Essential characteristics of mass-produced transistors are given by way of an example in Fig. 4. Highest values of noise coefficient have been attained today from 1 dB at 3 GHz to 5.6 dB at 24 GHz.

On the basis of this, a study was made of several amplifiers in hybrid scaled circuits of frequently used frequency bands; their noise coefficients are given in Fig. 5. Of great help in the design of amplifiers are the detailed scientific analytical methods of synthesis and optimalization pertaining to these objectives [7]. The use of cooling by liquid nitrogen [77] permits further noise reduction of the field-effect GaAs transistor, since it's dominated by thermal noise [8]. Highest values of effective noise temperature in the 4 GHz band come up to only 30K [9]. This point is also shown in Fig. 2.

The possibility of various applications for gallium-arsenide field-effect transistors was mentioned earlier. To this we should also add the latest experiments with microwave mixers showing above-normal amplification and better linearity than conventional diode mixers. Some of them come equipped with dual gates which permits instantaneous attainment of great amplification of change ($G = 11$ dB), and low noises ($F_2 = 6.5$ dB) in the X-band [10]. Circuit connections of such a mixer are given in Fig. 6. We must add here that these types of mixers are designed at this time using experimental data, since there is a lack of accurate values for parameter S for field-effect transistors excited by a local oscillator.

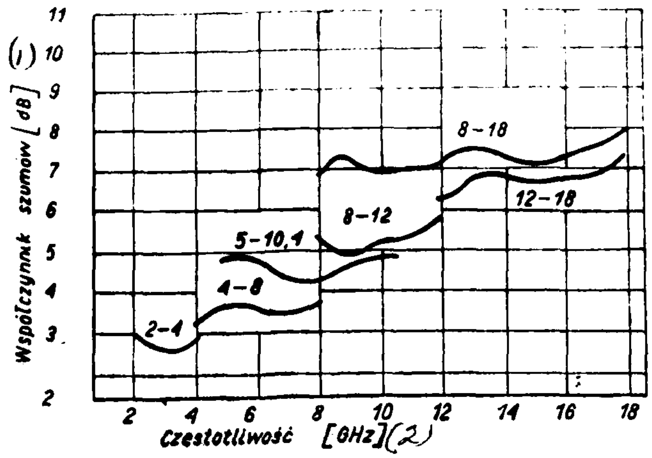


Fig. 5. Noise coefficients in typical gallium-arsenide field transistor amplifiers.

KEY: (1) Noise coefficients; (2) Frequency.

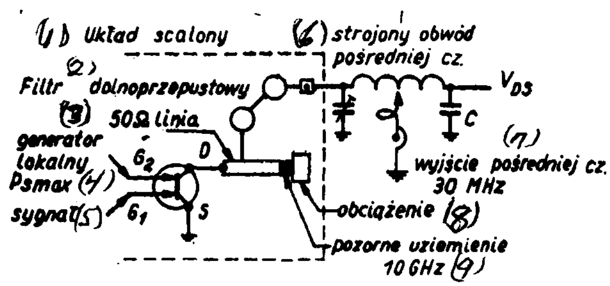


Fig. 6. Dual-gate gallium-arsenide field transistor used as microwave mixer.

KEY: (1) Scaled circuit; (2) Low-pass filter; (3) 50 ohm line; (4) Local oscillator; (5) Signal; (6) Tuned medium-frequency network; (7) Medium-frequency output 30 MHz; (8) Load; (9) Phantom ground 10 GHz.

Polar-arsenic-gallium transistors have lately found application also as microwave limiters taking advantage of suitable current-voltage shape characteristics for signal limiting [11].

These transistors owe their success to their use in low signal and low noise amplification. It has also been said that they adapt themselves very well for use as power amplifiers, having very low distortion. A special transistor design has been developed incorporating several parallel source-gate-drain sets in one unit or holder. The frequency characteristics of various types of these transistors are shown in Fig. 7 [12], where it can be seen that their output power exceeds 1 W at 8 GHz.

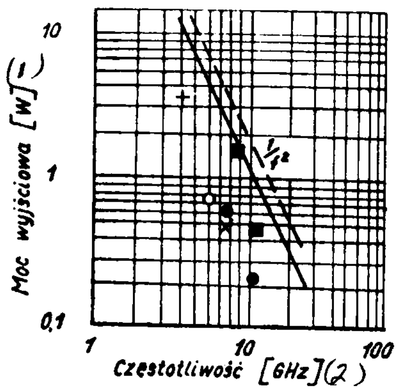


Fig. 7. Growth of output power of gallium-arsenide field transistors.

KEY: (1) Output power; (2) Frequency.

In the catalogs of various companies technical data is supplied for such transistors. We must, however, stress that there is yet a lack of data for high signal parameter S, though high input-output impedance signal values are included.

Counting the advantages and applicability of gallium-arsenide transistors, we cannot forget about their possibility for use as generators. We know already that they put out oscillations even around 100 GHz [13], though their main generating application lies in the area of the centimeter wave band, where we get an increment of a watt with 25% efficiency using experimental data in the design of such generators since there is a lack of data in high signal S parameters. A bad fault of these generators is the noise they produce near the carrier wave, which is dependent on the quality of gallium-arsenide. It is 20 dB greater than for bipolar silicon transistors [14]. Intensive work in generators is going on. It is expected to be able to attain 4 watts of power at 10 GHz shortly, and in the near future at 20 GHz [15]. High generator efficiency of above mentioned transistors will make them highly competetive with travelling wave tubes. The possibility of application of these transistors in wave (Beverage) antennas, even mounted on an aircraft, is seen.

At this point we should end our consideration of gallium-arsenide field transistors, though it must be said that there has appeared a new type of field transistor made of silicon. Silicon is a well known and technologically mastered substance; consequently there should be no surprise at the attempt to make use of it in microwave applications. This new silicon field transistor named SIT (Static Induction Transistor), is made like the junction field-effect transistor (JFET), but with a short vertical channel. Its effect depends on the injection of majority carriers into the region depleted of charge, framed with the area of the gate, and directed by the gate voltage and drain [16]. This is actually a transistor of the decimeter band since it generates 100 W at 200 MHz or delivers 13 W of power amplifier output at 1 GHz.

In this general modernization effort, bipolar transistors are not left behind either, though they are inferior in noise compared to field transistors from the frequency aspect (Fig. 8). However, in the 5-6 GHz band they are extremely competitive economically, since their cost in quantity is at the very least less. This applies not only to the afore-mentioned low noise transistors, but especially to power transistors. These transistors attain a power of several watts at the above-mentioned frequencies thanks to the internal input-output circuit matching in the range of 1-2 GHz. Special construction of these transistors can give up to 40 W of output power (Fig. 9). To these bolongs, for example, the new structure called SET (Stepped Electrode Transistor) leading to lowering of base-collector capacitance and base resistance through an apparent realization of zero gap between the emitter junction and the metal-impregnated base (Fig. 10) [17]. We can also obtain greater power, for example 400 W, from a dozen such tansistors joined in parallel [18]; thus the possibility of obtaining a kilowatt of continuous power in this way in the next few years is foreseen.

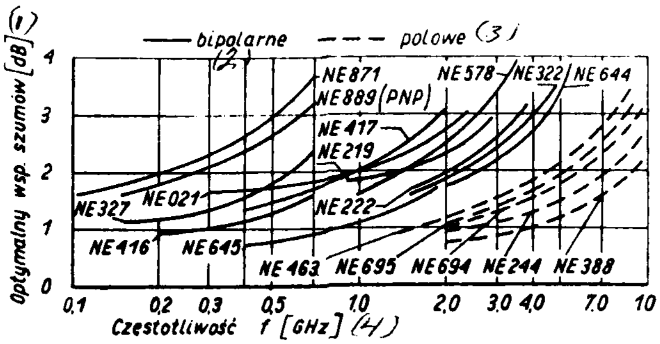


Fig. 8. Noise coefficient of bipolar and field transistors.

KEY: (1) Optimal noise coefficient; (2) Bipolar; (3) Field; (4) Frequency.

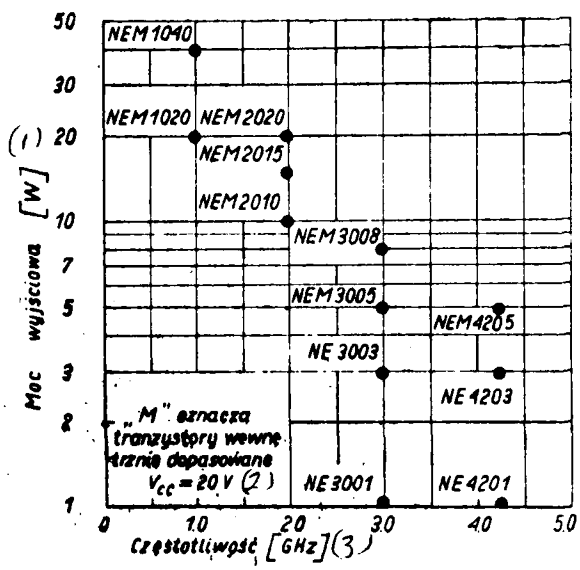


Fig. 9. Output power of bipolar power transistors.

KEY: (1) Output power; (2) "M" indicates transistors matched internally $V_{cc}$ = 20 V; (3) Frequency.

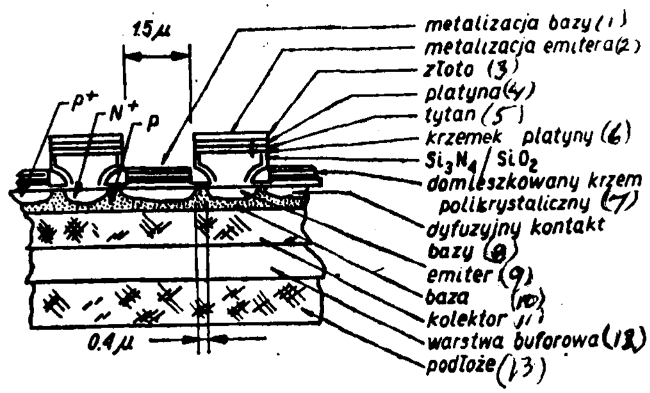


Fig. 10. New construction of bipolar SET (Stepped Electrode Transistor) transistor.

KEY: (1) Metal-impregnated base; (2) Metal-impregnated emitter; (3) Gold; (4) Platinum; (5) Titanium; (6) Silicide of platinum; (7) Doped polycrystalline silicon; (8) Diffused junction base; (9) Emitter; (10) Base; (11) Collector; (12) Buffer zone; (13) Foundation.

Comparison of power obtained from gallium-arsenide polar transistors and from the bipolar silicon-type *relative to frequency* is shown in Fig. 11. From the given data it can be seen how far the so called microwave transistorization has advanced. In conclusion, some additional information.

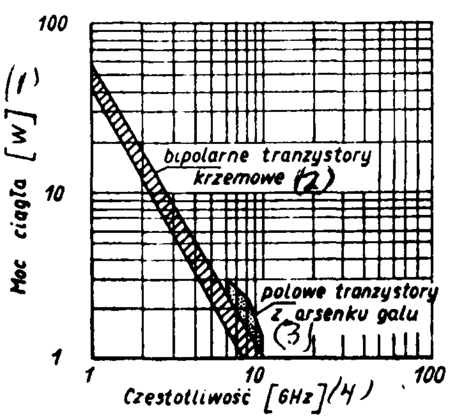


Fig. 11. Power comparison of gallium-arsenide field transistors with silicon bipolar transistors.

KEY: (1) Continuous power; (2) Bipolar silicon transistors; (3) Gallium-arsenide field transistors; (4) Frequency.

Higher power of bipolar transistors can be obtained by including two additional duplicate avalanche and convection zones between the base and collector, thus creating a new variation of the transistor known as CATT (Controlled Avalanche Transit Time Triode) [19]. This has not found wide application thus far.

We will now discuss developments in the area of diode oscillators and amplifiers. Known for a long time and widely used, the avalanche-transit time diode is still an important element in microwave circuits, and the sole one that can supply high power and efficiency above 12 GHz (Fig. 12). Gallium-arsenide diodes in continuous power applications, and silicon diodes in impulse work, show efficiency up to 35% in the X-band. At higher frequencies reaching 100 GHz, an output of over 1 W is obtained by using double drift zones and a diamond base [20].

These diodes can work in a wide frequency spectrum from 3 to 300 GHz. The lower limit mentioned here has been reached by new types of diodes using junction metal semiconductors with the help of implanted ions, giving continuous power levels of over 10 W with about 20% efficiency [21, 22].

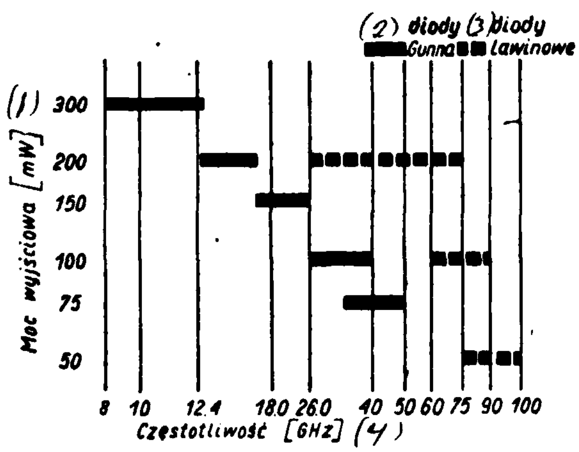


Fig. 12. Power comparison of Gunn diode oscillators and avalanche-transit diode oscillators.

KEY: (1) Ouput power; (2) Gunn diodes; (3) Avalanche diodes; (4) Frequency.

In the technical literature we find several design solutions for avalanche-transit diode power amplifiers up to 10 W made of gallium-arsenide and silicon used in the centimeter wave band [23, 24]. The latest development, however, is a 35 GHz amplifier attaining amplification of 33 dB and width of the one dB band greater than 700 MHz, constructed with gallium diodes (Fig. 13). A 5 W output power is attained via connection of 8 diodes in a resonant circuit with the help of magnetic fields of individual coaxial resonators (Fig. 14) [25].

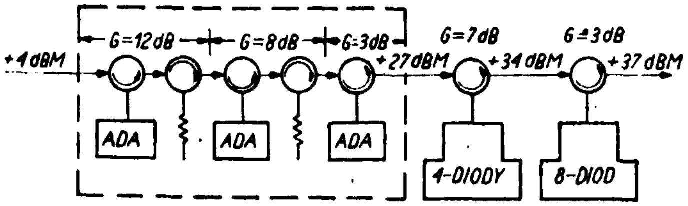


Fig. 13. 5 W continuous power amplifier at 35 GHz with avalanche-transit diodes.

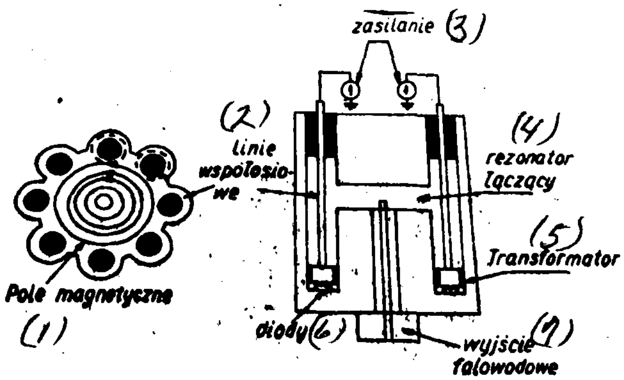


Fig. 14. Resonating coupler consisting of 8 avalanche diode oscillators.

KEY: (1) Magnetic field; (2) Coaxial lines; (3) Supply; (4) Connecting resonator; (5) Transformer; (6) Diodes; (7) Waveguide output.

In impulse applications of avalanche-transit diodes, a special type of diode can be used, the co called TRAPATT, which takes advantage of the oscillations of electron-hole plasma created as a reflection of a travelling wave through the avalanche diode from a wideband network [12]. Impulse power of 10 W is produced with a generator in the X-band, with efficiency greater than 2%, although the main area of its application lies in the lower frequencies up to 400 MHz. To these outstanding achievements we should add the attainment of peak power levels up to 120 W, with 44% efficiency at 2.3 GHz for .5-microsecond impulses at 1% utilization of the available cycle. These diodes, used in the mode discussed above, can be connected in series attaining power above a kilowatt at around 2 GHz. Putting several diodes in series on one diamond cooler permits construction of semiconductor elements with several dozen watts of power [26].

Diodes working in the TRAPATT mode correct the optical release of charged energy, as for example with the help of a semiconductor laser [27]. Main interest lies, however, in TRAPATT amplifiers regarding their application in phased antennas. At a frequency of ca. 3 GHz, 100 W of peak power are attained with 30% efficiency and amplification of 6 dB. A three-decibel band width transcends a little over 15% [28].

BARRIT diodes, in which the load is placed across the p-n junction also belong to the transit diodes. These diodes are less noisy than avalanche, and can be used effectively as local oscillators [20, 29]. However their smaller generating output power limits their use. They are manufactured by some companies, but not to any great extent. Instead, these diodes are used differently; specifically to create oscillations in a volume of semiconductors which are usually gallium-arsenide, but lately have been more often of phosphide-indium. These find wide application, and are known as GUNN diodes, though the name is connected mostly with their basic applications. From Fig. 12 it is seen that Gunn diodes do not reach very high in the frequency range compared to avalanche-transit diodes, but they are less noisy than the latter, more or less by an order of magnitude. Highest generating values for gallium-arsenide diodes are up to 70 mW at 60 GHz, but only with 2% efficiency [30].

The Gunn effect was discovered in a different semiconductor material, namely phosphide-indium, though for a long time in the above-mentioned application gallium-arsenide was king, since it was better known. Lately it has been shown that phosphide-indium can give better efficiency with lower noise, especially in the millimeter wave band [31]. Continuous output with high efficiency is limited, however, to a dozen or so milliwatts, though in impulse work a power level of 5-10 W is achieved at this frequency with 15% efficiency [12]. Generating effects of phosphide-indium can be observed even at 80 GHz [31]. Today, intensive work is being carried out with this material and diodes are made from it, and we can expect that these types of diodes will be generally included in the manufacturer's catalogs.

Gunn diodes find wide application in power amplifiers for example, (diodes from gallium-arsenide give 100 mW at 1 dB compression is equal to 28 dB amplification at 14 GHz [30]). On the other hand phosphide-indium diodes are used in higher frequency applications (for example: 26-40 GHz) with 11 to 14 dB of noise. Equivalent gallium-arsenide diodes have noise up to 23 dB [31, 32]. The above-mentioned amplifiers still compete effectively with field transistor amplifiers. Comparison of power gains of various types of diode generators for continuous and impulse power is shown in Fig. 15. The greatest power gains are expected to be gotten from Gunn diodes working in the LSA (Limited Space Accumulation) mode, though these gains are as yet unrealized and are backed up only with a few experimental results achieved in laboratories.

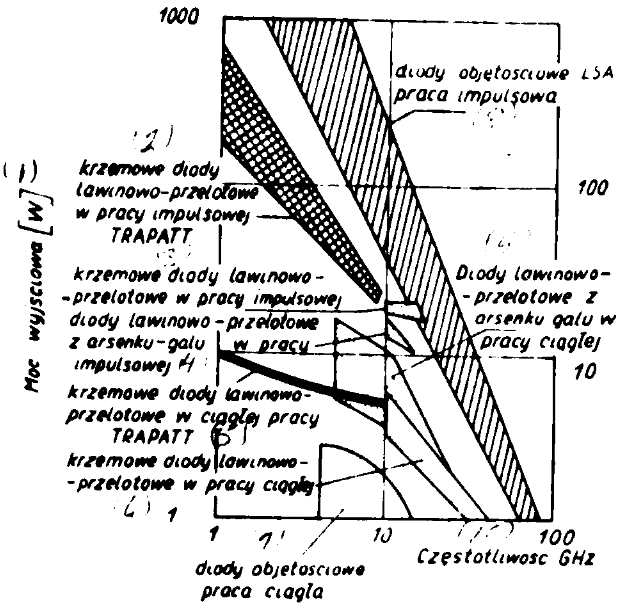


Fig. 15 Comparisons of power gains of various types of diode oscillators.

KEY: (1) Power output; (2) Silicon avalanche-transit diodes working as TRAPATT impulse diodes; (3) Silicon avalanche-transit diodes working as impulse diodes; (4) Gallium-arsenide avalanche-transit diodes working as impulse diodes; (5) Silicon avalanche-transit diodes in continuous power application working as TRAPATT; (6) Silicon avalanche-transit diodes in continuous power application; (7) Continuous power output of volumetric diodes; (8) Volumetric diodes in impulse LSA application; (9) Gallium-arsenide avalanche-transit diodes in continuous power application; (10) Frequency.

Advances in microwave semiconductor devices are tied in with the design of new types of holders. Habitually, microwave device manufacturers fit available holders and those made for other uses even though the great variety of these semiconductors necessitates using special type of holders, especially when there is a need to include with them ancillary assemblies [33]. The use of new insulation materials in holder construction such as oxide of beryllium or quartz should improve significantly the properties of microwave devices.

Passive microwave devices are presently not being intensely developed, and progress in this area will depend on the development of semitconductor devices, although here also there are possibilities in taking advantage of the echo of spin waves in ytterium garnets in the design of delayed microwave lines. Circulators, ferrous insulators have become widely used in microwave systems, not to speak of the adaptation of ytterium garnets as spherical resonator filters [14].

There is a resurgence in use of elements concentrated in the X-band about which we talked in former conferences, equally in generators and filters (Fig. 16) [34, 35]. Progress is also noted in microlines, specifically in the millimeter wave band [18].

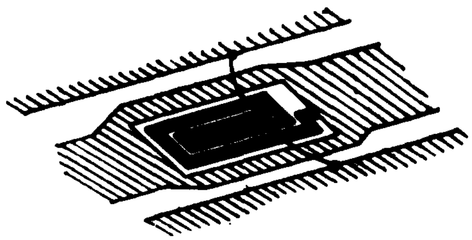

Fig. 16. Induction element in conjunction with microline.

A greater portion of microwave devices noted earlier are manufactured by a hybrid process which is especially well adapted to small assembly-line production [36]. The reason for its application is a decrease of production wasts and supervision and inspection time, resulting in lesser cost. Great need for this method of production will be in the area of satellite television receivers. Work is going on mainly in the direction of field transistor integration in microwave amplifiers, mixers, and medium-frequency amplifiers [18, 38].

Further development of monolithic microwave technology depends on the speed up of work in logic circuits [39], especially since gallium-arsenide replaced silicon as their basic material. In the beginning, the Gunn effect was used to achieve a fast change of transistor state obtaining a delay of 60 ps; later, the excellent characteristics of gallium-arsenide field transistors began to be taken advantage of from direct current to 4 GHz with prospects of application above 5 GHz [39, 40]. Low power consumption of logic elements of this type, permits the design of complicated circuits whose work is only limited by power lost as heat. Monolithic integration is one practical solution for subnanosecond logic circuits.

In ending the review of technical and scientific developments regarding solid state microwave electronics, we should direct our attention to the development of technology in the submillimeter wave band or light waves. Though these problems are beyond the mainstream of this conference, it is important to know that their development is tied with utilization of the methods of microwave technology.

In the same way, the technology of mechanical waves in solid state elements (microwave acoustics) utilized in microwave applications is tied with these proceedings [42, 43].

In ending this article we need to remember that in the five years 1976-1980, a 40% growth of semiconductors is expected on the world markets [44], as well as a 50% increase of passive subassemblies and cables together with contacts. Our national economy will naturally demand greater growth dynamics.

BIBLIOGRAPHY


1. *Flyagin V. A., Gaponov A. V., Petelin M. I., Yulpatov V. K.:* The Gyrotron. IEEE Trans. on Microwave Theory and Techniques, 1977 czerwiec, str. 514.
2. *Godlove T. F., Granatstein V. L.:* Relativistic electron beam interaction for generation of high power at microwave frequencies. 1977 IEEE Microwave Theory and Techniques Symposium Digest, str. 60, D1.3.
3. SWB: Relativistic source development speeds up. Microwaves, 1977 lipiec, str. 14.
4. *Vernon F. L., Millea M. F., Bottjer M. F., Silver A. H., Peterson R. J., McColl M.:* The super-Schottky diode. IEEE Trans. on Microwave Theory and Techniques, 1977 kwiecień, str. 286.
5. Cryogenics cuts noise in 300 GHz receivers. Electronic, 1977 marzec 31, nr 7, str. 35.
6. Special issue on microwave field effect tranistors. IEEE Trans. on Microwave Theory and Techniques, 1976 czerwiec.
7. *Besser L., Swenson S.:* Take the hassle out of FET amp design. Microwave Systems News, 1977 wrzesień, str. 97.
8. *Pierro J.* Cryogenically cooled GaAs FET amplifier with a noise temperature under 70 K at 5.0 GHz. IEEE Trans. on Microwave Theory and Techniques, 1976 grudzień, str. 972.
9. *Miller R. E., Phillips T. G., Inglesias D. E., Knerr R. H.:* Noise performance of microwave GaAs F.E.T. amplifiers at low temperatures. Electronics Letters, 1977 styczeń 6, nr 1, str. 10.
10. *Cripps S. C., Nielsen O., Parker P., Turner J. A.:* An experimental evaluation of X-band mixers using dual-gate GaAs MES FETS, 7th European Microwave Conference and Microwaves 77 Digest, Kopenhaga, 1977 wrzesień, str. 101, B81.4.
11. *Fukunda S., Kitamur M., Ara Y., Haga I.:* A new microwave amplitude limiter using GaAs field effect transistor. 1977 IEEE Microwave Theory and Techniques Symposium Digest, C3.5.

12. *Gibbons G.*: Recent advances in solid state microwave devices. 7th European Microwave Conference and Microwaves 77 Digest, Kopenhaga, wrzesień 1977, str. 71.

12a. *Tserng H. Q., Sokolov V., Macksey H. M., Wisseman W. R.*: Microwave power GaAs FET amplifiers. IEEE Trans. on Microwave Theory and Techniques, 1976 grudzień, str. 936.

13. FET oscillates at 100 GHz. Microwave Systems News, wrzesień 1977, str. 26.

14. *Fawcette J.*: FETs show versatility. Microwave Systems News, sierpień 1977, str. 11.

15. *Bearse S. V.*: GaAs FETs star in a new role. Microwaves, luty 1977, str. 3[illegible].

16. *Kajiwara K., Yukimoto Y., Shirahata K.*: High power microwave static induction transistor. 1977 IEEE Microwave Theory and Techniques Symposium Digest, A4.6.

17. Bipolars treaten Satcom TWTs. Microwave Systems News, kwiecień 1977, str. 95.

18. *Torrero E. A.*: High frequency components play catch-up. IEEE Spectrum, listopad 1976, str. 31.

19. *Bearse S. V.*: The CATT treads softly into bipolar territory. Microwaves, październik 1975, str. 14.

20. *Bearse S. V.*: Impatts and Trapatts star in new circuits. Microwaves, czerwiec 1976, str. 9.

21. *Cohen E. D.*: Trapatts and Impatts — State of the art and applications. Microwave Journal, luty 1977, str. 22.

22. *Nakagami T., Tokoyo N., Kato M.*: Millimeter-wave signal power amplifiers using IMPATT diodes. IEEE, Millimeter Waveguide System Conference Publication No 146, listopad 1976, str. 221.

23. *Tatsuguchi I., Gewartowski J. W.*: A 10 W, 6 GHz, GaAs IMPATT amplifier for microwave radio systems. Bell System Technical Journal, luty 1976, str. 167.

24. *Braddock P. W., Modges R. D., Genner R.*: Silicon IMPATT cascaded amplifier 6 W (C.W.) at 9,6 GHz. Electronics Letters, grudzień 1974, nr 25/26, str. 538.

25. *Bayuk F. J., Raub J. E.*: Ka-band solid state power combining amplifier. 7th European Microwave Conference and Microwaves 77 Digest, Kopenhaga, wrzesień 1977, str. 482.

26. Six Trapatts yield 35 W at 7.8 GHz. Electronics, czerwiec 1976, nr 12, str. 30.

27. *Altman L., Mattera L.*: Several solid-state technologies show surprising new paces. Electronics, grudzień 1976, 26, str. 90.

28. *Fong T. T., McCandless J. B., Nakaji E. M., Ying R. S.*: Fixed tuned high power F-band TRAPATT amplifier. 1977 IEEE International Solid State Circuits Conference Digest, str. 124, THAM:11.2.

29. *Sobol H., Sterzer F.*: Microwave power cources. IEEE Spectrum, kwiecień 1972, str. 20.

30. *Boss J. C.*: New device developments for communication systems. Eurocon 77 Digest, str. 962, 2.13.1.

31. *de Loen J. C.*: In P Gunn-effect devices beginn to surface in the US. Microwaves, luty 1977, str. 13.

32. *Hamilton R. J. Jr., Long S.*: Gunn amps fill the K-band gap. Microwave Systems News, sierpień 1977, str. 40.

33. *Mundt M., Fosco P.*: Packaging deserves more attention. Microwave Systems News, czerwiec 1977, str. 73.

34. *Howes M.*: Breadth of microwave engineering emphasized at Copenhagen. Microwave Systems News, sierpień 1977, str. 11.

35. *Davis R.*: Improved power FETs and IMPATTs spark interest at Solid state conference. Microwave Systeme News, kwiecień 1977, str. 13.

36. *Pengelly R.*: Integrated microwave transistor ampifiers. Electronics and Power, lipiec 1976, str. 440.

37. *Ertel A.*: Monolithic IC techniques produce first all-silicon X-band switch. Electronics, styczeń 1967, nr 2, str. 76.

38. *Magershack J.*: Impact of active microwave solid state devices on modern communication systems. Eurocon 77 Digest, str. 690, 2.13.2.

39. *Van Tuyl R., Liechti Ch.*: Gallium arsenide circuits spawns. IEEE Spectrum, marzec 1977, str. 47.

40. *Hashizume N., Kataoka S., Komamiya Y., Tomizawa K., Morisue M.*: GaAs 4 bit gate of integrated Gunn elements and MES FETs. Institute of Physics Conference Series, No 33b, Gallium Arsenide and related compounds, 1977, Chapter 5, str. 245.

41. *Filensky W., Klein M., Beneking H.*: The GaAs MES FET as pulse regenerator, amplifier and laser modulator in G bit/s range. IEEE Journal of Solid State Circuits, czerwiec 1977, nr 3, str. 276.

42. *Davis R. T.*: Miniature SAW filters developed. Microwaves, luty 1978, str. 10.

43. *Collins J.*: SAW scoreboard. Microwave Systems News, czerwiec 1977, str. 87.

44. World microwave forecast. Microwave Systems News, styczeń 1977 str. 36.

DISTRIBUTION LIST

DISTRIBUTION DIRECT TO RECIPIENT

| ORGANIZATION | MICROFICHE | ORGANIZATION | MICROFICHE |
|---|---|---|---|
| A205 DMATC | 1 | E053 AF/INAKA | 1 |
| A210 DMAAC | 2 | E017 AF/RDXTR-W | 1 |
| B344 DIA/RDS-3C | 9 | E403 AFSC/INA | 1 |
| C043 USAMIIA | 1 | E404 AEDC | 1 |
| C509 BALLISTIC RES LABS | 1 | E408 AFWL | 1 |
| C510 AIR MOBILITY R&D LAB/FIO | 1 | E410 ADTC | 1 |
| C513 PICATINNY ARSENAL | 1 | FTD | |
| C535 AVIATION SYS COMD | 1 | CCN | 1 |
| C591 FSTC | 5 | ASD/FTD/NIIS | 3 |
| C619 MIA REDSTONE | 1 | NIA/PHS | 1 |
| D008 NISC | 1 | NIIS | 2 |
| H300 USAICE (USAREUR) | 1 | | |
| P005 DOE | 1 | | |
| P050 CIA/CRB/ADD/SD | 2 | | |
| NAVORDSTA (50L) | 1 | | |
| NASA/NST-44 | 1 | | |
| AFIT/LD | 1 | | |
| LLL/Code L-389 | 1 | | |
| NSA/1213/TDL | 2 | | |