NETWORK INTEGRATION APPROACHES FOR MULTIPLE-DIODE HIGH POWER MICROWAVE GENERATION

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I. INTRODUCTION

Rapid strides are now being made in solid-state microwave power generation. With the recent introduction of negative-resistance avalanche junction diodes and gallium arsenide bulk-effect devices, a new impetus was given to research.

This paper is an attempt to assess the present status of these devices and to look into the future. Solid-state devices are already displacing vacuum tubes for low power system functions, including transmitters for line-of-sight communication links. What are the possibilities that they can also replace high power microwave tubes? Here, we attempt to assess the probability of success and to foresee some of the directions which such research may take. We point out certain special problems to be solved and present new circuit concepts which appear promising at this time.

Prophecy is a perilous occupation. It is expected and hoped that this paper will be outdated in the near future. If the present rate of advance continues, new inventions and new approaches are likely to change our outlook in ways we have not foreseen.

II. PRESENT STATUS OF DEVICE RESEARCH

Intensive research is being conducted at many laboratories on several different types of solid-state microwave devices. The most significant of these are (1) Microwave transistors, (2) Varactor multipliers to be driven by UHF transistors, (3) Avalanche transit-time diodes, (4) "anomalous mode" avalanche diodes, and (5) Gallium arsenide diodes using negative differential mobility. Progress during the past 3 years has been dramatic and new power output and efficiency records are frequently reported.

The "state-of-the-art" is commonly presented as a scatter diagram of power vs. frequency, with lines following a low $P \sim f^{-2}$ representing present "record" capabilities. Fig. 1 shows a recent version (Feb. 1968) with data as collected by M. R. Barber of BTL. It is, no doubt, obsolete today.

These data are research laboratory results and in most cases the devices are not available for system applications. In some cases, these record achievements are obtained by operating in short pulse conditions at power densities approaching the burn-out level.

Circuit developments for optimum use of the new devices are not far advanced at this time, except in the case of transistors in the lower frequency microwave bands where hybrid integrated circuitry has proven successful. Experiments with avalanche and bulk-effect gallium arsenide devices have been largely confined to oscillations. High power sources for sophisticated system application will require amplifier circuitry.

III. GENERAL DEVICE PROBLEMS FOR HIGH POWER GENERATION

We are concerned with the future possibility of replacing, advantageously, such devices as magnetrons, traveling-wave tubes, klystrons, or cross-field amplifiers as basic sources for Radar systems or high power communications links. For such applications, average power in the 1-10 kilowatt range is commonly needed. None of the existing devices for frequencies above ~ 1.5 GHz has shown a capability of greater average power than 1-5 watts, although peak short-pulse power has, on occasion, been reported in the kilowatt range.

The possibility of great increases in the average power from single lumped-element devices of the presently established types appears to be remote. Such devices must come in small bits because of limitations due to impedance levels, internal element resistivity, allowable voltage limits, and difficulties in cooling. However, other device concepts are known which may prove to be successful in lifting these limitations. These involve the distribution of thin layers of active semiconductor material over substantial areas of dielectric heat-conductive material. Preliminary experiments in at least three laboratories have shown that thin-sheet gallium arsenide devices are feasible.

To obtain high average powers from the proven device types will require the cooperative use of hundreds or thousands of elementary devices. The major concern of this paper is to describe and analyze certain integrated circuit network approaches for multiple-element sources.

Numerous fundamental and difficult problems must be solved in developing such complex devices. These include:

(1) Heat dissipation (Power density is high in all existing devices, requiring the distribution of active material over a substantial area of heat sink.)

(2) Multimoding and Spurious Output (Intercoupling of many discrete or widely distributed active elements presents special network problems in avoiding spurious modes of oscillation.)

(3) Complexity and Cost (Techniques are needed for driving distributed arrays of active elements in synchronism and for combining their outputs which are simple and low in cost.)

(4) Efficiency (Improvements in elementary devices are needed. These must come through fundamental device research.)

Certain geometrical concepts for high power device design are pictured in Fig. 2. In a, we show a square wafer attached to a heat sink; in b, we show an elongated narrow version. Transistors, avalanche diodes, and bulk-effect diodes have been built in these shapes although we show a diode device here for simplicity. The square device is severely limited in size by temperature rise, series electrical resistance, and rf impedance. The elongated geometry offers improvements by effectively providing a wider distribution of active material. Other techniques exist which are functionally equivalent. Fig. 2c shows an unproven functional concept for continuous distribution of a very thin layer of active material over substantial areas of heat sink. This offers a future possibility of increasing the average power output of a single device by as much as one or two orders of magnitude.

IV. NETWORKS FOR MULTIPLE DEVICES

Two basically different approaches are recognized for combining large numbers of active devices, (1) the federal approach using many complete single-device oscillators or amplifiers, interconnected by transmission line corporate-feed networks using power combiners; and (2) unified networks in which the many elementary devices are imbedded in a large network which is not separable into many complete useful amplifiers or oscillators.

The well-known federal approach is illustrated in Fig. 3. Here we show how 21 identical amplifier circuits can be combined to provide 16 times the output of a single amplifier. Unified approaches are less well understood. These can include such techniques as coupling a large number of diodes lightly to a single-mode cavity resonator, or to a single traveling-wave mode of a waveguide or transmission line. Fig. 4 shows these ideas in a simplified schematic form. Special network techniques to be described are necessary to avoid spurious multi-mode oscillations in such networks. One promising technique involves frequency-separation of modes, such that the desired mode of operation is far removed from all undesired modes of resonance.

A modified technique will be described for a distributed amplifier in which the diodes are coupled directionally to the transmission line. By adding stabilizing resistors which are not directly coupled to the desired mode, certain classes of self-oscillation can be avoided in a distributed amplifier.

V. CONCLUSION

The present status of solid-state device research indicates that high power is achievable by combining large numbers of elementary devices in "federal" or "unified" networks. The latter offer advantages in network complexity and cost, particularly at higher frequencies. With continued progress in device and network research, it is believed that desirable and useful high power amplifiers can be developed for system use in any of the popular microwave bands.

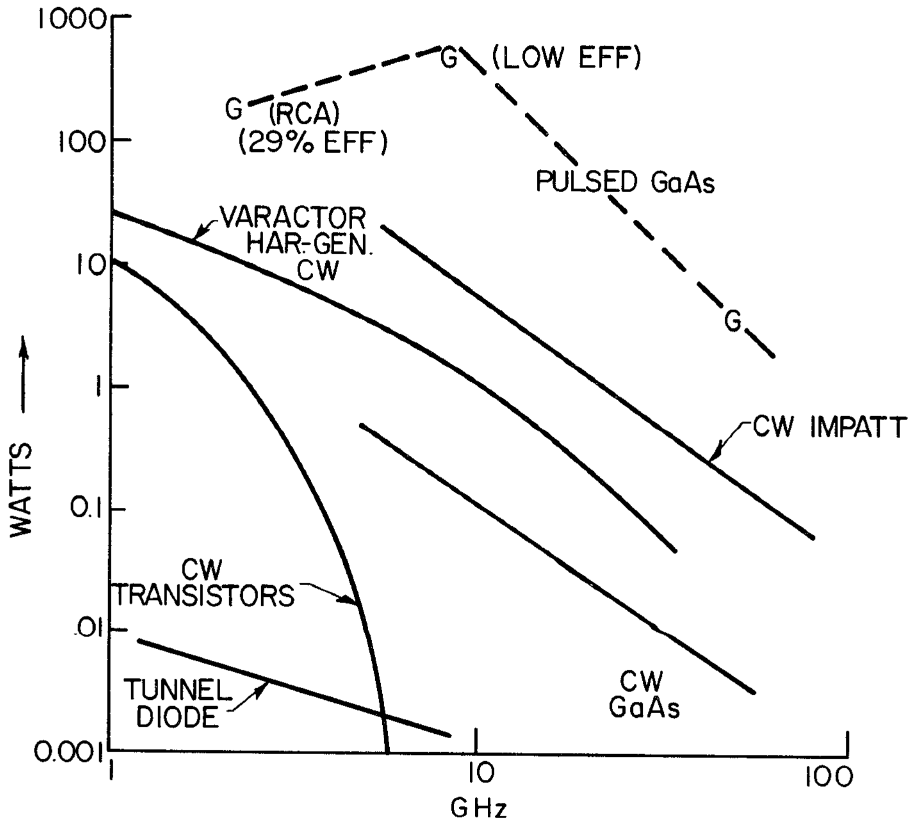


Fig. 1 Chart illustrating approximately the present state-of-the-art in solid-state power generators of various types. (Courtesy of Mr. M. R. Barber, BTL, Feb, 1968). These are research laboratory achievements. Devices of such characteristics may not be commercially available.

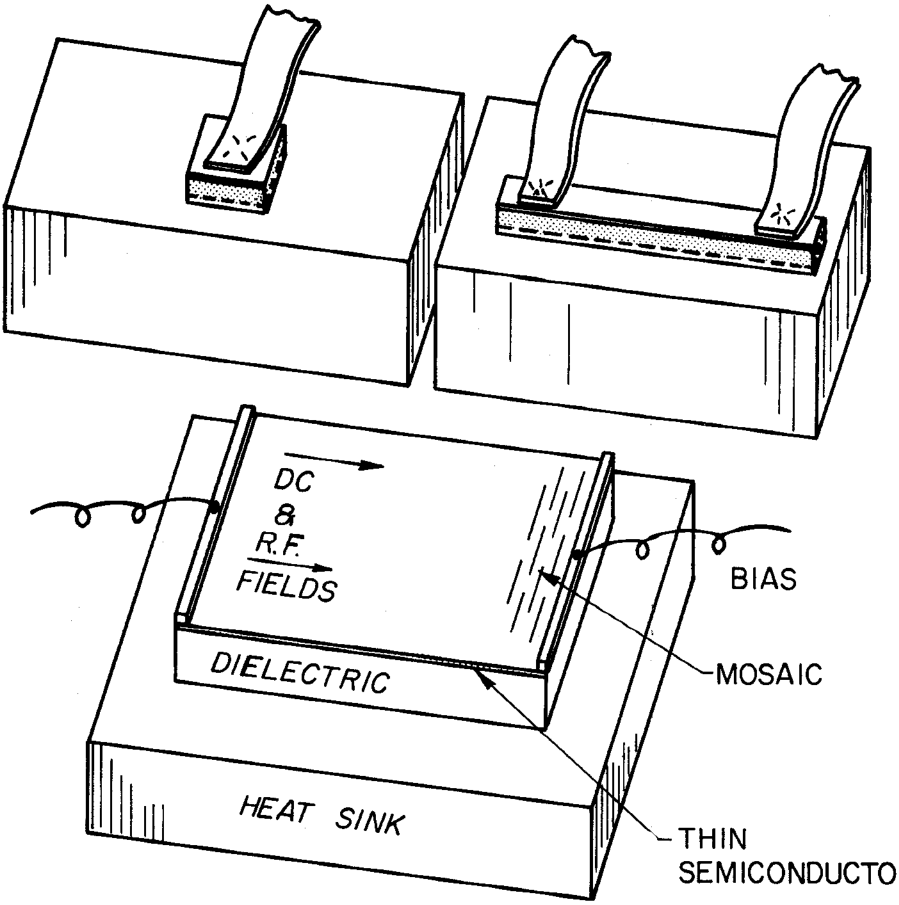


Fig. 2 Alternative geometrical configurations for present and future devices. Upper sketches show diodes of avalanche and gallium arsenide types. Lower figure is a research concept for increased power through continuous distribution of a thin active semiconductor over a large area of dielectric heat sink. Various mosaic patterns on the surface may allow coupling of semiconductor space-charge waves to external circuits.

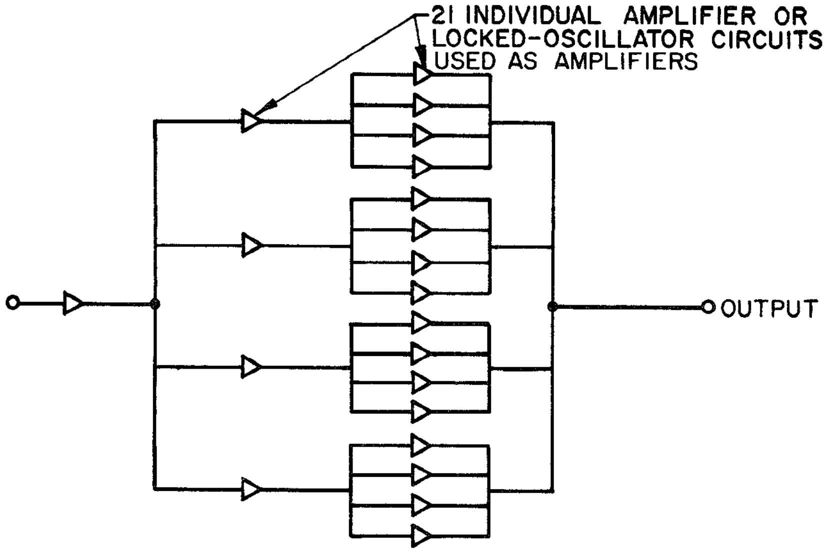
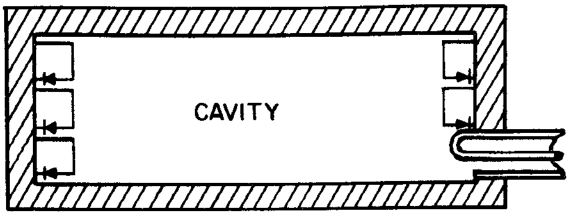
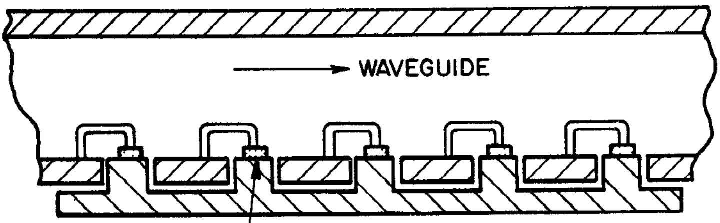


Fig. 3 "Federal" approach to high power generation, using many low power circuits, intercoupled by transmission line combining networks.



(a)



(b)

Fig. 4 The "Unified" network approach to Oscillators and Amplifiers. Many diodes can be lightly coupled to high power waves in a cavity resonator or a transmission line.