RECENT PROGRESS OF MICROWAVE INTEGRATED CIRCUITS IN JAPAN

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ABSTRACT

This paper reviews the recent progress of microwave integrated circuits in Japan. Trends and some topics of research and development on microwave integrated circuits, and their impacts on microwave systems are presented.

Introduction

Because of such significant advantages as small dimensions, high reliablity, mass-producibility and low cost, intensive research and development of microwave integrated circuits (MICs) have been made in Japan as in other countries. Moreover, since about 1972, the MICs have been applied practically to the front-end circuits of communication equipment and radar. By this time, the annual sales amount for MICs has attained about ten thousand million yen (about fifty million dollars) in Japan.

At present, the applications of the MICs with bipolar transistors and diodes mounted on alumina or teflon-fiberglass substrates, are steadily growing in many microwave systems, while R&D efforts on MICs using GaAs MESFETs are making rapid progress. They are going to be applied to commercial systems as low noise and high power amplifiers.

In this paper, first, recent R&D trends and some current topics concerning Japanese MICs are described. Next, the present condition of their industry, and their impacts on microwave systems are discussed. Lastly, a forecast on future MICs in Japan is presented.

Recent R&D Trends

In order to estimate the recent MIC R&D trends in Japan, the number of presentations in Technical Group on Microwaves is classified according to their themes in Table 1. This Technical Group belongs to The Institute of Electronics and Communication Engineers of Japan, and holds a meeting once a month. About forty persons attend every meeting. Table 1 shows that studies on GaAs FET increased rapidly in 1977, and studies on such devices as Gunn, IMPATT and Schottky-barrier diodes, are decreasing gradually. The presentations concerned with MICs are about a quarter of all presentations, except for optical fibers and devices.

The MIC R&D situation will be described in some detail, according to the main items of Table 1.

In the field of MICs with solid-state devices, R&D emphasis has been placed on GaAs MESFETs. Some of the results will be reviewed in the next section. In this Japanese session, a 400-Mbits/s 4-PSK phase regenerator using GaAs FET, and a 4 to 8 GHz miniaturized GaAs amplifier are presented.

As the MICs with bipolar transistors, a 4-GHz 12-W internally matched power amplifier has been reported.[1] Moreover, a UHF high-power transistor amplifier using high-dielectric (ε=39) substrate (presented in this session), and a UHF transistor VCO using high-dielectric substrate for land mobile telephone,[2] have been developed.

As examples of PIN diode MIC, limiters for S- and X-band radars are presented in this session, and a 5-GHz 4-bits phase shifter has been reported.[3] Moreover, an active filter with a PIN diode and a dielectric resonator are proposed in this session.

Various kinds of strip-line analysis have been reported.[4] One of them, the induction of an approximate dispersion formula for microstrip lines is reported in this session. Many studies of planar circuits, such as computer-aided MIC filter synthesis using planar circuits, have been reported.[5,6] The analyses and experiments of many kinds of passive MIC, such as interdigitated coupler,[7] have also been reported.

Various kinds of equipment composed of MICs have been developed. Some examples of them are a microwave automatic vehicle identification system,[8] phase-locked oscillator modules for active phased array radars,[9] front-end modules for Doppler radars[10] and receivers for satellite broadcasting.[11,12]

Table 1. The number of presentations in the Technical Group on Microwave, IECE of Japan

Items of Themes			No. of presentations **			
			1976	1977	1978	Total
Microwave Solid-State Circuits	Oscillator or Amplifier	IMPATT, GUNN	11 (2)	15 (1)	7 (2)	33 (5)
		FET	1 (1)	15 (5)	17 (7)	33 (13)
		Bipolar Tr.	3 (2)	1 (1)	4 (3)	8 (6)
		TWT	2	1	0	3
		General problems *	4	8	1	13
	Other solid-state circuits		14 (5)	13 (4)	5 (2)	32 (11)
Passive Microwave Circuits	Transmission lines		11 (8)	13 (3)	11 (4)	35 (15)
	Nonreciprocal circuits		14 (8)	10 (2)	8 (4)	32 (14)
	Microwave acoustics		10	6	5	21
	Other passive circuits		23 (6)	26 (5)	22 (6)	71 (17)
Systems, Measurement equipment			3 (1)	7 (1)	6	16 (2)
E M C			5	4	8	17
Microwave power applications			6	8	9	23
Optical fibers & devices			26	21	33	80
Total			133 (33)	148 (22)	136 (28)	417 (83)

* Synchronization problems of oscillators, Intermodulation of amplifiers, etc.

** The No. of presentations concerning MICs are in parenthesis.

Current MIC Topics

A high speed digital modulator, GaAs FET power amplifiers and MICs for applications above 20 GHz, are briefly reviewed as current MIC topics in Japan.

High Speed Digital Modulator

A 2-Gbits/s double-balanced modulator for high speed digital communication systems, has been developed.[13] This modulator is constructed with a MIC magic-tee and a diode circuit with four Schottky-barrier beam-lead diodes. With a novel combination of coplanar waveguides, slotlines and microstrip lines, a simple double-balanced circuit with octave bandwidth (4 to 8 GHz) has been obtained. Modulator insertion loss was 3.2 dB, and isolation between any two ports was more than 25 dB. 2-phase PSK operation was confirmed experimentally for 2-Gbits/s pseudorandom data stream.

GaAs MESFET Amplifier

15-W internally matched GaAs FET amplifiers have been developed. By integrating four FET and matching circuits on a high-dielectric (ε=39) substrate, 6.5 dB gain and 15 W saturated power were obtained within the 5.6 to 6.4 GHz band. Datails will be reported in other session.[14]

A GaAs FET power amplifier for satellite-borne transponders has also been developed.[15] This amplifier is composed of 3-stage single-ended and 3-stage balanced amplifiers, and 4W output power and 42 dB gain were obtained.

MICs for Applications above 20 GHz

A 20-GHz band double-balanced mixer has been develpoed.[16] It is composed as circuit similar to the high speed digital modulator. With this broadband construction, less than 5 dB conversion loss, and 1-dB bandwidth of 1.5 GHz were obtained. Isolations between any two ports were more than 20 dB within 18 to 21 GHz.

Millimeter-wave ICs, such as 3-dB branch-line coupler, 10-dB directional coupler and ring resonator, have been constructed on 0.2 mm thick alumina substrates, and successfully experimented on in the 50-GHz band.[17] Other Japanese equipment using millimeter-wave ICs reported recently were 50 to 80 GHz band image line branching filters,[18] 300- and 450-GHz band frequency multipliers[19] and 50-GHz band mixers with alumina substrates.[20]

State-of-the-art MICs for Commercial Use

Industrial MIC Features

Important industrial MIC features are planar form and miniaturization due to wavelength reduction. The planar nature enables various photolithographic methods and printing techniques, which give advantages of accurate pattern production, reproducibility and mass-producibility. Furthermore, improved reliability is obtained by decreasing the interconnections by the integration of multi-circuit functions. Wideband performance is achieved by improving power transistor matching to the MIC circuits having low impedance characteristics or internally matching technique.

An easy configuration is provided by the open planar structure for the incorporation of various devices and bias supplies. This feature closely matches GaAs FETs, which have been developed recently. The inherent ability of the GaAs FETs could be exhibited only with MIC technology. Adjustment of the circuit to minimize FET tolerance effects can be easily accomplished in operational state. The following section shows the impacts of these MIC features on industrial products. Table 2 summarize state-of-the-art MIC applications to commercial uses in Japan.

MIC Impacts on Various Radio Equipments

Communication Equipments Communication equipments used in systems, such as terrestrial fixed and mobile systems and satellite systems, require high quality, high reliability, compactness and low weight.

The 20-GHz radio-relay system (20L-P1), which conveys 400 Mbits/s on a radio channel, and the millimeter waveguide system, which conveys 800 Mbits/s, are currently being developed in Japan.[21,22,23] All the 1.7-GHz IF circuits and some baseband circuits for these repeaters consist of alumina substrate MICs, which fully satisfy the above-mentioned system requirements. They are so compact that the volume of the repeater becomes less than one tenth of the conventional microwave repeater. The small 20L-P1 repeater housing (2.3 meter ϕ, 3 meter height) mounted on the top of a steel pole can accommodate eighteen repeaters. Consquently, such an economical system has been realized as a conventional microwave system in spite of the about ten times increase in number of relay stations. Several hundred 20L-P1 repeaters are going to be manufactured a year. They are expected to make good use of the mass-producibility and reproducibility of MICs.

In other radio communication equipment, MICs have already been applied to mixers, local oscillators, multipliers etc. GaAs FET low noise amplifiers[24] and power amplifiers[25,26] using MIC techniques are now being provided rapidly. The replacements of a parametric amplifier with a low noise FET amplifier removes complex composition and unstable operation and gives high reliability and low cost. The replacement of a TWT with a power FET amplifier gets rid of high voltage requirement and ensures longer life time.

Broadcasting Equipments The application of MIC and transistor amplifier techniques to repeaters in the UHF band TV translator station, which covers a poor reception area, mainly in the shadow of mountains, enables small size, low weight, high reliability and wideband performance of about 100 MHz, which makes the same repeater able to cover various channels without any optimization, with consequent good producibility and maintainability.

As Field Pick Up (FPU) equipments[27] at about 7 GHz and 13 GHz connecting the TV camera with FPU base station require mobility, it has been very effective to realize compactness, low weight (1/4 the conventional value), small power consumption (1/4)

Table 2 MIC applications to commercial uses in Japan

Applications	MIC sub-assemblies	frequency	MIC to equipment ratio (cost) %	No. of product per year
Communications				
20L-P1 repeater	IF cct BB cct	1.7 GHz, 200 MHz	40	several 100's
microwave repeater	LNA LO PA MIX	2 GHz ~ X band	10	10000
mobile	PA MIX LO	140 ~ 800 MHz	several	several 1000's
satellite	LNA MIX LO PA IF cct	4 GHz ~ X band	10	several
Broadcasting				
TV translator station	PA LNA MIX	UHF	70	several 100's
field pick up	MOD PA LO MIX	7, 13 GHz	50	100
X band TV receiver	MIX LO IF cct	12 GHz	60	100 (experimental)
Radar sensor	LO MIX	10 GHz	20	100

cct : circuit, BB : baseband, LNA : low noise amplifier, LO : local oscillator, PA : power amplifier
MIX : mixer, MOD : modulator

provided by utilizing MICs in all RF band circuits, except the antenna. Now, various wireless TV camera applications have become available.

For TV broadcasting satellite receivers and SHF TV broadcasting receivers, low cost, small size, reliable and maintenance-free units are required in order to meet the needs of consumer market. For this purpose, designs and experiments using planar circuit and MIC techniques are intensively promoted.[12,28] Since it is in the experimental stage at present, only several hundred receivers have been manufactured. Low cost ones, however, can be expected when produced in large volume.

Radar Sensor Applications Due to the progress in solid-state oscillators, simple radar sensors, such as those used in Automated Marshalling Yards for railway use and speed meters to check vehicle speed, established a new field of radars. The replacement of all RF circuits, except the antenna, with MIC modules in the radar sensor,[29] Provides not only compactness but easy handling. A small size radar sensor also meets the requirements for vehicle mounted anti-collision radar units.[30] Many applications will be found in the future.

Projections for The Future

The advanced MIC techniques are being directed towards high power capability, larger integration in multi-functions and cost reduction. In a few years, MICs will be applied to almost all the microwave circuits, except specialized ones which require very high power, very low loss and very high Q. One of the necessary MIC techniques for further advances will be the incorporation of active device chips to reduce the parastic impedance which leads to operation in the broadband and no optimization. In order to ensure the active device chips high reliability, large scale air tight encapsulating technique must be developed. Other necessary techniques will be new heat radiation for high power capability and high density construction and the improvement of thick film ICs for cost reduction.

Further study should be oriented to the operation in bands higher than 20 GHz and the monolithic IC approach. They will be able to provide cheap and small size microwave equipment to meet not only specialized use but personal use such as television satellite receivers, vehicle anti-collision radars and so on.

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