CELL-BASED GaAs MMICs FOR SMALL SATELLITE APPLICATIONS

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Highly integrated, reliable microwave components are needed for small satellite applications. The GaAs integrated circuit industry has been developed largely due to military electronic requirements. In particular, the library cell approach by Pacific Monolithics holds promise for making simple and complex microwave systems available at a cost not prohibitive for small satellite applications. This paper outlines the cell library approach, cells now in the library and some microwave systems built by integrating components from the cell library.

INTRODUCTION

The small satellite concept will extend the demand for well-characterized semicustom electronic components for satellite applications. As with any industry, availability of satellite launch opportunities, and lowered life-cycle costs will dramatically increase the commercial demand for satellites. Commercial applications are now under consideration and development that would have been unthinkable only a few years ago. With the proper nurturing both from the logistics and design aspects, this process will accelerate.

The electronics area is key to the lowered costs necessary for the development of the satellite industry. All satellites rely upon electronic systems to provide the backbone of the operational concept. The widespread availability of PC-based information processing, for instance, has made possible very low-cost satellite housekeeping and information storage systems, as well as ground stations.

Microwave electronics is used for all information processing functions with which the satellite communicates with ground-based equipement, or other satellites. These include command and control telemetry reception, data gathering and data transmission. However, a new approach to electronics is necessary for the new satellite industry.

The traditional method of building satellite electronics is to specify and develop a full custom design for each individual satellite system, with a concentration on ground-based reliability documentation and testing. Each system is complex and expensive for two reasons. First, it is made of expensive microwave components, and second, each component and subassembly, as well as the entire system, is exhaustively tested for reliability reasons before delivery for launch.

While the traditional approach is sufficient for construction of high cost military satellite systems, a new design philosophy is better suited to the small satellite concept, that is GaAs monolithic circuits

Currently available monolithic GaAs cell-based electronics addresses performance, cost and reliability issues. GaAs monolithic technology has been developed to the point where low-cost circuits can be designed, developed and produced with performance which in many cases exceeds that of the hybrid circuitry it replaces in applications such as the small satellits.

First, the design and recurring costs for highly complex, integrated subsystems is drastically reduced over that for a traditional microwave design. Second, the high integration level, and the high reliability features of the GaAs MMIC architecture cut both the number of test points required (due to the high integration levels possible), and the probable number of failures (due to parts count, high radiation tolerance and high junction temperature tolerance of GaAs MMICs).

GaAs CELL LIBRARY DESIGN

The use of GaAs MMICs facilitates the production of extremely small, highly integrated and reliable microwave electronics. A drawback of MMICs, in full custom design situations, is the substantial NRE required for the chip design. The use of a standard cell library design approach can substantially reduce the front-end cost and design time for satellite microwave electronics.

Background - The Lumped-Element Approach

The major technology advance that made a GaAs MMIC microwave cell library practical was the use of the lumped-element circuit components to replace conventional transmision line circuit components. Lumped element circuits are very compact. Fig. 1 is a comparison of a 2 gain stage amplifier realized in transmission line and in lumped element technology. The distributed design is 1.5 by 2.5 mm, and the lumped design is .9 mm square. A substantial reduction in size results from the use of lumped elements. The comparable lumped element design in this case requires

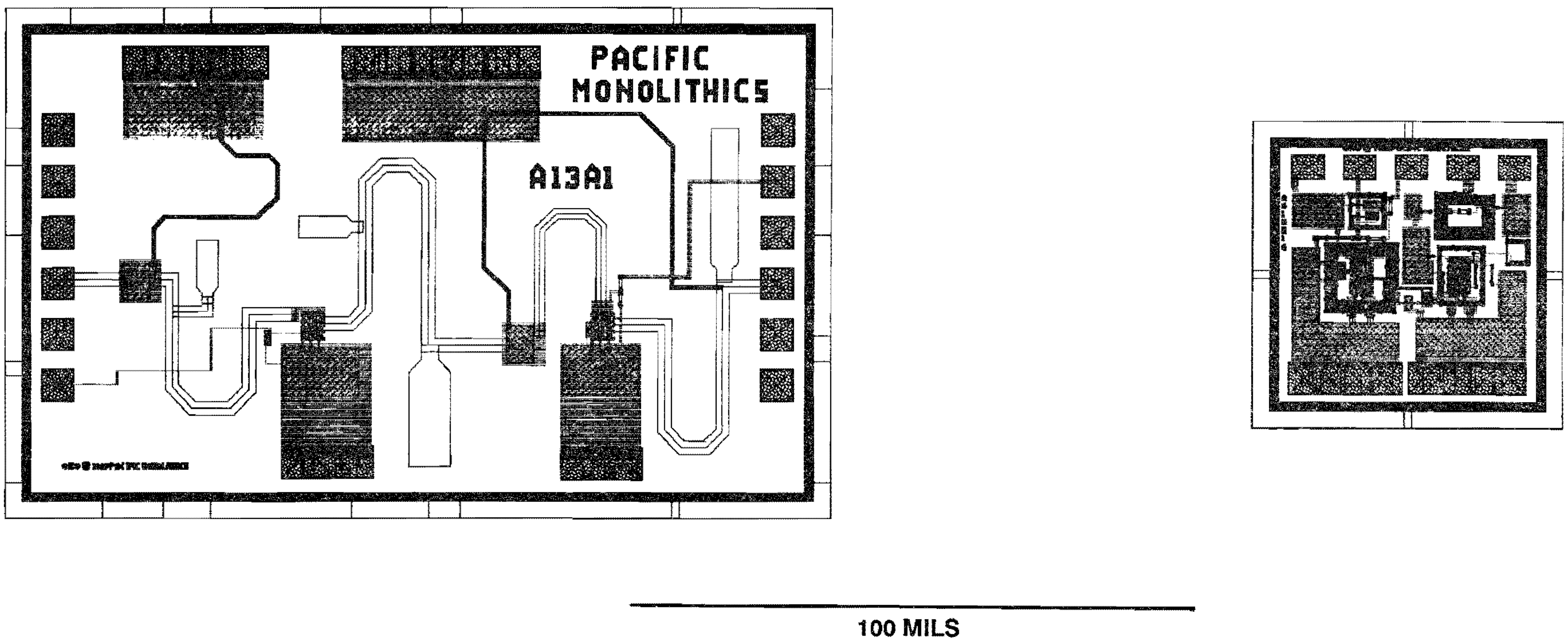


Figure 1. Distributed and Lumped-Element 2-Stage Amplifier chips

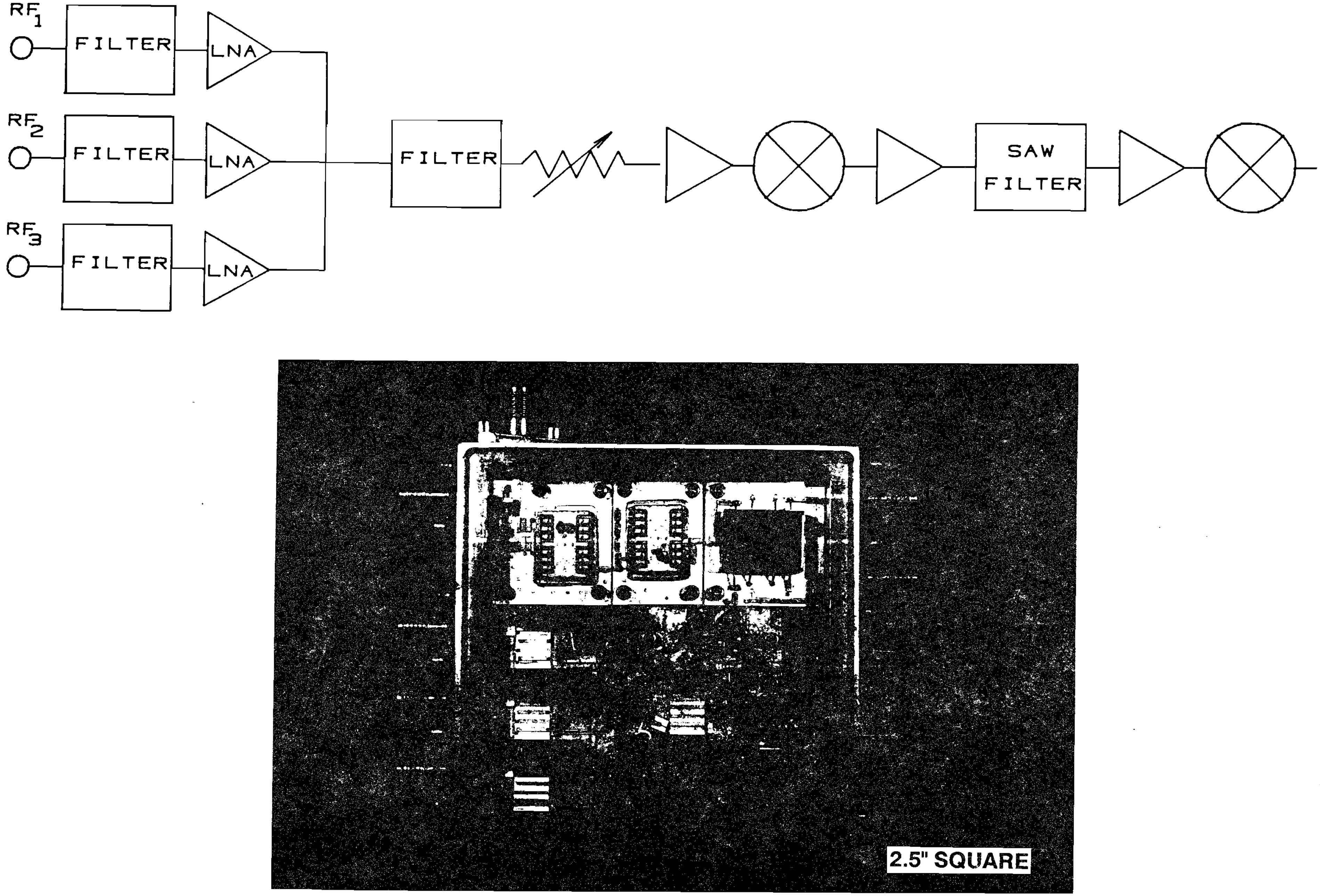


Figure 3. Three-Channel Converter System

approximately 20 percent of the chip area of the distributed design.

The reduction in size permits a microwave cell library approach on a practical basis. It should be noted that a cell library approach uses more real estate than full custom. It is also important to realize that often, in order to obtain optimum microwave performance, active components must be placed very close to each other. By using a lumped element circuit design approach, the real estate inefficiency caused by using a cell library methodology does not cause a significant impact on chip size, and therefore, circuit performance or cost.

Fig.1(a) is a 2 stage amplifier using transmission line interconnects. Fig. 1(b) shows a comparable 2 stage amplifier using lumped element interconnects. The lumped element design is .8 x .8 mm. The lumped element design is 13.5 times smaller.

Microwave Signal Processing Functions - The Cell Families

Table 1 shows the major classes of microwave signal-processing functions. The cell library has been designed to be very flexible in order to address a number of microwave signal processing systems and subsystems such as command and control telemetry, data links, radar transmitters and receivers, EW receivers, communications receivers, GPS receivers, Microwave Landing System receivers, and expendable counter measure systems.

Key elements in these families have been developed and tested, and are used routinely to develop semicustom GaAs MMICs. New cells are constantly being generated. Table II is a listing of the major cells in the PM Library at this time.

GaAs CELL-BASED ELECTRONIC SYSTEMS

A number of microwave electronic systems have been built at Pacific Monolithics using the GaAs cell library for military and satellite applications.

Fig. 2 shows a single-chip FM-CW radar subsystem developed by integrating microwave circuit cells onto a GaAs chip. The circuit includes many gain stages, a mixer, and a voltage controlled oscillator. The oscillator is externally controlled to sweep frequency, resulting in the FM-CW transmitted signal. The power amplifier for the transmitter as well as the receiving amplifier are both on chip. The transmitted frequency is used for the LO for the received

Table 1
MICROWAVE SIGNAL PROCESSING FUNCTIONS

- Amplifiers
  - Low Noise
  - Power
- Converters
  - Up/Down
  - Image Reject
  - High Dynamic Range
- Oscillators
  - SAW
  - DRO
  - VCO
  - Phase Locked Oscillators
- Modulators
  - Amplitude
  - Frequency
  - Phase
- Special Functions
  - Detectors
  - Switches
  - Limiters
  - Couplers
  - Phase Shifters

Table 2
GaAs MMIC Cell Library

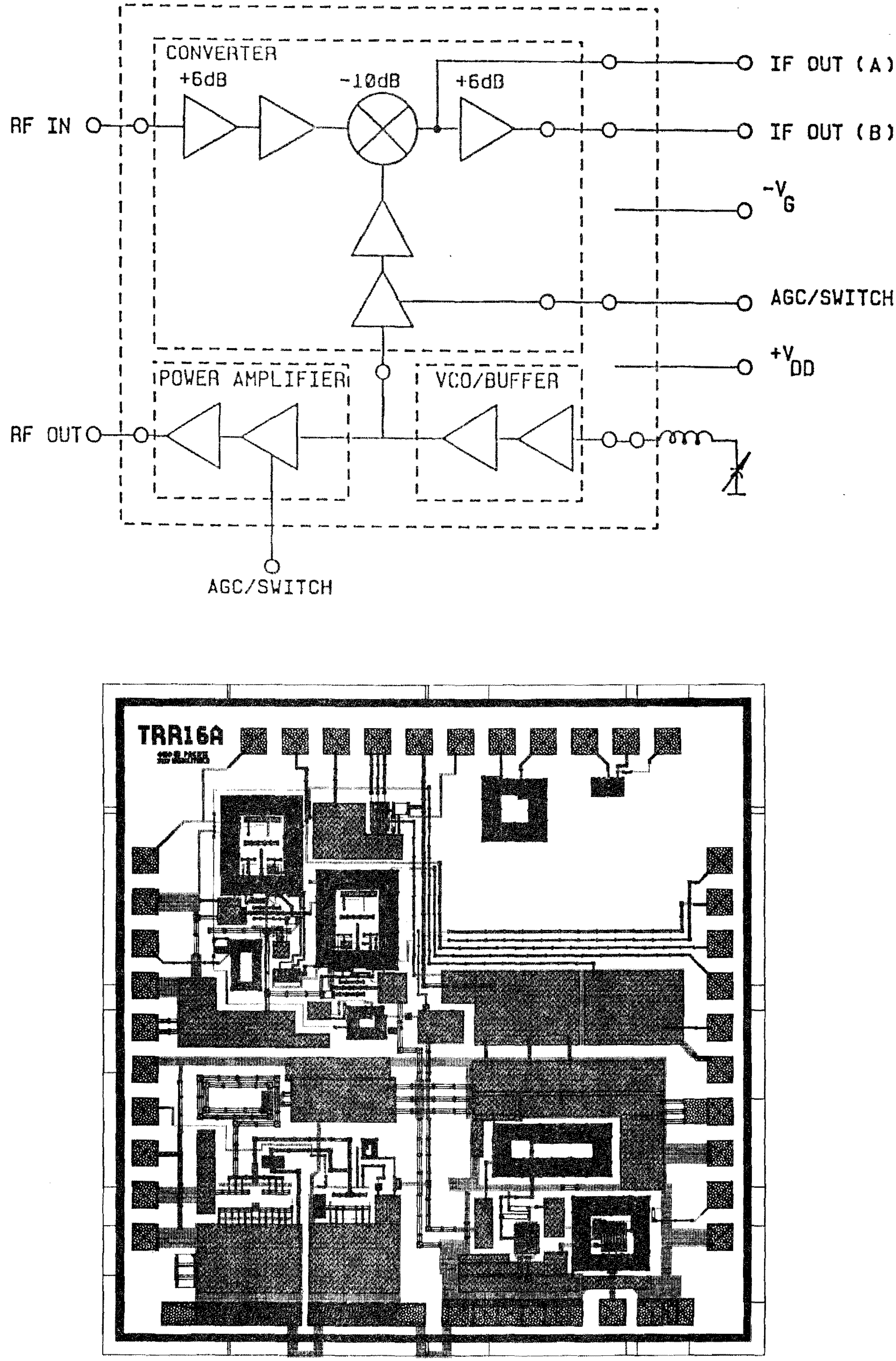
MMIC Cell #	Freq (GHz)	Gain (dB)	Cell Function
MMIC Amplifiers			
AG01A	2-6	10	Amplifier, Gain Block
AL18A	2-6	~10	Amplifier, Low Noise
AG1001G	2-6	10	Amplifier, Higher Power
AG1001A	2-6	10	Amplifier AGC
AG10A	2-6	10	Amplifier, Temp Comp
AP04C	3-7	10	Power Amplifier
AP04A	2-6	10	Power Amplifier
AG03A	2-6	10	Amplifier, High Yield
AG1003A	2-6	10	Amplifier, High Yield
AC161A	2-7	10	Power Amplifier
AGC151A	2-7	10	Amplifier, Ultra Flat
AGC152A	2-7	10	Amplifier, Tilt
AGC153A	2-7	10	Amplifier, Higher Tilt
AGC154A	2-7	10	Amplifier, Negative Slope
AGC155A	2-7	10	Amplifier, Low Current
AGC156A	2-7	10	Amplifier, Unmatched
AL95A	1-6	10-16	Unmatched LNA
ALC121A	2-8	>10	Low Noise Amplifier
AG1006A	2-6	20	Amplifier, Univ Gain Block
Other MMICs			
FDG12A	1-6	6	Active Doubler
PDG12A	1-4	0	Active Splitter
CG141A	+5	10	Converter
CG142A	5	0	Converter
6-18 GHz MMIC Amplifiers			
AGR12A3	6-18	8±1	Amplifier, Universal Block
AGR12A2	5-28	10±1	Amplifier, Broadband
AGR12A1	6-18	9±1	Amplifier, Cascadable
AGR12A4	6-18	12±2	Amplifier, Cascadable
AG1072DR	6-12	6±0.5	Amplifier, Univ Gain Block
AG1073A	7-17	9±1	Amplifier, High Efficiency
AG1073B	6-18	+ Slope	Amplifier, High Producibility
AG1073C	7-17	11±2	Amplifier, Low Noise
AG1073D	7-17	12±0.5	Amplifier, Low Noise
AG1073E	7-17	9±1	Amplifier, High Efficiency
AG1073ER	6-18	9±1	Amplifier, High Efficiency
AG1073F	7-17	9±1	Amplifier, Matched
AG1073G	7-17	5±1	Amplifier, Matched
AG1073I	7-17	6±1	Amplifier, High Gain Match
AG1073IR	7-18	~6 dB±2	Amplifier
AGR12A5	6-18	~8 dB±2	Amplifier
ALF103A	6-12	5 dB±1	Amplifier, High Power
ALF104A	6-10	7±0.5	Amplifier
AGF14A1	6-16	7±1	Amplifier
AGF14A2	8-14	8±0.5	Amplifier
AGR12A5	6-18	8 Min	Amplifier
6-18 GHz MMIC Converters			
C1071A	7-17	12±4	Converter
C1071B	7-17	12±4	Converter
C1071I	7-17	0	Converter
CR12A1	10-15	–2	Converter

MMIC Cell #	FREQ (GHz)	Gain (dB)	Cell Function
Digital IC's			
DD01A	DC-1.5	—	Divide by Two
DT01A	DC-3	—	2:1 MUX
DT01A	DC-3	—	2 Input NOR Gate
DT01A	DC-3	—	Inverter
DD01A	DC-1.5	—	Master/Slave D-Flip/Flop
DCJ121A	DC-2	—	Dual Complementary Clock Driver
DDJ121A	DC-2	—	Complementary Divide by Two
DDJ162A	DC-1.3	—	Lower Power Divide by Two
DDJ163A	DC-1.2	—	Lowest Power Divide by Two
DP02A	DC-100 MHz	—	7 to 20 Line Phase Shifter Controller
Special Building Blocks			
AL62B	0.1–8	15	Low Noise Amp
AGO6A	2–6	20	Limiting Amp
AL82C	2–12	8	Amplifier Distributed
AL82A	2–18	5	Amplifier Distributed
CV0301	1–3	30	Downconverter
CV0201	1–3	25	Downconverter
C1070A	7–15	15	Downconverter
CV0801	5–8	25	Downconverter
M971B	0.01–2	25	VHF, UHF Converter
CV0601	3–6	40	Downconverter
CV0602	3–6	20	Downconverter
DD01B	0–2	—	Flip Flop/Latches
DT01C	0–3.0	—	Random (glue) Logic Cells (NOR, NAND, INVERT, AND-OR)
AL94C	8–12	—	Oscillator
M80A	0.01–2	–4	UHF, VHF Mixer
M82A	6–12	–10	Diode Mixer
M83A	10–16	–10	Diode Mixer
M84A	12–18	–10	Diode Mixer
SW1201A	0.3–12	–3	SPDT Switch
AT1202A	1–12	–3.5	Attenuator
AT	2–18	–3	Attenuator
HWC	2–10	–4	Power Splitter
HVM	5–10	–6	Vector Modulator
P01A	5–10	–6	QPSK Modulator
H18	2–12	–6	BPSK Modulator
IS01	2–12	–3	Active Isolator
B971A	1–3	–2	Active Balun
B02A	6–12	–2	Passive Balun
BC01A	2–6	–2	90° Hybrid
B03A	3–6	–3	Passive Balun
P1037A	1–6	–8	4-Bit Generic Phase Shifter

Table 2
GaAs MMIC Cell Library
(cont.)

MMIC Cell #	FREQ (GHz)	Gain (dB)	Cell Function
Low Frequency MMIC Amplifiers			
PM06			
AI01A	.2-2	20	Low Noise Gain Block
AG971A	.03-1	20	Amplifier, Gain Block
AG971B	.03-1.5	26	Amplifier, Gain Block
AG971C	.03-1.5	40	Amplifier, Gain Block
AL971A	.03-1	11	Amplifier, Gain Block
AL971B	.9-3	20	Amplifier, Gain Block
AL971C	0.3-1.1	15	Amplifier, Gain Block
AP971A	.3-1	25	Amplifier, Gain Block
AP971B	.5-1	25	Amplifier, Gain Block
AGB121A	.02-1	20	Low Noise Amplifier
AGB122A	.02-2	29	Low Noise Amplifier
ALB121A	.9-2.5	27	Low Noise Amplifier
APB121A	.3-3	25	Low Noise Amplifier
APB122A	.3-1.1	25	Low Noise Amplifier
ALB141A	.9-2.5	22	Low Noise Amplifier
AGB141A	.05-2	7	Amplifier/Attenuator
AGB142A	.05-2	22	Amplifier/Switch
ZB141A	dc-.1		Operational Amplifier
APB151A	.1-2	19	Power Amplifier
AGB161A	.03-2	16	Amplifier
AGB161A	.95-1.05	20	Amplifier
ALB161A	.03-1.1	21	Amplifier
Low Frequency MMIC Mixers			
PM08A			
M81A	200 X 0.5 µM	FET QUAD	Mixer QUAD
M971A	.01-1	25	Mixer/Amplifier
M971B	.01-2	25	Mixer/Amplifier
MB121AM	.01-1.2	11	Mixer/Amplifier
MB122AM	0.1-1.8	20	Mixer/Gilbert Cell
MB151A	.01-2	14	Mixer/Gilbert Cell
MB161A	.01-2	12	Mixer/Gilbert Cell
MB162A	.01-1.8	20	Mixer/Gilbert Cell
Low Frequency MMIC Components			
V971A	.2-2	11	Oscillator/Limiter
V971B	.2-2	11	Oscillator/AGC Amp
1/2 of ALB161A	.2-2	16	Oscillator
PSB141A	.1-.8	0	Phase Splitter, 90°
B971A	.03-1	0	Phase Splitter, 180°
ZB144A	.02-1.5	0	Phase Splitter, 180°
ZB141A	.03-2	–6	Buffer Amplifier
ZB164A	.03-4	0	Buffer Amplifier
ZB143A	.001-6	–1	Switch
ZB165A	.001-6	–1	Switch, Ultra Flat
MMIC Control Elements & Phase Shifters			
H90	6-10	–4	90° Phase Shifter
H180	2-18	–3-4	180° Phase Shifter
HAT	2-12	–1.5	Push-Pull Attenuator
HSW	2-12	–2.5	Push-Pull Switch
H2B	6-10	–10	2-bit 0 Shifter
P01A	6-10	–10	Modified 2-Bit Ø Shifter
P02A	6-10	–4	Modified 90° Ø Shifter
S01A	.5-12	–2.5-3	Single Ended Switch

MMIC Cell #	FREQ (GHz)	Gain (dB)	Cell Function
MMIC Control Elements & Phase Shifters (Cont'd)			
T01A	.5-12	–3	Single Ended Attenuator
T01C	.5-12	–3	Single Ended Attenuator
SL124A	.5-12	2	Single Ended Switch
SL125A	.5-12	–3	Single Ended Switch
TA124A	.5-12	2	Single Ended Attenuator
TA125A	.5-12	•	Single Ended Attenuator
Other MMICs			
HDG	6-10	–4-20	Seg. Dual Gate FET Attenuator
HDV	6-10	–4	Seg. Dual Gate Vector Modulator
AGS122A	2-6	11	Balanced, Amplifier
AGS162A	2-6	11	Balanced, Amplifier
AGS121A	1-3	10	Balanced, Amplifier
AGS123A	3-9	10	Balanced, Amplifier
AGS124A	6-12	8	Balanced, Amplified
AIP121E	.05-2	7	IF Amplifier
MMIC Oscillator			
V971A	.05-2	—	Oscillator, for Use w/SAW
V971B	.05-2	—	Oscillator/Low Phase Noise
GA9	3.5-6	—	Oscillator, Negative Bias
GA13S10	3.5-6	—	Oscillator, Negative Bias
V81A	16-18	—	Oscillator, Balanced
V02A	3-6	—	Oscillator, Balanced GA9
VH101B	3-6	—	Oscillator, No Neg Bias
VH102A	2-3	—	Oscillator-R, Low AM Noise
VH103A	6-12	—	Oscillator
VH103B	12-18	—	Oscillator Idss
VH120A	2-4	—	Oscillator/VCO Choke
VH122A	11-18	—	Oscillator/Power Detector
VH120B	2-4	—	Oscillator/Common Drain
VH1402	1-2	—	Oscillator/Common Drain
VH1404	2-4	—	Oscillator/Common Drain
VH1408	4-8	—	Oscillator, Low AM Noise
VH1412	6-12	—	Oscillator, Low AM Noise
VH1418	9-18	—	Oscillator, Low AM Noise
VBM1418	12-18	—	Oscillator, Balanced
MMIC Converter/Mixer			
C01A	.8-3	—	Converter, Balanced
C02A	1.2-2.6	—	Converter, Balanced
C03A	1.4-2.8	—	Converter, Single-Ended
C04A	3-6	—	Converter, Balanced
CR05A	3-6	—	Converter, LNB
CI06A	3-5	—	Converter
CV07A	3-5	—	Converter, Dual "HV Chip"
C11A	5-8	—	Converter, Balanced
CI06C	3-5	—	Image Reject Mixer
CQ08B	2-4	—	QPSK Demodulator
CQ09B	2-4	—	QPSK Demodulator
CQ10B	4-5	—	QPSK Demodulator
C12A	5-8	—	High Efficiency
MH126B	2-6	—	4 Diode Mixer
CIH140A	3-4	—	Hi Dynamic Range IRM



(100 mils, edge-to-edge)

Figure 2. FM-CW Radar Chip