

Chapter 1

Introduction

Among electronic circuits, signal amplification is one of the most important radiofrequency (RF) and microwave circuit functions. The introduction of radar during World War II provided the first significant application requiring amplification of microwave signals. In recent times, the wireless communication revolution has provided an explosion of RF and microwave amplification applications. During the last two decades, amplifier technology has made tremendous progress in terms of devices (low noise and power), circuit computer-aided design (CAD) tools, fabrication, packaging, and applications. Low-cost power amplifiers for wireless applications are a testament to this explosion.

Early microwave amplifiers were the exclusive province of vacuum tube devices such as Klystrons [1–3], traveling-wave tube (TWT) amplifiers [2–4], and magnetrons [2, 3]. Today, microwave amplification is dominated by solid state amplifiers except for applications at high output powers ($\gtrsim 100$ watts). Today, the most common vacuum tube application is the 900-watt microwave oven using a 2.45-GHz magnetron. The power levels achievable for tube amplifiers are on the order of 10^3 higher than achievable for solid state amplifiers. The microwave oven magnetron, with a manufacturing cost of about \$10 ($\sim \$0.01/\text{watt}$), has no solid state competition in sight. Likewise, today's \$0.50/watt 900-MHz to 2-GHz cell phone solid state transistor amplifier and \$0.30/watt 200–500-W L/S-band base station transistor power amplifiers have no tube competition.

Solid state amplifiers are of two general classes: those based on two-terminal negative resistance diode devices, and those based on three-terminal devices known as transistors. Early solid state amplifiers were dominated by two-terminal devices because diodes are typically much easier to fabricate than transistors. Quite an array of two-terminal amplifier designs have been introduced, including parametric amplification (varactor diodes) [5–8], tunneling diodes [7–9], transferred electron diodes (Gunn and LSA diodes) [8, 10, 11], and avalanche transit-time diodes (IMPATT, TRAPATT, and BARITT) [8, 12]. Such diodes are used only for special amplifier functions.

1.1 TRANSISTOR AMPLIFIER

Today, solid state amplification is dominated by use of three-terminal transistors [13–36]. Using a small voltage applied at the input terminal of the device, one can control, in an efficient manner, a large current at the output terminal when the

common terminal is grounded. This is the source for the name *transistor*, which is a unification of the words *transfer resistor*.

Solid state transistors may be grouped into two categories: bipolar and unipolar devices. The bipolar devices are comprised of silicon (Si) bipolar junction transistors (BJTs) and silicon germanium (SiGe) and gallium arsenide (GaAs) heterojunction bipolar transistors (HBTs). The unipolar devices include Si metal oxide semiconductor field effect transistors (MOSFETs), GaAs metal semiconductor field effect transistors (MESFETs), and pseudomorphic high electron mobility transistors (pHEMTs). The switchover to three-terminal devices was largely due to cost. Diodes are typically less expensive to manufacture than transistors but the associated circuitry to achieve gain from a two-terminal device is much more expensive than that for a three-terminal device. For example, a transistor (without any matching network) connected between 50-ohm input and output terminals can provide 15–20 dB gain at radiofrequencies and 6–8 dB at 20 GHz. In addition, design of three-terminal amplifiers for stable operation and routine high-yield manufacturing is exceedingly simple.

Signal amplification is a fundamental function in all RF and microwave systems. When the strength of a weak signal is increased by a device using a direct current (DC) power supply, the device along with its matching and biasing circuitry is known as an amplifier. Here the DC power from the power supply is converted into RF power to enhance the incoming signal strength. If a device is a transistor, the signal is applied to the input terminal (gate/base) and the amplified signal appears at the output (drain/collector) and the common terminal (source/emitter) is usually grounded. The matching networks help in exciting the device and collecting the output signal more efficiently. Figure 1.1 shows a schematic representation of a single-stage transistor amplifier. Basic constituents are a transistor, input and output matching networks, bias circuitry, and input and output RF connections. The DC bias and RF connections may be made to connectors if housed in a fixture or to lead frame if assembled in a package depending on the amplifier fabrication scheme.

There are various types of amplifiers used at RF and microwave frequencies. Basic types consist of low-noise, buffer, variable gain, linear power, saturated high-power, high-efficiency, narrowband, and broadband amplifiers. The design of

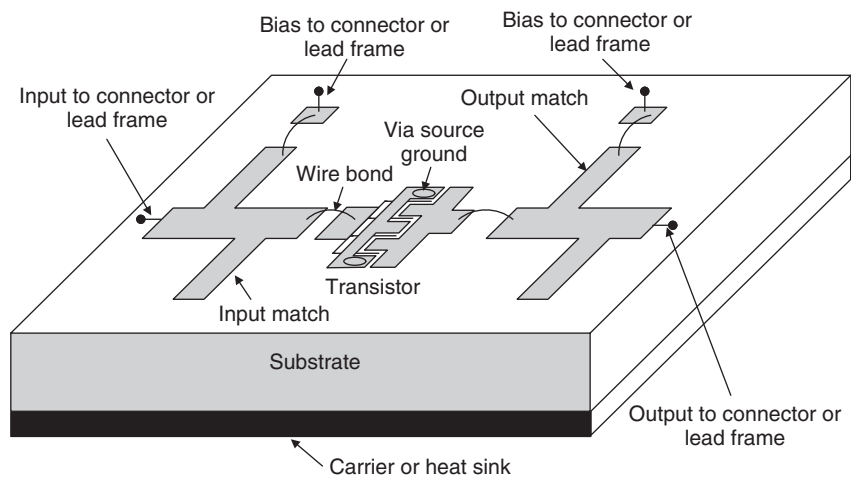


Figure 1.1 Schematic representation of a transistor amplifier.

amplifiers requires essentially device models/ S -parameters, CAD tools, matching and biasing networks, and fabrication technology. Each type mandates additional insights to meet required amplifier specifications. For example, a low-noise amplifier (LNA) needs a low-noise device and a low-loss input matching network while a power amplifier (PA) requires a power device and low-loss output matching network.

RF and microwave amplifiers have the following characteristics:

- Band-limited RF response
- Less than 100% DC to RF conversion efficiency
- Nonlinearity that generates mixing products between multiple signals
- RF coupled and no DC response
- Power-dependent amplitude and phase difference between the output and input
- Temperature-dependent gain, higher gain at lower temperatures and vice versa

1.2 EARLY HISTORY OF TRANSISTOR AMPLIFIERS

The use of Si based bipolar transistors and GaAs based MESFET for amplifiers have been reported since the mid-1960s and early 1970s, respectively. Most of the initial work on Si based bipolar transistor amplifiers was below C-band frequencies, whereas GaAs based MESFET amplifiers were designed above L-band frequencies (see Appendix C for frequency band designations). Low-noise HEMTs were reported in the early 1980s. Internally matched narrowband MESFET power amplifiers working from S- through X-band were available during the 1980s and Ku-band amplifiers were introduced in the early 1990s.

The GaAs monolithic microwave integrated circuit (MMIC) amplifier was reported in 1976 and since then there has been tremendous progress in both LNAs and PAs. Some of the early development milestones in MMIC amplifiers are as follows:

- X-band low-power GaAs MESFET amplifier in 1976
- X-band GaAs MESFET power amplifier in 1979
- K-band GaAs MESFET LNA in 1979
- Q-band GaAs MESFET power amplifier in 1986
- V-band GaAs HEMT LNA in 1988
- X-band GaAs HEMT power amplifier in 1989
- W-band HEMT LNA/power amplifier in 1992

1.3 BENEFITS OF TRANSISTOR AMPLIFIERS

Major benefits of transistor amplifiers versus tube amplifiers are smaller size, lighter weight, higher reliability, high level of integration capability, high-volume and high-yield production capability, greater design flexibility, lower supply voltages, reduced maintenance, and unlimited application diversity. Transistors have much longer operating life (on the order of millions of hours) and require much lower warming time. Solid state amplifiers also do not require adjustment in the bias or the circuit, as required in tubes, over long periods of operation.

In comparison to solid state diode amplifiers, transistor amplifiers have greater flexibility in terms of designing matching networks, realizing high-stability circuits, and cascading amplifier stages in series for high gain. The outstanding progress made in monolithic amplifiers is attributed to three-terminal transistors, especially on GaAs substrates. Monolithic amplifiers are fabricated on wafers in batches, and hundreds or thousands can be manufactured at the same time. For example, over 15,000 amplifiers, each having a chip size of 1 mm^2 , can be obtained on a single 6-inch diameter GaAs wafer. Thus monolithic amplifiers have a great advantage in terms of the manufacturing cost per unit. In general, monolithic amplifiers will have advantage in terms of size and weight over hybrid integrated techniques. It is worth mentioning that the weight of an individual or discrete chip resistor or a chip capacitor or an inductor is typically more than an entire monolithic amplifier chip. Many of today's high-volume applications using amplifiers are in hand-held gadgets. Both hybrid and monolithic MIC technologies are used and considered reliable. However, a well-qualified MMIC process can be more reliable because of the much lower part counts and far fewer wire bonds.

1.4 TRANSISTORS

During the past two decades outstanding progress has been made in microwave and millimeter-wave transistors. The low-noise and power performance as well as the operating voltages have significantly been advanced. Among low-noise devices, the pHEMT is the most popular due to its low noise figure and high gain characteristics. Other devices for small-signal applications are MESFETs, MOSFETs, and SiGe HBTs. Today, a designer has several different types of power transistors available as discrete devices (in chip or packaged form) or as part of a foundry service to design power amplifier MMICs. Several solid state devices are being used to develop power amplifier (PA) circuits including BJTs, laterally diffused metal oxide semiconductor (LDMOS) transistors, MESFETs, or simply FETs, both GaAs and indium phosphide (InP) based HEMTs, GaAs based HBTs and silicon carbide (SiC) based FETs, and gallium nitride (GaN) HEMTs. Each device technology has its own merits, and an optimum technology choice for a particular application depends not only on technical issues but also on economic issues such as cost, power supply requirements, time to develop a product, time to market a product, and existing or new markets.

HEMTs have the highest frequency of operation, lowest noise figure, and high power and PAE capability. Due to the semi-insulating property of GaAs substrates, the matching networks and passive components fabricated on GaAs have lower loss than on Si. The GaAs FET as a single discrete transistor has been widely used in hybrid microwave integrated circuit (MIC) amplifiers for broadband, medium-power, high-power, and high-efficiency applications. This wide utilization of GaAs FETs can be attributed to their high frequency of operation and versatility. However, increasing emphasis is being placed on new devices for better performance and higher frequency operation. HEMT and HBT devices offer potential advantages in microwave and millimeter-wave IC applications, arising from the use of heterojunctions to improve charge transport properties (as in HEMTs) or pn-junction injection characteristics (as in HBTs). HEMTs have a performance edge in ultra low-noise, high-linearity, and high-frequency applications. The MMICs produced using novel structures such as pseudomorphic and lattice matched HEMTs have significantly improved power and power added efficiency (PAE) performance and high-frequency (up to 280 GHz) operation. The pHEMTs that utilize multiple epitaxial III-V compound layers have

shown excellent millimeter-wave power performance from Ku- through W-bands. HBTs are vertically oriented heterostructure devices and are very popular as low-cost power devices when operated using a single power supply. They offer better linearity and lower phase noise than FETs and HEMTs.

On the other hand, bipolar transistors require only a single power supply, have low leakage, low $1/f$ noise or phase noise, and are produced much cheaper on Si. The SiGe HBTs have the low-cost potential of Si BJTs and electrical performance similar to GaAs HBTs. Thus discrete silicon BJTs, SiGe HBTs, and MOSFETs have an edge over GaAs FETs, HEMTs, and HBTs in terms of cost at low microwave frequencies. For highly integrated RF front ends, GaAs FETs and HEMTs are superior to bipolar transistors and Si substrate based devices due to high performance multifunction devices and lower capacitive loss, respectively. The electrical performance and cost trade-offs between Si and GaAs generally favor silicon devices due to single power supply operation and lower cost, whereas GaAs based devices are preferred due to superior low-noise and power (high breakdown voltage) performance and high-frequency operation.

Many of these transistors are available as discrete devices as well as a foundry to design monolithic amplifiers. Discrete transistors are available in die form and in plastic and/or ceramic packages. The ceramic package devices are for high-frequency and high-power applications. Plastic packaged transistors are for low-cost and high-volume applications.

1.5 DESIGN OF AMPLIFIERS

The design of RF and microwave amplifiers has several facets impacting their performance. The most important factors include the selection of semiconductor technology, device models, circuit architecture and design methodology, matching networks, packaging, and thermal management. Thus amplifier design becomes an art, to meet several often conflicting requirements, and an experienced designer will outperform beginners.

The design of an amplifier for a particular application and frequency range is quite complicated in the sense that it has to meet physical, electrical, thermal, and cost requirements. Salient features of an amplifier design are given in Figure 1.2. The amplifier performance requirements in terms of frequency band, gain, noise figure, power output, PAE, linearity, and input and output VSWR are determined by the device sizes, the circuit design topology, matching networks, the number of gain stages, the aspect ratio for the devices between the stages, design methodology, fabrication technology, and packaging. More often it involves trade-offs in terms of size, electrical performance, reliability, and cost. The amplifier designs are normally performed using device S -parameters, linear and nonlinear models, and matching component models.

Design of amplifiers, in a broad sense, falls into two categories: low noise and power. In a low-noise amplifier, the transistor's input is matched for optimum noise figure and the transistor's output is conjugately matched to $50\text{-}\Omega$ system impedance for maximum gain and return loss (RL). In a power amplifier, the $50\text{-}\Omega$ system impedance is matched to a required load at the transistor's output for maximum power and the transistor's input is conjugately matched for maximum gain and RL. In linear amplifiers the input and output are matched for better linearity. Thus, in an amplifier, the device's input is either matched for minimum noise or maximum gain or linearity and output is matched for maximum gain or optimum power and PAE or linearity. The matching networks are comprised of distributed and lumped elements. In an amplifier, the supply

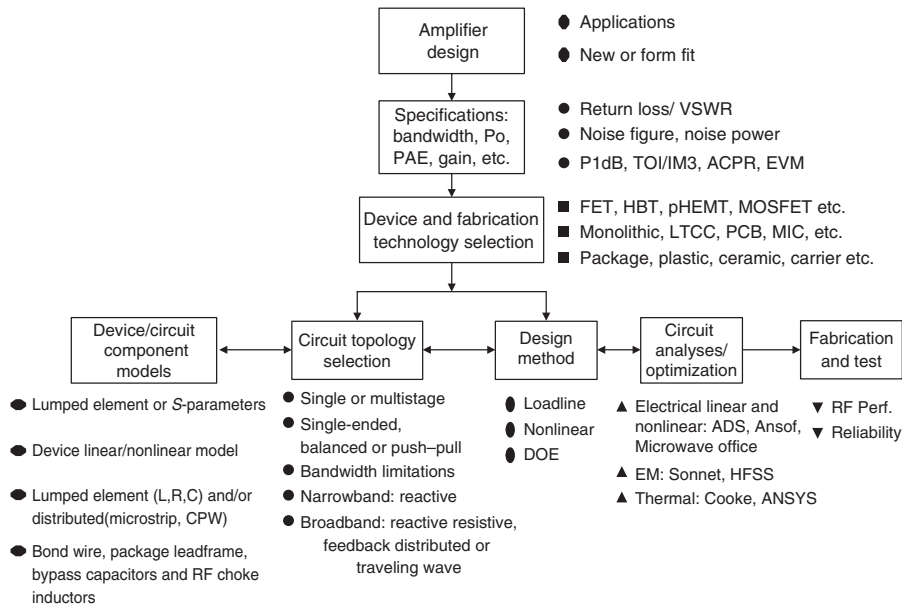


Figure 1.2 The salient features of amplifier design.

voltage (drain or collector) is applied through an RF choke or through the biasing circuit, which is usually an integral part of the matching network.

A low-noise or small-signal amplifier is designed using a device's noise model or noise parameters and S -parameters. The amplifier design must be conditionally stable. Narrowband power amplifier design can be carried out using a device's source-pull and load-pull data to design the amplifier's input and output matching circuits. This technique provides approximate electrical performance such as gain, power, and power added efficiency calculated by using measured small-signal S -parameters of the active device. However, for broadband applications, the aforementioned technique is very involved. Accurate nonlinear models for active devices provide a more suitable technique by using nonlinear computer-aided design (CAD) tools. These models help in determining matching networks over the desired bandwidth of the amplifier and also assist in simulating large-signal performance such as gain, VSWR, P_{1dB} , PAE, P_{sat} , TOI or ACPR or EVM, and harmonic levels. All these terms are defined in Chapter 3. These models also provide accurate solutions for multistage power amplifiers. The amplifier design must be conditionally stable, and also odd-mode, parametric, and low-frequency oscillation conditions must be prevented. However, in power amplifiers, unconditional stability is generally desired.

Power amplifiers are nonlinear circuits. Thus linearization of such circuits for multiple-carrier communication applications is required to minimize distortion. The design of such circuits can be obtained either by using measured source-pull and load-pull data, or accurate nonlinear models, or by using some sort of distortion cancellation technique.

The initial cost of developing MMIC based amplifiers is far greater than in hybrid based technology. Also, the tuning of the fabricated MMICs is difficult. Therefore the design phase of MMIC amplifiers becomes very critical to achieve first-pass success to minimize expensive design iterations. In the design of such products, an extensive

accurate modeling library of active devices, passive circuit components, and other parasitic reactances including discontinuities, cross-coupling, bonding pads, connecting wires, and package lead frame becomes an integral part of an amplifier design.

1.6 AMPLIFIER MANUFACTURING TECHNOLOGIES

Several RF/microwave amplifier manufacturing technologies are being used to reduce component counts, size, and cost. These are printed circuit board, thin-film and thick-film integrated circuit (IC) hybrid, low- and high-temperature cofired ceramic, monolithic IC, and multichip module. Over the past decade, the trends in amplifier fabrication technology have shifted from hybrid IC to monolithic IC. The majority of power amplifiers are fabricated by using some sort of hybrid technology. At radiofrequencies, discrete matching components such as inductors, capacitors, and resistors are added on a printed circuit board to build power amplifiers. At microwave frequencies, thin-film technology is used to design hybrid amplifiers and internally matched amplifiers, to assemble MMIC amplifiers, and for high power combining. An MMIC technique for amplifiers is preferred especially for broadband, high-frequency, and large-volume applications.

The choice of suitable semiconductor technology depends on its performance capability and cost. For example, at S-band GaAs pHEMT and MESFET devices have superior performance compared to Si LDMOS transistors, however, Si LDMOS technology is mostly used to develop high-power amplifiers (on the order of hundreds of watts) for base station transmitters for cellular networks. Because the LDMOS is based on well-established and low-cost Si technology, meeting cost targets and providing desired gain, linearity, and reliability are not a problem. On the other hand, the GaAs pHEMT meets low-noise and power performance needs for millimeter applications.

1.7 APPLICATIONS OF AMPLIFIERS

In general, a microwave system requires a group of amplifiers. Low-noise amplifiers are integral parts of receivers while transmitters are based on several stages of power amplifiers. RF/microwave power amplifiers are important circuit components used in every system including cordless and cellular telephones, base station equipment, spaceborne, airborne, and ground based (fixed/mobile) satellite communications, wireless local area networks, terrestrial broadcast and telecommunications, point-to-point radio (PPR), very small aperture terminal (VSAT) wideband satellite communications, air traffic systems, global positioning system (GPS), phased array radar (PAR), electronic warfare (EW), and smart weapons. Most of these systems require low-cost (high-volume) and more reliable solid state power amplifiers. Cordless and cellular telephones require low-bias operation (2–5 V), single power supply, and very high-efficiency (analog versions) or high-linearity (digital versions) amplifiers. Cellular telephones may also require dual, triple or quad-mode operation including multiple frequencies in both digital and analog versions. Power amplifiers for point-to-point radio and very small aperture terminal applications are operated typically at 8 V. The output power requirements are in the range of 0.2–4 W. On the other hand, for a phased-array antenna (PAA), the amplifiers are typically operated at 10 V and the output power requirements are in the range of 20–40 W per element.

The power level of amplifiers is dictated by the intended application. For example, for cellular base stations and EW, the power levels are in tens to hundreds of watts,

while for satellite and radar systems, their levels may be a magnitude higher. For portable wireless handsets and wireless LANs, the required power levels are an order of magnitude lower, usually less than 1 watt. Based on the modulation schemes, the handset requirements can be grouped into two categories: constant envelope and nonconstant envelope. In the former scheme, there is no information contained in the amplitude of the transmitted signal. In this case, the amplifiers are operated in high-efficiency mode. Common applications are groupe special mobile (GSM) and digital European cordless telecommunication (DECT). The latter scheme enhances the spectral efficiency of the signal by incorporating the intended information in the amplitude of the transmitted signal. Most popular applications are code division multiple access (CDMA), wideband code division multiple access (WCDMA), and local area network (LAN). Usually, the amplifiers are operated in linear mode at the cost of amplifier efficiencies. For wireless base stations, high linearity is of paramount importance in power amplifiers. For example, personal communication service (PCS) (1.8–2.0 GHz) requires power levels in the range of 5–200 W.

Modern active-aperture antenna subsystems for phased-array applications require hundreds or even thousands of transmit/receive (T/R) modules, each delivering tens of watts of output power. These phased-array antenna subsystems are employed in airborne communication and radar systems, ground based and ship based tactical radars, as well as space based radar and communication systems. Typical T/R module requirements for these systems include (a) small size, dictated by required antenna element-to-element spacing, (b) low weight, especially in airborne and spaced based systems, (c) precise control of insertion phase and amplitude for good beam pointing accuracy and low side lobe levels, (d) high reliability, (e) high power added efficiency (PAE) to reduce prime power and cooling requirements, and (f) low cost, since thousands of modules may be required for a single system. Thus 5–10% improvement in PAE can greatly affect the DC power requirements and thermal design techniques. The MMIC amplifier technique looks very attractive in realizing a couple of tens of watts of power. These chips are further combined using standard hybrid MIC techniques to obtain much higher power levels. Higher efficiency operation of these devices is becoming one of the most important factors in reducing prime power and cooling requirements for advanced systems. These characteristics are particularly useful for space and military applications where weight, size, and power added efficiency can impose severe limitations on the choice of components and systems.

Figures 1.3 through 1.7 show examples of typical microwave amplifiers. These include a small-signal MMIC amplifier, plastic packaged driver and high-voltage power amplifiers, hybrid power amplifiers, ceramic packaged power amplifiers, and MMIC power amplifiers. Figure 1.8 shows an example of a printed circuit board used for plastic amplifier testing.

The phase-array antenna, which uses a large number of elements, benefits significantly from low-cost transceiver (T/R) modules using several amplifiers. Figure 1.9a shows a simplified block diagram of a T/R module whose size and cost can be reduced drastically by monolithic integration of amplifiers or all microwave functions except the circulator and the antenna. Figure 1.9b shows an X-band radar GaAs MMIC chipset employing three amplifier chips: limiter/LNA, driver, and HPA and several buffer amplifiers used in the control chip for loss compensation.

Requirements for power amplifiers vary drastically from one application to another. Usually communication applications require linear operation, while for radar applications high PAE is of prime importance. Personal communication systems working in

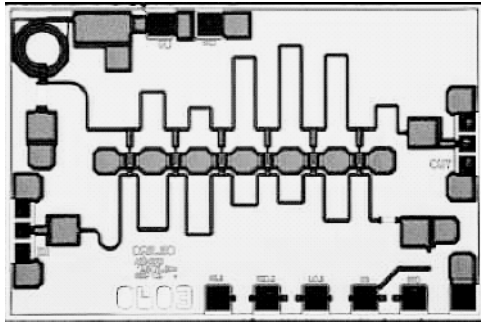


Figure 1.3 Single-stage broadband low-noise MMIC amplifier. Chip size is $3 \times 2 \text{ mm}^2$.

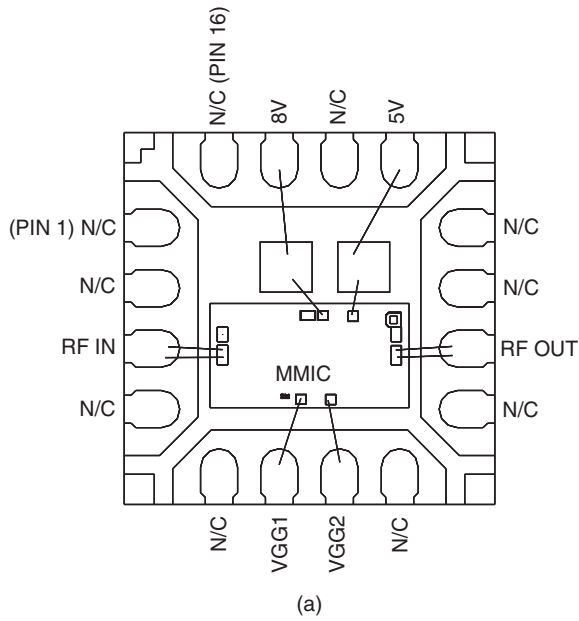


Figure 1.4 Example of a plastic packaged driver amplifier: (a) MMIC wiring to the lead frame and (b) top view of the package. Small shunt objects on the supply lines are decoupling capacitors.

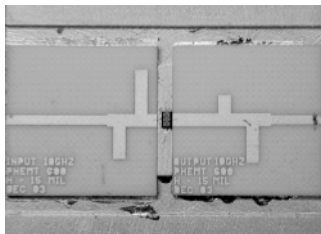


Figure 1.5 Examples of hybrid MIC amplifiers: (a) LNA using pHEMT and (b) amplifier in a metal housing with connectors and single supply.

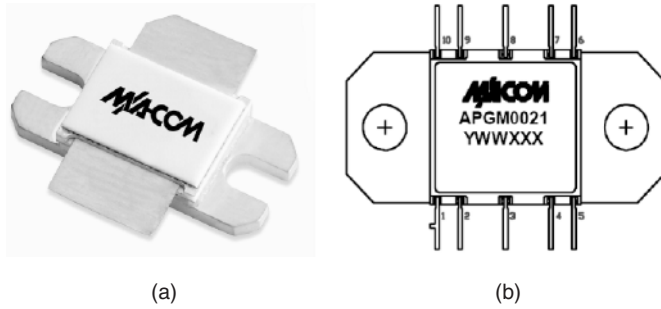


Figure 1.6 Examples of ceramic packaged devices: (a) discrete transistor and (b) MMIC amplifier.

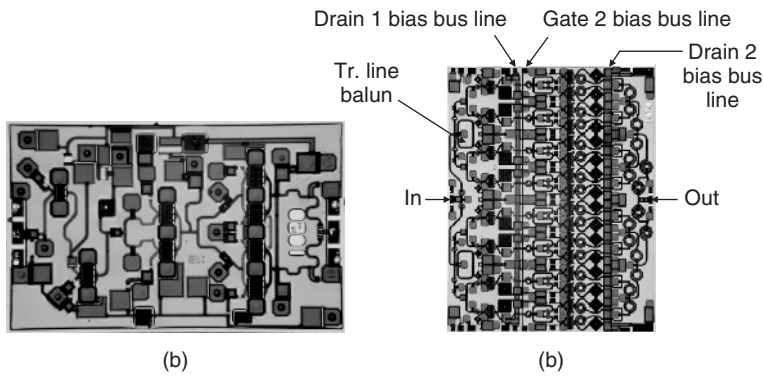


Figure 1.7 Examples of MMIC amplifiers: (a) K-band four-stage 1-W driver, chip size is $3.1 \times 2.0 \text{ mm}^2$ and (b) 2–8 GHz 8-W power amplifier, chip size is $5.0 \times 6.3 \text{ mm}^2$.

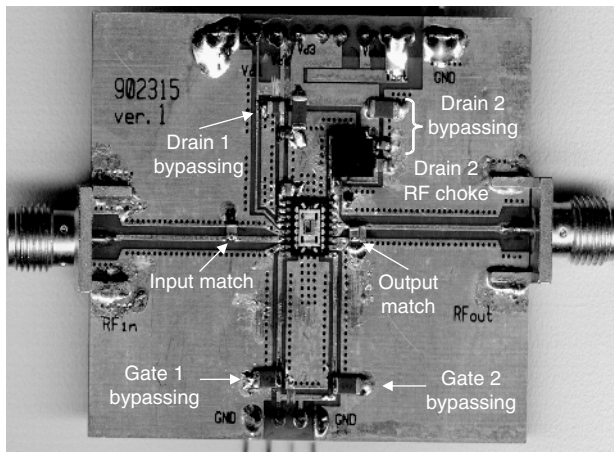


Figure 1.8 Example of a prototype PCB, with a power amplifier in a TSSOP 16-pin plastic package, for RF testing.

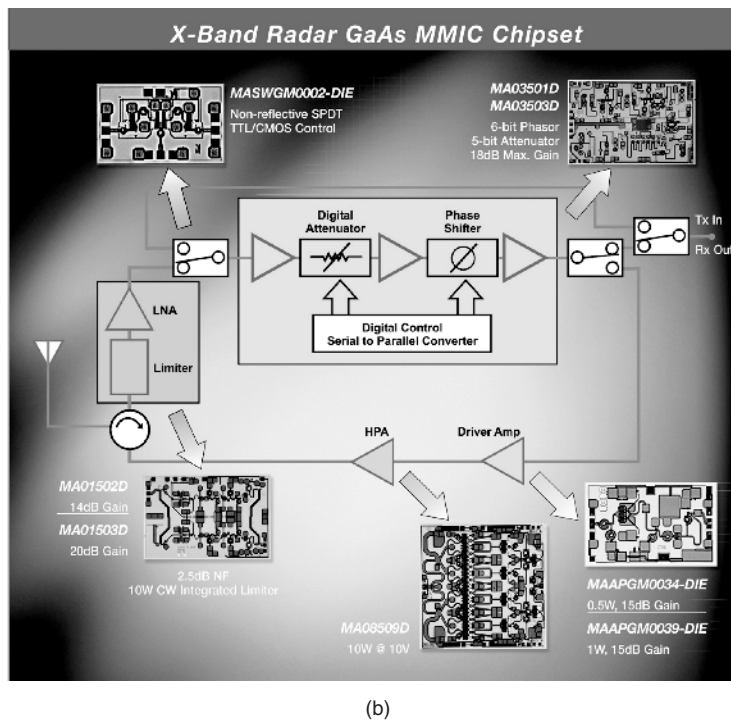
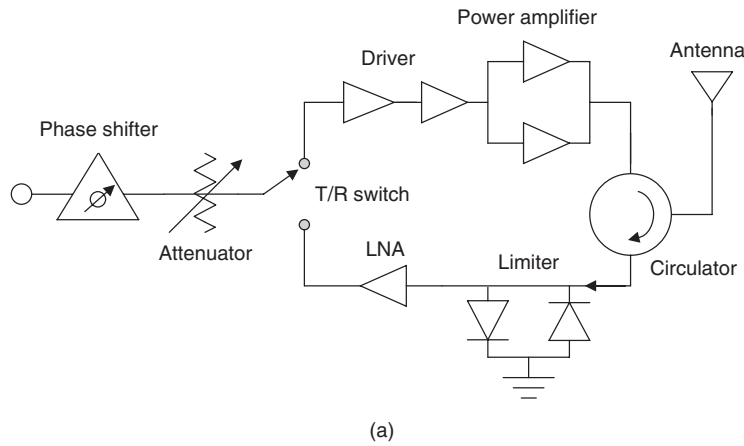


Figure 1.9 (a) A block diagram that illustrates the amplifier functions of a T/R module. (b) X-band radar GaAs MMIC chipset showing three amplifier chips: limiter/LNA, driver, and HPA and several buffer amplifiers used in the control chip for loss compensation.

the 800-MHz to 2.5-GHz range use different digital modulation and access schemes. They require high-efficiency and linear power amplifiers for hand-held as well as for base station applications.

There are several emerging commercial and military applications that require broadband and high-power amplifiers. These include broadband wireless access systems, communication, and electronic warfare.

Table 1.1 Percentage of Cost Split for Plastic and Ceramic Packaged Amplifiers

Item	Plastic	Ceramic
MMIC die	85	33
Package and assembly	5	58
Test	10	9

1.8 AMPLIFIER COST

The cost of an amplifier depends on its capability (power, PAE, noise figure, frequency, etc.), fabrication techniques, complexity (die, package, mechanical structure for support, etc.), and applications (low or high volume). Cost is first and foremost driven by manufacturing volume. Complex amplifiers in very high-volume commercial use cost less than relatively simple amplifiers with very little volume. One can buy low-noise and low-power amplifiers in plastic packages for as low as \$0.25–2.00, while high-power modules cost \$2000–5000. Microwave driver amplifiers (0.50–2 W) in die form or packaged sell for \$5–30. High-power (10–20 W) X-band MMIC amplifiers are available in the \$100–200 range in moderate quantities. RF and low microwave frequency range HPAs (100–200 W), with a mostly internally matched configuration, cost about \$100–200. Millimeter-wave frequency HPAs are still quite expensive because of low volume requirements.

The cost of low-power (1–2 W) amplifiers based on GaAs MMIC can approximately be split into three categories: die, package and assembly, and test yield. Table 1.1 provides an example of plastic and ceramic packaged amplifier costs. The cost model is based on several assumptions and represents production cost only. The end-to-end yield has been assumed to be 80%. Automation in fabrication, assembly, and testing in high-volume production greatly improves the product yield and final cost.

1.9 CURRENT TRENDS

Microwave and millimeter-wave transistor amplifiers have advanced dramatically. Si based CMOS technology circuits operating up to 70 GHz and GaAs/InP based technology operating up to 280 GHz have been realized. The Si LDMOS transistor is a primary power device for base station transmitters up to S-band frequencies. Devices such as pHEMTs and HBTs made on InP, SiC, and GaN substrate materials have performed beyond 100 GHz. SiC based GaN pHEMT technology has also advanced rapidly and is finding special application where high-power, high-efficiency, low-noise, broadband, and millimeter-wave operation are required. Extremely high-frequency circuits enable a wide range of new applications to be developed in communications, security, medicine, sensing, and imaging. Power amplifiers are vital components in evolving broadband wireless applications including TV broadcasting, voice over Internet protocol (VoIP), video on demand (VOD), online gaming, mobile streaming, and mobile video telephony.

Recently, SiC based transistors operating at 30–50 V have advanced rapidly. SiC MESFETs have increasing applications in high-power wideband at low microwave frequencies and GaN HEMTs on SiC are finding numerous applications where high-power and high-frequency operation is required. Much higher power densities for such devices

meet the current need in reducing the cost of solid state power amplifiers. Another emerging technology is GaN HEMT on SiC. This technology has the potential of meeting cost targets for numerous applications, including base station and radar transmitters. These devices are capable of generating hundreds of watts at C/X-band, tens of watts in the millimeter-wave region, and 1–2 W at 100 GHz. Since this technology has an order of magnitude higher breakdown voltage and power density potentials along with an outstanding thermal dissipation substrate, it has all the ingredients required for high-power amplifiers.

The RF and microwave industry is still growing and there is strong evidence that it is being fully supported to meet current trends. New high-volume applications demand low-cost solutions for transmitters based on transistor amplifiers. Current trends are in the areas of improved device models and integrated CAD tools. In a new competitive business environment, it is essential to have accurate device models and suitable circuit design tools to develop state-of-the-art circuits to meet system requirements, including cost and production schedule. It becomes essentially important for amplifier design engineers to develop amplifier products for specific applications on time. For emerging wideband applications that require very high-power (50–200 W) amplifiers with PAE as high as 50%, new circuit topologies to meet these challenging performance goals will be required.

There are continuous trends for improving the performance of LNAs and PAs in order to make them cheaper for high-volume applications. Thus advancements in RFIC and MMIC technologies and packaging will continue with the pace set in the past decade. For high-volume applications, a package (plastic or ceramic) has become an integral part of RFICs and MMICs for power amplifiers. Achieving the smallest size and cheapest product cost requires inexpensive and high-performance leadless surface-mount and ball-grid array packages. Plastic packaging is a preferred technique for small-signal amplifiers and more and more power devices are being housed in plastic packages. Low thermal resistance is another important requirement for such packages.

1.10 BOOK ORGANIZATION

The book primarily deals with the operating principles and design of RF and microwave transistor amplifiers. It is organized into four parts consisting of 22 chapters using a top–down approach. An overview of the chapters is shown in Figure 1.10. In the first part there are seven chapters dealing with the fundamentals of amplifier design. It includes network theory, amplifier definitions, transistor basics and their models, impedance matching elements, and matching techniques. The second part focuses on the design of amplifiers in six chapters. Each of the six chapters deals with important features of various amplifier types. Topics such as amplifier analysis, design methods, high-efficiency, broadband, and linearization techniques, and high voltage and high power are discussed in this part. The other amplifier topics such as manufacturing techniques, biasing, thermal and stability analyses, and power combining constitute the third part, which has six chapters. In the fourth part there are three chapters: two chapters deal with integrated function amplifiers and packages, and the final chapter is devoted exclusively to transistor and amplifier measurements. These chapters will also help in understanding the basic requirements of a successful amplifier design. In addition, several appendixes are included at the end that will be useful for RF and microwave designers.

14 Chapter 1 Introduction

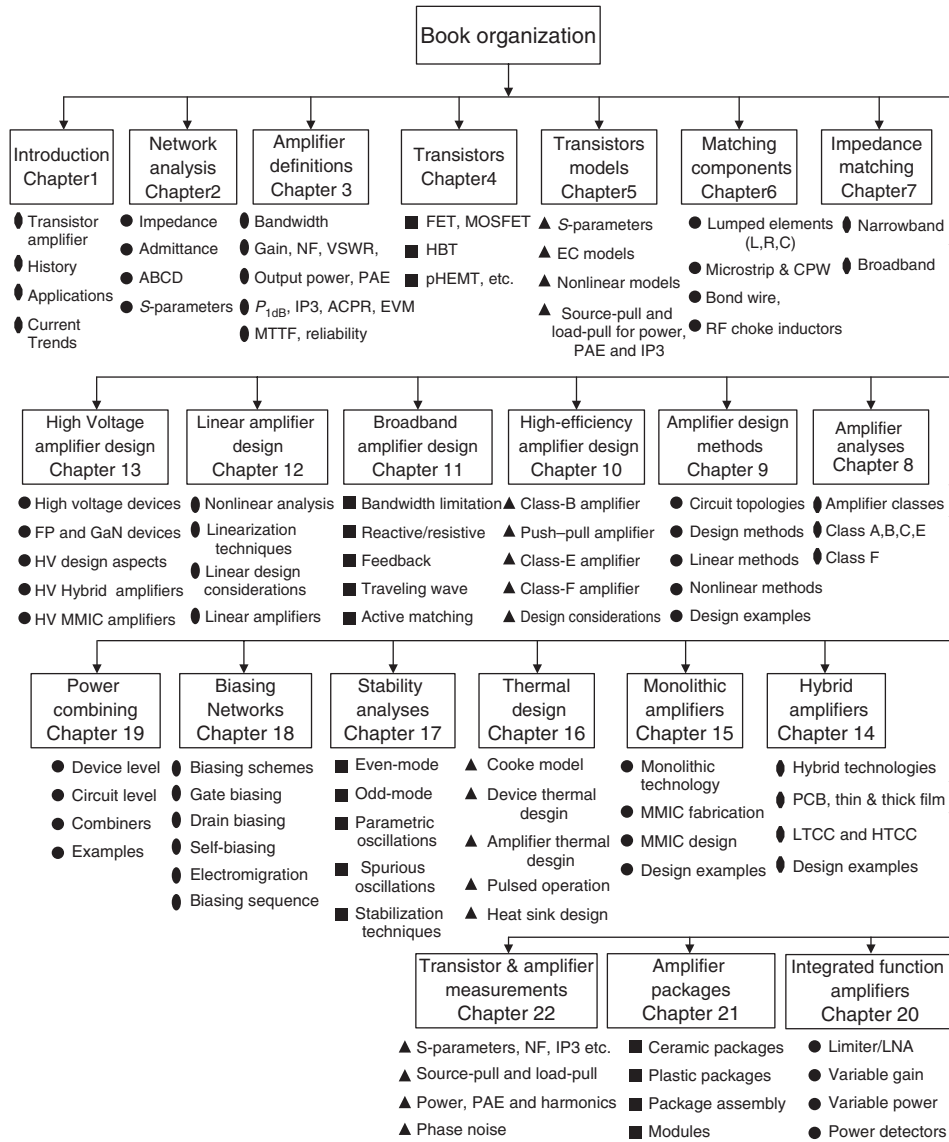


Figure 1.10 Book organization overview showing the connectivity between chapters.

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