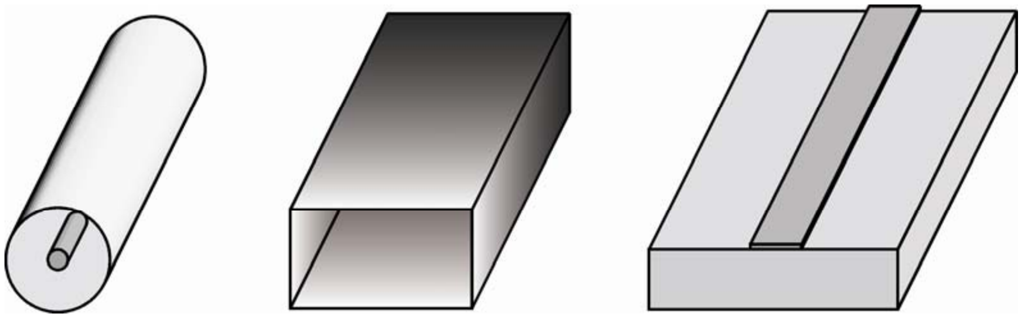
CHAPTER 1

Microwave Integrated Circuits

CHAPTER OUTLINE

1.1 CLASSIFICATION OF MICROWAVE INTEGRATED CIRCUITS

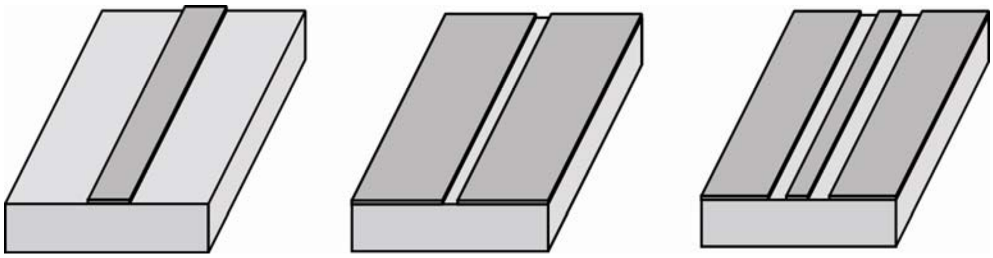
Active microwave circuit can be defined as a circuit in which active and passive microwave devices such as resistors, capacitors, and inductors are interconnected by transmission lines. At low frequencies, the transmission lines are a simple connection; however they are no longer just simple connections at microwave frequencies and their operation becomes a complicated distributed circuit element. Subsequently, microwave integrated circuit is classified based on the fabrication method of the transmission lines used for interconnection.



(a) (b) (c)

Figure 1.1 Some common transmission lines used in microwave circuits: (a) coaxial line (b) rectangular waveguide, and (c) microstrip line

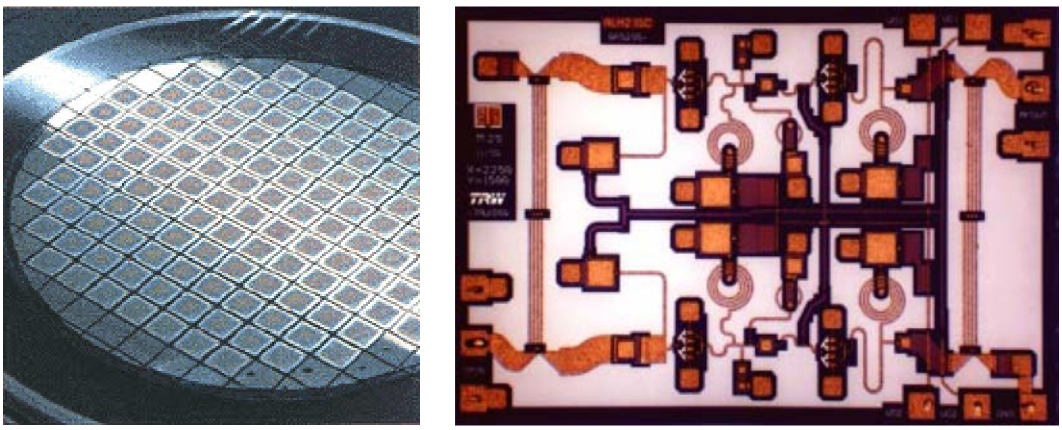
There are various types of transmission lines in microwave circuits. Common examples of transmission lines are waveguides, coaxial, and microstrip lines. Figure 1.1 shows the transmission lines used in microwave circuits. Although there are special cases of microwave integrated circuit composed of coaxial lines and waveguides, in most cases microwave circuit is integrated using planar transmission lines. Therefore, the content of this book is restricted to microwave circuits integrated using planar transmission lines; examples of which are microstrip, slot lines, and co-planar waveguide (CPW), as shown in Fig. 1.2. Such planar transmission lines are frequently employed in the large-scale production of microwave circuits and generally forms the basic transmission lines for microwave circuits. The following text explains how microwave integrated circuits are classified with planar transmission lines.



(a) (b) (c)

Figure 1.2 Some common planar transmission lines used in microwave circuits: (a) microstrip (b) slot line, and (c) CPW (CoPlanar Waveguide)

The implementation of planar transmission lines on substrates can be largely classified into the two groups of *monolithic* and *hybrid integrated circuits*. In monolithic Integration, active and passive devices as well as the planar transmission lines are grown *in situ* on one planar substrate which is usually made from semiconductor material and is called *wafer*.



(a) (b)

Figure 1.3 Monolithic integration: (a) wafer and (b) the single circuit on wafer[1]

[1] TRW Inc., ALH216C K-Band HEMT Low-Noise Amplifier, 1997

Figure 1.3 shows the example of monolithic integration. Figure 1.3(a) shows a photograph of the top side of a wafer and Fig. 1.3(b) showing a single monolithic circuit (the identical circuits are repeatedly produced on the wafer in Fig. 1.3(a)) containing active and passive devices and planar transmission lines. An advantage of the monolithic integration is that it is well suited for large-scale production, which leads to lower cost. The disadvantage is that it takes a long time to develop and fabricate, and a small-scale production results in highly prohibitive cost.

Hybrid integration is a fabrication method in which, the transmission lines are implemented by conductor patterns on a selected substrate with either *printing* or *etching*; and active and passive devices are assembled on the patterned substrate by either soldering or wire-bonding. In implementing transmission lines by conductor patterns on substrate, the substrate material as well as the conductor material for the transmission lines needs to be carefully considered because these to a large extent affect the characteristics of transmission lines. Hybrid integration is thus classified into three kinds based on the method by which the lines are formed on the substrate; namely *printed circuit board* (PCB), *thick-film* substrate, and *thin-film* substrate.

Figure 1.4 shows an example of how connection lines are formed on a PCB substrate. Both sides of the dielectric material are attached with a copper clad which is then etched to obtain the desired patterns. For PCB substrate materials, *epoxy-fiber-glass* (FR4), *teflon*, and *duroid* are widely used. FR4 substrate (that is a kind of epoxy-fiber-glass) can be used from lower frequencies to approximately 4 GHz, while the others such as teflon or duroid can be used up to the millimeter wave region, depending on their formation. Generally, all these materials lend themselves to soldering while wire-bonding as an integrated circuit assembly is typically, not widely used. Furthermore, compared with other methods which will be explained later, PCB can provide a lower cost; its fabrication is easy and takes a shorter time to produce. In addition, production on a small-scale is possible without the use of expensive assembly machines; it is easy to fix and could also be used on a large-scale production; and is thus widely used.

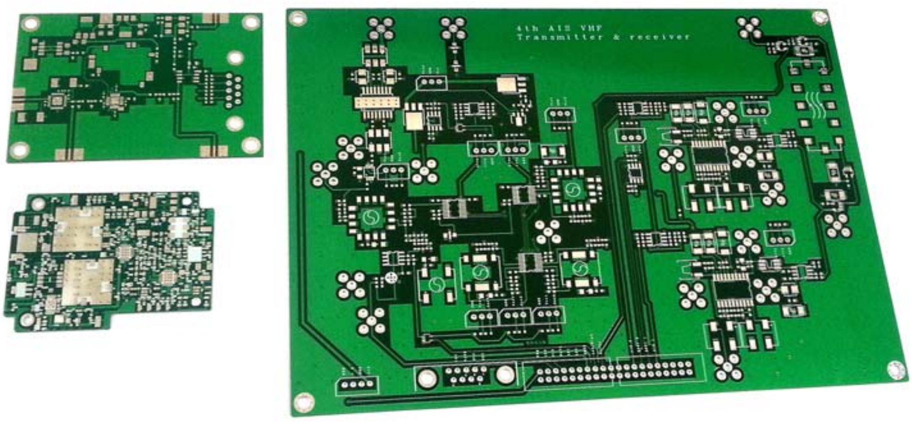


Figure 1.4 A photograph of PCBs

Thick films substrate are produced by screen printing techniques; in which conductor and dielectric patterns are printed using screen on ceramic substrates. The reason for naming it thick film is that, the patterns formed by such technique are generally much thicker than that formed using thin film techniques. As a benefit of using printing techniques, multiple printing is possible. Through the printing of dielectric materials, it is also possible to form capacitors. Due to the use of ceramic substrate which is more tolerant to heat, it is easy to assemble active devices in the form of chips. On the other hand, considering lines and patterns formed by this process, the pattern accuracy of thick film is inferior to some extent compared to thin film. The cost and development time, on case by case basis, could be seen to lie between those of PCB and thin film process. Figure 1.5 shows a photograph of an IC fabricated and assembled using thick film process.

Figure 1.5 A photograph of substrates fabricated by thick film process

Thin film technique is very widely used in the fabrication of microwave circuits for military and microwave communication systems. In the case of the thin film process, a similar ceramic substrate material used as in thick film is employed, but compared to thick film substrate; a fine surface-finish substrate is used. The most widely used substrate is 99% alumina (Al_2O_3). The pattern formation on the substrate is by photolithographic process, which can produce fine tracks of conductor patterns close to those in semiconductor process. As in the case of thick film, it is possible to assemble directly semiconductor chips and wire-bonding is primarily used in the assembly. Thin film compared to PCB and thick film, is more expensive, and due to the requirement of fine tracks, a mask fabrication is accompanied and the process generally takes a longer time. Passive components such as resistors and air-bridge capacitors are also possible with this process. Furthermore, integrated circuits produced by thin film require special wire bonders and micro-welding equipment for assembly. Compared to monolithic integration process, it tends to be cheaper in terms of the cost; however the thin film process tends to have large unknown and not precisely described parasitic circuit elements accompanied due to assembly such as wire bonding. Figure 1.6 is a photograph of thin film circuits fabricated by thin film technique.

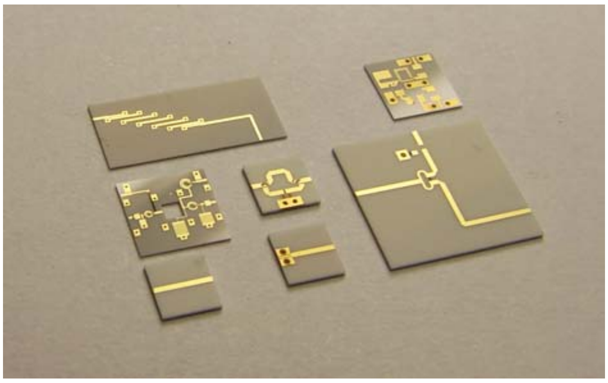


Figure 1.6 A photograph of substrates produced by thin film process

The choice of integration method depends on the application and situation, taking into account several factors that were mentioned before. For instance, factors such as, the operating frequency of integrated circuit, the forms of semiconductor components (chip or packaged), the forms of the passive components, large-scale fabrication costs, and method of assembly should all be considered in selecting the optimum method of integration.

1.2 MICROWAVE CIRCUITS IN COMMUNICATION SYSTEM

Integrated circuit classification has been discussed previously. Integrated circuit was found to be classified based on the method of implementing the planar transmission lines, for the purpose of connecting active and passive devices. The functions of integrated circuits vary greatly and the next matter has to do with which circuit designs are referred to. Examples of such circuits are low noise amplifier (LNA), power amplifier (PA), oscillator, mixer, directional coupler, switch, attenuator, filter and a host of other microwave integrated circuits. Among these, directional coupler, switches, attenuators, filters, etc are basically passive microwave circuits although they are very widely used. Thus, they are not covered in this book because they are considered to be outside the scope of the book. Furthermore, although components such as switches, variable attenuators, phase shifters and other control circuits are important and composed of semiconductor devices, they are generally not regarded as the basic building blocks of a wireless system. This book will therefore cover the basic design theory as well as devices related to these circuits such as amplifiers, oscillators and mixers, which are the most frequently used circuits to build wireless communication systems.

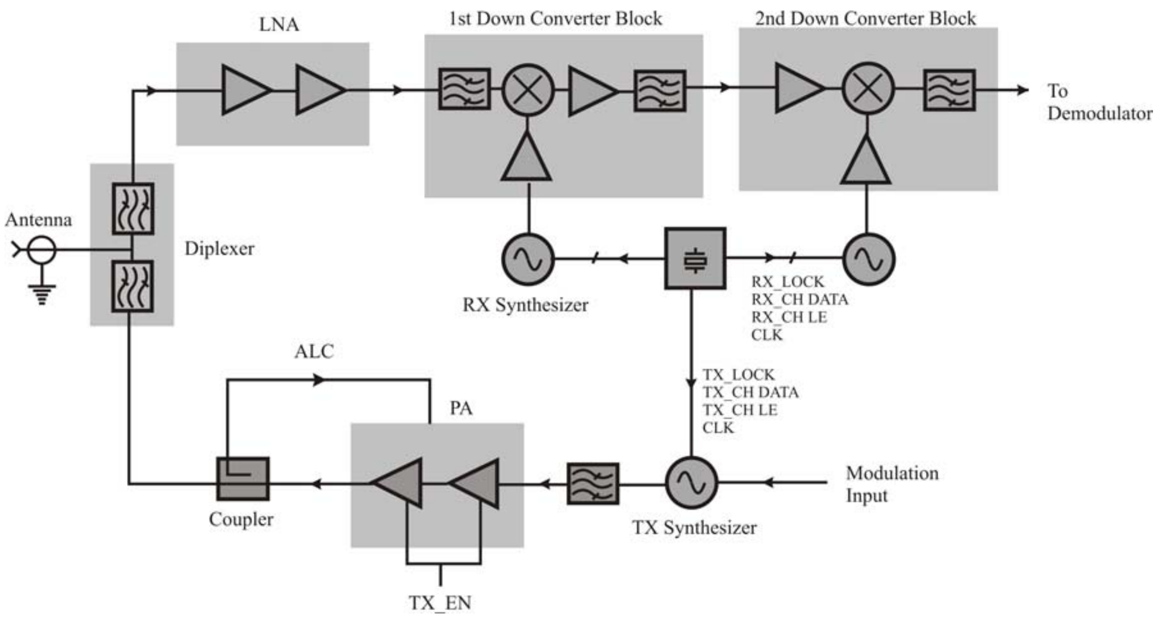


Figure 1.7 A block diagram of an analog mobile phone handset

Figure 1.7 is a block diagram of an analog cellular phone handset. This block diagram represents also a general transceiver for the transmission and reception of analog signal (usually voice). Weak RF signals received from the antenna first go through a filter called a diplexer and the signal in the receiver frequency band is filtered. The filtered signal is too weak for demodulation or signal processing, and an amplifier called low noise amplifier is required to amplify the signal. Next, because the signal frequency is so high, the mixer shown in Fig. 1.7 translates the carrier frequency to a lower frequency band called IF (Intermediate Frequency). Multiples of other signals generally coexist with the signal in the IF. In order to select the desired signal (usually called the channel) from the multiples of other signals or to filter out possible spurious signals that presents at the mixer output, the signal is passed through a narrow band bass filter that has a bandwidth of about the signal bandwidth. Note that the mixer requires the input signal from a *local oscillator* (LO) for the translation of the signal frequency to the IF. The LO frequency is generally synthesized using *phase locked loop* (PLL). The IF signal is then passed through a demodulator for the recovery of the original signal.

In the transmission operation, the input signal goes to the modulation input of transmitting VCO, and the signal is modulated to have the desired carrier center frequency that is similarly synthesized by PLL technique, which results in *frequency modulated* (FM) signal. The modulated signal is then pass through the band pass filter to filter out unnecessary spurious. The average output power level of the modulated signal is generally low; thus in order to obtain the desired RF power output level, the signal needs to be amplified by a power amplifier (PA). The signal is then passed through a diplexer, without affecting the receiver, and radiated via the antenna.

It could thus be inferred that, the key circuits in building a communication system are low noise amplifier, power amplifier, oscillators and mixers. Therefore, this book will address the design and evaluation method of these circuits and the detailed discussion of these will be covered.

1.3 SUMMARY

Among active microwave circuits, the most commonly used are amplifiers, oscillators, and mixers, and their fabrication can be classified into monolithic and hybrid integration. In hybrid integration, the lines used for interconnection is implemented on a separate substrate, and on this, active and passive devices are assembled. Based on the fabrication method of the substrate, hybrid integration can be further classified into integrations based on PCB, thick film, and thin film. In the selection of integration, one cannot be said to be superior to the other; the choice is made depending on the application and given situation, and taking into consideration several other factors.

REFERENCES

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[3] K. C. Gupta, *Microstrip lines and slot lines*, 2nd edition Artech House 1996.