## 5.1 Microwave filter Design

Filter is a two-port network used to control the frequency response at a certain point in an RF or microwave system by providing transmission at frequencies within the passband of the filter and attenuation in the stopband of the filter. Typical frequency responses include low-pass, high-pass, bandpass, and band-reject characteristics. Applications can be found in virtually any type of RF or microwave communication, radar, or test and measurement system.

filter theory and design with the frequency characteristics of periodic structures, which consist of a transmission line or waveguide periodically loaded with reactive elements. These structures are of interest in themselves because of their application to slow-wave components and traveling-wave amplifier design, and also because they exhibit basic passband-stopband responses that lead to the image parameter method of filter design. Filters designed using the *image parameter method* consist of a cascade of simpler twoport filter sections to provide the desired cutoff frequencies and attenuation characteristics but do not allow the specification of a particular frequency response over the complete operating range. Thus, although the procedure is relatively simple, the design of filters by the image
parameter method often must be iterated many times to achieve the desired results.

A more modern procedure, called the *insertion loss method*, uses network synthesis techniques to design filters with a completely specified frequency response. The design is simplified by beginning with low-pass filter prototypes that are normalized in terms of impedance and frequency. Transformations are then applied to convert the prototype designs to the desired frequency range and impedance level. Both the image parameter and insertion loss methods of filter design lead to circuits using lumped elements (capacitors and inductors). For microwave applications such designs usually must be modified to employ distributed elements consisting of transmission line sections. The *Richards transformation* and the *Kuroda identities* provide this step.

## FILTER DESIGN BY THE IMAGE PARAMETER METHOD

The image parameter method of filter design involves the specification of passband and stopband characteristics for a cascade of simple two-port networks. The method is relatively simple but has the disadvantage that an arbitrary frequency response cannot be incorporated into the design. This is in contrast to the insertion loss method. The image parameter method also finds application in solid-state traveling-wave amplifier design.

## FILTER DESIGN BY THE INSERTION LOSS METHOD

A perfect filter would have zero insertion loss in the passband, infinite attenuation in the stopband, and a linear phase response (to avoid signal distortion) in the passband. Of course, such filters do not exist in practice, so compromises must be made; herein lies the art of filter design.

The insertion loss method, however, allows a high degree of control over the passband and stopband amplitude and phase characteristics, with a systematic way to synthesize a desired response. The necessary design trade-offs can be evaluated to best meet the application requirements. If, for example, a minimum insertion loss is most important, a binomial response could be used; a Chebyshev response would satisfy a requirement for the sharpest cutoff. If it is possible to sacrifice the attenuation rate, a better phase response can be obtained by using a linear phase filter design. In addition, in all cases, the insertion loss method allows filter performance to be improved in a straightforward manner, at the expense of a higher order filter. For the filter prototypes to be discussed below, the order of the filter is equal to the number of reactive elements.

### Power Loss Ratio:

*In the insertion loss method a filter response is defined by its insertion loss, or power loss ratio, PLR*

$$P_{\mathrm{LR}} = \frac{\text{Power available from source}}{\text{Power delivered to load}} = \frac{P_{\mathrm{inc}}}{P_{\mathrm{load}}} = \frac{1}{1-|\Gamma(\omega)|^2}.$$

## 5.2 Microwave Amplifier Design

Power amplifiers are used in the final stages of radar and radio transmitters to increase the radiated power level. Typical output powers may be on the order of 100–500 mW for mobile voice or data communications systems, or in the range of 1–100 W for radar or fixed point radio systems. Important considerations for RF and microwave power amplifiers are efficiency, gain, intermodulation distortion, and thermal effects. Single transistors can provide output powers of 10–100 W at UHF frequencies, while devices at higher frequencies are generally limited to output powers less than 10 W. Various power-combining techniques can be used in conjunction with multiple transistors if higher output powers are required.

So far we have considered only small-signal amplifiers, where the input signal power is low enough that the transistor can be assumed to operate as a linear device. The scattering parameters of linear devices are well defined and do not depend on the input power level or output load impedance, a fact that greatly simplifies the design of fixed-gain and lownoise amplifiers. For high input powers (e.g., in the range of the 1 dB compression point or third-order intercept point), transistors do not behave linearly. In this case the impedances seen at the input and output of the transistor will depend on the input power level, and this greatly complicates the design of power amplifiers.

### Characteristics of Power Amplifiers

The power amplifier is usually the primary consumer of DC power in most hand-held wireless devices, so amplifier efficiency is an important consideration. One measure of amplifier efficiency is the ratio of RF output power to DC input power:

This quantity is sometimes referred to as drain efficiency (or collector efficiency). One drawback of this definition is that it does not account for the RF power delivered at the input to the amplifier. Since most power amplifiers have relatively low gains, the efficiency tends to overrate the actual efficiency. A better measure that includes the effect of input power is the power added efficiency, defined as

$$\eta_{PAE} = \mathrm{PAE} = \frac{P_{\mathrm{out}} - P_{\mathrm{in}}}{P_{\mathrm{DC}}} = \left(1 - \frac{1}{G}\right)\frac{P_{\mathrm{out}}}{P_{\mathrm{DC}}} = \left(1 - \frac{1}{G}\right)\eta,$$

where G is the power gain of the amplifier. Silicon bipolar junction transistor amplifiers in the cellular telephone band of 800–900 MHz band have power added efficiencies on the order of 80%, but efficiency drops quickly with increasing frequency. Power amplifiers are often designed to provide the best efficiency, even if this means that the resulting gain is less than the maximum possible.

Another useful parameter for power amplifiers is the compressed gain, G1, defined

as the gain of the amplifier at the 1 dB compression point. Thus, if G0 is the small-signal (linear) power gain, we have

$$G_1(\mathrm{dB}) = G_0(\mathrm{dB}) - 1.$$

As we have seen in Chapter 10, nonlinearities can lead to the generation of spurious frequencies and intermodulation distortion. This can be a serious issue in wireless transmitters, especially in a multicarrier system, where spurious signals may appear in adjacent channels. Linearity is also critical for nonconstant envelope modulations, such as amplitude shift keying and higher order quadrature amplitude modulation methods.

## Design of Class A Power Amplifiers

Since class A amplifiers are ideally linear, it is sometimes possible to use small signal scattering parameters for design, but better results are usually obtained if large signal parameters are available. As with small-signal amplifier design, the first step is to check the stability of the device. Since instabilities begin at low signal levels, small-signal scattering parameters can be used for this purpose. Stability is especially important for power amplifiers, as high-power oscillations can easily damage active devices and related circuitry. The transistor should be chosen on the basis of frequency range and power output, ideally with about 20% more power capacity than is required by the design. Silicon bipolar transistors have higher power outputs than GaAs FETs at frequencies up to a few GHz, and are generally cheaper; GaN HBTs are becoming very popular for high-power applications at RF and low microwave frequencies.