An IFA antenna does not provide a lot of design freedom, so it is mostly used in single-band applications, such as GPS, BT, or WiFi. Although an IFA antenna is similar to an L antenna with a shunt matching inductor, there is a minor difference. Because the active length of an L antenna starts from the feeding point, it can be designed to be smaller than an IFA antenna. An L antenna also requires a smaller area on the PCB, because it only needs one contact pad. The drawback of an L antenna is that the lumped matching inductor it requires has some inherent losses, thus the efficiency of an L antenna is normally a few tenths of dB lower than an IFA antenna's. If there is enough board area for two pads, one for grounding and one for feeding, an IFA antenna is a better choice, as it provides better efficiency and also saves a matching component, which costs a few pennies.

4.2 Planar Inverted-F Antenna (PIFA)

4.2.1 Single Band PIFA

Shown in Figure 4.10 is a planar inverted-F antenna (PIFA). PIFA antennas can be thought of as a mutation of IFA antennas. Both IFA and PIFA antennas have a ground strip and a feeding strip. By replacing the radiating strip of an IFA antenna with a patch, we get a PIFA antenna. In most cases, the patch of a PIFA antenna is above the ground plane.

In all the following samples in this section, the width of both feeding and grounding strip is 1 mm; the dimension of PCB, which is used as the ground, is

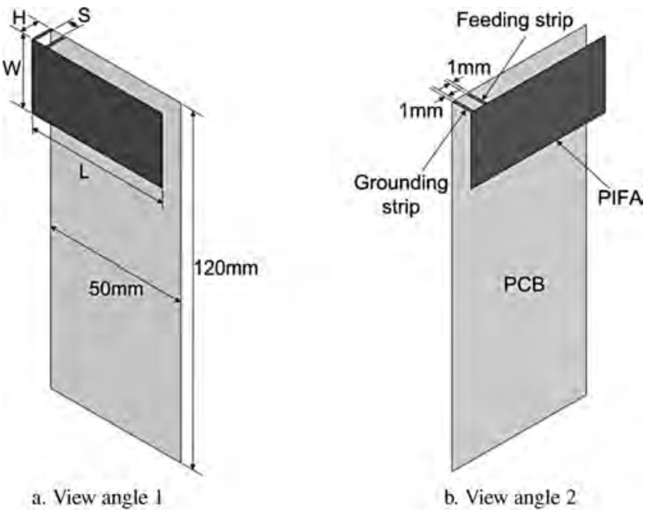

Figure 4.10 PIFA antenna

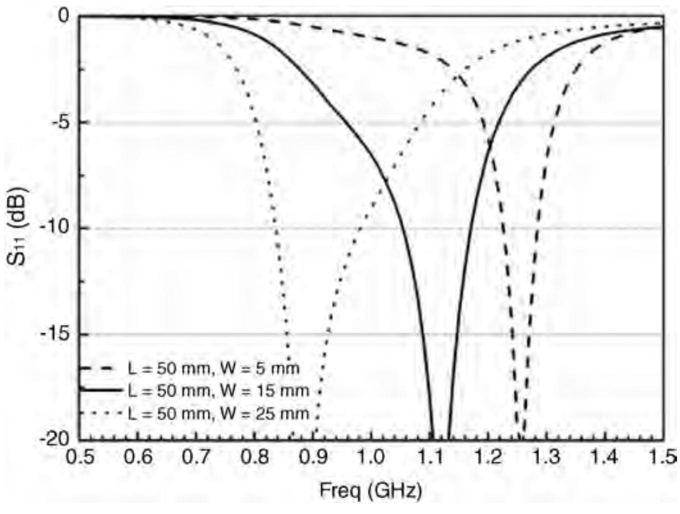

Figure 4.11 Three PIFA antennas with different widths H = 7 mm

50 mm*120 mm. If the PCB size is changed, the antenna response will change accordingly. The ground's impact on a PIFA antenna is the same as that on an external antenna. Refer to Section 3.4 for further details.

In Figure 4.10, the dimension H is the distance between a patch and a ground. The S is the edge-to-edge distance between feeding and grounding strips. Similar to IFA antennas, the matching of antennas can be tuned by adjusting S.

Let's start with single-band PIFA antennas. Shown in Figure 4.11 are simulated results of three PIFA antennas. The dimension L of all three antennas is 50 mm, which is the same as the PCB width. The dimension W of three antennas is 5 mm, 15 mm, and 25 mm respectively. To best match individual antennas, the dimension S, the distance between feeding and ground strips, is tuned case by case. The optimal S for 5 mm, 15 mm, and 25 mm patches are 1.5 mm, 4 mm, and 4 mm respectively. When the W is 5 mm, the antenna is more like an IFA than a PIFA. With the increase in W, the resonant frequency of a PIFA antenna decreases. This phenomenon gives us a hint that, unlike an IFA antenna, the resonant frequency of a PIFA antenna is not solely decided by the patch's length.

For a PIFA antenna, the resonant frequency is proportional to the summary of its length and width. As shown in Figure 4.12, a PIFA's width plus its length is roughly a quarter of a wavelength at its resonant frequency.

When discussing a single band PIFA antenna, most books prefer to give a current distribution which shows two clear current flows. Both of them start from the upper-left corner and end at the bottom-right corner. One of them passes the bottom-left corner and the other one passes the opposite top-right corner. That is a quite intuitive but coarse simplification. The real current distribution is a little more complex than

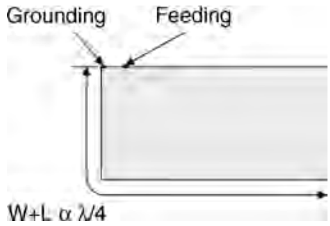

Figure 4.12 Estimating the resonant frequency of a PIFA

that. In many cases it is difficult to see a clear current pattern when you simulate a PIFA antenna.

Shown in Table 4.1 is a comparison between three antennas. The second column in Table 4.1 is the calculated resonant frequencies based on the assumption that W + L equals to a quarter of wavelength. The third column is the actual frequency. The fourth column is the ratio between the calculated frequencies and the actual ones. The actual resonant frequency of a patch is normally lower than the theoretical one. That is due to the loading effect of the edge capacitance between patch and ground.

The critical parameter, which controls the bandwidth of a PIFA antenna, is H, the distance between a patch and a ground. Shown in Figure 4.13 are the reflection coefficients of three antennas with different heights. All patches have the same L and W, which are 50 mm and 25 mm respectively. The H of three patches is 5 mm, 7 mm, and 9 mm respectively. All three antennas are individually tuned, their S are 3 mm, 4 mm, and 7 mm accordingly. By increasing the H from 5 mm to 9 mm, an antenna's −10-dB bandwidth is almost tripled.

As a summary, there are three design guidelines for single band PIFA:

- The dimension H is the most critical parameter which decides an antenna's overall performance. However, because H is directly related to a device's thickness, it is a tough task to bargain about it with industry design engineers or mechanical engineers. If there is only a 5 mm height clearance and a quad-band GSM antenna is required, then PIFA is not an appropriate candidate. A folded monopole antenna, discussed in Section 4.3, is a better choice.

Table 4.1 Accuracy of simplified frequency calculation formula

	Calculated Freq. (GHz) $\lambda/4 = (W + L)$	Actual Freq. (GHz)	Actual Freq./Calculated Frequency
W = 5 mm, L = 50 mm	1.36	1.26	0.92
W = 15 mm, L = 50 mm	1.15	1.12	0.97
W = 25 mm, L = 50 mm	1.00	0.89	0.89

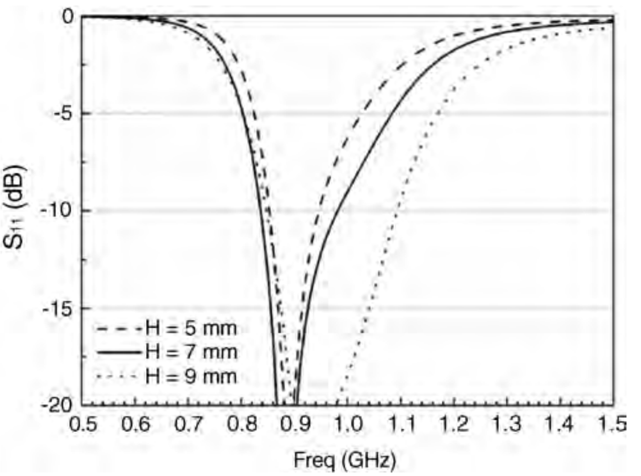

Figure 4.13 PIFA antenna's bandwidth vs. height. L = 50 mm, W = 25 mm

- By adjusting the total length W + L, the antenna's working frequency can be tuned. In practice, the L should be similar to the PCB's width that results in wider bandwidth.
- The dimension S is the tuning parameter which optimizes an antenna's matching. One can either use a wider strip with a larger S or a narrower strip with a smaller S to achieve the same matching. A larger S is better for manufacturing, because a fixed process tolerance causes less electrical variance in the antenna. From a mechanical point of view, a narrower strip is better for spring finger type of designs, because it is more flexible and it is easier to achieve the required spring force.

4.2.2 Multi-Band PIFA Antenna with Slits

If you have already discovered PIFA antennas, then you might find that the following explanation is somewhat different from other books. All versions of PIFA explanations are partially correct, including the following version. As a PIFA antenna is a distributed radiating system, too many parameters play a role in deciding the antenna's characteristic. To explain such a complex matter, one has to substantially simplify it and that is the reason for the different explanations.

There are several ways to design a multi-band PIFA antenna. The most popular way is to cut slits on the patch, as shown in Figure 4.14. Similar to a single band PIFA antenna, a dual-band PIFA antenna also has a grounding strip and a feeding strip. Two critical dimensions, D and C, are used here to describe the slit. The dimension D is the distance between the patch's corner and the opening of the slit. The dimension C is the slit's length. The dimension P is the distance between the horizontal part of

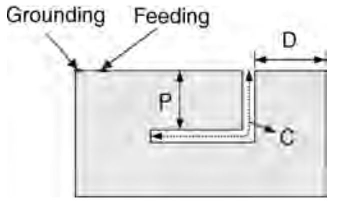

Figure 4.14 Dual-band PIFA antenna

slit and the edge of patch. The P is not really a critical dimension, however, it decides the shape of the slit.

Shown in Figure 4.15 are the decisive paths of different bands. Figure 4.15 only serves the purpose of predicting the trends of frequency shifting when different dimensions are adjusted. One should not try to use the illustrated critical path shown in Figure 4.15 as a way of calculating a patch's resonant frequency. In reality, trying to predict a patch's resonant frequency with a calculator is not really an efficient design approach. There are always so many unknown parameters, such as the permittivity of both the antenna support and the phone cover, the electrical property of nearby objects, and so on. Usually, all these unknowns can make the theoretical calculation far removed from the correct answer. A better approach is to memorize the effect of each parameter first, then make a PIFA with a piece of copper tape, install it on a mock-up phone, cut a slit on the PIFA, and tune it by trial and error.

The impacts of the two critical dimensions are listed below:

- The distance D can affect the resonant frequency of both the lower and the higher bands. It always shifts two bands in the opposite directions. For example, if we decrease D, the critical path of the lower band will be shorter, thus increasing its resonant frequency. In the meantime, the critical path of the higher band is increased, thus inducing a lower resonant frequency.
- The slit's length C only influences the higher band. The slit is about half the total critical path of the higher band. Increase C can lower the high band.

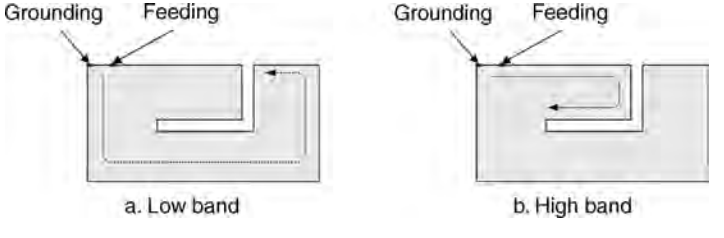

Figure 4.15 Decisive paths of different bands

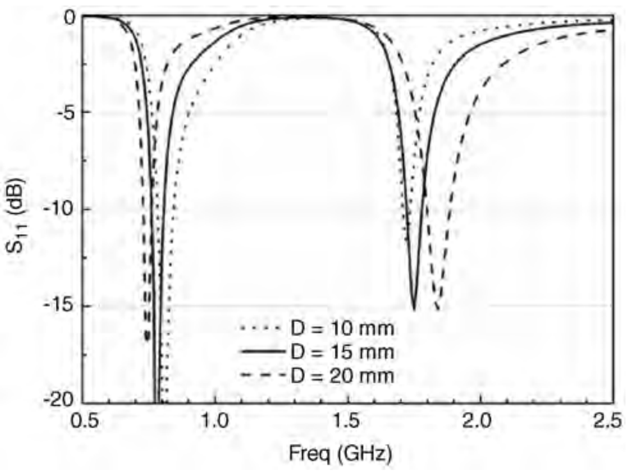

Figure 4.16 Impact of dimension D. 50 mm*25 mm Patch, P = 15 mm, C = 40 mm

Of course, in the real world, the effect of any dimension change cannot be exclusively constrained in a single band. In fact, it is safer to claim that it has more impact on some bands than others. To help understand the design rules, the following design examples are provided. In all the following examples, the area of patch is 50 mm*25 mm; the area of ground is 120 mm*50 mm. H, which is the distance between ground and patch as shown in Figure 4.10, is 7 mm. The impact of D is illustrated in Figure 4.16. By adjusting D, both low and high resonances frequency can be tuned simultaneously and in opposite directions.

Illustrated in Figure 4.17 are the impacts of slot length C. With the increase of a slot's length, the resonant frequency of higher band decreases. It can be seen that the resonant frequency at the lower band still drifts a little bit. For all three cases shown in Figure 4.17, the dimension P is fixed, the modification of C is realized by only increasing or decreasing the length of the horizontal portion of the slit.

Shown in Figure 4.18 are the results when the dimension P is changed while keeping the slit length C fixed. Although not significantly, the dimension P also has some impact on the higher band. It can be used in some circumstance as a means to provide the "extra mile" for tuning.

Shown in Figure 4.19 are the radiation patterns of a PIFA antenna. At the low band, which is 0.78 GHz in this case, the radiation pattern is similar to a dipole's. The radiation is mostly generated by the vertical current along the edge of the ground plane. The vertical polarized field E_θ is the dominant field component. At the higher band, which is 1.75 GHz, the amplitudes of E_θ and E_φ are in the same order of magnitude. Shown in Figure 4.19e is the radiation pattern of the total E field at 1.75 GHz. It confirms again that it is the ground plane, instead of the antenna element itself, which definitively decides the radiation patterns.

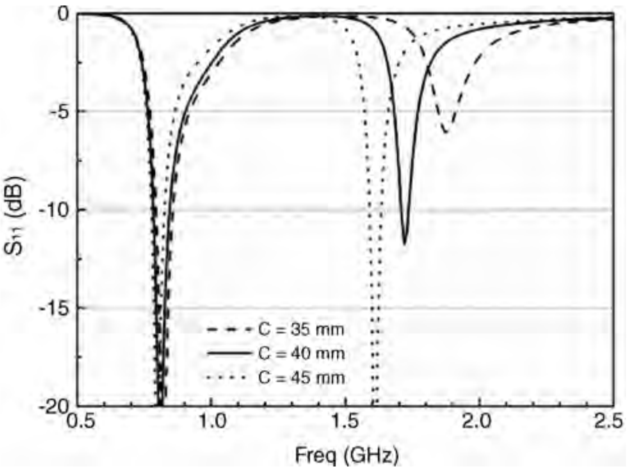

Figure 4.17 Impact of dimension C. 50 mm*25 mm Patch, P = 15 mm, D = 10 mm

When designing any kind of antenna, antenna engineers may find themselves in a situation where one band has more than enough bandwidth but the other band cannot meet the specification. Knowing how to exchange bandwidth between bands is an essential technique. For a PIFA antenna, cutting the slit shape differently can have some effect on the bandwidth ratio between bands. The other way to change the ratio is by adjusting the slit's width. Shown in Figure 4.20 are the simulated results of three PIFA antennas with the same dimensions but different slit widths. With the decrease

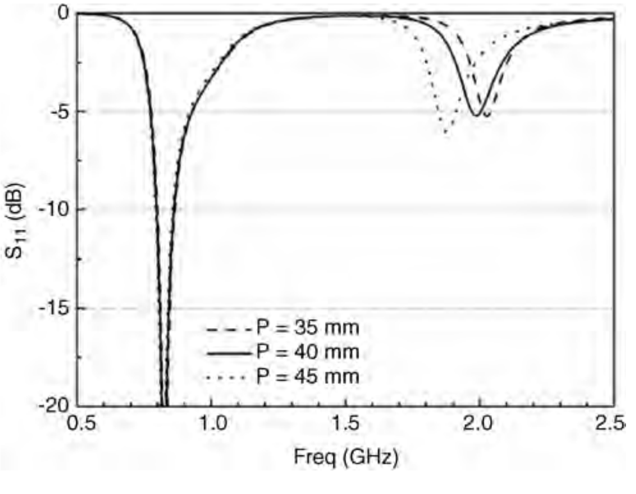

Figure 4.18 Impact of dimension P. 50 mm*25 mm Patch, C = 35 mm, D = 10 mm

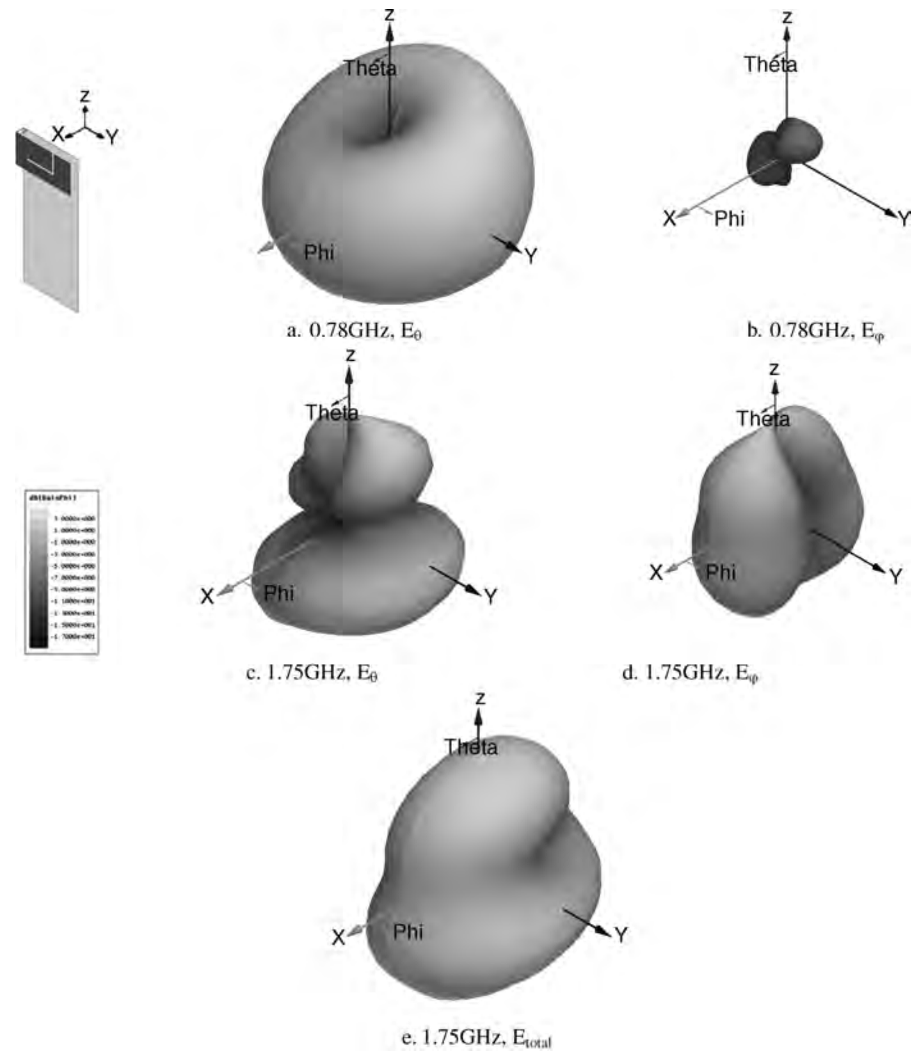

Figure 4.19 Radiation patterns of PIFA antenna, P = 15 mm, D = 15 mm, C = 40 mm

in the slit's width, the bandwidth increases at the lower band and decreases at the higher band.

If an antenna still cannot meet the specification after the performance of both bands have been balanced, the only way out is to attempt to increase the patch's height, which is the dimension H shown in Figure 4.10a. This definitely is an uphill battle.

So far, we have shown how to adjust both bands simultaneously or modify the high band independently. By combining both methods, we can tune the resonances freely in a quite wide range. Now let's discuss some matching techniques. The easiest way

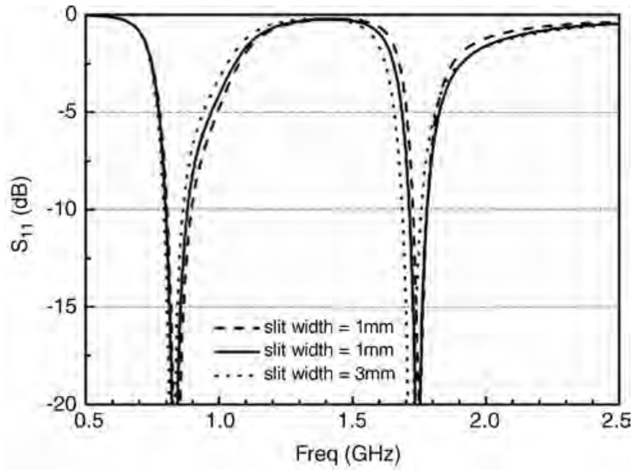

Figure 4.20 Bandwidth trade-off between low and high bands

to match an antenna is to design a matching circuit. However, a matching circuit always has some inherent loss. For a patch antenna, some of the dimensions can be modified, so we should always try to achieve a good match by tweaking the patch itself first. By comparing Figures 4.16 and 4.17, we can see that there are different ways to cut the slit to achieve two required resonant frequencies, and their matching conditions are also different.

Besides the patch itself, another useful tuning mechanism is the feeding and grounding structure. Shown in Figure 4.21 is the equivalent circuit of feeding and grounding strips. The grounding strip is equivalent to a shunt inductor, so it has more

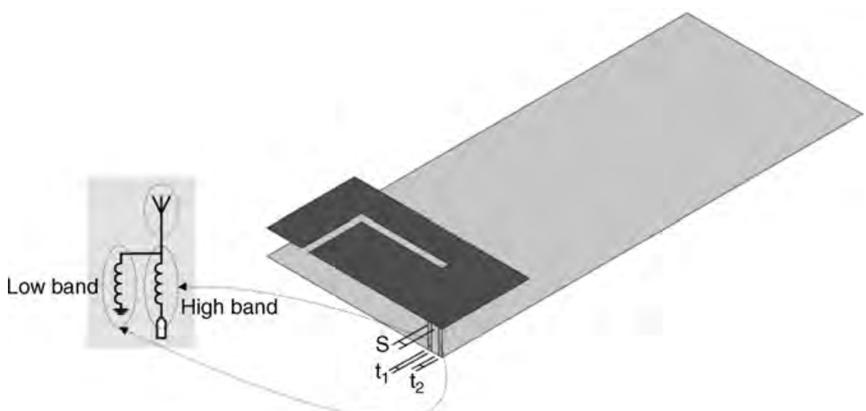

Figure 4.21 Equivalent circuit of feeding and grounding strips

impact on the lower band. The feeding strip is equivalent to a series inductor, and it can be used to tune the high band. To increase the inductance of grounding strip, the following methods can be used:

- Increase the length of grounding strip by bending the strip.
- Decrease the width of grounding strip, t_2.
- Increase the distance between feeding strip and grounding strip, S.

Similarly, the inductance of feeding strip can also be increased by increasing the length or decreasing the width of the strip. Shown in Figure 4.22 are two other ways of matching. Figure 4.22a shows how to use the slit to increase the shunt inductance. Figure 4.22b shows how to add some distributed shunt capacitance. Another effect of the stub shown in Figure 4.22b is to increase the total current length, thus decreasing the overall resonant frequency. If you have a brainstorming session on this topic, lots of matching structures can be invented. Where should we stop and hand over the remaining tasks to lumped matching element? There is no right or wrong answer to this question. Normally it is a purely personal choice. Some engineers prefer a self-matched design without requiring any lumped components. Many of those engineers treat antenna design as an art. Some engineers like to reuse previous designs and want to push dimension changes to the minimum. For them, a matching circuit is the favorite choice.

Putting the personal preference aside, there are some objective criteria that can be used to evaluate any antenna design. How sensitive is a design to manufacturing tolerance? What kind of manufacturing process can it use? Is a design easy to be tuned when frequency drifts? Does frequency tuning require expensive and time-consuming tooling modifications? What is the efficiency of an antenna?

It is not difficult to imagine that the weight of each criterion varies from project to project. For a low-end phone, cost might be the first consideration. For a high-end phone, it is most likely that all physical constraints have been pushed to the limit, the only goal for an antenna engineer is to meet the specification at any cost. The duration of a project is also an important factor when selecting different approaches. In fact,

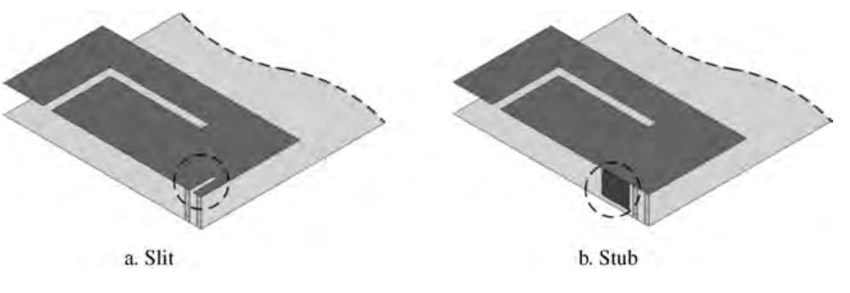

Figure 4.22 Other ways of matching

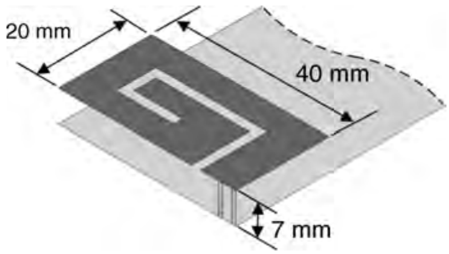

Figure 4.23 A small PIFA

most issues mentioned here are not academic at all, they are purely practical matters. Section 4.2.5 is dedicated to this topic.

Referring to Figure 4.15, if the patch size gets smaller, to maintain the resonant frequency at the lower band, the opening of the slit needs to be moved closer to the feeding point, and the slit must be routed through the other direction. Shown in Figure 4.23 is an example of such a small PIFA. The rules for tuning the small PIFA antenna shown in Figure 4.23 are pretty much the same as that shown in Figure 4.15. The critical dimensions are the slit's length and the opening position of a slit. The length of the slit has more impact on the higher band, while the slit's open position affects both bands.

Shown in Figure 4.24 are the simulated results of a small PIFA antenna when the slot length varies. By decreasing or increasing the slot length by 2 mm, the resonant frequency at a higher band is shifted up or down by around 35 MHz respectively. Meanwhile, the lower band response is relatively immune to those changes.

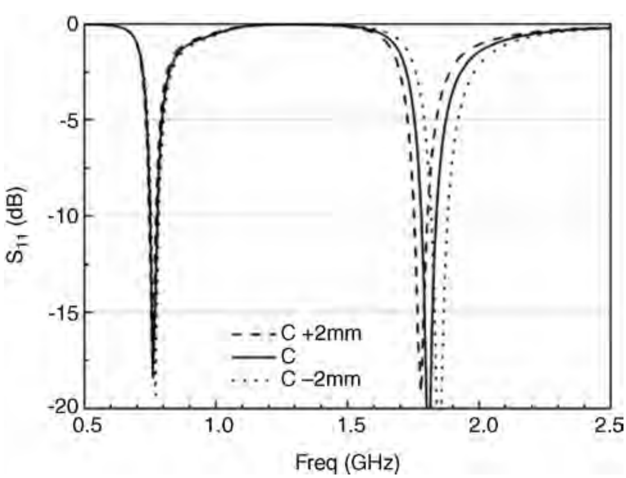

Figure 4.24 A small PIFA: slot length variations

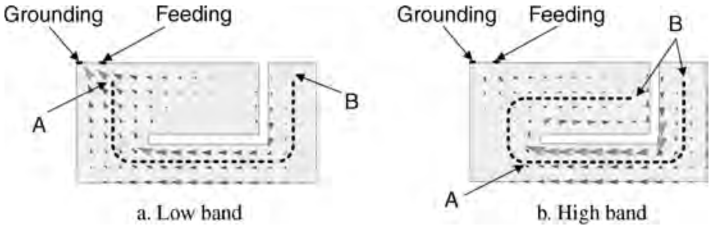

Figure 4.25 Current distributions of a "normal" PIFA

So far we have discussed how to design and tune a PIFA antenna. The topic of current modes on a patch has deliberately been avoided in order to minimize confusion in the first stage of learning. Although the current distribution on a patch can provide a very useful insight on how different patches work, it frequently makes a new engineer confused about how to tune a PIFA antenna. Of course, if we want to make some innovation in the field of antennas, current modes is a topic we must discuss.

The current distributions of a "normal" PIFA antenna at both low and high bands are illustrated in Figure 4.25. The dashed lines in Figure 4.25 are the significant paths. At the low band, the current distribution along the critical path is more like a quarter-wavelength monopole. The current reaches its maximum at point A, which is around the feeding point. At point B, the current decays to zero.

In the high band, the current is more like a dipole along the critical path. It has the maximum in the middle, which is marked by point A. At both ends, which are marked as point B, the current decays to zero. As we know, a monopole antenna is not able to resonate when the antenna length is half of an effective wavelength, because its port impedance is too high to be matched. On the other hand, unlike a monopole, which is fed from one end of a radiator, a high-band patch mode is accessed from the middle, which explains why it has a decent impedance matching.

Although with regards to antenna tuning, a "normal" PIFA and a "small" PIFA are quite similar, their current distribution is totally different. Shown in Figure 4.26 are current distributions of a "small" PIFA antenna. The critical current paths of a "small"

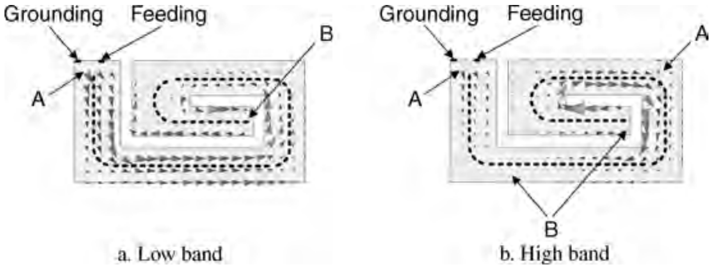

Figure 4.26 Current distributions of a "small" PIFA

PIFA antenna at both bands are the same. At the lower band, the current along the critical mode is similar to a monopole, which has the peak current at point A and zero at point B. At the higher band, the total critical path corresponds to the third order mode, which is three-quarter wavelength. There are two peak current spots and two zero current spots. One might wonder, should the resonant frequency of the third order mode be three times its basic mode? To explain that, we need to recall the technique we discussed in Section 3.1.2.2. There, by adjusting the pitch of a helix, the resonant frequency of the third order mode can be tuned in a wide range. Similarly, the third order mode of a "small" PIFA antenna can also be tuned to where we want.

Although mathematical formulas are given in many papers or books to calculate resonant frequencies of different bands, sometimes we do not need them. There are so many unknowns when designing an antenna for a real device, no formula can give an accurate prediction. The best way is to find out what the effect of each parameter is, then tune the antenna accordingly.

4.2.3 Multi-Band PIFA with Separate Branches

When the antenna area is big enough, a better design approach is to use two independent branches to cover low and high bands separately. The antenna shown in Figure 4.27a is such an example. The antenna's size is 60 mm*25 mm. The ground's size is 60 mm*120 mm. The antenna is divided into two branches by the grounding strip. In Figure 4.27a, the feeding strip is located on the side of longer branch. This arrangement is more favorable to the performance of the lower band.

As the two branches are far apart, the responses at the low and high band are decoupled. The tuning process of this antenna is quite easy. When designing a large antenna, the first step is to adjust the length of both branches to get the resonances at the expected bands. Then by tweaking the distance between the feeding strip and the grounding strip, the matching at the lower band can be tuned. The final step is to design a matching circuit as shown in Figure 4.27b to obtain a good matching at the higher band.

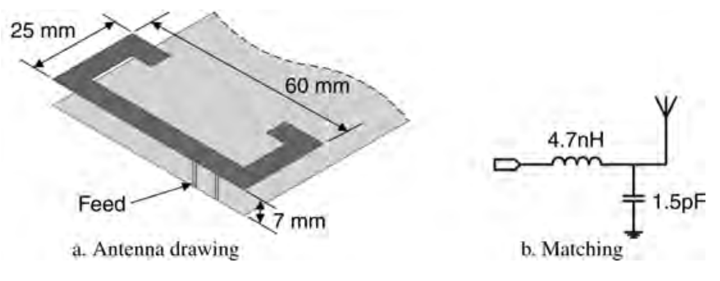

Figure 4.27 A large PIFA

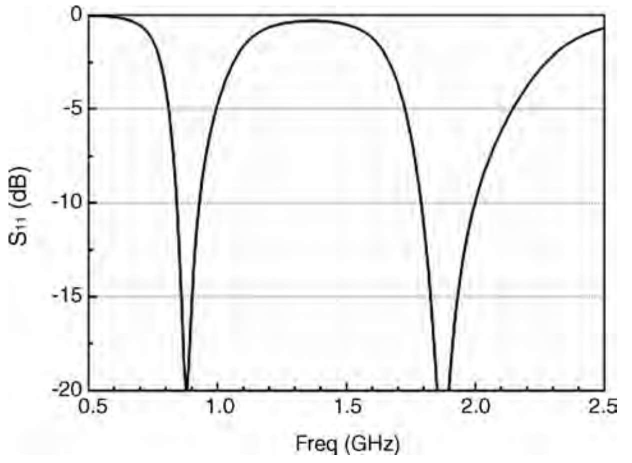

Figure 4.28 Reflection coefficient of the large PIFA antenna

Shown in Figure 4.28 is the simulated reflection coefficient of the large PIFA antenna. By comparing this result with results shown in Figures 4.16 and 4.24, it is clear that the antenna has a wider bandwidth at both bands. As a rule of thumb, a larger antenna area is always better, which gives more design options and it is easier to achieve better performance.

4.2.4 Multi-Band PIFA with Parasitic Element

There are many ways to expand PIFA antennas' bandwidth, which include using one slit with branches or multiple slits. PIFA variants using those techniques are too many to be enumerated in this book. Interested readers can find some enlightening examples in Professor Wong's book [1]. The technique we are going to discuss here uses the parasitic element.

Shown in Figure 4.29 is a PIFA with a parasitic element. The parasitic element is electrically connected to the ground through a metal strip. There is no direct

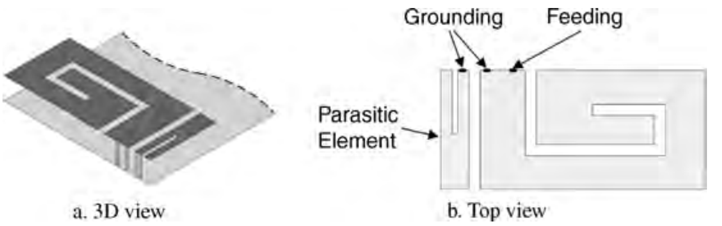

Figure 4.29 PIFA with parasitic element

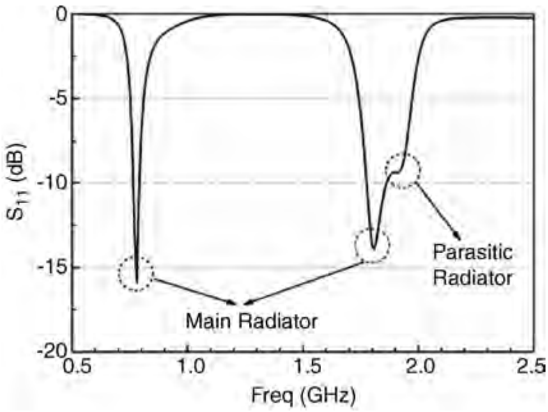

Figure 4.30 Reflection coefficient of a PIFA with a parasitic element

connection between the main radiator and the parasitic radiator. However, they are electromagnetically coupled.

Shown in Figure 4.30 is the simulation result of a PIFA with a parasitic element. Similar to a normal PIFA antenna, the main radiator generates two resonances, one at the lower band and one at the higher band. The parasitic element only resonates at the higher band. The parasitic elements can frequently be found in penta-band 3G phones, which normally require frequency coverage over 1710∼2170 MHz at the higher band. A quad-band 2G phone only needs to cover 1710∼1990 MHz.

In practice, the parasitic element is normally used to cover the highest band. As higher frequency means smaller parasitic radiator, this makes antenna design easier. The other reason for using parasitic elements at the highest band is an antenna's overall performance. With the existence of parasitic element, the efficiency of the main radiator might degrade from one-tenth of a dB to a few dB. By assigning the resonance of a parasitic element to the highest frequency, the adverse effect on the lower band can be mitigated.

4.2.5 Manufacturing PIFA Antenna

Regarding designing techniques for PIFA antennas, this is as far as this book will go. The aim of this book is to aid in jump-starting an antenna project. This book mostly focuses on the core principles of antenna designing. However, there are so many phones on the market, that if you do some reverse engineering, you can discover various elegant tricks. The book does not touch upon those advanced techniques. On the academic side, Professor Kin-Lu Wong is one of the most innovative scholars in the mobile antenna world. Professor Wong has written two books [1, 6] that cover advanced techniques.

In this section, we are going to discuss the various processes of manufacturing PIFA antennas. The cheapest technology used to make an internal antenna is metal stamping. In production, a metal stamping antenna can be tuned quite quickly if the parameter needing to be adjusted is known and already included in the tooling design. The minimum number of parts necessary for a metal stamping antenna is two: one plastic carrier and one metal radiator. Multiple heat stakes are used to assemble the two parts together. As heat stakes are designed as a part of the plastic carrier, this feature is actually free. An assembly fixture is required to melt all the heat stakes and deform them into a mushroom shape. Shown in Figure 4.31 are some production metal stamping antennas. Most of the time, the volume available for antenna designing is irregular. To optimize the performance, an antenna must take full advantage of an irregular space. However, it is not difficult to see that those antennas still follow the basic design principles. Spring fingers are frequently used in metal stamping antennas as the contact feature. As spring fingers are formed from the same metal sheet which antennas are made of, they are also free. To meet the humidity and other environment requirements, spring fingers must be gold plated. To cut down on the manufacturing costs, a selective gold plating process can be used to minimize the plated area.

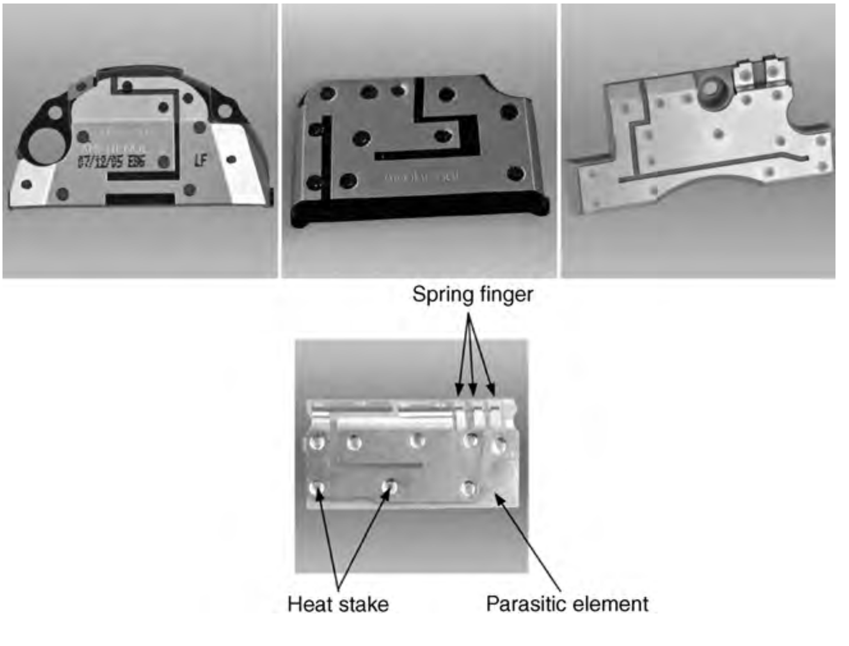

Figure 4.31 Metal stamping technology (Reproduced with permission from Shanghai *Amphenol* Airwave, Inc.)

Figure 4.32 Integrated antenna with other components (Reproduced with permission from Shanghai *Amphenol* Airwave, Inc.)

At the dawn of internal antennas, dedicated volumes were reserved for antenna designing. With the continuous shrinking of mobile devices, eventually antennas have had to co-exist with other components, such the microphone, the speaker, the camera, and so on. Shown in Figure 4.32 are some samples of integrated antennas. If one is putting other components underneath an antenna, they must be RF isolated. Take the speaker as an example. There are two lead lines out of a speaker. Both of them must be isolated by inserting series inductors into signal paths.

Normal metal stamping process can only bend metal sheets, so all the antennas shown above are not truly three-dimensional. They are either composed of multiple flat surfaces, or combinations of flat and cylindrical surfaces. The deep draw process can manufacture a true three-dimensional metal radiator. Shown in Figure 4.33 is an antenna made by the deep draw process. This antenna is also an integrated antenna. The exploded drawing is shown in Figure 4.33b. Only parts #1 and #2, which are the metal radiator and the plastic carrier respectively, are destined for the antenna functionality. All the other parts are intended for the functionality of the speaker.

Compared with metal stamping technologies, the flex circuit technology has better consistency but it is a little more expensive. In many state-of-the-art designs, the antenna volume is quite tight, which means the performance margin is relatively slim. Because flex antennas have better consistency, they also have better yield rate. The flex itself cannot provide connecting features, some extra parts, such as metal spring fingers or pogo pins, are needed.

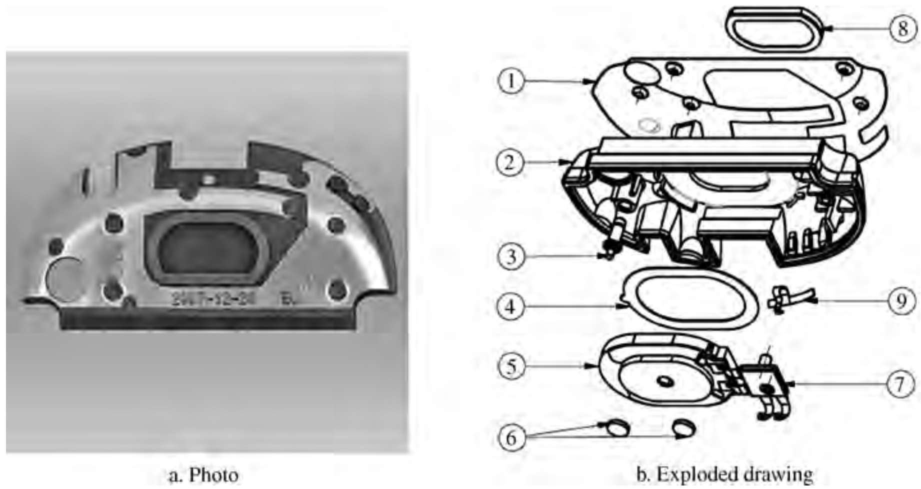

Figure 4.33 3D metal stamping integrated antenna (Reproduced with permission from Shanghai *Amphenol* Airwave, Inc.).

The flex technology is not a true three-dimensional technology, see Figure 4.34. A flex can only wrap around a combination of two-dimensional surfaces. The most advanced and also the most expensive technologies in antenna manufacturing are double-shot molded interconnect device (DS-MID) and/or laser direct structuring (LDS). They have the best consistency, because the antennas are part of the plastic structure instead of separate parts. Both of them are based on a technique called selective metallization. The DS-MID process begins with the application of a shot of plateable thermoplastic resin into an injection-mold cavity. Next, the cavity is changed and a second shot of nonplateable thermoplastic resin is molded around the first shot to create a circuit pattern from the plateable material. These parts are then

Figure 4.34 Flex technology (Reproduced with permission from Shanghai *Amphenol* Airwave, Inc.)

Figure 4.35 Antenna made by DS-MID technology (Reproduced with permission from Shanghai *Amphenol* Airwave, Inc.)

plated with a layer of copper. The DS-MID takes the longest lead time, because any modification to the antenna pattern requires tooling changes. The LDS is a relatively new process. The thermoplastic resin used in LDS process is nonplateable after the molding process and can be transformed to plateable by using a laser beam to activate it. The LDS process literally draws the antenna pattern on to the plastic. The pattern can be adjusted quite easily by uploading a new pattern file to the laser. Similar to the DS-MID, a plating process is required to deposit copper onto the part's surface. Shown in Figure 4.35 is an antenna made by the DS-MID process.

When choosing from different antenna technologies, an engineer needs to take into consideration cost, consistency, and lead time. It is always a good idea to consult experienced engineers and antenna manufacturers.

4.3 Folded Monopole Antenna

A PIFA antenna implies that there is a ground plane underneath the antenna element. When a phone with a PIFA antenna is used in a talking position, the ground is sandwiched between the head and the antenna. The ground functions as a shield, which can direct some of the near field energy away from the head, thus decreasing the radiation to the user's brain. However, from an antenna design point of view, the antenna bandwidth can be significantly expanded if the ground can be removed. When the ground is removed, the antenna is no longer a PIFA, it is called a folded monopole antenna.

For all phones with PIFA antennas, in my experience, the antennas are on the top of the phone. The "ancient" wisdom is that by putting an antenna on the top of a phone, the hand effect on the antenna can be mitigated. When the phones became thinner and smaller, the volume left for antenna also become too small to fulfill the bandwidth requirement. An obvious way to ease the pressure on antennas is by using monopole antennas. However, a monopole antenna cannot be placed on the top of a phone, because as there is no ground acting as the shield between the user's head