Multiband hybrid loop-notch antennas

Brian S Collins

BSC Associates Ltd., Ely, UK, brian.collins@ieee.org

Keywords*:* loop antenna; notch antenna; dual-band; wide-band

Abstract: The paper describes a class of simple hybrid loop-notch antennas and provides practical examples and measured results. The antennas are capable of wide-band and dual-band operation with high efficiency and resistance to detuning.

1 Introduction

The dependence of the bandwidth and efficiency of small antennas on currents flowing in their associated groundplanes has received a great deal of study. Vainikainnen et al. [1] showed the dependence of bandwidth on the dimensions of the groundplane and the present author showed simulations of the excitation of the groundplane modes that account for this behaviour [2]. Antennas for handsets and other small devices are typically monopoles of PIFAs physically positioned at the end of the groundplane. These are unbalanced antennas that we may regard as end-exciting the groundplane at its high impedance point. With the extension of the frequency bands in use for mobile phone services, the design of these antennas has developed to allow the coverage of multiple bands; a branched PIFA on a 100-mm long platform will typically cover 824-960 MHz and 1710-2170 MHz.

As the dimensions allowed for the antenna are reduced, the Q-factor of the antenna increases and the gain/bandwidth performance is reduced. What is not obvious is the limit for the dimensions of the exciting device – which we usually regard as the antenna – and the performance of the platform as a whole.

In addition to the more usual monopoles, PIFAs, and their derivatives, antennas positioned at the end of the groundplane have included magnetic dipole antennas (MDAs) and isolated ‘islands’ used to drive the groundplane. Examples include included antennas for the UHF-TV band [3] and antennas for various single mobile radio and other bands [4].

2 Loaded Notches

2.1 Geometry

In this paper we examine the potential performance of a class of capacitively-loaded antennas intermediate between loops and notches. These are intrinsically current-drivers and perform best when placed away from the ends of the host platform.

Notch antennas have a long history of application in usually regarded as having a high Q and a correspondingly narrow bandwidths. A capacitively-loaded notch can be regarded as a configuration intermediate between a loop (in which the loading capacitance C is effectively very large) and a notch (in which $C = 0$). For given loop dimensions the resonant frequency falls as C is increased.

Antennas for mobile handsets and M2M platforms typically operate in two groups of operating frequency bands; this requirement is usually addressed by using branched monopoles or branched PIFAs, in which long and short radiating elements, serving the lower and upper frequency bands are excited in parallel.

In the initial phase of the present investigation, two separate notches were used, fed in series by a common feedline as shown in Fig. 1. This arrangement has a large number of independent dimensions (degrees of freedom) – a situation that can usually be exploited by the antenna designer! These include the width, depth and separation between the two notches, as well as the loading capacitances, the position and Z_o of the feedline and its terminating capacitance.

A single notch, embedded in a groundplane, is shown in Fig. 2. The dimensions chosen were of the order of $0.1\lambda \times 0.05\lambda$, and the notch was excited by means of a microstrip line passing across the short dimension of the notch and terminated as a capacitive open circuit stub. The resonant frequency of the antenna was adjusted by capacitive loading of the open end of the notch and the distributed capacitance terminating the feedline. Loading of the notch was variously realized by using a chip capacitor or by arranging a narrow, and often extended, gap between the two sides of the notch at or near its open end. With no loading capacitance the antenna forms a classical notch, while if the capacitance is large the antenna becomes a classical loop. With the chosen values of capacitance the antenna has characteristics intermediate between these forms.

Feed arrangement

Typical loop antennas are fed by means of a small loop contained within the main radiating loop; by choosing the right relationship between the areas of the two loops, the resistive component of the input impedance is arranged to be 50 ohms at resonance. Notches are fed across their narrow dimension, if possible at a position chosen to provide R_{in} = 50 ohms. In its simplest form, the antenna investigated here comprises a capacitively-loaded notch cut in the groundplane and fed by a microstrip line passing across it at a position chosen to yield R_{in}= 50 ohms at resonance. The unfed end of the feed line extends beyond the edge of the notch and is terminated in an open circuit (Fig. 1), the length of overlap being chosen to provide the required operating frequency and bandwidth.

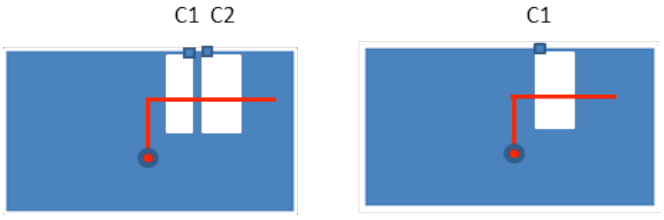

Fig. 1: Starting points. Two capacitively loaded notches fed in series by a microstrip line (left) and a single loaded notch fed by a microstrip line (right). The antennas were constructed on 0.8-mm thick FR4 with the groundplane and notch on one face and the feed on the other face.

In order to obtain operation on non-contiguous frequency bands, two loaded notches were positioned close together and fed by a single microstrip line passing across both notches – feeding them in series. The most significant modification made to these basic schemes was the use of closely-spaced PCB conductors to provide the loading capacitances; these were simple to adjust, although they may have contributed some loss that could be avoided in a production design.

To ensure that the measured results were influenced as little as possible by the feed cable, the coaxial input connector was positioned near the mid-point of the PCB and a coaxial choke was used to suppress currents on the cable outer. In practice it was found that even without the choke, touching the cable with a hand had little influence on the measured input impedance.

The most surprising result found during the course of this work was that it was possible to obtain a very satisfactory dual-band response from a single notch fed in the manner described.

3 Configurations and measured results

3.1 Dual-notch antenna for 850/900/1800/1900/2100 MHz

Experimental work began with the dual notch configuration shown in Fig. 2. By optimizing the feed structure and the capacitive loading arrangement, this provided a measured terminal efficiency greater than 50% over almost all the bands 824–960 MHz and 1710–2170 MHz. The very large number of dimensions needed to specify its geometry is indicative of the large number of degrees of freedom that are available in the design of this apparently simple antenna.

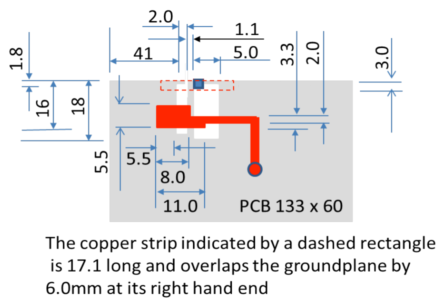

Fig. 2: A series-fed pair of loaded notches. The tuning chip capacitor has a value of 1.3 pF. The feedline and capacitive loading strip are on the rear face of the 0.8-mm thick FR4 PCB.

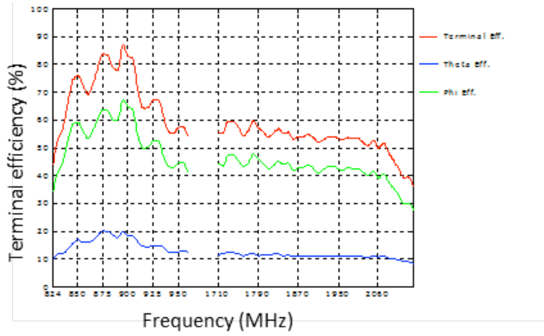

Fig. 3: Measured terminal efficiency of the antenna shown in Fig. 2.

The overall dimensions of this antenna were 18 mm x 13 mm (0.05λ x 0.034λ at 824 MHz). Its efficiency (Fig. 4) was limited by its impedance bandwidth, which could probably be extended by further optimization and the use of an input matching circuit. By extending its overall dimensions to 23 mm x 23 mm it proved possible to extend the useful bandwidth (efficiency >50%) of a dual notch to 730–960 MHz and 1700–2700MHz. Radiation patterns of this antenna are shown in Figs 5 and 6. Dual notches of generally similar configuration can be designed to cover band combinations such as GPS/WiFi (2.4 GHz), and WiFi 2.4/5 GHz.

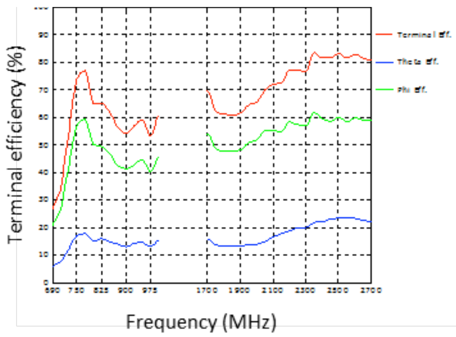

Fig. 4: Terminal efficiency of 23 mm x 23 mm multi-band dual notch on a PCB 133 mm x 60 mm.

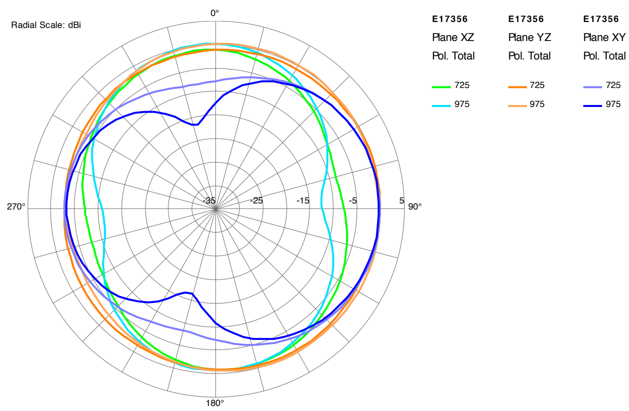

Fig. 5: Dual notch 23mm x 23mm. Polarization sum radiation patterns at 725 MHz and 960 MHz. The PCB lies in the x-y plane with its long axis along the 0-degree axis.

The radiation patterns in Figs 5 and 6 are plotted for the total power in both polarizations. It will be seen that even in the high band the patterns display only two significant notches, these being in the plane of the PCB. They are not as deep as would be obtained from typical end-mounted PIFAs.

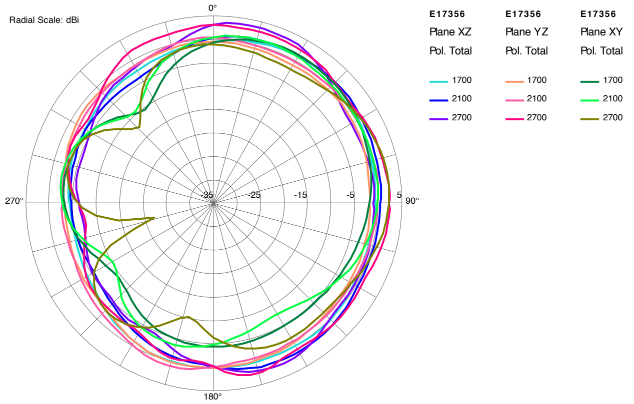

Fig. 6: Dual notch 23mm x 23mm. Polarization sum radiation patterns at 1700, 2200 and 2700 MHz. The PCB lies in the x-y plane with its long axis along the 0/180 degree axis.

3.2 A single-notch pentaband antenna

A single loaded notch antenna is also capable of providing operation in two non-contiguous frequency bands. An example of this is shown in Fig. 7, with measured terminal efficiency in Fig. 8. The low band efficiency of this antenna is very high and could be improved by some re-positioning of the optimum frequency. The efficiency at the edges of the low band is almost the same as the reflection loss caused by the band-edge VSWR; dissipative losses appear to be very small. High-band efficiency may have been reduced by dissipative loss caused by the very narrow capacitive loading gaps and could be improved by using one or more chip capacitors in their place.

A single notch with dimensions 22m x 25mm was shown to provide an efficiency exceeding 50% over the band 698–969 MHz, but this has not yet been successfully combined with an upper operating frequency band.

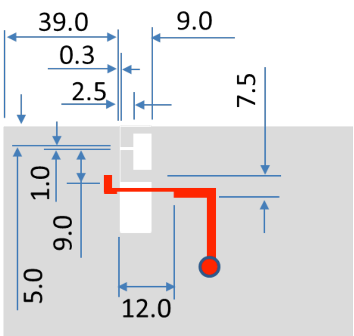

Fig. 7: A single loaded notch providing pentaband coverage. The feed track is 2.5 mm wide except for the section across the notch which is 1.3 mm wide.

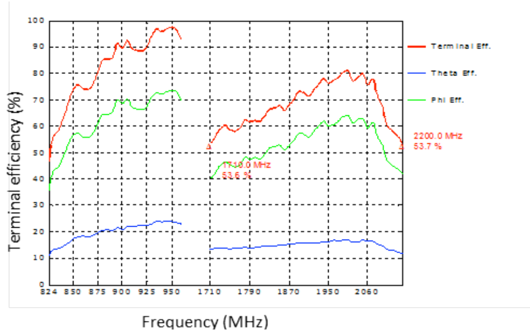

Fig. 8: Terminal efficiency of the single 27 mm x 9 mm pemtaband notch illustrated in Fig. 7.

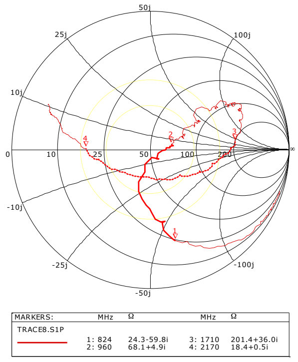

Fig. 9: Smith chart plot of the impedance of the single notch pentaband antenna at the coxial input connector with no added matching network.

3.3 Longitudinal notches

While a lateral notch as shown in Figs 2 and 7 may be suitable for some radio-enabled platforms, it may be less so for others, so a longitudinal notch was investigated (Fig. 10). Although operation was obtained on non-contiguous bands, it proved difficult to obtain a wide low-band operating bandwidth from this configuration, despite allowing the length of the antenna to grow to 50 mm. Low-band efficiency was typically less than 50% and the high band response could not be extended sufficiently to cover more than 1710-1990 MHz. The configuration made it difficult to provide additional matching features on the feed structure, as typically seen in Figs 2 and 7. Reduced bandwidth was obtained if the same structure was positioned at the end of the PCB, parallel with its short axis.

In the context of the present investigation the configuration shown in Fig 10 is described as being a longitudinal notch (or slot), but it may equally be viewed as a pair of inverted-L antennas, with the longer element fed capacitively from the feed line and the shorted element fed parasitically.

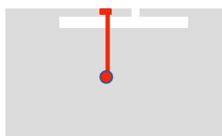

Fig. 10: Configuration of a longitudinal notch.

3.4 Further applications

Dual notches of the type described have been used by the author for coverage of the full GNSS frequency bands (1104–1608 MHz). Single notches (6.0 mm x 4.5 mm) have been used for dual band 2.4/5GHz WiFi applications, including wrist-worn devices and pendants.

4 Discussion

As with most small antennas on electrically small platforms, the antennas described in this paper operate by driving current in the host PCB. They operate best when placed near the centre of a long edge of a groundplane (133 mm x 60 mm for all experiments reported here). As the antenna is moved towards the corner of the PCB the impedance bandwidth and efficiency of the antenna both fall. In the configurations discussed here, the antenna operates as a low-impedance current driver. By contrast, conventional end-mounted PIFAs and monopoles act as high impedance electric-field drivers and are most effective when placed on the (high impedance) ends of a groundplane. The compact multi-band folded loop antenna described in [5] provides large bandwidths when end-mounted on a handset PCB, but the total length of the antenna conductor is much greater than the dimensions discussed here and its mode of operation is more complex than that of a simple loop.

A further interesting difference between these antennas (which can be regarded as magnetic dipoles) and PIFAs/monopoles, is their detuning behaviour. The resonant frequency of a PIFA or monopole is typically reduced when approached by the user's body, the effect being caused by additional capacitive loading of the resonant element. By contrast, when a loop antenna is approached by a parallel conducting plane, its resonant frequency *increases* because the conducting plane acts as a short-circuited turn, reducing the inductance of the loop and causing a consequent increase in resonant frequency. This characteristic is easily demonstrated for the antennas described. If the loading capacitance is very small (effectively a classical notch), the capacitive effect of an approaching conductor dominates and the resonant frequency falls. As the loading capacitance is increased, the antenna behaves more like a loop so there will be a 'sweet spot' where the behaviour lies between the two and the resonant frequency is little affected. This does not imply that no loss is created by the approach of a user's body, but its effects are less severe than with a conventional PIFA or monopole.

The notches may be fed by any of the usual methods for feeding a loop, using a subsidiary small coupling loop or tapping the feed onto part of the loop itself. The method described, using a capacitive stub, is simple and effective. The tuning capacitance across the open ends of the notch determine the optimum frequency, while the degree of coupling is adjusted by choice of the position of the feedline to provide a close match at the chosen frequency. The feed method is similar to the arrangements described in [7] and [7] where it is applied to open ended slots of more conventional length.

As with any embedded antenna, radiation depends on the excitation of groundplane currents, so the design of the groundplane must be carried out with this function in mind [8]. Continuous flood groundplanes must be provided on both faces of the PCB, bonded together with vias at regular intervals around their perimeters. Small components may be mounted through apertures in the groundplane, but large components should be covered with screening cans to allow currents to flow continuously in the groundplanes. This practice not only optimises the efficiency and bandwidth of the antennas, but also reduces unwanted coupling that can induce noise into receiving systems.

The radiating system characteristic of both notch and PIFA antennas on small platforms combines a small (implicitly high-Q) exciting device coupled to a larger, low-Q radiating PCB. Such a system usually has a combined Q given by:

$$1/Q = 1/Q_1 + 1/Q_2. \qquad (1)$$

In the case of these embedded antennas it is unclear whether this applies, and there seems to be no recognised expression for the minimum dimensions (and maximum Q?) of the 'antenna'.

The antenna described has a small footprint, requires no additional matching circuits and is easily embedded in a PCB that supports other electronic circuits.

5 Conclusion

It has been demonstrated that in combination with a hybrid capacitively/inductively coupled input line, small embedded loaded-notch antennas are capable of providing usefully wide bandwidths and high efficiency in two non-contiguous frequency ranges.

References

[1] P. Vainikainen, J. Ollikainen, O. Kivekäs, and I. Kelander, "Resonator-based analysis of the combination of mobile handset antenna and chassis", *IEEE Trans AP*, Volume 50, No 10, Oct. 2002, pp. 1433–1444.

[2] B. S. Collins, "Improving the RF performance of clamshell handsets", *IEEE International Workshop on Antenna Technology (iWAT 2006),* pp. 265–268.

[3] J. Holopainen, "Antenna for handheld DVB terminal", *MSc Thesis*, Helsinki University of Technology, 2005.

[4] J. Anguera, A. Andujar and C. Garcia, "Multiband and small coplanar antenna system for wireless handheld devices", *IEEE Trans AP* Volume 61, No. 7, pp 3782–3789.

[5] M. Harper, D. Iellici and C. Tomlin, "A loop antenna for mobile handset and other applications", *Patent Application,* Microsoft Technology Licensing LLC.

[6] M. A. C Niamen and C Delaveaud, "A Compact Dual-Band Notch Antenna for Wireless Multistandard Terminals", *IEEE Antennas & Wireless prop. Letters*, Volume 11, 2012, pp 877–880.

[7] H. Nakano and J. Yamauchi, "Printed slot and wire antennas: A review", *Proc. IEEE*, Volume 100, No.7, July 2012, pp 2158–2168.

[8] B. S. Collins, "Embedding antennas in user equipments", *IEEE Wireless Communications & Networking Conference,* WCNC 2007, Hong Kong, March 11-15 2007, pp 2334-2337.