Corrugated circular microstrip patch antennas for miniaturisation

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New concepts for a corrugated circular microstrip patch antenna (CCMPA), which is moving in the radial direction and works at a frequency of 1.575 GHz (GPS), using linear and circular polarisation for miniaturisation are designed and fabricated. The linearly-polarised antenna has a reduction of 8.08% in patch diameter, a reduction of 21.12% in area and an increase of 1% in bandwidth compared with a circular microstrip patch antenna (CMPA). The radiation patterns of E- and H-plane for a corrugated-type antenna follow the general CMPA and the gain of the linearly-polarised antenna is 6.8 dBi. Also, the circularly-polarised antenna has a gain of 2.8 dBi and an axial ratio of 1.3 dBi at 1.575 GHz.

Introduction: Size reduction and low weight of all parts in a system is one of the important conditions for a movable system. In this regard, a microstrip patch antenna (MPA) has some advantages in its movable system: light weight, low volume, low profile being examples [1–3]. The MPA with high-dielectric substrate extends over a wide range as the method for miniaturisation. But, because the antenna efficiency ascribes to the dielectric constant, the method of only using a high dielectric has a limitation in efficiency, which is the attenuation of gain. Therefore, a CCMPA, the structure of which increases in greater circles in the radial direction, was devised and designed to reduce patch size. The characteristics of the CCMPA were compared with a general CMPA under the same dielectric constant.

Antenna structure: Fig. 1a shows the structure of a linearly-polarised CCMPA. A corrugated patch surface, diameter 91 mm, is placed on the foam with a relative dielectric constant of 1.06 close to the air constant. The raised carving part (RC), which is relatively remote from the ground plane, has a foam gap of 8 mm from the ground plane. The depressed carving part (DC), which is relatively near to the ground plane, has a foam gap of 3 mm from the ground plane. Therefore, the RC part is 5 mm higher than the DC. The optional breadth ratio for RC and DC is constant at 1/2. The circularly-polarised CCMPA was then designed. Fig. 1b shows the structure of the circularly-polarised CCMPA with a diameter of 92 mm. There are two small chamfers on each edge of the patch to give rise to circular polarisation. All conditions are the same as a linear CCMPA except the chamfers and the patch diameter.

Results: The E- and H-plane radiation patterns using a coaxial feeding method for a linearly-polarised CCMPA are shown in Fig. 2a. The return loss is below −20 dB at the designed frequency. These patterns are the same as the patterns of a general MPA with a ground plane greater than five times the wavelength. E- and H-plane patterns have a symmetric trend between the left and right sides. As measured data, each (linearly-polarised CCMPA and circularly-polarised CCMPA) has a maximum gain of 6.2 dBi and 2.8 dBi, −10 dB return loss bandwidth of 71 (4.5%) and 140 MHz (8.9%), −3 dB beam width of 61° and 76°. The axial ratio for the circularly-polarised CCMPA is 1.3 dB at 1.575 GHz. These characteristics are shown with the general CMPA in Table 1. Alternatively, two chamfers on the patch of the circularly-polarised CCMPA were used to give circular polarisation and the patterns are shown in Fig. 2b. However, there is a reduction of 8.08% in the patch diameter and a reduction of 21.12% in the patch area. As a result, the designed linearly-polarised CCMPA and circularly-polarised CCMPA have a noticeable size reduction in comparison with the general CMPA. The size reduction is thought to result from the shortened current length along the patch surface that is below as a result of the corrugated patch structure.

Fig. 1 Structure and dimensions of linearly-polarised and circularly-polarised CCMPA

a Linearly-polarised CCMPA
b Circularly-polarised CCMPA

Fig. 2 Radiation patterns and axial ratio of CCMPA

a Linearly-polarised CCMPA
· · · · reference dipole
--- E-plane
--- H-plane
b Circularly-polarised CCMPA
· · · · reference dipole
--- horizontal polarisation (X-Z plane)
--- horizontal polarisation (Y-Z plane)
--- · · · axial ratio
Table 1: Comparison with CCMPA and general CCMPA

<table>
<thead>
<tr>
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<th>General CCMPA</th>
<th>Linear CCMPA</th>
<th>Circular CCMPA</th>
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<tbody>
<tr>
<td>Return losses</td>
<td>-33.8 dB</td>
<td>-29 dB</td>
<td>-15.15 dB</td>
</tr>
<tr>
<td>-10 dB return loss bandwidth</td>
<td>55.5 MHz (3.5%)</td>
<td>71 MHz (4.5%)</td>
<td>140 MHz (8.9%)</td>
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<tr>
<td>Gains at 9°</td>
<td>7.1 dB</td>
<td>6.2 dB</td>
<td>2.9 dB</td>
</tr>
<tr>
<td>Beamwidths</td>
<td>E-plane 72°</td>
<td>H-plane 76°</td>
<td>92°</td>
</tr>
<tr>
<td>Axial ratio</td>
<td>1.3 dB</td>
<td>(1.575 GHz)</td>
<td></td>
</tr>
<tr>
<td>Patch diameter</td>
<td>99 mm</td>
<td>91 mm</td>
<td>92 mm</td>
</tr>
</tbody>
</table>

Conclusion: A corrugated antenna showing a reduction of 8.08% in patch diameter and 21.12% in patch area by maintenance of the fundamental mode for general CCMPA as well as shortening of current length has been reported. Each linearly-polarised CCMPA and circularly-polarised CCMPA has the improved characteristic of 71 MHz (4.5%) and 144 MHz (8.9%) in comparison with the general CCMPA in the aspect of -10 dB return loss bandwidth at 1.575 GHz. Therefore, the CCMPA proposed in this Letter has been confirmed to be appropriate for the miniaturisation of antennas.

References
2. BALANIS, C.A.: "Antenna theory analysis and design" (John Wiley & Sons, New York, 1997), Chap. 14

Generalised analysis of switched-capacitor step-down quasi-resonant converter

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Conventional switched-capacitor converter circuits have a high current stress because of the short circuit when charging and discharging the capacitors. A novel switched-capacitor quasi-resonant step-down converter family with a generalised analysis that can improve the current stress problem is presented. Measured efficiency is high and all the circuits can operate under zero-current switching.

Introduction: Switched-capacitor DC-DC converters [1] use capacitors for energy storage, therefore the main advantage is that it is not necessary to include an inductor in the design and circuit size can be reduced. The fabrication of the converter in an integrated circuit is also possible. However, the main drawback of the circuit is the momentary short-circuit when charging and discharging the capacitor; this generates switching loss and electromagnetic interference. A zero-current switching method for the switched-capacitor quasi-resonant (SCQR) converter was proposed in [2]. In this Letter we describe extending the principle of the switched-capacitor resonant converter into a generalised method. A switching-capacitor cell is proposed to the switched-capacitor converter and hence a series of circuits of various conversion ratios and zero-current switching of all switches can be obtained.

Concepts: The proposed SCQR converters are shown in Fig. 1 and 2 where the circuits give the output voltage equal to 1/3 and 1/n of input voltage, respectively. The output voltages of the proposed family of converters are dependent on the number of switched-capacitor cells, which is formed by C2, D5, D4, D3 as shown in Fig. 1. For other fractional output, this cell can be extended to the 1/n version as shown in Fig. 2. Each capacitor C1 (i>1) in the switched-capacitor cells is for sharing the input voltage together in series and releasing the energy in parallel with C1 to the load where the diodes decide the direction of the current flow to charge the capacitors. For a converter with 1/n conversion ratio (1/n mode converter), there should be (n-2) switched-capacitor cells. Ls is to ensure zero-current switching, and the current of all the transistors must pass through Ls.

Fig. 1 1/3 mode SCQR converter

Fig. 2 1/n mode zero-current switching SCQR converters

Principles of operations: The 1/3 mode SCQR converter is analysed. There are a total of four states of operation in each switching period. Fig. 3 shows the computer simulation waveforms of the converter. Assuming the output capacitor CD is very large to keep the output voltage constant, the capacitance of C1 is equal to that of C2 (called C), and there is no power loss in the circuit, the analysis of each state is as follows.

(i) States of operations: (i) State I [t0-t1]: At t0, Q1 is switched on while Q2 is switched off. C1 and C2 are charged in series with D5, D4, L5 and the load. At this moment, C1 and C2 resonate with Ls in series. The charging current of the capacitors resonates from zero at t0 to the peak and is back to the zero at t1 in sinusoidal waveform so that Q2 is switched on under zero-current switching condition. The equations of this state are:

\[ V_s = L_s \frac{di_s}{dt} + (n-1)v_C + V_0 \]  

\[ i_s = C \frac{dv_C}{dt} \]  

where \( V_s \) is the input voltage, \( V_0 \) the output voltage, \( v_C \) the resonant capacitors (C1 or C2) voltage, \( i_s \) the resonant inductor (Ls) current, and \( n \) represents the 1/n version of the circuits.

(ii) State II [t1-t2]: Q1 keeps to be on and Q2 is still off. At t1, the inductor current reaches zero and the diodes D5 and D4 stop the resonance. Both the inductor and input currents are equal to zero. \( C_0 \) is discharged to the load. \( v_C \) stays constant and \( v_L = 0 \).

(iii) State [t2-t3]: Q1 is switched off and Q2 is switched on at t2. C1 and C2 are discharged in parallel to Ls and the load. D3, D4, D5 and D6 are conducting. These two capacitors resonate with Ls in sinusoidal waveform which is similar to State I. Since the current of Q1 is zero at t2, Q2 is switched off in zero-current switching condition while Q3 is zero-current switched on. At t3, the inductor current is resonated to be zero.

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