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Inkjet Printed Bandpass Filters and Filtennas using Silver Nanoparticle Ink on Flexible Substrate

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Abstract—This paper presents an inkjet printed CPW filtenna designed at 5.8 GHz. The proposed structure consists of a CPW pseudo-interdigital bandpass filter and a CPW inset-fed antenna. The bandpass filter is fabricated using inkjet printing technology. The structure is printed on flexible Kapton substrate with polyimide film using silver nanoparticle ink. The filter is then used to suppress the spurious harmonics of the antenna. Measurements from the fabrication confirm the accuracy of the design method and the simulation results.

I. INTRODUCTION

Inkjet printing is fast becoming an emerging technology to manufacture printed electronics due to its direct-write technique. As compared to conventional etching techniques, it is able to reduce the material usage and the waste generated. Inkjet printing is simpler, generally faster and has low fabrication costs than other additive manufacturing techniques. Over the last few years, inkjet printed technology has been implemented in a wide range of applications, from displays and lighting to RF and microwave applications. In recent years a number of inkjet printed electronics have been reported in published work [1]-[6]. These electronics have been usually printed on specific substrates in order to decrease losses. For example, antennas on Liquid Crystal Polymer (LCP) substrates [1], coplanar waveguides (CPW) and filters on LCP substrate [2]-[4], inkjet printed antennas on paper substrates [5], inkjet printed CPW inductors on Kapton substrate [6]. However, there has been no reported work on employing Kapton substrate with flexible polyimide film for inkjet printed filters using silver nanoparticle ink. In this paper, the design and modelling of an inkjet printed filtenna is presented. The filtenna consists of a pseudo-interdigital bandpass filter integrated with an inset-fed antenna using inkjet printing technology. The structures are single-layer CPWs without any background metallization. In Section II, the design of the structures is detailed. Section IV presents the results. Conclusions of the results follow in Section V.

II. DESIGN OF FILTERS, ANTENNAS AND FILTENNAS

The two pole pseudo-interdigital filter has a center frequency of 5.8 GHz with transmission zeros to improve rejection. As shown in Fig. 1, it has rectangular CPW lines around it which serve as ground planes and act as a replacement for background metallization. It consists of two folded resonators in the middle, where the lengths of resonators define the center frequency. In this case, the length of the inner fingers is $\lambda_g/4$; where $\lambda_g$ is the guided wavelength at center frequency of 5.8 GHz. The gap between all the fingers of the resonators is the same. Decreasing the gap between the resonators broadens the bandwidth; whereas increasing causes higher insertion loss. A standard CPW antenna with fundamental resonant frequency 5.8 GHz is designed. As shown in Fig. 2, inset transmission line feeding was chosen to reduce the total area. Increasing of inset feed length reduces the input impedance at resonant frequency but causes slight effect on the frequency itself. The filtenna is formed by replacing the inset-feedline by the designed filter; as presented in Fig. 3.

Fig 1. Geometry of bandpass filter.

Fig 2. Geometry of inset-fed antenna.
is 18.5 dB. As desired, the spurious harmonics of the antenna
the fundamental frequency is observed. The resulting return
other frequencies. After integration of the filter, a slight shift in
However as seen, it also has spurious harmonics at various
are shown in Fig. 8. The antenna has a fundamental resonant
frequencies below and above the passband. The transmission
accuracy of the inkjet printer. Two transmission zeros appear at
conductivity of ink. The loss is also attributed to the positional
arises from the printed metallic
shows the insertion loss to be at 5 dB. This difference in loss
bandwidth. The simulation result shows the insertion loss to be
that the filter is centered
parameters of the bandpass filter presented in Fig. 4 show
the filter is centered at 5.8 GHz and has a 14% fractional
bandwidth. The simulation result shows the insertion loss to be
about 2.1 dB in the passband. However, the measured result
shows the insertion loss to be at 5 dB. This difference in loss
arises from the printed metallic layers, dielectric losses and low
conductivity of ink. The loss is also attributed to the positional
accuracy of the inkjet printer. Two transmission zeros appear at
frequencies below and above the passband. The transmission
zeroes improve near-bandwidth rejection. The return loss is
more than 15 dB for most of the passband bandwidth.

![Fig. 4. S-parameters of bandpass filter.](image)

The simulated S-parameters of the antenna and the filtenna
are shown in Fig. 8. The antenna has a fundamental resonant
frequency at 5.8 GHz with a return loss of about 27 dB.
However as seen, it also has spurious harmonics at various
other frequencies. After integration of the filter, a slight shift in
the fundamental frequency is observed. The resulting return
loss of the filtenna at the new resonant frequency of 5.75 GHz
is 18.5 dB. As desired, the spurious harmonics of the antenna
have been fully suppressed because of the integration of the filter.

![Fig. 5. S-parameters of antenna and filtenna.](image)

### III. RESULTS

All structures are designed on 50 μm thick Kapton substrate
of a dielectric permittivity $\varepsilon_r = 3.4$ and a loss tangent
$\tan\delta = 0.0021$. Simulations are done using the commercial
software emSonnet. The fabricated filter was characterized
using high frequency measurement system. The system
comprises of Süss MicroTech PM5 RF probe station, Agilent
PNA-L vector network analyzer N5230A, high frequency
interconnecting cables and coplanar ground-ground
Cascade Microtech APC50-GSG-250 probe station. The
measuring system was calibrated on compatible impedance
calibration substrate implementing standard SOL (Short
Open Load) calibration method. The simulated and measured
S-parameters of the bandpass filter presented in Fig. 4 show
that the filter is centered at 5.8 GHz and has a 14% fractional
bandwidth. The simulation result shows the insertion loss to be
about 2.1 dB in the passband. However, the measured result
shows the insertion loss to be at 5 dB. This difference in loss
arises from the printed metallic layers, dielectric losses and low
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accuracy of the inkjet printer. Two transmission zeros appear at
frequencies below and above the passband. The transmission
zeroes improve near-bandwidth rejection. The return loss is
more than 15 dB for most of the passband bandwidth.

![Fig. 3. Geometry of filtenna.](image)

### IV. CONCLUSION

Inkjet printing presents a very encouraging future for low-
cost fabrication process of passive RF and microwave circuits.
In this paper, inkjet printing is utilized to design and fabricate a
bandpass filter centered at 5.8 GHz. The simulated and
measured results have been presented. The filter is integrated
with a CPW antenna having spurious harmonics to form a
filtenna. The filtenna has resonant frequency at 5.8 GHz and
the spurious harmonics are fully suppressed because of the
integrated filter. The results of the antenna and filtenna are
given. Although the losses are substantial, these can be reduced
by increasing the printed layers’ thickness and/or by increasing
the concentration of silver in the ink or the curing temperature
and time resulting in an increase in the electrical conductivity
of the metallization.

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