Periodic Interconnects for Internal MRI

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Abstract

Thin film cables based on a microstrip with a periodically patterned ground plane are proposed as interconnects for use in internal magnetic resonance imaging. Patterning of the ground plane allows low-frequency impedance matching to 50 Ω. Experimental confirmation is provided using two metre long cables and resonant detectors fabricated by double-sided patterning of copper-clad polyimide, which are wrapped around catheter probes for endoscopic delivery into the body. High-resolution ^{1}H magnetic resonance imaging is demonstrated at 1.5 T.

1. Introduction

High-resolution magnetic resonance imaging of internal organs such as the biliary tree requires close coupling of a detector. Catheter-mounted microfabricated coils are typically used, with the signal being taken via an internal co-axial cable. To allow use with a guide wire, thin-film cables that can be wrapped around the outside of the catheter are needed. Unfortunately common formats such as microstrip (Fig. 1a) and coplanar waveguide (Fig. 1b) can only achieve 50 Ω impedance on thin flexible substrates using very small conductor widths and gaps. Here we propose alternatives based on microstrip with periodically patterned conductors for low-frequency impedance matching.

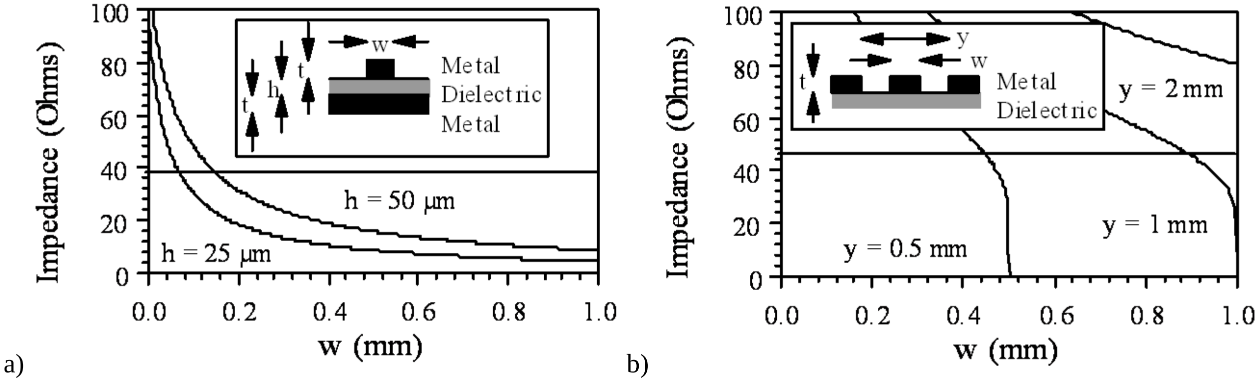

Fig. 1. Variation of impedance with dimension for a) microstrip and b) coplanar waveguide on polyimide.

2. Theory

Fig. 2 shows arrangements based on a) a microstrip with a periodically patterned ground plane and b) a periodic double meander. In each case the structure can be modelled as a diatomic lattice based on a unit cell with alternating values of L and C (Fig. 3a).

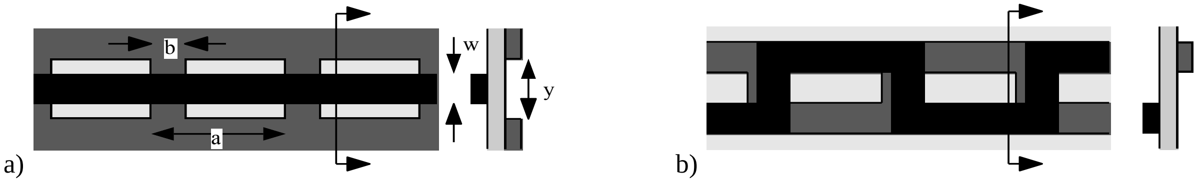

Fig. 2. Alternative arrangements for periodic interconnects.

The dispersion diagram then has two branches as shown in Fig. 4a. However, if the two values of inductance and capacitance are sufficiently different, the optical branch is at very high frequency and at low frequency the structure may be modelled as a monotomic lattice (Fig. 3b).

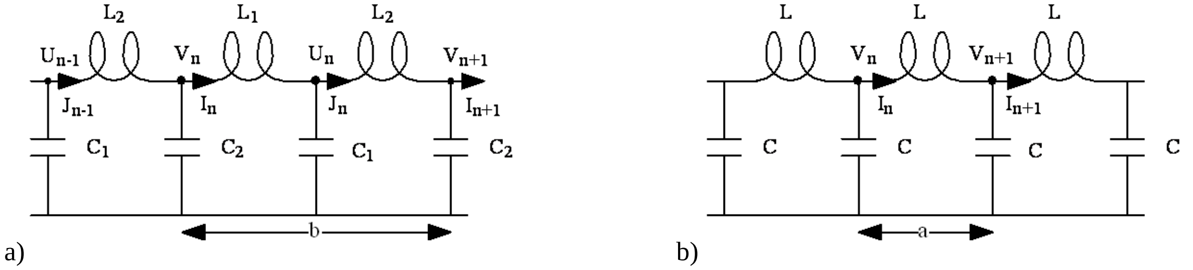

Fig. 3 a) Diatomic and b) monatomic lattices.

In this case the dispersion characteristic and impedance are:

$$\omega/\omega_0 = 2\sin(ka/2)\ ;\ \omega_0 = 1/\sqrt{(LC)}\ ;\ Z_0 = Z_0'\exp(jka/2)\ ;\ Z_0' = \sqrt{(L/C)} \quad (1)$$

The cutoff frequency $\omega_m = 2\omega_0$ and the low frequency impedance Z_0' are governed by L and C, which may be adjusted by the unit cell dimensions. The reflection $R = (Z_0 - Z_L)/(Z_0 + Z_L)$ at a junction with a real load Z_L is then very low at DC, as shown by the frequency variation of $S_{11} = 10\log_{10}|R^2|$ in Fig. 4b.

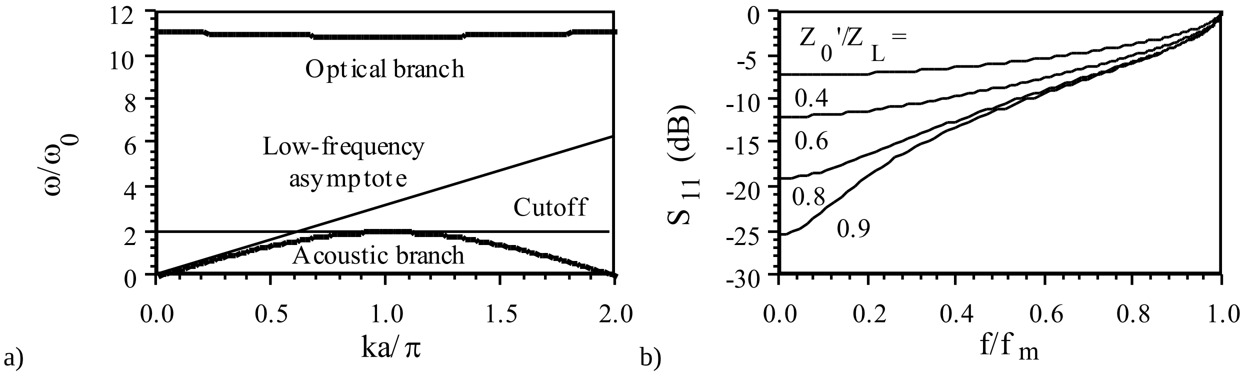

Fig. 4. a) Dispersion diagram for diatomic lattice; b) frequency variation of S_{11} for monatomic lattice.

3. Experimental verification

Experiments were carried out using flexible resonant RF detectors and cables fabricated by double-sided patterning of Cu-Kapton-Cu trilayers. Cables were fabricated in two-metre lengths with a period a = 16 mm and spliced to microfabricated detectors carrying integrated capacitors for tuning and matching of a 60 mm long two-turn rectangular coil (Fig. 5). Layer thicknesses of 35 μm, 25 μm and 35 μm were used, with track widths of 1 mm for the interconnect and 0.5 mm for the detector.

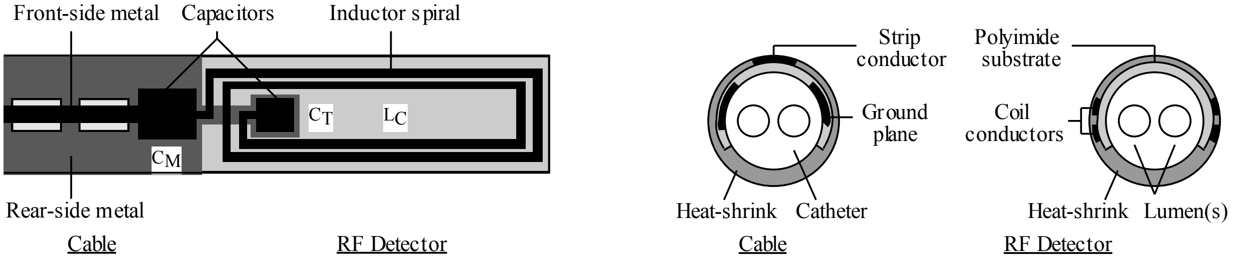

Fig. 5 Arrangement of detector and periodic interconnect on catheter probe.

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Z_0' is controlled by the geometric ratio b/a of the ground-plane defect. Interconnects were fabricated in arrays with stepped ground plane dimensions and the optimum design was selected for use. Fig. 6 compares the frequency variation of S_{11} and S_{21} measured using a 50 Ω network analyser, which shows that good impedance matching has been achieved using a line with b/a = 1/8. The cut-off is 2.5 GHz.

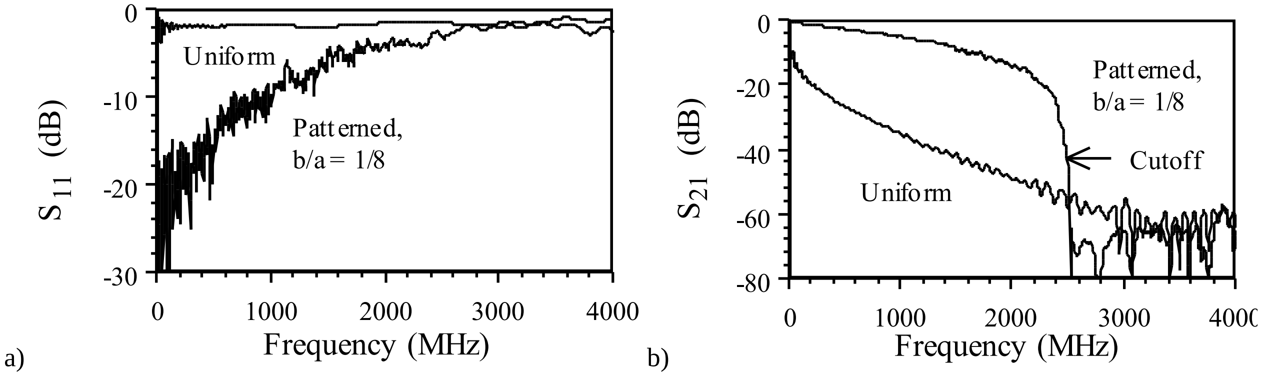

Fig. 6. Frequency variation of a) S_{11} and b) S_{21} for uniform and periodically patterned microstrip.

Cables from the array (Fig. 7a) were attached to 8 Fr (2.7 mm dia) catheters using heat shrink tubing (Fig. 7b) and used for ^{1}H MRI at 1.5 T. The detector was inserted into the RH hepatic artery of a butchered porcine liver (Fig. 7c). High-resolution axial images were obtained using a T_2-weighted fast recovery fast spin echo sequence, with TR = 33 msec, TE = 15 msec, and 10^o flip angle (Fig. 7d).

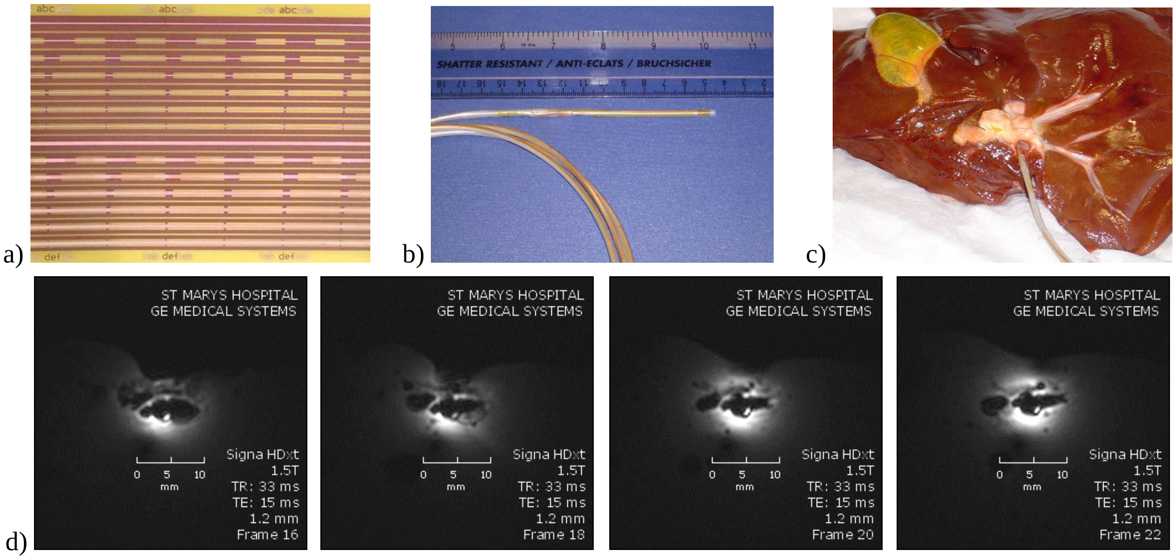

Fig. 7 a) Cable array, b) catheter-mounted detector, c) arrangement for ^{1}H MRI; d) axial images of a biliary tree.

4. Conclusions

MR signals have been successfully transmitted from a catheter-mounted detector to the receiver using a periodically patterned thin-film cable, which allows impedance matching to be achieved by layout.

References

[1] Hurst G.C., Misic G.J. "Coils for insertion into the human body" pp 1373-1378 in *"Encyclopedia of nuclear magnetic resonance"*Grant D.M., Harris R.K. Eds, John Wiley and Sons, Chichester, 1996

[2] Wheeler H.A. "Transmission-line properties of a strip on a dielectric sheet on a plane*" IEEE Trans. Micr. Theory & Tech.* Vol. MTT-25, pp 631-647, 1977

[3] Wen C.P. "Coplanar waveguide: a surface strip transmission line suitable for nonreciprocal gyromagnetic device applications" *IEEE Trans. Microwave Theory and Tech.* Vol MTT-17, pp 1087-1990, 1969