

Aluminum-Wood Antenna

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ABSTRACT

The objective of this work is to develop a low cost ground microstation for the reception of Worldspace satellite signals. Among the antennas operating over the frequency bands used for satellite reception, microstrip antennas have been selected because of their small size and the possibility of cheap manufacture. Wood and aluminium have been used to manufacture our antenna. Printed circuit processes are replaced by a simple gluing procedure. Since the patch antenna is made out of aluminium, copper wires and connectors cannot be directly soldered to it. This problem is avoided by feeding the patch through a slot in the ground plane and thus mimicking a SSFIP type antenna. For the wood, locally available tree species were first tested for suitability as microstrip antenna substrates. Two measurement methods were used at microwave frequencies: the waveguide technique and the open resonator technique. Successful receiving tests of Afristar Worldspace satellite radio were carried out.

Keywords: SSFIP antenna, wood substrate, aluminium patch, gluing assembling.

I. INTRODUCTION

In our laboratory, Laboratory of Electromagnetics and Acoustics (LEMA), several antennas have been designed with conducting materials not made of copper. For instance, our laboratory designed a Beryllium bronze (BzBe) wire antenna for a project to study the terrestrial movements of the European tree frog (*Hyla arborea*) [1]. In another project, called SOLANT, solar cells were used as patch antennas, replacing printed copper sheets [2]-[3]. In the same project, ground planes made of stainless steel were also used in the design of slot antennas [4]. Opening a new and innovative line, in this work we will use aluminium for the radiator, the ground plane and the feed line (it should however be noted that, as far as conductivity is concerned, aluminium is closer to copper than some other metals used elsewhere).

For the antennas that can be usually found in the market, they very seldom make use of wood as an antenna material. For antennas using materials other than the standard high-tech substrates such as FR4, Kapton, Rohacell, the only people who happen to use them are some peculiar individuals like radio amateurs [5]. These particular people sometimes use wood, either as support [6], or to make the mast of their antennas. Cardboard, aluminium foil and materials as curious as potato chips cans [7] are also used to create exciting antennas very appealing for young people and hence useful for educational purposes. Our work gets inspiration from these attempts and aims to use local materials that can be processed

by local people and labour force in order to reduce the price of the antenna.

II. SSFIP ANTENNA TYPE

The structure of SSFIP [8] antenna is shown in the FIGURE 1. Initially we will replace the foam by wood (Balsa). Then we will replace the top layer, which plays the role of protecting cover, by linseed oil. Then we will replace the copper patch by an aluminium patch. Finally we will replace the copper ground plane where the slot is engraved by an aluminium ground plane with the same slot, the FR4 substrate by wood (Ayou) and the copper feed line by an aluminium feed line. At the end we will have an antenna only made with wood and aluminium (FIGURE 2). The system will be assembled by a simple gluing procedure (standard two-part epoxy glue).

We will first simulate, and then manufacture antennas with linear polarization and quantify the increase of the losses, which affect particularly the gain of these antennas. Once a linearly polarized antenna has been successfully analyzed and

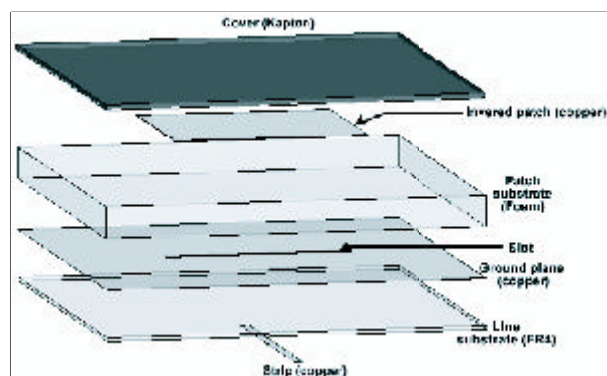


Figure 1. SSFIP antenna

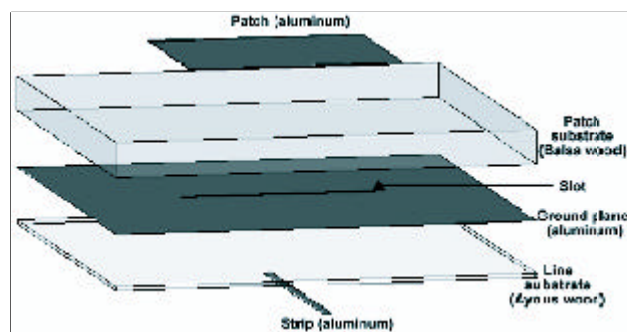


Figure 2. Aluminum-wood antenna

built, the next step will be to move to the realization of a circularly polarized antenna.

For the wood, locally (Cameroon) available tree species were first tested for suitability as microstrip antenna substrates. Two measurement methods were used at microwave frequencies: the waveguide technique and the open resonator technique. Extensive tests confirm that losses increase with the density of the wood. These losses in the wood are the main limiting factor when using wood as a microstrip antenna substrate as they can reduce considerably the antenna gain. Losses can be constrained to reasonable values by using specific low density wood.

III. ANTENNAS DIMENSIONS

In order to determine whether our project is feasible, we will first find out whether the gain of our antenna built with a wood substrate is large enough for operation with a Worldspace receiver. Then we will measure the gain of all the designed antennas at the same resonant frequency. Since the dimensions of the antenna's patch are related to the resonant frequency and the relative permittivity of the substrate, it will be difficult to have all the antennas with the same size. Equations related to the antenna dimensions are well documented in the literature [16]. Once the resonance frequency is known, the final dimensions of all the elements of the microstrip antennas were obtained after simulations. All the following antenna's dimensions in this section are related to the wavelength and are optimized through simulations. Since we want to measure the loss of quality, all the antennas must have the same resonant frequency and the same dimensions, especially for substrates because the losses come mainly from substrates. In order to make a valid comparison we will keep constant for each type of antenna the dimensions of elements which have negligible effects on the antennas' resonant frequency or are not dependent on the available dimensions in the market and we will realize linearly polarized antennas. The dimensions are summarized in the TABLE I. Before using the dielectric constants in the table below, we first characterize Ayous, wood locally available in Cameroonian forest.

IV. COMPARATIVE STUDY

It is difficult to simulate, and then to manufacture, at a nonindustrial level, antennas having exactly the same frequencies of resonance. However, the frequency dispersion is not so large, so we take the average value of all these resonant frequencies and then quantify the gain losses by using the SSFIP antenna as a reference. After calculation we obtain $f_{\text{omoy}} = 1.468$ GHz as average value. Measured reflection coefficients at resonance are always below -15 dB so we can consider that all the antennas are well matched during the gain measurements. At the frequency $f_{\text{omoy}} = 1.468$ GHz we measure the reduction in gain as compared to that of SSFIP antenna. The results obtained are summarized in TABLE II.

We also noticed that the bandwidths of these antennas fall within the range of those of microstrip antennas. For microstrip antennas the bandwidth decreases when the substrate permittivity increases [18]. In our measurements we note an opposite effect: the measured bandwidths (5.86% – 10.82%) grow as the substrate permittivity increases (1.07 ($\tan(\delta) = 0.0008$) – 1.77 ($\tan(\delta) = 0.0577$)). This phenomenon observed in measurement values is mainly due to dielectric

losses, which play a preponderant role on the increase of the bandwidth. This phenomenon highlights the effect of dielectric

TABLE II
COMPARATIVE GAIN MEASUREMENTS AT 1.468 GHZ

Denomination	Gain Loss (dB)	Gain (dB)
SSFIP Antenna	0	10.02
Wood (Balsa) SSFIP antenna	-0.89	9.13
Balsa antenna	-1.05	8.97
Ayous-Balsa antenna	-1.43	8.59
Ayous antenna	-3.64	6.38

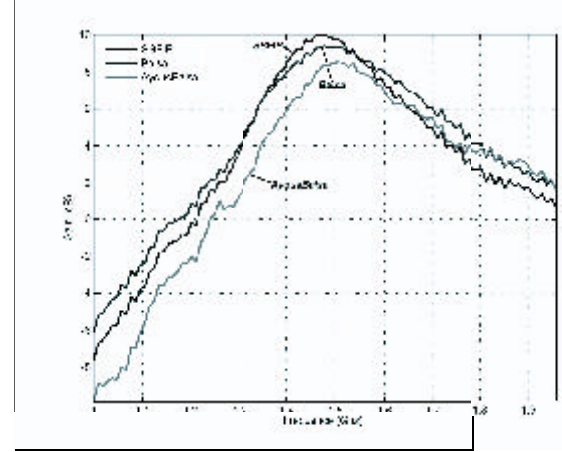


Figure 3. Three antennas gain measurement method

losses on the increase in bandwidth of the SSFIP type antenna. In the other hand, using the resonant frequency equation from [16] we verify that the calculated and the measured values of the resonant frequency are very close: this verification confirms the validity of our measurements.

TABLE II shows us that all the gain values are greater than the 6 dB gain of the Worldspace receiver antenna. We also notice a large difference, of about 3 dB between the SSFIP antenna and the Ayous antenna. But this difference is reduced by half, down to 1.43 dB between the SSFIP antenna and the Ayous-Balsa antenna: this result confirms the assumption we made earlier, according to which losses in Ayous-Balsa antenna will be definitely lower than those of Ayous antenna. We finally measured the intrinsic gains of the Balsa and Ayous-Balsa antennas by using the method of three antennas [17], taking as third antenna the SSFIP antenna (FIGURE 3). We notice that the gains of the three antennas are greater than 7 dB over the DAB frequency band and this is a satisfactory information to use these wood antenna for satellite reception.

V. ALUMINUM-WOOD ANTENNA MEASUREMENTS

A. Linearly polarized Ayous-Balsa antenna

The Ayous-Balsa antenna's parameters are summarized in TABLE III.

1) **Reflection measurement:** On the rectangular coordinates graph (FIGURE 4) we have simulated and measured values of reflection coefficient. We notice a frequency shift of 0.04 GHz between measurement and simulation. This frequency shift must certainly come mainly

from the assembly and the joining of the various elements. The curves have however the same look.

2) **Radiation pattern:** We measured the co-polar and crosspolar field patterns in the E plane (FIGURE 5) and in the

H plane (FIGURE 6). The values of the field are measured in dB and are represented in polar coordinates. We notice a perfect symmetry of the curves. In addition we notice a good linear polarization

TABLE I
ANTENNAS PARAMETERS

Antenna	Denomination	Width (mm)	Length (mm)	Thickness (mm)	Description
SSFIP antenna	Strip	3	107.3	0.012	Copper
	Line substrate	150	180	1.6	FR4
	Ground plane	150	180	0.012	Copper
	Slot	42	1.5	0.012	
	Patch substrate	150	180	8	Rohacell ($\epsilon_r = 1.07$, $\tan(\delta) = 0.0008$)
	Patch	80	80	0.017	Copper
Wood SSFIP antenna	Strip	3	107.3	0.012	Copper
	Line substrate	150	180	1.6	FR4
	Ground plane	150	180	0.012	Copper
	Slot	44	1.5	0.012	
	Patch substrate	150	180	8	Balsa ($\epsilon_r = 1.2$, $\tan(\delta) = 0.026$)
	Patch	76	76	0.017	Copper
Balsa antenna	Strip	3	107.3	0.012	Copper
	Line substrate	150	180	1.6	FR4
	Ground plane	150	180	0.012	Copper
	Slot	44	1.5	0.012	
	Patch substrate	150	180	8	Balsa ($\epsilon_r = 1.2$, $\tan(\delta) = 0.026$)
	Patch	76.5	76.5	0.14	Aluminum
Ayous antenna	Strip	3	107.3	0.012	Copper
	Line substrate	150	180	1.6	FR4
	Ground plane	150	180	0.012	Copper
	Slot	40	1.5	0.012	
	Patch substrate	150	180	8	Ayous ($\epsilon_r = 1.77$, $\tan(\delta) = 0.0577$)
	Patch	63	63	0.14	Aluminum
Ayous – Balsa Antenna	Strip	4	107.3	0.14	Aluminum
	Line substrate	150	180	1.2	Ayous ($\epsilon_r = 1.77$, $\tan(\delta) = 0.0577$)
	Ground plane	150	180	0.14	Aluminum
	Slot	38	4	0.14	
	Patch substrate	150	180	8	Balsa ($\epsilon_r = 1.2$, $\tan(\delta) = 0.026$)
	Patch	75	75	0.14	Aluminum
	Cover				No cover

TABLE III
LINEARLY POLARIZED AYOUS-BALSA ANTENNA
PARAMETERS

Denomination	Width (mm)	Length (mm)	Thickness (mm)	Description
Strip	4	107.3	0.14	Aluminum
Line substrate	150	180	1.2	Ayous ($\epsilon_r = 1.77$, $\tan(\delta) = 0.0577$)
Ground plane	150	180	0.14	aluminum
Slot	38	4	0.14	
Patch substrate	150	180	8	Balsa ($\epsilon_r = 1.2$, $\tan(\delta) = 0.026$)
Patch	75	75	0.14	Aluminum

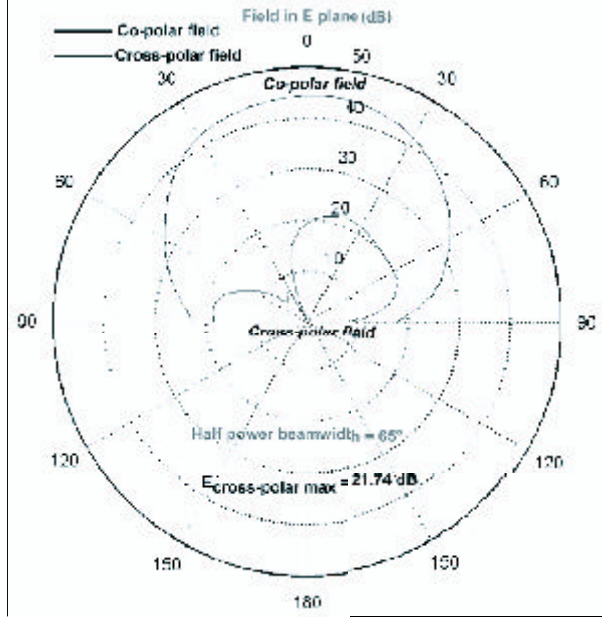


Figure 5. Ayous-Balsa antenna: Measured Co-polar and cross-polar patterns in the E plane

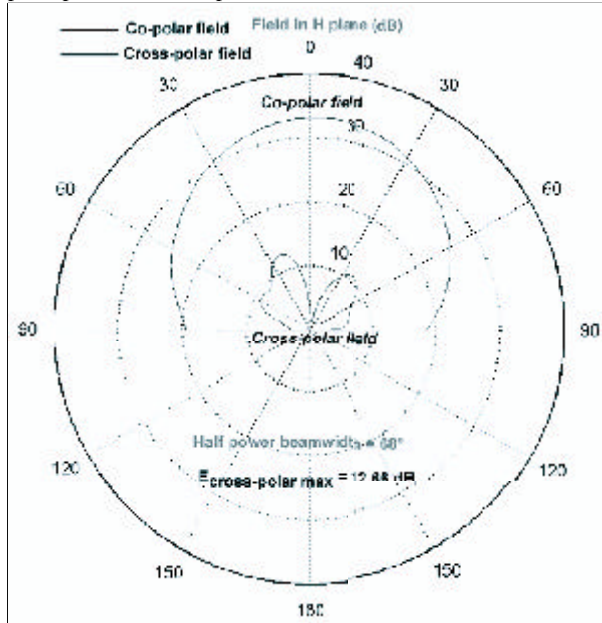


Figure 6. Ayous-Balsa antenna: Measured Co-polar and cross-polar patterns in the H plane

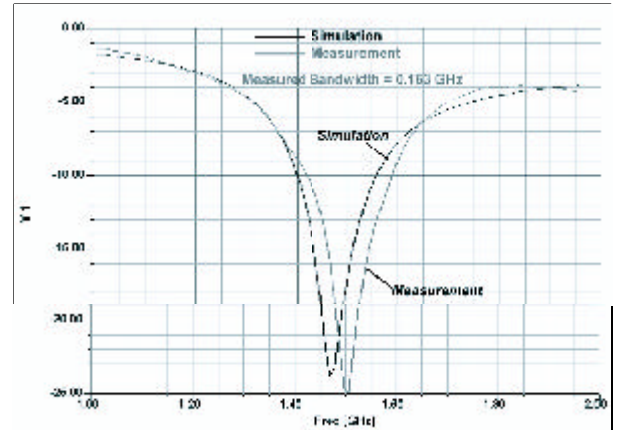


Figure 4. Ayous-Balsa antenna reflection: Cartesian coordinates diagram

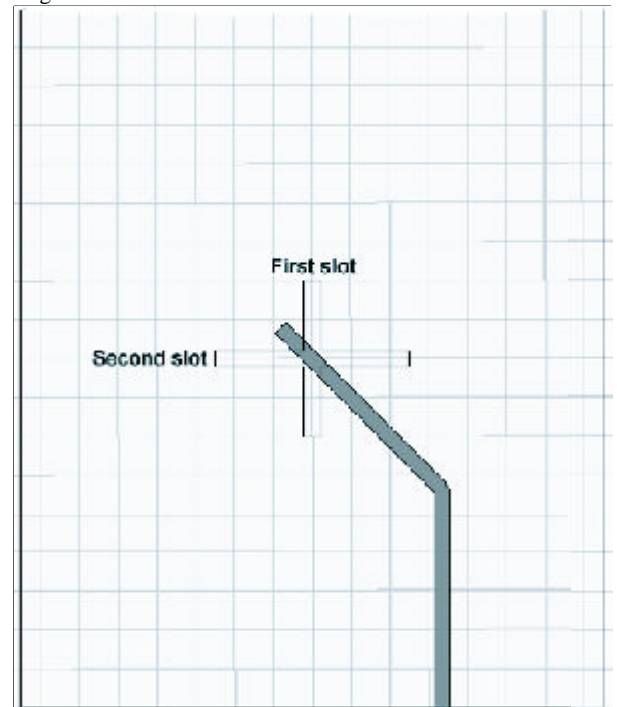


Figure 7. Left circularly polarized Ayous-Balsa antenna

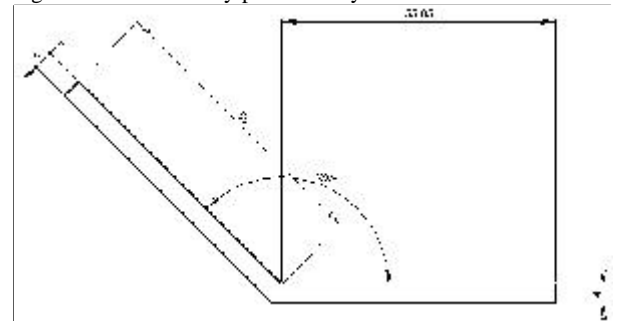


Figure 8. Strip dimensions of left circularly polarized Ayous-Balsa antenna

B. Circularly Polarized Ayous-Balsa antenna

The schematic of the circularly polarized antenna in the plane is represented by the FIGURE 7 and its feed line is represented by the FIGURE 8.

The parameters of the antenna are summarized in TABLE IV.

We notice here a notorious difference between measurements and simulation on the level of the reflection (FIGURE 9). This difference comes mainly from manufacture errors.

In addition the measurement of the radiation pattern (FIGURE 10) with a spinning dipole gives a better ellipticity. Nevertheless this ellipticity can be improved.

Finally, we build and joined to the antenna a low noise amplifier (LNA) and we carried out receiving tests of Worldspace radios. We successfully received at least all Worldspace radio stations from Afristar satellite with the Ayous-Balsa antenna (FIGURE 11).

TABLE IV
LEFT CIRCULAR POLARIZED AYOUS-BALSA
ANTENNA PARAMETERS

Denomination	Width (mm)	Length (mm)	Thickness (mm)	Description
Strip			0.14	Aluminum
Line substrate	150	180	1.2	Ayous ($\epsilon_r = 1.77$, $\tan(\delta) = 0.0577$)
Ground plane	150	180	0.14	Aluminum
First slot	4	40	0.14	
Second slot	50	4	0.14	
Patch substrate	150	180	8	Balsa ($\epsilon_r = 1.2$, $\tan(\delta) = 0.026$)
Patch	70	76	0.14	Aluminum

VI. CONCLUSION

Our first idea was to use local materials to design antennas. Since we planned to use aluminium for the radiating patch, we might well had to face the notorious technological problem: connecting aluminium to copper was always difficult and problematic, either by soldering or by welding. Therefore we used here the SSFIP configuration, which was a good compromise between simplicity and performances. The different blocks of the antenna were assembled by simply gluing the layers with a standard two-part epoxy glue. As we could remark, this was the first time that antennas were designed and manufactured with wood as line and patch substrates, and aluminium as patch, ground plane and feed line. As far as wood is concerned the moisture effects on the antenna performances were taken into account. We used linseed oil to protect the wood against moisture and we verify through measurements that this oil had no effect on antenna performances. But we still were looking for local techniques to stabilise the wood. We manufactured antennas with different technologies and we did compare measurements, essentially to quantify the reduction in gain with respect to the reference SSFIP antenna. All the designed antennas (Balsa, Ayous-Balsa, and Ayous antennas) exhibited a large enough gain to be connected to a Worldspace receiver. As we could expect, we observed a reduction in gain of -1.43 dB for the Ayous-Balsa antenna, which is smaller than that of the Ayous antenna. These measurements, which we had just taken, confirmed that antennas can be manufactured at a lower cost, by using only wood and aluminium, with a simple assembling process: gluing. The best antenna built upon a wood substrate provided a gain of

8.54 dB, a value just 1.46 dB less than the maximum value obtained with a SSFIP reference antenna.

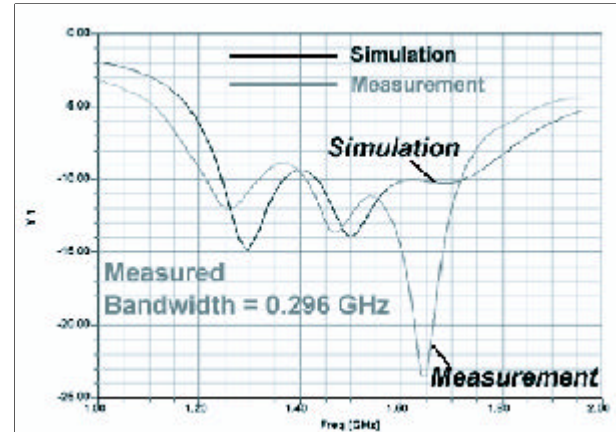


Figure 9. Ayous-Balsa antenna reflection: cartesian coordinates plot

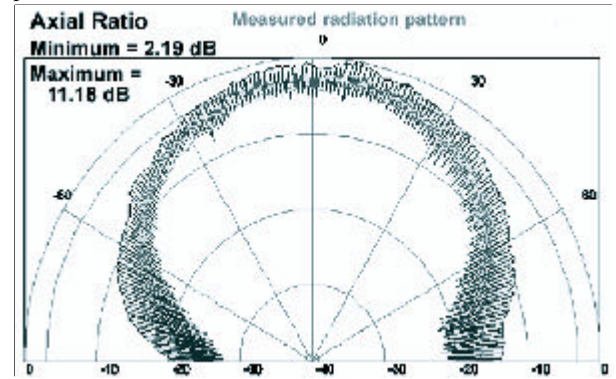


Figure 10. Ayous-Balsa antenna: Measured radiation pattern



Figure 11. Worldspace signals' receiver system

In addition, radiation diagrams in linear and circular polarization were even better than for the reference antenna. We designed several antennas with the same wood family and we noticed no modification on the antenna characteristics. Successful receiving tests of Afristar Worldspace satellite radio were carried out, confirming the possibility of using very low technologies and easily available materials to produce wood-aluminium antenna suitable for general satellite reception while reducing its fabrication cost by a factor of ten.

VII. REFERENCES

- [1] J. Pellet, L. Rechsteiner, A. Skrivervik, JF. Zrcher, N. Perrin, Use of the harmonic direction finder to study the terrestrial habitats of the European tree frog (*Hyla*

arborea), Amphibia-Reptilia, No. 27, March 3, 2006, pp 138–142.

[2] S. Vaccaro, J.R. Mosig, P. de Maagt, **Patch and slot antennas integrating high efficiency GaAs solar cells for space applications**, Journées Internationales de Nice sur les antennes (JINA'02), Nice, France, **Vol. II**, 12-14 Novembre, 2002, pp 117–120.

[3] S. Vaccaro, **SOLANT: study and development of planar antennas integrating solar cells**, Ph.D. thesis, Ecole Polytechnique Fédérale de Lausanne, Faculté Sciences et Techniques de l'Ingénieur, 2003, <http://library.epfl.ch/theses/?nr=2689>.

[4] S. Vaccaro, P. Torres, J.R. Mosig, A. Shah, J.-F. Zrcher, A.K. Skrivervik, P. de Maagt and L. Gerlach, **Stainless steel slot antenna with integrated solar cells**, IEE Electronics Letters, **Vol. 36**, No 25, 7th December, 2000.

[5] <http://www.f8byc.net/menu4/page8.html>.

[6] <http://www.nodomainname.co.uk/Omnicolinear/2-4collinear.htm>.

[7] <http://www.myotis.ch/exoops/modules/mydownloads/cache/files/pringles.pdf>.

[8] J.F. Zrcher, F. E. Gardiol, **Broadband patch antennas**, Artech House, London, UK, 1995.

[9] O. Vidémé B., J.R. Mosig, J.-F. Zrcher, **Le bois comme diélectrique pour une antenne microruban**, 9ième Journée de Caractérisation Microondes et Matériaux (JCMM 2006), St. Etienne, France, 28-30 mars, 2006, Session Posters, P13.

[10] Y. Amino, **Mechanical performance evaluation of bamboo-timber composite beams**, Ph.D. thesis, Ecole Polytechnique Fédérale de Lausanne, Faculté Environnement Naturel Architectural et Construit, 2002, <http://library.epfl.ch/theses/?nr=2582>.

[11] Kurt Galik, M. Tabassum Afzal, B. Colpitts, **Dielectric properties of softwood species measured with an open-ended coaxial probe**, Proceedings 8th International IUFRO Wood Drying Conference 2003, Brasov, Romania, 24-29 August, 2003, pp 110–115.

[12] H. Sahin, N Ay, **Dielectric properties of hardwood species at microwave frequencies**, Journal of Wood Science, **Vol. 50**, No 4, August, 2004, pp 375–380.

[13] R. H. Lang, A. Franchois, Y. Pieiro, **Microwave permittivity measurements of two conifers**, IEEE Transactions on Geoscience and Remote Sensing, **Vol. 36**, No. 5, September, 1998, pp 1383–1395.

[14] http://www.kayelaby.npl.co.uk/general_physics/2_6/2_6_5.html.

[15] L. Solymar and D. Walsh, **Lectures on the electrical properties of materials**, Second edition, Oxford University Press, London, UK, 1979, p. 257.

[16] J. R. James & P. S. Hall, **Handbook of microstrip antennas**, Peter Peregrinus Ltd, London, UK, 1989.

[17] C. A. Balanis, **Antenna theory: analysis and design**, Third edition, John Wiley and Sons Inc., New Jersey, USA, 2005.

[18] Wayne S. T. Rowe and Rod B. Waterhouse, **Theoretical investigation on the use of high permittivity materials in microstrip aperture stacked patch antennas**, IEEE Transactions on Antennas and Propagation, **Vol. 51**, No. 9, September, 2003, pp 2484–2486.