A Multifunctional Antenna for Terrestrial and Satellite Radio Applications

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***Abstract* ¾ A multifunctional antenna is presented for the application in terrestrial radio services like GSM 900MHz, DCS 1800MHz as well as for satellite radio services like GPS 1575 MHz. At the terrestrial frequency bands GSM 900MHz and DCS 1800MHz the antenna exhibits an omnidirectional radiation characteristics in horizontal plane for vertical polarized waves. At the frequency bands of the satellite radio services like GPS and Globalstar the antenna exhibits a radiation characteristics with a vertical main lobe and a circular polarized field.**

I. INTRODUCTION

Multifunctional antennas such as dual band antennas and multiband antennas can be used for two or more radio services in the same time [1-6] and even for the combination of terrestrial radio services and satellite services in one antenna [7]. The antenna structures are in common specialized to the radio services they are applied for. In the following we present a multifunctional antenna which is not restricted to special radio services. It can be applied to the transmission and reception of a variety of terrestrial and satellite radio services in the same time. While for the terrestrial radio services e.g. GSM900 or DCS1800 the antenna transmits and receives vertically polarized waves omnidirectional in the horizontal plane the same antenna transmits and receives circularly polarized waves with a vertical main lobe at the frequencies of the satellite radio services.

II. THE MULTIFUNCTIONAL ANTENNA

The multifunctional antenna consists of four vertical monopole antenna elements each covered by a triangular structure in horizontal plane (Fig.1). The monopole antenna elements are connected each with a twoport. Each of the twoports consists of a matching circuit to match the monopole antennas to 50Ω and an individual phase shift circuit for frequency dependent phase shifting. The outputs of the twoports are connected by a power divider and a feedline with an external port. The external port of the antenna can be used bidirectional for transmission and reception of the radio services. The matching circuit can be realized with few passive lumped elements and alternatively by a planar filter structure. At the frequency bands for terrestrial radio services the four monopole antenna elements are excited all in phase. In this case the four antenna elements of the multifunctional antenna automatically behave like one electrically small monopole antenna which transmits and receives vertical polarized waves with an omnidirectional radiation characteristic in the horizontal plane for terrestrial radio services. At the frequency bands for satellite radio services the four monopole antenna elements 1,2,3 and 4 are excited with the phase shift of 0°, 90°, 180°, and 270°. In this case the horizontal planar structures of the four antenna elements behave like two electrically small crossed dipoles in horizontal plane which transmit and receive circular polarized waves in vertical main lobe direction for satellite radio services.

The multifunctional antenna can be applied for many combinations of already existing and planned radio services in the range between 860MHz and 2.5GHz. For different combinations of radio services the same antenna structure can be used. Only the parameters of the matching circuit are dependent to the considered frequency bands.

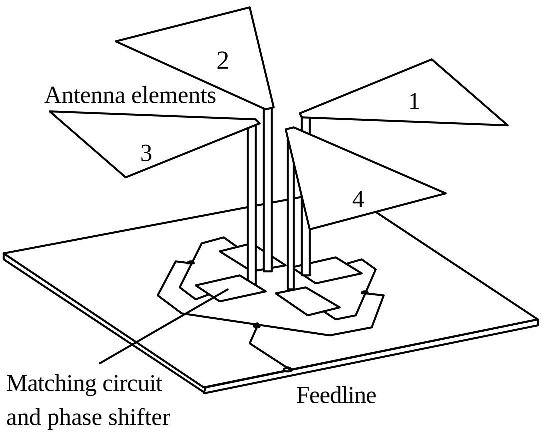

Fig.1: multifunctional antenna

All radio services are transmitted and received via one microstrip feed line. In fig. 2 the circuit is shown, connecting the feed line with the four matching twoports of the antenna elements. In the case of transmission a signal with wave amplitude $\underline{a}_o$ is fed into port 0. For a low loss power divider we obtain at the inputs of the phase shifters $|\underline{a}_1|=|\underline{a}_o|/2$. The inputs of the phase shifters are matched to 50Ω. The phase shifters produce a face shift which is frequency dependent. At the frequencies of terrestrial radio services the phase difference φ between the output signals of neighbored phase shifters is 0°. In this case the antenna elements are fed in cophase condition and hence the antenna elements behave together like one vertical monopole antenna. At the frequencies of satellite radio services the phase difference φ between the output signals of neighbored phase shifters is 90°. In this case the antenna elements 1, 2, 3 and 4 are fed with the phase 0°, 90°, 180° and 270° respectively. Hence the antenna elements form together two crossed dipole antennas in horizontal plane. In order to obtain matching at the inputs of the antenna elements we place matching circuits between the outputs of the phase shifters and the inputs of the antenna elements. The matching circuits ensure the matching of the antenna elements for all the considered frequency bands. For the realization of the multifunctional antenna the design of the matching circuit and design of the phase shifters is the most crucial part. There is electromagnetic coupling between the four antenna elements 1,2,3, and 4. Hence the inputs of the antenna elements can be seen as the inputs of a fourport structure. Due to the symmetry properties at the antenna fourport the reflection factor at each of the ports of the antenna elements can be calculated from the fourport scattering parameters. For the reception and transmission mode of the terrestrial radio services the reflection factor is calculated with $\underline{\rho} = \underline{S}_{11} + 2\underline{S}_{21} + \underline{S}_{31}$. For the reception and transmission mode of the satellite radio services the reflection factor at each of the ports of the antenna elements can be calculated from the scattering parameters with $\underline{\rho} = \underline{S}_{11} - \underline{S}_{31}$. From these reflection factors the effective impedances at the ports of the antenna elements 1,2,3,4 are derived at the center frequencies of the considered radio services. Each of the antenna elements 1,2,3,4 has got a frequency dependent radiation resistance $R_s(f)$ and, due to the top capacitances, a capacitive reactance $X_a(f)$. The impedance at the ports of the antenna elements is the base for the derivation of the parameters of the matching circuit.

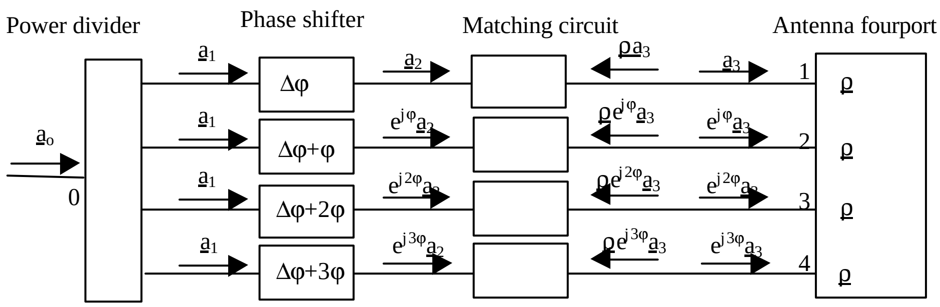

Fig. 2: Antenna circuit

The matching circuits at the antenna elements 1,2,3,4 can be realized with the inductive reactance X_L and the capacitive reactance X_C.

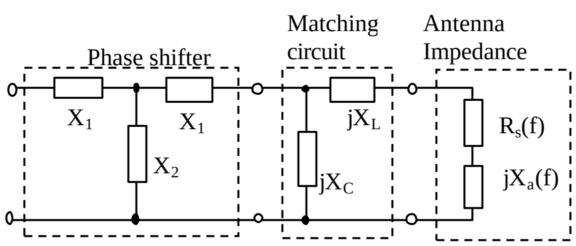

Fig.3: Matching circuit with phase shifter

Also the phase shifters can be realized by the inductive/capacitive reactances X_1 and X_2 as shown in fig.3. In order to achieve matching at the input ports of the matching circuits we obtain the required reactances X_L and X_C for the center frequencies f_1, f_2, f_3 ... of the considered radio services (Zw=50Ω).

$$X_C(f_i) = -\sqrt{\frac{Z_w^2 R_s(f_i)}{Z_w - R_s(f_i)}} \quad (1)$$

$$X_L(f_i) = -X_a(f_i) + \sqrt{(Z_w - R_s(f_i))\, R_s(f_i)} \quad (2)$$

$$i \in 1,2,3,...$$

this means that for every radio service a special reactance X_C and X_L is required. Each of these reactances is realized by a passive circuit consisting of inductances and capacitances. If the antenna should be realized for a number of *n* radio services, at least *n* inductances and capacitances are required for each of these passive circuits in order to obtain the required values for the reactances X_C and X_L at the center frequencies of the radio bands. If the value of a reactance at the center frequency of one frequency band is lower than the value of the reactance at the next lower frequency band, one further inductance or capacitance is required. In fig. 4, the lumped element circuit is shown which is the matching circuit for the three frequency bands GSM900, GPS and DCS1800. In this example the elements L', C_1 and C_2 are used to form X_C and the elements L_1, L_2, C' and C'' are used to form X_L. The capacitor C'' yields a further degree of freedom for the fine adjustment of the antenna and for choosing the parameters of the lumped elements.

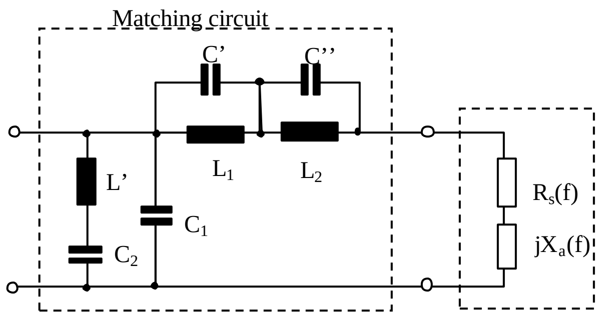

Fig.4: Lumped element matching circuit for three radio services

In an alternative way the required phase difference between the antenna elements can be obtained by using delay lines of different length for the antenna elements 1,2,3,4 instead of using the four phase shift circuits. The length of the delay lines for the antenna elements 1,2,3,4 is *L*, *L+l*, *L+*2*l*, *L+*3*l* respectively. If the antenna is applied to the radio services GSM (900MHz), DCS1800 (1800MHz), GPS (1575MHz) and Globalstar (1616MHz and 2500MHz) the length *l* is equal to the wavelength at 913MHz on the delay lines. In fig. 5 it is shown that with a length difference of *l* between the delay lines of neighbored antenna elements there is no difference in phase for the frequencies at 900MHz and 1800MHz of the terrestrial radio services. In the case of the satellite radio services GPS at 1575 MHz and Globalstar (at 1616MHz and 2500MHz) there is a difference in phase of 90°. Hence, for the radio services GSM, DCS1800, GPS and Globalstar the matching circuits with phase shifting for the antenna elements 1,2,3,4 can be realized as shown in fig.5.

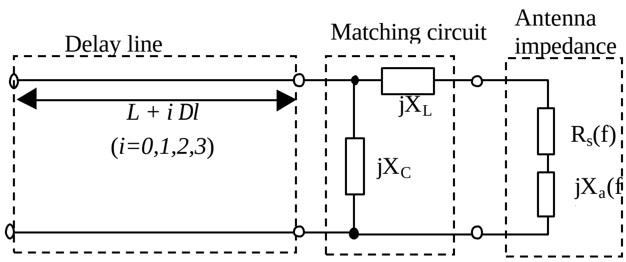

Fig.5: Matching circuit using a delay line for phase shifting: for the antenna element 1, 2, 3 and 4 a delay line with the length L, L+*D*l, L+2*D*l and L+3*D*l is used

For the derivation of the parameters of the lumped elements of the matching circuit an antenna fourport is realized as shown in Fig.6.

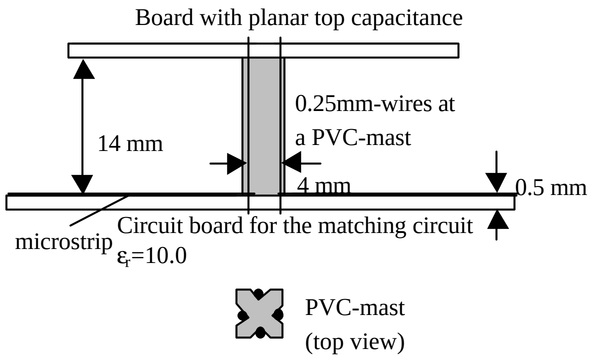

Fig.6: Dimensions of the realized antenna structure

For the realized multifunctional antenna-fourports, the scattering parameters are measured using a Network-Analyzer. The reference plains are located on the circuit board of the matching circuit in a distance of 5 mm from the feed points of the antenna elements. Due to the symmetry conditions of the antenna fourport the reflection factor $\underline{\rho}$ is calculated for terrestrial radio services with $\underline{\rho} = \underline{S}11 + 2\,\underline{S}21 + \underline{S}31$ and for satellite services the reflection factor is calculated for with $\underline{\rho} = \underline{S}11 - \underline{S}31$. From the reflection factors the effective impedances of the antenna elements are calculated for the center frequencies of the considered radio services at 900 MHz, 1575 MHz and 1800 MHz. Using equations (1) and (2) the parameters of the lumped elements in the matching circuit are calculated. Based on these parameters the matching and the bandwidth at the required center frequencies are derived. In Fig.7 the transmitted power versus frequency is shown for the radio services GSM

900, DCS 1800 and GPS. The results are based on measured scattering parameters of the antenna fourport and the calculated lumped element parameters of the matching circuit shown in fig.4.

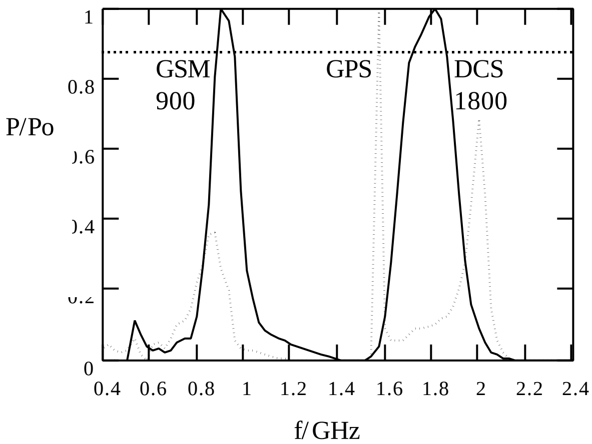

Fig.7: Transmitted power versus frequency: Result for the maching circuit shown in fig.4 (pervaded line: terrestrial radio services; dashed line: satellite services)

The antenna structure is modeled using a wiregrid method. In figs. 8,9 and 10 the two-dimensional radiation characteristics for the radio services GSM 900, DCS 1800 and GPS are shown, which fulfill the requirements for the considered radio services.

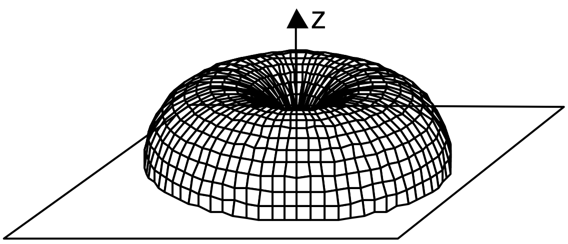

Fig.8: Radiation characteristics of the multifunctional antenna at GSM 900

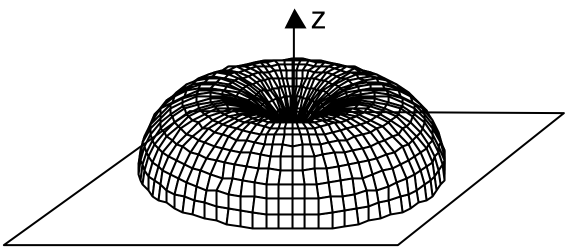

Fig.9: Radiation characteristics of the multifunctional antenna at DCS 1800

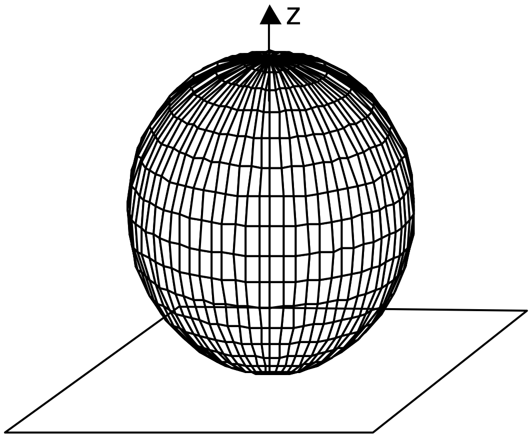

Fig.10: Radiation characteristics of the multifunctional antenna at GPS

CONCLUSIONS

A multifunctional antenna is presented for the application of various terrestrial and satellite services. Based on the measured scattering parameters of the antenna a matching circuit is developed for GSM900, DCS1800 and GPS. Concerning bandwidth and radiation characteristics the antenna fulfills the requirements of these services. Work is in progress to extend the matching circuits for Globalstar

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