Patch-Array-Antenna Feed Network Providing Bandwidth Improvement

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Abstract
Patch antennas are known for narrow bandwidth, depending on substrate height, but which can be improved by multilayer construction or by integration of extra matching circuits. The contribution presents a new approach to bandwidth improvement of patch array antennas, where conventional single layer patch elements are combined through a modified feed network. The network includes matching elements for each patch radiator without additional space requirement and without degradation of the fundamental feed network purpose. A 24 GHz 2 x 4 element array is shown to provide an improvement of bandwidth from 6% of the patch element alone to 13% of the array.

Kurzfassung
Patch-Antennen sind bekannt für ihre geringen Bandbreiten, die von der Substrathöhe abhängen und die entweder durch einen Mehrschichtaufbau erhöht werden können oder durch zusätzlich eingefügte Anpass-Netzwerke. Der Beitrag zeigt einen neuen Ansatz zur Bandbreitenerhöhung von Patch-Gruppenantennen, in dem konventionelle Patch-Strahler über ein modifiziertes Verteilnetzwerk gespeist werden, welches geeignete Anpass-Elemente für jeden Strahler integriert, ohne zusätzlichen Platzbedarf und ohne die vorgegebene Signalverteilungsaufgabe zu stören. Eine nach dem vorgestellten Konzept realisierte 24 GHz 2 x 4 - Element-Gruppenantenne steigert so die ursprüngliche Patch-Anpassungsbandbreite von 6 % auf 13 %.

1. Introduction

Patch array Antennas, e.g. /1/, comprise a number of patch elements which are combined in a feed network consisting of power dividers and connecting transmission lines. The conventional approach to the design of feed networks aims at a division of power from the input port to the patch elements with ideal match at any level within the network up to the patch element; at this point the frequency dependent impedance of the patch element leads to a mismatch with frequency-offset from the patch resonant frequency. The patch element impedance match bandwidth is known to depend heavily on the subtrate thickness with practical relative bandwidths on the order of 0.5 to 10 %. Employing the conventional approach to the design of feed networks, this impedance match bandwidth is maintained (or even reduced) at the network input port.

Conventional impedance bandwidth enhancement approaches aim at broadening the patch element's own bandwidth by employing multilayer construction, using e.g. parasitic elements and electromagnetic coupling, or by employing a matching filter network attached to each element, e.g. /2/, /3/. The latter approach requires additional circuit area for every patch element, which often is in conflict with the required circuit area for the feed network.

This presentation provides a new approach of feed network design in which the network is used for power division and, at the same time, for broadbanding of the impedance match of the array antenna.

2. Broadbanding Circuit

The principle of operation can be explained using a single element feed network, shown in Fig. 1. The patch element is represented by an equivalent resonator of parallel type which is characterized by a certain bandwidth or quality factor. The feeding transmission line includes two shunt capacitances C_1 and C_2, spaced by length l_1 from the patch element and by length l_2 between each other. The two capacitances form a transmission resonator whose center frequency is controlled by $l_2 \approx n\ \lambda/2$ and whose bandwidth depends on the size of C_1 and C_2. If centre frequency and bandwidth are matched to the patch resonator characteristics, and the spacing l_2 is chosen such that the patch equivalent resonator is transformed into the dual type with regard to the transmission resonator (series resonator matched by parallel resonator and vice versa, see /4/) the combination produces double tuning which can improve bandwidth on the order of a factor of 2 - 3 (at -10 dB match). As is well known from filter theory, parallel capacitances may be replaced by series capacitances, or parallel or series inductances, with or without additional transmission line sections (inverters), or combinations of series- and parallel- circuits or capacitances and inductances; all of these may create transmission resonator characteristics as required for impedance matching of the patch elements. One practical example is given in Fig.2, where the reflection coefficient is shown for a single patch element represented by a parallel resonant circuit..

The concept of transmission resonator matching can be translated from a single element antenna to a multielement antenna, given that the feed network is of the symmetrical *corporate* type and that all elements are connected to the central feed port via equal length to provide uniform phase distribution. In this case, we can employ the concept of *equivalent unilateral feed network* to represent the two-dimensional divider network by a one-dimensional serially connected transmission line network of the type used in Fig.1; from there on it is straight forward to implement a transmission resonator into this network in an analoguous way as done in Fig.1.

To make this point clear, an applicable network is shown in Fig.3(a), where four patch elements are fed by a symmetric tree of dividers and connecting transmission lines (*corporate feed network*). In its left hand part, the figure also shows a partitioning of the transmission line pattern into areas „belonging" to individual elements: Due to the symmetry properties of the network, the connecting line serving two radiators may be assumed to be a parallel circuit of two individual lines of equal characteristic impedance (double the full line impedance) and carrying the same currents (half the full line current) at the same voltage (the full line voltage); this description amounts to the assumption of a „magnetic wall" in the center of the transmission line. Running down the feed network from the element to the center feed point we can represent the parallel divider network by an equivalent unilateral network of transmission lines connected purely in series, Fig.3(b). In the concept of the *equivalent unilateral feed network*, the same lengths of transmission lines are used as in the original network, but the characteristic impedances are higher than in the original network by a factor of two, four, etc., corresponding to the number of elements supplied by the particular transmission line section. In the example of Fig. 3 it is assumed that the patch element has a resonant frequency resistance of $R=Z_C$, with Z_C the characteristic impedance of the first feed line connecting the patch element which provides impedance match at the center port for the patch resonant frequency (single tuned match).

3. Experimental Antenna

In Fig.4(a), the layout of an experimental 2x4 – element patch array antenna is shown. This antenna originally was designed without the stub-matching elements and exhibited a single-tuned impedance match bandwidth (-10 dB) of 6% around 24 GHz. However, it was found that the vertical coaxial probe launcher (SMA-connector at the back) produced a discontinuity of high reflection between the coaxial transmission line port and the microstrip port on the front: Fig. 4 shows results from a time-gated reflection coefficient measurement on a vertical SMA – to – microstrip transition. Note that, in an effort to improve the transition, the diameters of pin and groundplane opening already have been reduced; initial trials with full diameters resulted in complete failure due to extreme mismatch loss at the launcher discontinuity. From Fig. 4, we can conclude that the launcher can be described approximately as a series capacitance of $-30\,\Omega$ reactance at 24 GHz.

In an attempt to improve the antenna impedance match, it was found that double tuning broadbanding occured when stubs were placed downstream from the central feed point near the patch elements, as shown in Fig.5(a). The *equivalent unilateral feed network* for this configuration is given in Fig.5(b), where two additional capacitances are included in order to represent the uncompensated parasitic reactances of the T-junctions. These parasitic effects were included in the equivalent circuit and in subsequent design simulations, after a time domain reflection analysis had shown considerable mismatch of the T-junctions; any further refinements of the unilateral feed network with respect to other discontinuity effects, so far, have not been considered.

With respect to the basic matching scheme of Fig.1, the main elements of the matching circuit in Fig.5 are the short stub (length below $1/4\,\lambda$), acting as a shunt capacitance, and the SMA-launcher, acting as a series capacitance at 24 GHz; together with the transmission lines between them (length about $2.5\,\lambda$), they create the transmission resonator.

The measured reflection coefficient is shown in Fig.6, where a –10dB bandwidth of approx. 13% can be found. Additionally, radiation pattern measurements were made over the full 10dB-bandwidth and it was verified that the antenna operated properly with uniform phase and amplitude distribution accross the complete range and that the antenna gain was maintained at high level.

4. Conclusion

Matching transmission resonator circuits can be implemented as part of the feed network in symmetrical divider networks of corporate type; this allows double tuning of patch elements without sacrificing valuable space on the radiating surface of the substrate. However, the choice of circuit element types for the matching transmission resonator and of their positions in the feed network is not unique, and, similar to the design of transmission line filters, the properties of the transmission lines and of their discontinuities need to be simulated very precisely in order to design the matching circuit successfully; it is therefore necessary to either use exact field theoretical simulations of patch and network elements or leave the layout to final experimental optimization.

Literature

/1/ R. James and P. Hall, *Handbook of Microstrip Antennas*, vol. 1 & 2, IEEE-Series, Peter Peregrinus Ltd., 1989

/2/ D. M. Pozar, “A Review of Bandwidth Enhancement Techniques for Microstrip Antennas“, pp.157-166, in D.M.Pozar and D.H.Schaubert, editors, *Microstrip Antennas*, New York, IEEE Press, 1995

/3/ H. F. Pues, A. R. Van De Capelle,“ Wideband impedance-matched microstrip resonator antennas“, Proceedings of the 2nd ICAP, York 1981, pp. 402 – 405

/4/ H. Meinke, F. W. Gundlach, *Taschenbuch der Hochfrequenztechnik*, Kapitel B.15, Springer-Verlag, 1962

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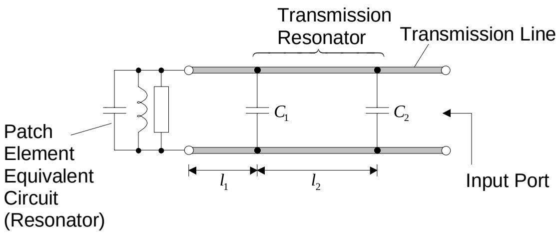

Fig. 1 Single element feed network for broadband impedance match

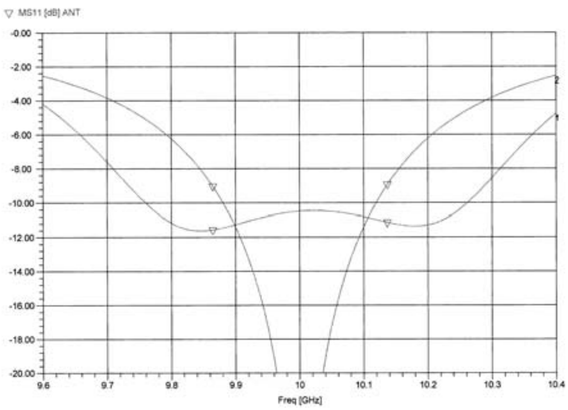

Fig. 2 Patch element reflection coefficient (curve 2, bandwidth 2.5%) and double tuned patch element reflection coefficient (curve 1, bandwidth 5%) using
$l_1 / \lambda = 0.34$, $l_2 / \lambda = 1.2$, $C_1 = 0.34 pF$,
$C_2 = 0.13 pF$

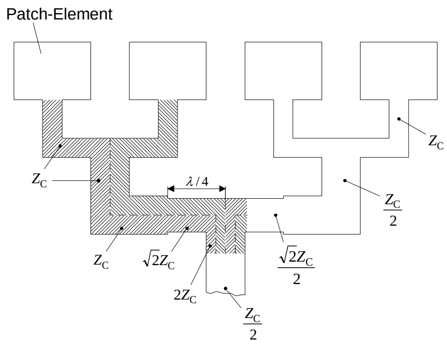

Fig. 3(a) Layout of patch array with corporate feed network

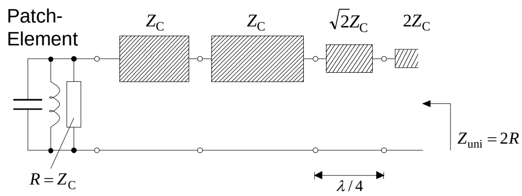

Fig. 3(b) Equivalent unilateral feed network of patch array

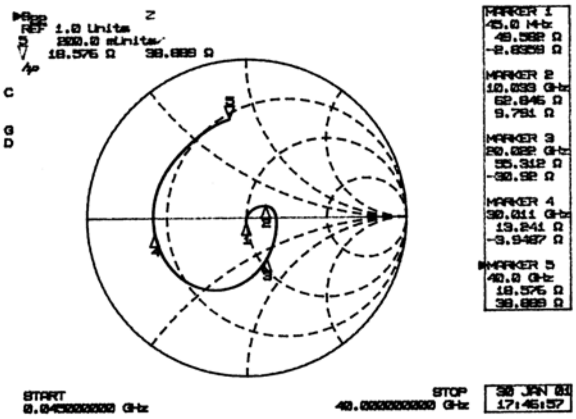

Fig. 4 Measured reflection coefficient of SMA-to-microstrip vertical probe launcher transition

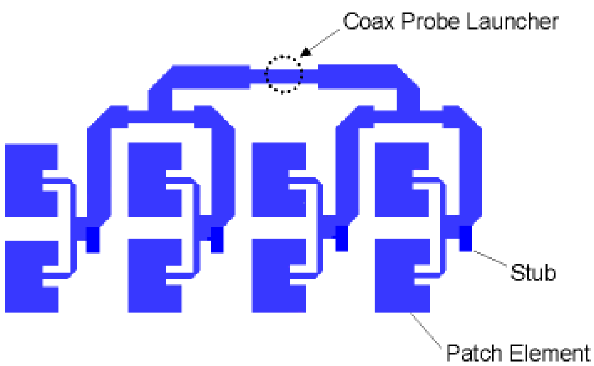

Fig. 5(a) Layout of 2x4 element patch array antenna

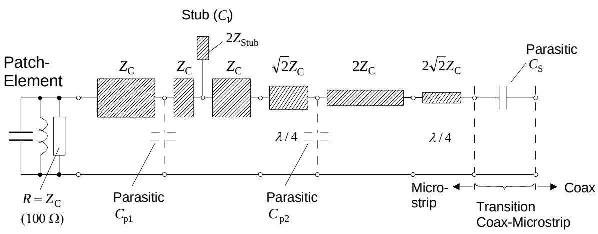

Fig. 5(b) Equivalent unilateral feed network for 2x4 element array

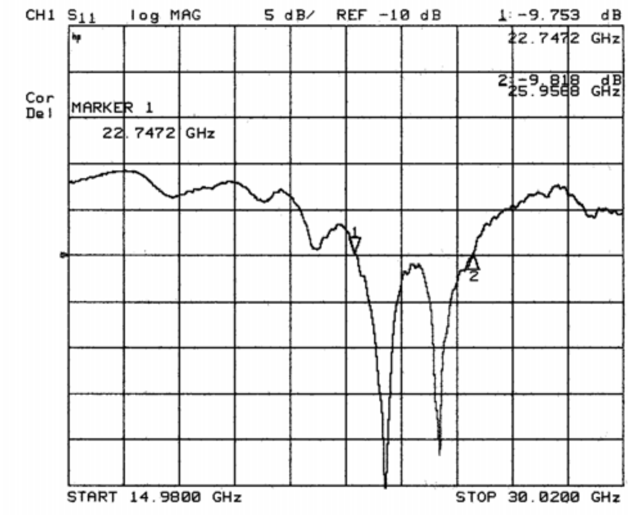

Fig. 6 Measured reflection coefficient of 2x4 element array