Active Frequency Selective Surfaces for Antenna Applications Electronically to Control Phase Distribution and Reflective/Transmissive Amplification

P. Edenhofer* 1), A. Alpaslan 2)

1) University of Bochum, Institute for High-Frequency Technique / Faculty of Electrical Engineering and Information Technology, 44780 Bochum, Germany
2) presently with Siemens AG, Kamp-Lintfort, Germany
e-mail: edh@hf.ruhr-uni-bochum.de

Abstract

A planar dipole grid antenna is described deposited on an *active frequency selective* (FSS) or *polarization sensitive* surface (PSS) *electronically tuneable* to control the spatial *phase distribution* and *reflective/transmissive amplification*. Such dipole grids can be used, for example, in reflector antenna systems composed of multiple reflective and/or transmissive subsystems to achieve and serve highly *cost-effective multi-purpose* applications. It is discussed how the resonant frequency or/and the type of polarization can be tuned just by varying the *steering voltage or current* of electronically tunable components such as *varactor diodes* or *YIG films*, respectively, implemented and integrated with each of the radiating dipole elements. The theoretical analysis for this paper is based upon a specific *Floquet theory* approach for single/double/triple periodic antenna structures. The resulting system of coupled vector integral equations for the unknown electric and magnetic current distribution is numerically solved by applying the *method of moments* supported by *Galerkin´s* process of weighting.

The experimental investigations were performed by developing a *waveguide simulation technique* in the frequency range of 7 to 16 GHz. Results of selected measurements are presented for quantities such as: the spatially dependent *reflection/transmission coefficients* (magnitude, phase) as a function of signal frequency; the intrinsic *input impedance* / matching of the various dipole elements involved, etc.; and – in addition to that - the resulting electronically achievable *phase advance/delay* and *amplification* of the active antenna system as well. A one/two-dimensional *enlarged* planar dipole grid of about 40 mm x 25 mm in aperture size was deposited inside an adequately *tapered* waveguide to reduce tolerance problems and to suppress higher order modes. Typical results are presented and discussed to demonstrate, e.g., that the resonant frequency~10 GHz can electronically be tuned around 9.85 GHz by a *bandwidth of 7 %* and around 10.1 GHz by *14 %* in case of *capacitive* or *inductive* tuning, respectively. Investigations show that electronic tunability is achieved preferably by using high-Ohmic voltage controlled components instead of low-Ohmic current controlled components, for instance, supporting *low-loss* and *low-noise* performance. Using properly selected HEMT-type integrated transistors the achievable *amplification* measured turned out be about *5.4 dB* at 10.3 GHz for an active one-element *strip* dipole grid (*reflection*-type amplifier) and about *3 dB* at 9.3 GHz for an active one-element *slot* dipole grid (*transmission*-type amplifier), respectively. A concluding discussion indicates how such kind of planar/conformal dipole grids may set up an integrated system of *multiple reflective/transmissive subreflectors* of a powerful *low-weight multi-purpose* microwave antenna system of *frequency multiplex* and *dual polarization* capability to serve various technical applications at the same time and at a high degree of flexibility and cost-effectiveness as well.

0-7803-9068-7/05/$20.00 ©2005 IEEE

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **01 JAN 2005**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Active Frequency Selective Surfaces for Antenna Applications Electronically to Control Phase Distribution and Reflective/Transmissive Amplification**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Bochum, Institute for High-Frequency Technique / Faculty of Electrical Engineering and Information Technology, 44780 Bochum, Germany**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001846, Applied Computational Electromagnetics Society 2005 Journal, Newsletter, and Conference.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Introduction • Electronic Circuitry

Double periodic arrays of *passive* strip or slot dipole grids [1,5] are widely applied in satellite antenna systems as frequency or/and polarization sensitive surfaces (FSS/PSS), e.g. dichroic subreflectors, at the benefit of saving weight, volume, and electric power [7]. Usually once designed and manufactured there is no possibility to change frequency or polarization characteristics of the FSS/PSS. For a variety of applications it would be attractive to have a controllable tunability for selection of frequency/polarization as well as reflectivity or transmittivity level [2]. Investigations were devoted to *active* tunable periodic grids controlling the resonant frequency by electronically switching PIN diodes [3]. As an alternative also optical tuning was achieved using periodic structures on semiconductive substrates [4]. An amplification of the incoming signal even along with the subreflector would contribute to enhance the SNR of a RX antenna system [8].

This paper presents various techniques to tune the reflection and transmission properties of FSS/PSS´s. By implementing each of the planar dipoles with *GaAs varactor diodes* an electronic tuning of the resonant frequency of a FSS was achieved [6]. Combining each of the grid elements with *YIG films* a controllable tuning was accomplished without any bias lines just by varying an externally applied magnetostatic field [9]. It is demonstrated how an *amplification* effect can be achieved, if the backscattering elements (metallized dipoles or slots) are integrated with specific segments of planar electronic circuitry (*diodes/transistors*) resulting in a *negative* real part of the input impedance for the equivalent one-port amplifier) [7]. One technically attractive advantage of such an active antenna configuration is that the incoming (linear) polarization of the received and amplified (by one-port reflection or two-port transmission) signal does not change, i.e. *conservation of polarization* is achieved [8]. This specific feature allows to operate the active antenna without any technical modification in forward and backward direction as well (reciprocity preserved). Usually decoupling of RX/TX radiating elements is done by taking cross-polarized input/output signals.

Theoretical Background • Numerical Results

Each planar dipole along the periodic grid of infinite extent is taken to be loaded by equal lumped linear/nonlinear elements (spatially homogeneous distribution). The inhomogeneous *impedance boundary condition* is applied to each dipole with lumped passive or/and *linearized loaded active* elements to balance the tangential vector components of the incident and scattered electric field with the voltage contributions provided by the individual lumped elements [6,8]. Starting from an *integral equation approach* the unknown current distribution along the surface is expanded in single/double periodic Fourier series according to *Floquet´s theorem*. A solution is taken in the *spectral* domain where a multiplication of both of the *Fourier transforms* for the current distribution and for the associate Green´s function can be used. The resulting matrix equation (inverse Fourier transforms introduced) is numerically solved by applying the *method of moments* (Galerkin´s weighting). Since lumped loaded dipole grids are expected to show enhanced features of inhomogeneous current distribution it was appropriate to choose a *subdomain rooftop* representation for the dipole currents.

Numerical results are represented for *continuous* shifting the *$\lambda/2$-resonant* frequency of a *strip* dipole grid (length 23 mm; width 0.5 mm) by varying: (a) *capacitive* loads of 10 fF to 1 pF for a maximum frequency shift of about 12 to 8 GHz equivalent to an electronic *shortening* of the dipole length; (b) *inductive* loads of 1 to 100 nH for a maximum frequency shift of about 8 to 2 GHz equivalent to an electronic *extension* of the dipole length. The λ-resonance of 12.2 GHz turns out to be fixed during tuning due to the intrinsic abrupt minimum of the dipole current at the center loaded lump position. Typical *phase* changes to be achieved are in the order of nearly 180 degree (*sharp* transition across "resonant" value of varying capacitance) and up to nearly 45 degree (*slow* transition) for the case of two-port *transmission* and one-port *reflection*, respectively. These features can be utilized electronically to tune (calibrate) the specified resonant frequency of a dipole grid against *manufacturing tolerances* or to control the *frequency shifting/beam steering* of the main lobe of a (phased) antenna array along with maintaining continuously varying focussing/defocusing effects to keep the *shape* of the main lobe close to *constant* during operations.

Experimental Setup • Results of Measurements

Measurements have been made for the reflection and transmission coefficients in magnitude and phase by means of a tapered *waveguide simulator setup* operating altogether from about *7 to 16 GHz* (fundamental TE 10-mode with varying angle of incidence from 32 to 13 degrees). A set of unloaded/loaded vertically polarized dipole elements (e.g. 10x1-/5x2-element array) is placed in one or two row(s) across the *enlarged rectangular aperture* (dielectric quartz substrat ε= 3.8; loss tangent 0.0001; thickness 0.28 mm) of the tapered waveguide to simulate a one/two-dimensional periodic dipole array of infinite extent (twofold *mirror principle*). Given the efforts and complexity of manufacturing active dipole grids, this concept of waveguide simulation is considered to be an efficient and cost-effective solution.

♦ *Electric* tuning – varactor diode: center-bonded *GaAs-diode* chip (dice) reversely biased and tuned with a DC voltage varying from – 4 V (~25 fF) to +0.5 V (~75 fF) across two highly resistive meander-type transmission lines (~10 kΩ between two adjacent dipoles). Shifting of resonant frequency was measured to be about *7 %* (corresponding to -4V to +0.5 V) with respect to center frequency at 9.9 GHz.

♦ *Magnetic* tuning – YIG-film: film size 36 mm x 5 mm, thickness 0.5 mm, saturation magnetization Ms = 1.75 kG; skewed terminations to reduce multiple reflections; *no bias lines necessary*; tuning with DC current varying from 0 to 1 A according to 0 to 2.7 kG. Shifting measured to be *13 %* from about 9.4 to 10.7 GHz. For uncontrolled YIG-loads (0 A) shifting of resonant frequency is measured towards lower frequencies (likewise capacitive load corresponding to high-valued dielectric constant at 14 for ferrite material). Measured transmission loss – 38 dB, drop of 20 dB observed for signals at 7 GHz due to *gyromagnetic resonance*.

♦ *Amplifying Periodic Structures • Negative Resistance Circuits*

Active dipole *strip grid / reflection-type* amplifier (R>1): HEMT-type transistor integrated in source circuitry together with a *capacitive feedback* element and a drain exit configuration. The feedback element is realized by an *open-ended* transmission strip line segment advantageously also representing one of the dipole arms whereas the other one is part of some metallic ground plane. In order to optimize HEMT operations the control voltages are fed from outside by *bias strip lines* oriented *orthogonally* across the *vertically* oriented dipole axis (polarization decoupling). An amplification of about *5.4 dB* was *measured at 10.3 GHz* for such a one-port amplifying dipole antenna. For transistor operations turned off the reflection coefficient measured is of the order of 10 dB, i.e. the dipole antenna is just loaded by some lossy resistance at the expense of reduced or negligible radiation.

Active dipole *slot grid / transmission-type* amplifier (T>1): Use was made of *electrically dual* circuitry (*magnetic* instead of electric dipole, etc.). A *horizontally* oriented slot dipole was preferably integrated with a similar HEMT-type environment as before, however two *short-cut* parallel transmission strip line segments were taken to realize the *inductive feedback* element in HF substrate technology. Here the open-ended strip line segment at the drain contact represents a short-circuit of the RF signal as to metallic ground plane, i.e. highly attractive *shielding* is separating the incident signals at one side from the amplified transmitted signals from the other side of the dipole “grid”. Consequently the technical *alignment* of the bias strip lines adequately to control HEMT operations along a dipole slot grid is certainly *less critical* than for a dipole strip grid. An amplification of about *3 dB* was *measured at 9.7 GHz*.

In conclusion, both types of *phased and amplifying dipole grids* can be used as reflective or transmissive subreflectors in *composite multiple reflector antenna systems* providing an additional (complementary) capability of amplification already at the *low-noise subreflector* system level.

References

[1] Wu, T.K.: Frequency Selective Surface and Grid Array. Wiley, 1995

[2] Chang, T.K.; Langley, R:J.; Parker, E.A.: Active Frequency-Selective Surfaces. IEE Proc. Microw. Antennas Propag., Vol. **143**, 1996, pp. 62-66

[3] Shuley, N.V.: Diode Loaded Frequency Selective Surfaces. Journees Int. de Nice sur les Antennas, JINA´92, Nice, France, Nov. 1992, pp. 313-316

[4] Vardaxoglou, J.C.: Frequency Selective Surface from Optically Excited Semiconductor on a Substrat. Electron. Lett., Vol. **34**, 1998, pp. 570-571

[5] Mittra, R.; Chan, C.C.; Cwik, T.: Techniques for Analyzing Frequency Selective Surfaces – A Review. Proc. IEEE, Vol. **76**, 1988, pp. 1593-1615

[6] Alpaslan, A.; Edenhofer, P.:Electronically Tunable Frequency Selective Surfaces. Int. Symp. on Electromagnetic Theory, U.R.S.I., Thessaloniki, Greece, 25-28 May 1998, Proc. Vol. I, pp. 130-132

[7] Alpaslan, A.; Edenhofer, P.: Active Dipole Grids as Electronically Tunable and Amplifying Antenna Reflectors. Millennium Conference on Antennas and Propagation, AP2000, Davos, Switzerland, 2ooo, ESA SP-**444**, p. 658

[8] Alpaslan, A.: Untersuchungen zu impedanzbelasteten doppeltperiodisch verteilten Dipolgittern als elektronisch steuerbare aktive Antennenreflektoren im Frequenzbereich von 7-16 GHz. Ph.D. Dissertation, University of Bochum / Germany, Institute for High-Frequency Technique, 2002

[9] Krug, J.; Edenhofer, P.: Oberflächenwellengespeiste aktive Strahleranordnungen in planarer Technik mit Phasensteuerung. AEÜ, Bd. **39**, 1985, pp. 77-86