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(54) Title: FERROELECTRIC DELAY LINE

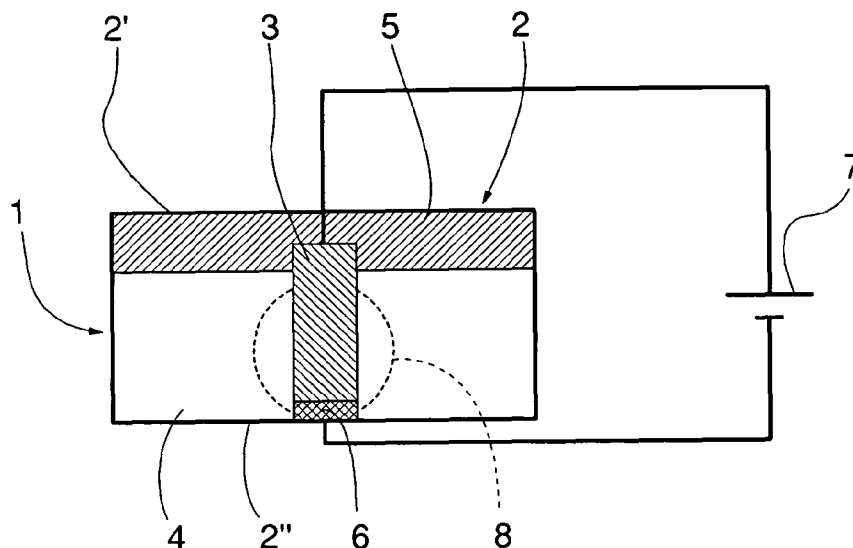


Fig. 1

(57) Abstract: An electrically tunable delay line (1) for radiofrequency applications, includes: a waveguide body (2); a metal ridge (3), longitudinally extending within said waveguide body (2); a ferroelectric member (6) also longitudinally extending within said waveguide body along at least a portion of the ridge (3); and a variable d.c. voltage source (7) for applying a variable transversal electrical field to said ferroelectric member (6) to vary a dielectric constant thereof and hence the delay imparted by the line (1). The ridge (3) is electrically insulated from the waveguide body (2) and is supported within a dielectric support member (5) carried by the waveguide body (2).

FERROELECTRIC DELAY LINE

Field of the invention

The present invention refers to delay lines, and more particularly it concerns a continuously tunable waveguide delay line in which delay tuning is obtained by varying the dielectric constant of a ferroelectric member within the waveguide.

Preferably, but not exclusively, the present invention has been developed in view of its use in transmitting apparatus in wireless communication systems exploiting the reconfigurability antenna technique and in the so-called Dynamic-Delay-Diversity (DDD).

10 Background of the Invention

A currently used technique for improving performance of wireless communication systems, in particular in downlink direction, adds a delay diversity to the space and/or polarisation diversity provided by transmitting antenna arrays. In other words, different elements in the array transmit differently delayed replicas of a same signal, undergoing time-varying delays. At a receiver, the differently delayed replicas give rise to alternate constructive and destructive combinations.

A wireless communication system exploiting this transmission technique is disclosed for instance in WO 2006/037364 A.

Use of this technique entails the provision of time-varying or tunable delay lines in the signal paths towards different antenna elements.

Assuming for sake of simplicity a single-frequency signal, so that it is equivalent to consider a time delay or a phase shift, a delay line with length L introduces a phase shift $\phi = \beta \cdot L$, or a delay $\tau = d\beta/d\omega$, on the signal propagating through it, β being the propagation constant of the line and ω being the angular frequency. Thus, in order to vary the phase shift (or the delay), either β or L is to be varied. The most commonly used solution relies on a variation of β .

Several tunable delay lines based on the variation of β are known in the art, and a class of such delay lines exploits the modulation of the dielectric constant ϵ_r of a ferroelectric material under the effect of an electrical bias field. Electrically-controlled ferroelectric delay lines exhibit low insertion losses and are continuously tunable, and thus obviate the drawbacks of commercially-available delay lines or phase shifters such as those based on MEMS (MicroEelectroMechanical Switch) devices, PIN-diodes or FET (Field Effect Transistors) circuits, Monolithic Microwave Integrated Circuits (MMIC), which suffer from high insertion losses and are tunable only in steps whose height can be reduced only with a significant increase of the device complexity.

A voltage-variable ferroelectric waveguide phase shifter according to the preamble of claim 1 is known from US 5,724,011 A. The prior-art phase shifter comprises a symmetrical ridge waveguide with two contacting slabs of ferroelectric material filling the gap between two confronting ridges. A flat electrode is disposed in the ferroelectric material, in the symmetry plane of the waveguide, and is connected to a variable voltage source to establish a variable transverse electrical field within the ferroelectric material and to consequently vary the delay of electromagnetic signals propagating along the waveguide.

US 6,756,939 B2 discloses a phased array antenna comprising ferroelectric voltage-tunable phase shifters realised as microstrip elements.

US 5,355,104 A discloses a phase shifter based on the "Suspended Strip Line" technology, with two conductive strips separated by a voltage controllable dielectric.

The article "Planar Microwave Integrated Phase Shifter Design with High Purity Ferroelectric Material", by F. De Flaviis et al., IEEE Transactions on Microwave Theory and Techniques, Vol. 45, No. 6, June 1997, pp. 963 - 969, discloses use of microstrip ferroelectric elements in phase shifters for operation up to X band.

The article "New Tunable Phase Shifters Using Perturbed Dielectric Image Lines", by Ming-yi Li et al., IEEE Transactions on Microwave Theory and Techniques, Vol. 46, No 10, October 1998, pp. 1520 - 1523, discloses a variable phase shifter using a dielectric line perturbed by a movable reflecting plate.

Summary of the Invention

The Applicant has observed that the prior-art phase shifter of US 5,724,011 has some drawbacks, in particular it uses a single-conductor transmission line, so that it exhibits a non-null cutoff frequency, limiting its operation range. Moreover the ferroelectric element is made with a tapered or stepped shape, to transform the impedance of the waveguide into the impedance of the phase shifter, and this makes the delay line fabrication more complex. Further, the element generating the variable delay comprises two parallel transmission lines, halving the characteristic impedance. Since the characteristic impedance of a guide loaded with ferroelectric material is already very low due to the high dielectric constant of ferroelectric materials, this in turn results in a greater difficulty for adapting the delay line to input/output connectors.

The Applicant has also observed that ferroelectric phase shifters making use of microstrip elements are not able to handle high powers, as requested by the preferred application. Further, the limited heat dissipation capability makes such devices unsuitable for DDD applications, where high signal powers are involved.

Finally, the Applicant observes that the presence of moving parts in variable phase shifters makes the device complex and prone to failure.

It is an object of the invention to provide an electrically tunable delay line, which is suitable for applications, like DDD, where high signal powers are involved, and which
5 obviates the drawbacks of the prior art devices.

According to a first aspect of the invention, there is provided a continuously electrically tunable delay line, including: a waveguide body; a metal ridge longitudinally extending within said waveguide body; a ferroelectric member also longitudinally extending within said waveguide body along at least a portion of the ridge, and a
10 variable d.c. voltage source for applying a variable transversal electrical field to said ferroelectric member to vary the dielectric constant thereof and hence the delay imparted by the line, wherein said ridge is electrically insulated from the waveguide body, said ferroelectric member is comprised between said metal ridge and a confronting wall of the waveguide body and said d.c. voltage source is connected
15 between said ridge and said confronting wall of the waveguide body.

The delay line may further include coaxial input/output connectors at opposed ends of the waveguide body, for connection to coaxial cables carrying input/output signals and means for impedance matching between the coaxial cables and the ferroelectric member.

20 According to a first embodiment, said impedance matching is achieved through a plurality of dielectric members located between each connector and the ferroelectric member and having different dielectric constants, increasing in a direction from a connector to the ferroelectric member, and electrical length $\lambda/4$, λ being the wavelength of a signal transmitted along the line.

25 According to a another embodiment, said impedance matching is achieved through a plurality of dielectric members located within each connector and having different dielectric constants, increasing in a direction toward the ferroelectric member.

Use of a delay line with two conductors allows having a substantially zero cut-off frequency of the fundamental mode of propagation, so that the limitations in the
30 characteristic frequency typical of single-conductor delay lines are eliminated. The delay line is moreover easy to manufacture, thanks to the provision of a single ferroelectric member. Moreover, it provides a good impedance matching when used in connection with coaxial cables for signal input/output, as it can be the case in the preferred application.

35 In a second aspect, the invention also provides an apparatus for transmitting a

signal to a plurality of users of a wireless communication system via diversity antennas, said apparatus including, along a signal path towards said diversity antennas, at least one tunable delay line generating at least one variably-delayed replica of said signal and consisting of an electrically-tunable delay line according to the invention.

5 In a further aspect, the invention also provides a wireless communication system including the above transmitting apparatus.

Brief description of the drawings

Further objects, characteristics and advantages of the invention will become apparent from the following description of preferred embodiments, given by way of non-limiting examples and illustrated in the accompanying drawings, in which:

- Fig. 1 is a schematic cross-sectional view explaining the basic principles of an electrically-controllable delay line according to the invention;
- Fig. 2 is a perspective view, in longitudinal cross-section, of a first embodiment of the invention;
- 15 - Fig. 3 shows graphs of the return and transmission losses, versus frequency, in a practical example of the delay line shown in Fig. 2;
- Fig. 4 shows graphs of the phase and the phase shift, versus frequency, in a practical example of the delay line shown in Fig. 2; and
- Fig. 5 is a perspective view, in longitudinal cross-section, of a variant of the first embodiment;
- 20 - Fig. 6 is a perspective view, in longitudinal cross-section, of a second embodiment of the invention;
- Fig. 7 is a schematic block diagram of a transmitting apparatus of a wireless communication system with dynamic delay diversity, using delay lines according to the invention.

Description of the preferred embodiments

Referring to Fig. 1, there is schematically shown in cross sectional view the structure of an electrically controllable delay line according to the invention, generally denoted by 1. The physical support for delay line 1 is a ridge waveguide, which consists of a metallic waveguide body 2 with rectangular cross-section and a longitudinal partition or ridge 3, also of rectangular cross-section, centrally arranged in the waveguide cavity 4 and electrically separate from waveguide body 2.

By way of non-limiting example, the drawings show a vertically arranged ridge 3, with the major sides of the rectangular cross-section parallel to the side walls of waveguide body 2. Other arrangements are however possible.

Electrical separation between waveguide body 2 and ridge 3 is provided by a member 5 of a dielectric material with low dielectric constant (e.g. Teflon®, $\epsilon_r = 2.1$), extending along top wall 2' of waveguide body 2, to which member 5 is secured. Member 5 also provides mechanical support for ridge 3, whose top part is embedded within Teflon® member 5, as shown in Fig. 1.

The active member of delay line 1 is a slab 6 of ferroelectric material, i.e. a dielectric material with electrically controllable dielectric constant, which is arranged between the bottom surface of ridge 3 and bottom wall 2" of waveguide body 2 and is secured to the latter. Several materials can provide the desired controllability of the dielectric constant. Typically, Barium Strontium Titanate (BST), having the general formula $Ba_{(1-x)}Sr_xTiO_3$, or BST composites are used in delay lines or phase shifters for microwave applications.

The presence of metal ridge 3 and dielectric members 5, 6 with far different dielectric constants (as it will be discussed later, in practical embodiments of the invention a material with a dielectric constant having an average value of the order of 500 is used) results in the electric field being essentially concentrated in the region where the active (ferroelectric) material is located. Moreover, the electrical separation of ridge 3 from waveguide body 2 results in a two-conductor delay line, which does not exhibit the frequency limitations of single-conductor delay lines. Indeed, the guide of the invention supports a quasi-TEM propagation characterised by zero cutoff frequency.

The variation of the dielectric constant of ferroelectric slab 6 necessary for delay tuning is obtained by applying a variable d.c. bias voltage of some kVs between ridge 3 (forming the positive pole) and bottom wall 2" of waveguide body 2. The source of that bias voltage is denoted by 7.

Connection of delay line 1 towards the exterior is obtained with coaxial connectors, of which the trace is shown by dashed-line circle 8 in the Figure, and insulation of the signal from the bias voltage is obtained by means of a commercially available DC block or a bias-tee (not shown) at the input and the output. Use of bias-tees solves also the problem of application of the bias voltage from source 7.

An important problem with a ferroelectric delay line is the impedance matching between the input-output coaxial connectors (impedance 50 Ω) with the active element (impedance of few ohms). A number of solutions for that problem are discussed below with reference to Figs. 2 to 6. In the Figures, corresponding elements are denoted by corresponding reference numerals, differing by 100 in the various Figures. For sake of

simplicity of the drawing, the dielectric member supporting the metal ridge has not been shown in Figs. 2, 5 and 6. In all embodiments discussed below, it is assumed that ferroelectric slab 106 is made of $\text{Ba}_{0.63}\text{Sr}_{0.37}\text{TiO}_3(1.5\text{MgO})$, use of which is disclosed in the paper "Parallel plate waveguide bulk ceramic ferroelectric phase shifter" by A. Deleniv et al., presented at the 35th European Microwave Conference, Paris 2005, pages 653 - 655 of the conference proceedings.

In delay line 101 shown in Fig. 2, the impedance matching between input/output connectors 108A, 108B and ferroelectric slab 106 is obtained by means of two sets of impedance matching dielectric members of rectangular-cross sections, symmetrically arranged at both sides of ferroelectric slab 106. The different dielectric members have different dielectric constants, increasing in the direction from connector 108A, 108B to ferroelectric slab 106, and have the same electrical length $\lambda/4$. In the example shown in the Figure, four dielectric members 109A to 112A and 109B to 112B, respectively, have been considered in each set. A set of dielectric members 109 to 112 and ferroelectric slab 106 define five delay line sections 101-1 to 101-5 characterised by different cross-sectional sizes and lengths of waveguide body 102 and/or ridge 103. In particular, waveguide body 102 and ridge 103 are narrower in correspondence of the first delay line section 101-1, and ridge 103 has different height in correspondence with the different sections, resulting in a step profile of its top surface and an indented profile of its bottom surface. The variation of the cross-sectional sizes of waveguide body 102 and ridge 103 in longitudinal direction contributes to improving the impedance matching.

The following table 1 reports the materials employed for the impedance-matching dielectric members 109 to 112 and ferroelectric slab 106, and the sizes and electrical characteristics thereof, in an exemplary practical embodiment of delay line 101. As far as the dielectric constant of the ferroelectric material (indicated in short by BST in the table) is concerned, reference is made to a variation range from 550 to 450 obtained by varying the applied field from 1 to 3 KV/mm, as reported in the paper of Deleniv et al.

Table 2 in turn reports the geometrical characteristics of ridge 103 and waveguide body 102 in the various sections.

TABLE 1

Section	Material	ϵ_r	Height [mm]	Width [mm]	Length [mm]
1	Plexiglas®	3,4	1.8	3.3	33
2	Al_2O_3	10	1.8	3	22

3	PE (polyethylene) +TiO ₂	30	1.3	3	10.75
4	TiO ₂	100	0.8	3	4.9
5	BST	450 - 550	1	3	20

TABLE 2

Section	Ridge (height x width) [mm]	Waveguide body (height x width) [mm]	Ridge and waveguide section length [mm]
1	3.4 x 3.3	20 x 12	33
2	5.4 x 3	20 x 20	22
3	7.2 x 3	20 x 20	10.75
4	7.7 x 3	20 x 20	4.9
5	7.5 x 3	20 x 20	20

Fig. 3 shows the behaviour of delay line 101 in terms of return and transmission losses at the above mentioned uppermost and lowermost values (550 and 450) of the variation range of dielectric constant ϵ_r , in the frequency band 1.9 to 2.2 GHz. Transmission loss is shown in the upper part of the Figure, and return loss in the lower part. The solid line refers to the uppermost value of ϵ_r , and the dashed line to the lowermost value. The graphs show that, within such band, the return loss is better than 15 dB and the transmission loss is below 1.5 dB.

Fig. 4 shows the behaviour of the phase at such values of the dielectric constant and the resulting phase difference (dotted line) in a frequency range from 1.5 to 2.5 GHz. In case of the assumed length of 20 mm for ferroelectric slab 106, delay line 101 allows obtaining a differential phase shift of about 100° at 2 GHz by varying the dielectric constant from 550 to 450 with a voltage variation from 1 to 3 kV. The corresponding differential delay, averaged over the frequency band 1.9 to 2.2 GHz, is about 0.22 ns.

Fig. 5 shows a delay line 201 according to a variant of Fig. 2. In this variant, the dielectric member of Plexiglas® is dispensed with, so that the delay line comprises four sections 201-1 to 201-4. Dielectric members 210A to 212A and 210B to 212B are made of the same dielectric materials as members 110 to 112 of Fig. 2, and still have electrical length $\lambda/4$. In this case however they have cross-sectional sizes identical to each other and to ferroelectric slab 206. Waveguide body 2 has constant cross-sectional size of 35 mm x 18 mm and ridge 203 has constant width and variable height,

the height variations resulting in a toothed profile of the top surface.

The following table 3 reports the materials employed for the impedance-matching dielectric members and the slab, as well as the sizes and electrical characteristics thereof in an exemplary practical embodiment of delay line 201, and table 4 reports the geometrical characteristics of ridge 203 in the various sections.

TABLE 3

Section	Material	ϵ_r	Height [mm]	Width [mm]	Length [mm]
1	Al ₂ O ₃	9,8	4.2	5.5	10
2	PE+TiO ₂	30	4.2	5.5	10
3	TiO ₂	100	4.2	5.5	12.56
4	BST	450 - 550	4.2	5.5	20

TABLE 4

Section	Ridge (height x width) [mm]	Ridge length [mm]
1	6,65 x 5,5	13,3
2	5,8 x 5,5	10
3	8,8 x 5,5	12,56
4	11,8 x 5,5	20

Waveguide 201 is more compact than waveguide 101 and is particularly suitable for operation in narrower frequency ranges.

In the embodiment shown in Fig. 6, delay line 301 still includes three impedance matching members 313A, B to 315A, B with identical cross-sectional sizes. In this case however dielectric slab 306 extends over almost the whole length of waveguide body 302 whose cross-section is 36mmx18mm and the impedance matching members 313A, B to 315A, B are located within connectors 308A, B. Sections 301-1 to 301-4 are still indicated in the drawing for sake of uniformity with the other embodiments, even if only the fourth section 301-4 is actually part of delay line 301.

Table 5 reports the materials employed for the impedance-matching dielectric members, as well as the geometrical sizes and the electrical characteristics thereof in an exemplary practical embodiment of delay line 301, in which ferroelectric slab 306 was 20 mm long, 3.7 mm high and 5.5 mm wide. The ridge had the same width as ferroelectric slab and was 26 mm long.

TABLE 5

Section	Material	ϵ_r	Diameter [mm]	Conductor diameter [mm]	Length [mm]
1	Teflon®	2.1	4.1	1.28	11
2	PE+TiO ₂	30	4.1	1.28	5,92
3	TiO ₂	100	4.1	1.28	5,32

The delay line is more compact, but this is paid with a reduction of the operating frequency band.

Fig. 7 schematically shows a transmitter of a wireless communication system using dynamic delay diversity, like the system disclosed in the above-mentioned WO 2006/037364 A. The transmitter can be employed in base stations, repeaters or even mobile stations of the system. Here, an input signal IN is fed to a base-band block 50 that outputs a base-band version of signal IN. The base-band signal is fed to an intermediate-frequency/radio-frequency block 55 connected to a signal splitter 60, which creates two or more signal replicas by sharing the power of the signal outgoing from block 55 among two or more paths leading, possibly through suitable amplifiers 65a, 65b...65n, to respective antenna elements 70a, 70b...70n. The first path is shown as an undelayed path, whereas respective tunable delay lines 75b...75n according to the invention are arranged along the other paths, each line 75b...75n delaying the respective signal replica by a time varying delay $\tau_b(t)...\tau_n(t)$. $V_b(t)...\tau_n(t)$ denote the variable voltages controlling tuning of lines 75b...75n. The delay variation law may be different for each line. Of course, a delay line could be provided also along the first path.

It is clear that the above description has been given by way of non-limiting example and that the skilled in the art can make changes and modifications without departing from the scope of the invention as defined in the appended claims. In particular, even if a horizontal waveguide body resting on a major face has been shown, a different orientation can be envisaged. Moreover, even if a specific barium strontium titanate has been mentioned, the skilled in the art will readily appreciate that different materials can provide the dielectric constant tunability required for obtaining the delay variation demanded by a specific application.

Patent Claims

1. An electrically continuously tunable delay line (1; 101; 201; 301) for radiofrequency applications, including:

- a waveguide body (2;102; 202; 302);
- 5 - a metal ridge (3; 103; 203; 303), longitudinally extending within said waveguide body (2;102; 202; 302);
- a ferroelectric member (6; 106; 206; 306) also longitudinally extending within said waveguide body along at least a portion of the ridge (3; 103; 203; 303); and
- 10 - a variable d.c. voltage source (7) for applying a variable transversal electrical field to said ferroelectric member (6; 106; 206; 306) to vary a dielectric constant thereof and hence the delay imparted by the line (1; 101; 201; 301),

characterised in that said ridge (3; 103; 203; 303) is electrically insulated from the waveguide body (2;102; 202; 302), said ferroelectric member is comprised between said metal ridge and a confronting wall (2") of the waveguide body (2;102; 202; 302) and said d.c. voltage source (7) is connected between said ridge (3) and said
15 confronting wall (2") of the waveguide body.

2. The delay line (1; 101; 201; 301) as claimed in claim 1, characterised in that said ferroelectric member (6; 106; 206; 306) has uniform cross-sectional sizes throughout its length.

20 3. The delay line (1; 101; 201; 301) as claimed in claim 1 or 2, characterised in that said ferroelectric member (6; 106; 206; 306) fills a gap between the ridge (3; 103; 203; 303) and a confronting wall (2") of the waveguide body (2;102; 202; 302).

4. The delay line (1; 101; 201; 301) as claimed in claim 1, characterised in that said ridge (3; 103; 203; 303) is supported within a dielectric support member (5) carried
25 by the waveguide body (2;102; 202; 302).

5. The delay line (1; 101; 201; 301) as claimed in any preceding claim, characterised in that said ferroelectric member (6; 106; 206; 306) is made of a barium strontium titanate or a barium strontium titanate composite.

6. The delay line (101; 201) as claimed in any preceding claim and further
30 including coaxial input/output connectors (108A, 108B; 208A, 208B) at opposed ends of the waveguide body (102; 202), for connection of the delay line (101; 201) with coaxial cables carrying input/output signals, characterised in that it further includes, between each connector (108A, 108B; 208A, 208B) and the ferroelectric member (106; 206), a plurality of dielectric members (109A to 112A, 109B to 112B; 210A to 212A,
35 210B to 212B) with different dielectric constants, increasing in a direction from a

connector (108A, 108B; 208A, 208B) to the ferroelectric member (106; 206), and with electrical length $\lambda/4$, λ being the wavelength of a signal transmitted along the line, for impedance matching between said coaxial cables and said ferroelectric member (106; 206).

5 7. The delay line (101) as claimed in claim 6, characterised in that different dielectric members (109A to 112A, 109B to 112B) have different cross-sectional sizes from each other and from the cross-sectional size of the ferroelectric member (106).

8. The delay line (101) as claimed in claim 7, characterised in that the waveguide body (102) has a region of reduced cross-sectional width in
10 correspondence with a dielectric member (109A, 109B) closest to each connector (108A, 108B).

9. The delay line (101) as claimed in claim 7 or 8, characterised in that the ridge (103) has a region of reduced cross-sectional width in correspondence with the dielectric member (109A, 109B) closest to each connector (108A, 108B) and has an
15 height increasing in the direction from a connector (108A, 108B) to the ferroelectric member (106).

10. The delay line (201) as claimed in claim 6, characterised in that all dielectric members (210A to 212A, 210B to 212B) have the same cross-sectional sizes as the ferroelectric member (206).

20 11. The delay line (201) as claimed in claim 10, characterised in that the ridge (203) has portions with different heights in correspondence with different dielectric members (210A to 212A, 210B to 212B) and with the ferroelectric member (206).

12. The delay line (301) as claimed in any of claims 1 to 5 and further including coaxial input/output connectors (308A, 308B) at opposed ends of the waveguide body,
25 for connection of the delay line (301) with coaxial cables carrying input/output signals, characterised in that it further includes, inside each connector (308A, 308B), a plurality of dielectric sections (313A to 315A, 313B to 315B) with different dielectric constants, increasing in a direction towards the ferroelectric member (306), for impedance matching between said coaxial cables and said ferroelectric member (306).

30 13. An apparatus for transmitting a signal to a plurality of users of a wireless communication system via diversity antennas (65a, 65b...65n), said apparatus including, along a signal path towards said diversity antennas (65a, 65b...65n), at least one tunable delay line (75b...75n) for generating at least one replica of said signal delayed by a time varying delay, characterised in that said tunable delay line
35 (75b...75n) is an electrically tunable delay line as claimed in any preceding claim.

14. A wireless communication system including the transmitting apparatus as claimed in claim 13.

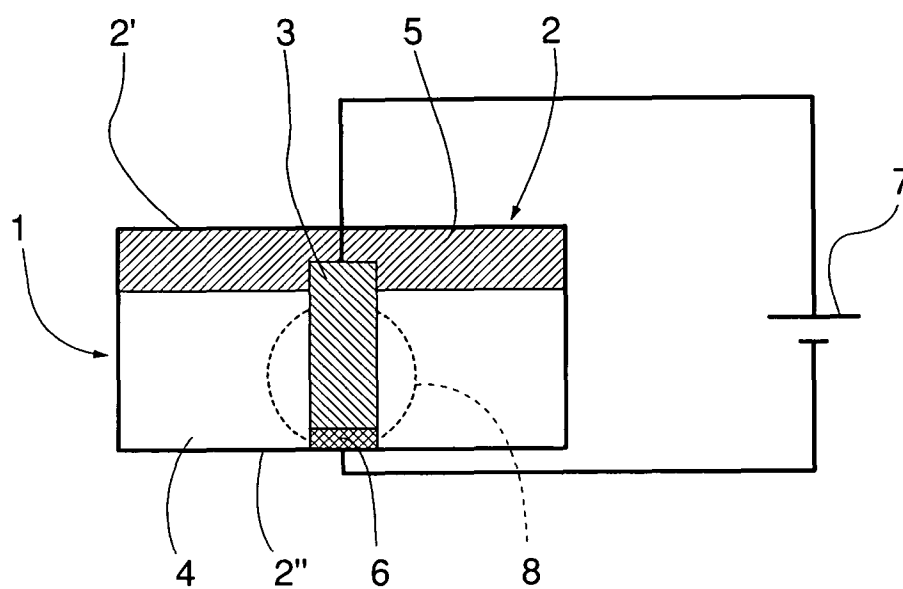


Fig. 1

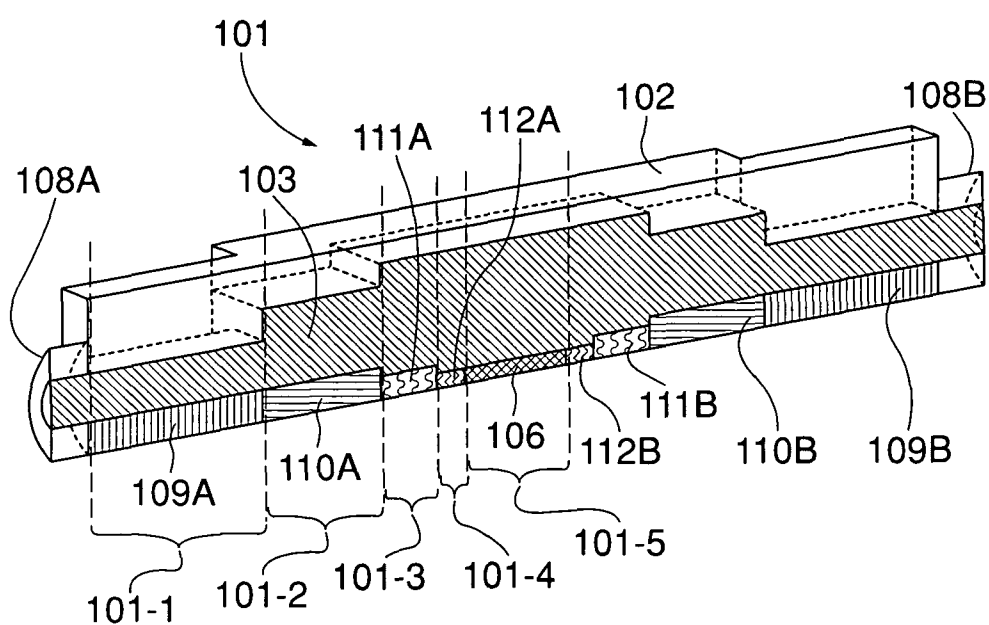


Fig. 2

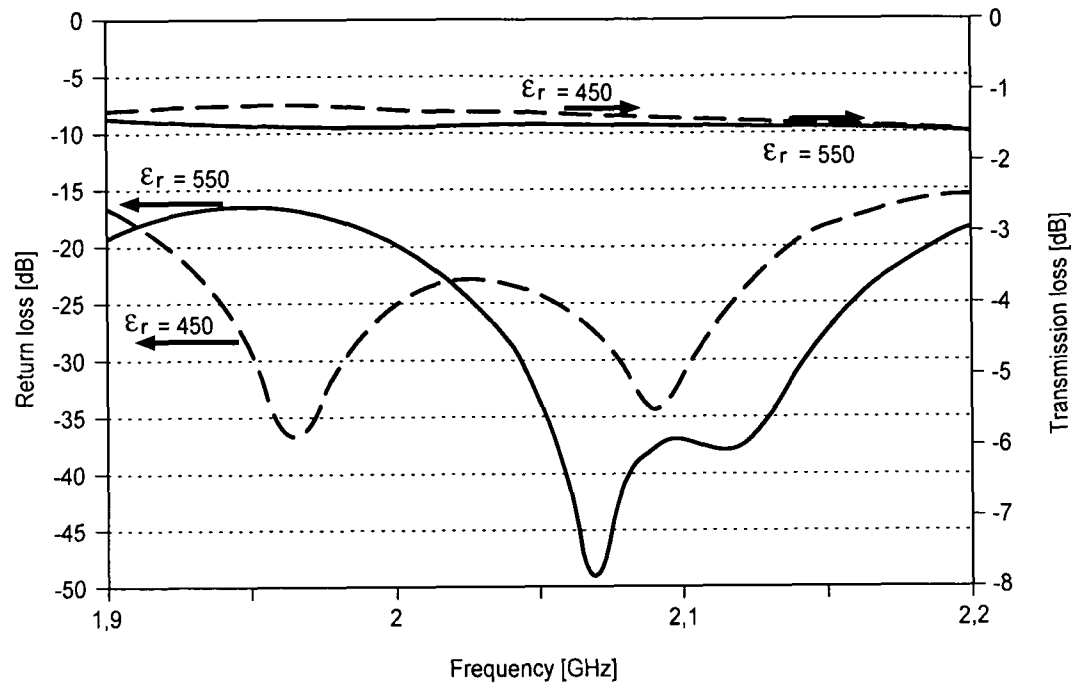


Fig. 3

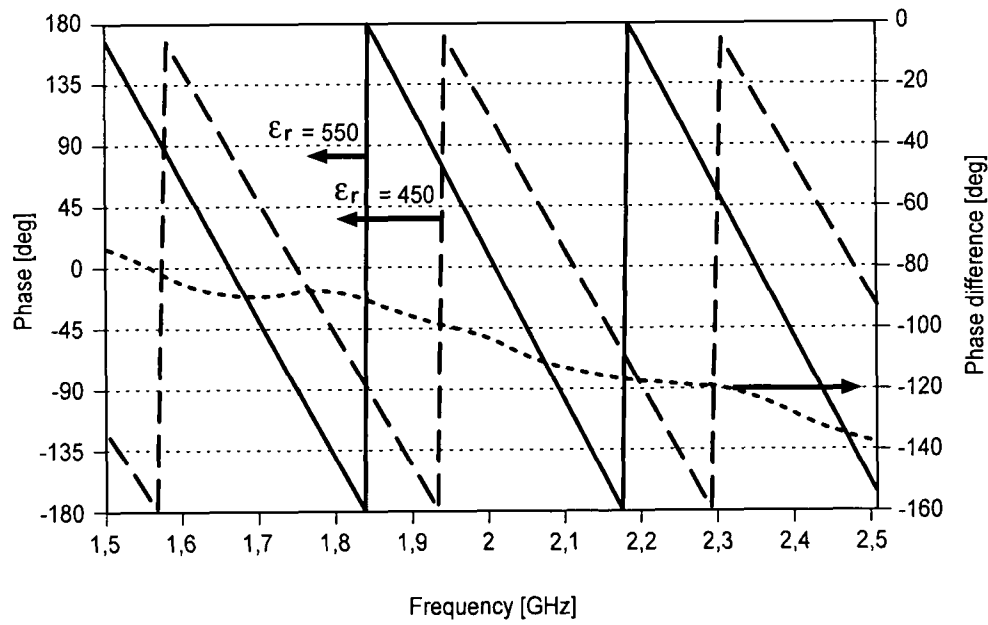


Fig. 4

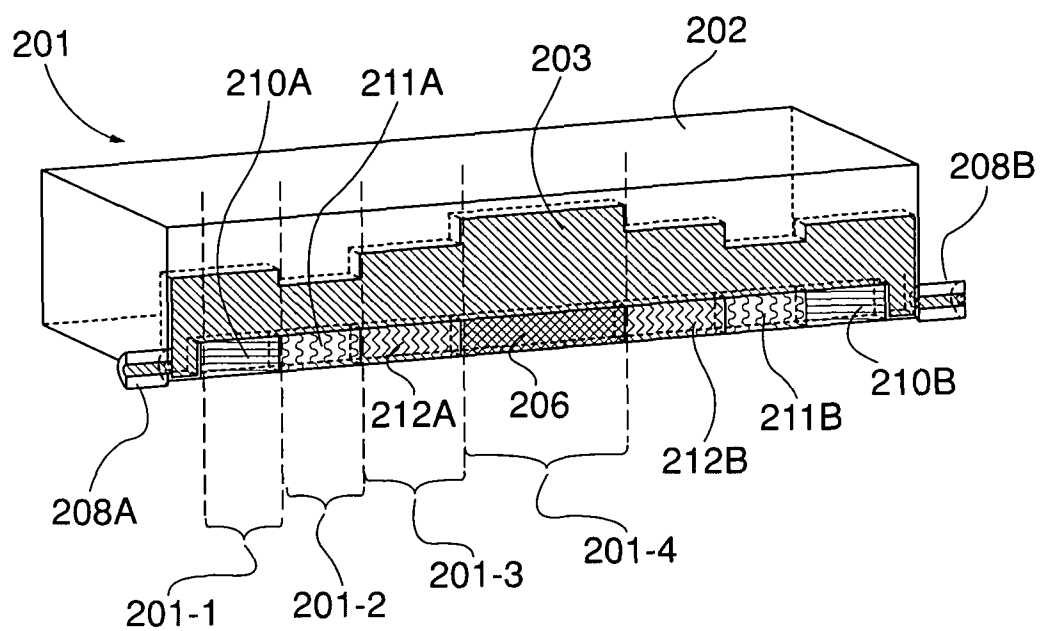


Fig. 5

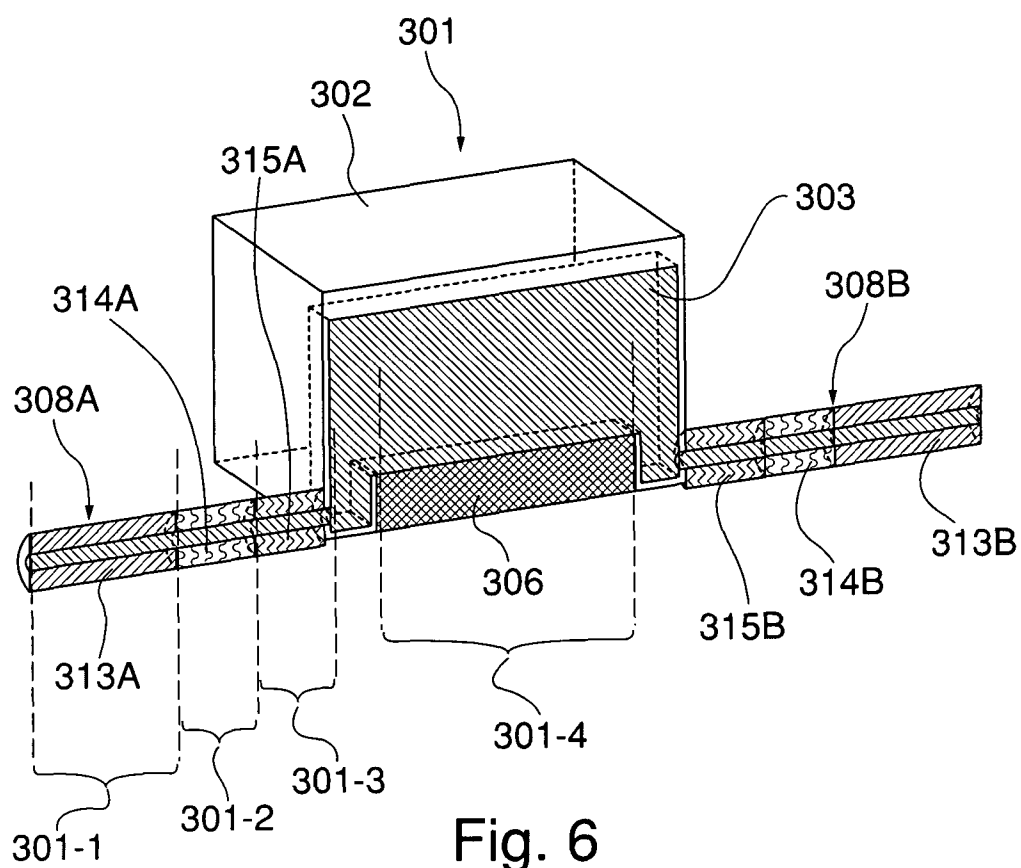


Fig. 6

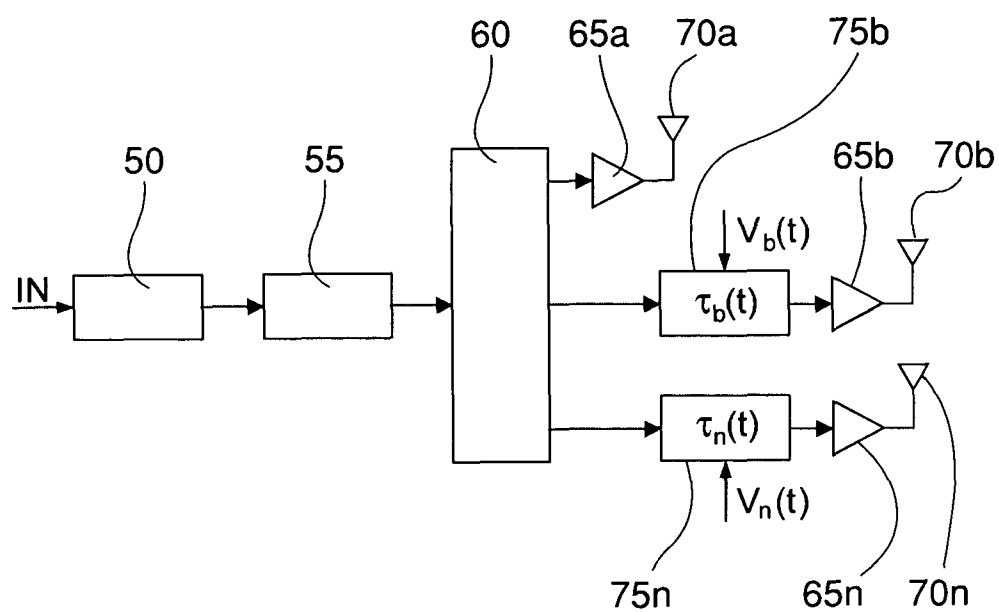


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2007/004824

A. CLASSIFICATION OF SUBJECT MATTER
 INV. H01P1/18 H01P9/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2002/033744 A1 (SENGUPTA LOUISE C [US] ET AL) 21 March 2002 (2002-03-21) paragraphs [0024], [0025]; figures 1,2 paragraphs [0038], [0039]; figures 7-9 paragraph [0044]	1-5, 13, 14
A	US 4 782 307 A (HSU RUI T [US]) 1 November 1988 (1988-11-01) column 3, line 3 - line 34; figure 2	1
A	US 2 989 709 A (HAROLD SEIDEL ET AL) 20 June 1961 (1961-06-20) column 5, line 28 - column 6, line 11; figures 2-4	1
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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2007/004824

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	EP 0 164 224 A (BRITISH TELECOMM [GB]) 11 December 1985 (1985-12-11) page 2, line 30 - page 3, line 13; figure 1 page 5, line 30 - line 34 -----	1
A	US 4 028 650 A (KONISHI YOSHIHIRO ET AL) 7 June 1977 (1977-06-07) column 5, line 52 - column 7, line 57; figures 12a-17b -----	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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