United States Patent

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[72] Inventor **Alberto Pimentel**
Paris, France
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[73] Assignee **Thomson-CSF**
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[33] **France**
[31] **158,569**

[54] **N-INPUT APERIODIC HYBRID COUPLER**
8 Claims, 4 Drawing Figs.

[52] U.S. Cl. **333/8,** 333/9, 333/11
[51] **Int. Cl.** **H01p 5/12**
[50] **Field of Search** 333/6, 7, 9, 11, 17

[56] **References Cited**

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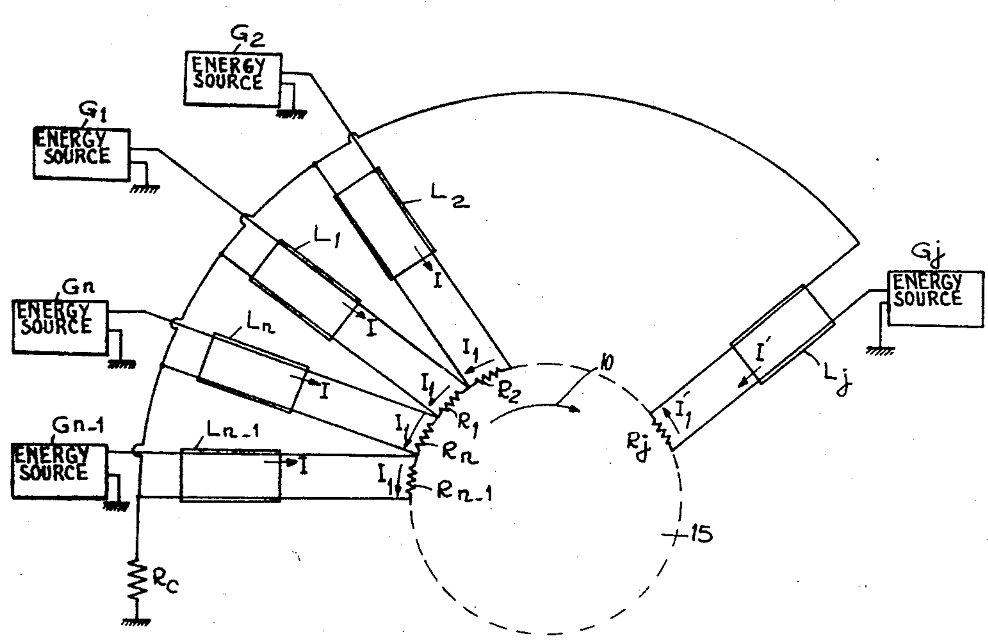
Primary Examiner—E. Lieberman
Assistant Examiner—Wm. H. Punter
Attorney—Cushman, Darby & Cushman

ABSTRACT: An aperiodic coupler having any number of inputs and comprising the same number of two-wire lines, each associated with a high permeability magnetic core.

Its insertion loss is negligible and it has substantial decoupling between any two inputs.



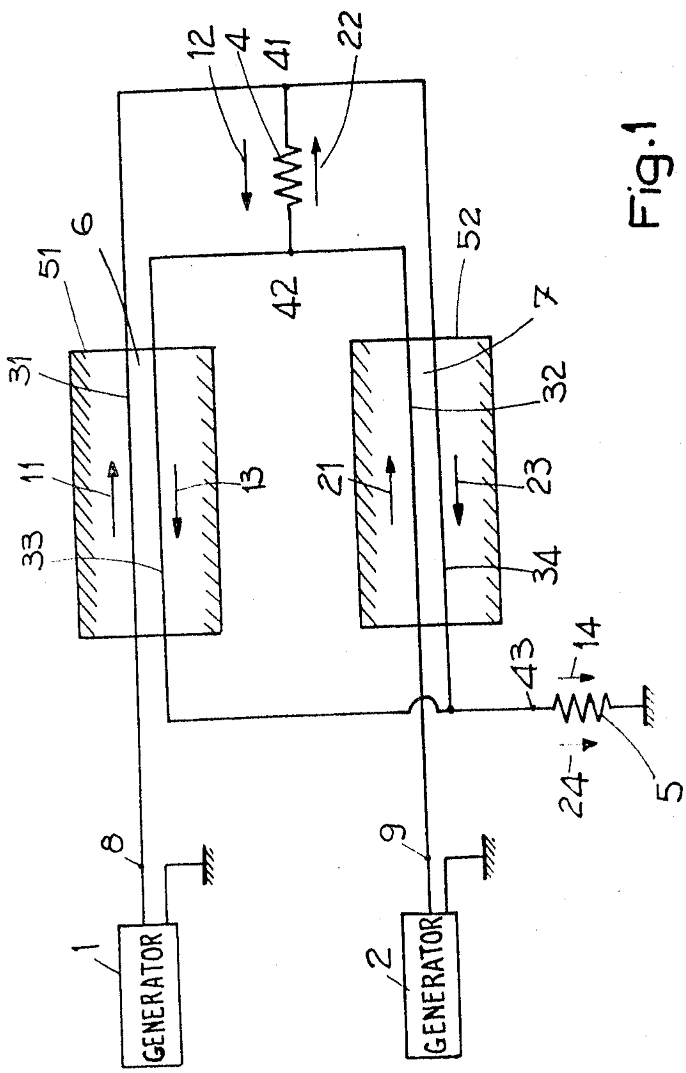


Fig.1
PRIOR ART

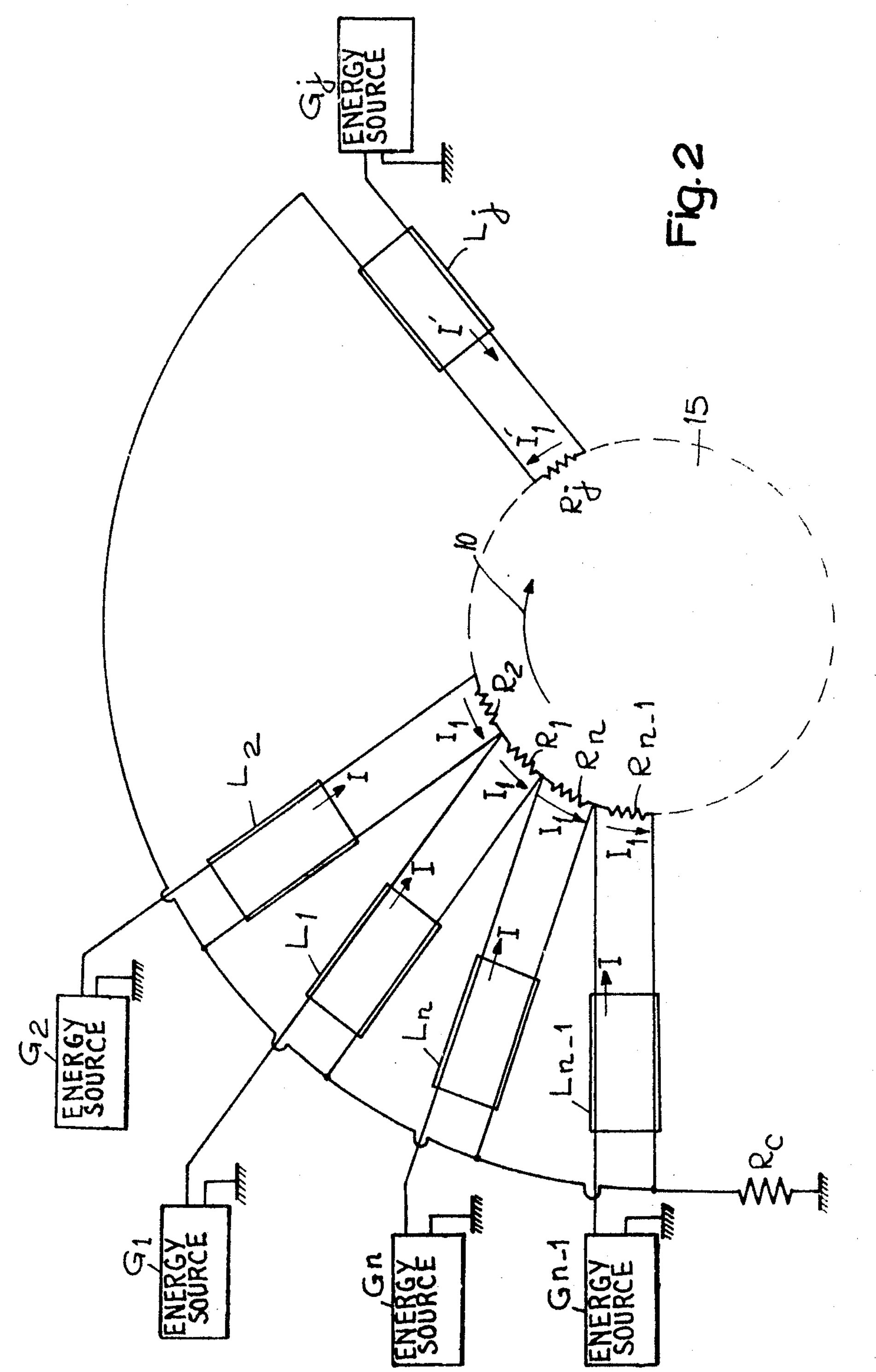

Gj
ENERGY SOURCE
Lj
I'
I1'
Rj'
10
15
R2
I1
R1
Rn
Rn-1
L2
I
L1
Ln
Ln-1
Rc
G2
ENERGY SOURCE
G1
ENERGY SOURCE
Gn
ENERGY SOURCE
Gn-1
ENERGY SOURCE

Fig. 2

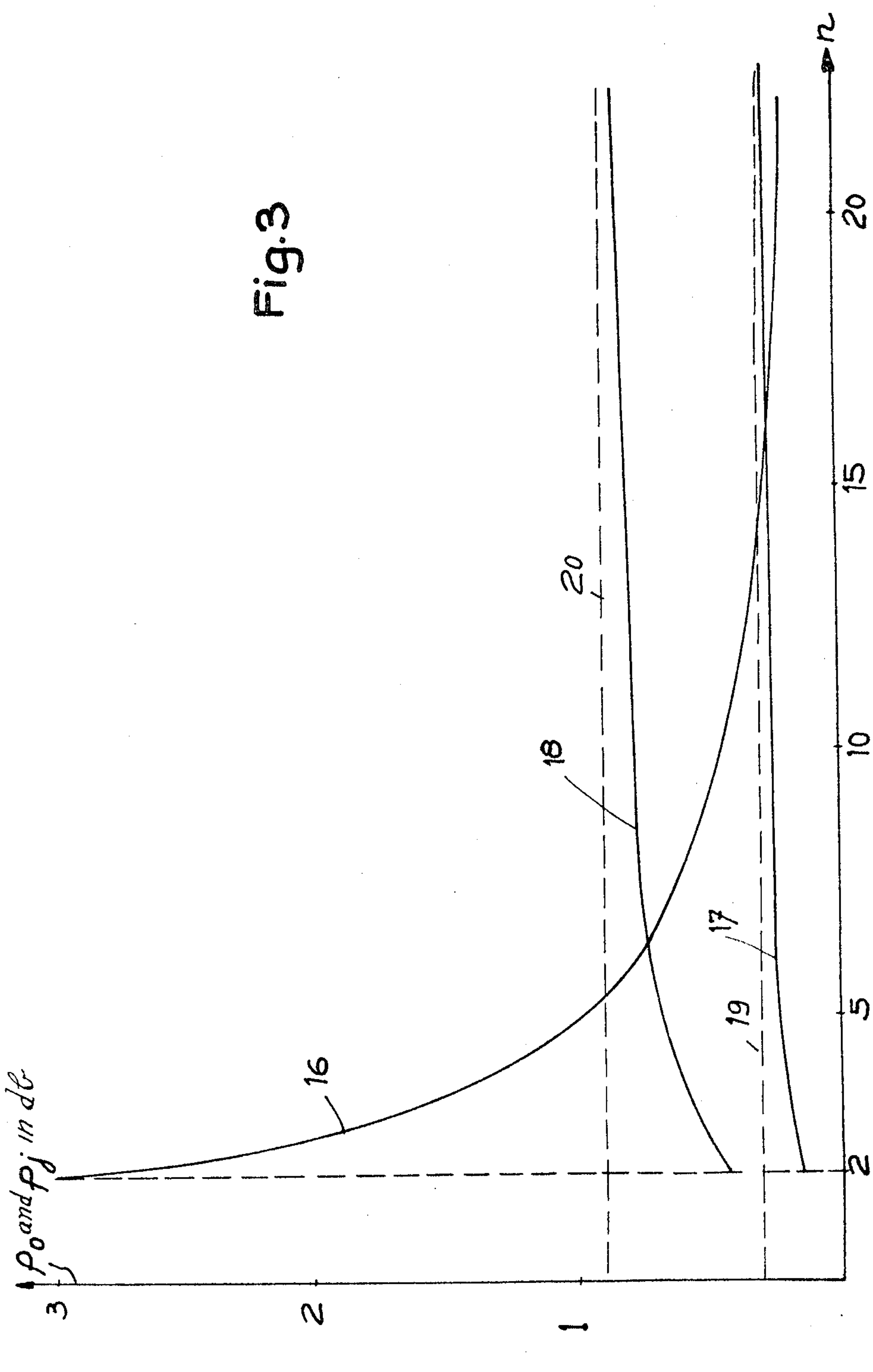


Fig.3
ρo and ρj in db
3
2
1
2
5
10
15
20
n
16
17
18
19
20

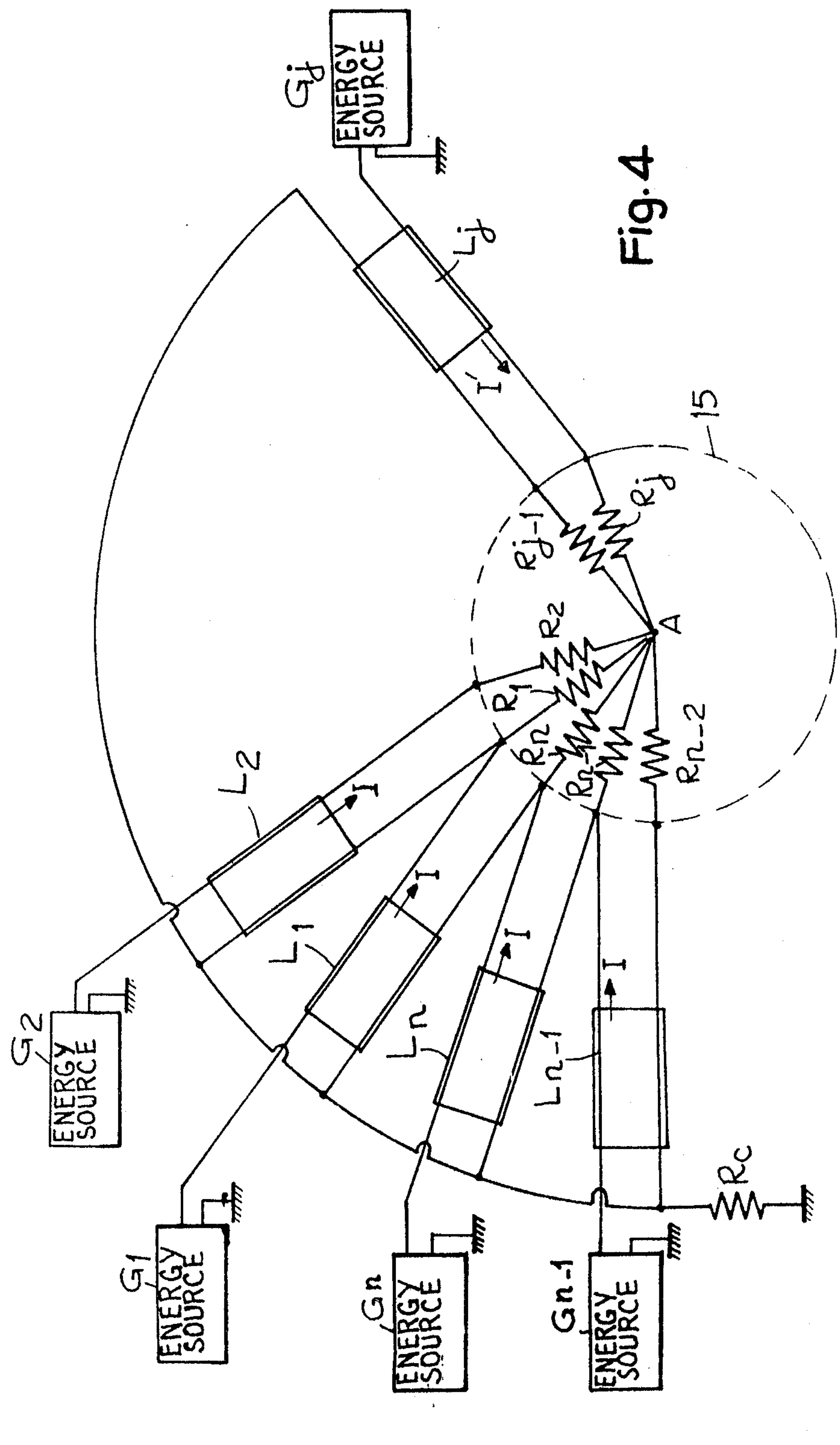

ENERGY SOURCE
Gj
Lj
I'
15
Rj
Rj-1
R2
A
R1
Rn
Rn-1
Rn-2
L2
I
L1
Ln
Ln-1
Rc
G2
ENERGY SOURCE
G1
ENERGY SOURCE
Gn
ENERGY SOURCE
Gn-1
ENERGY SOURCE

Fig. 4

N-INPUT APERIODIC HYBRID COUPLER

The present invention relates to n-input aperiodic hybrid couplers.

Two-input hybrid couplers are known, which enable two signals to be added or, conversely enable a single signal to be split into two others, whilst providing effective decoupling between the two-input or output channels.

It is also known to produce a pyramidal arrangement of several connected couplers. It is known, for example, to connect 2^g sources having the same power p to form a power source having a power $P=2^g\times p$, by means of 2^g-1 identical two-input couplers.

This kind of circuit makes it possible to add n sources, practically without any loss, and to decouple each of them from the others provided that n is a whole number power of 2.

However, if n is a number different from 2^g, insertion losses of several decibels exist.

This kind of circuit is not sufficiently flexible:

For example, in the case of a transmitter producing a given power P by means of the addition of the powers p produced by existing identical modules, in practice it is necessary to provide a number n of modules such that $n=2^g$,g being the smallest whole number which will give n a value equal to or immediately greater than a whole number n_1 which itself is equal to or is the nearest approximation above, P/p. The result is that the effective number n may tend towards $2\times n_1$, so that there is an energy waste which may reach a value equivalent to that of the useful energy.

It is the object of the present invention to overcome this drawback.

According to the invention there is provided an aperiodic hybrid coupler for coupling together n first energy providing or receiving terminals with one energy receiving or providing terminal, said coupler comprising: n pairs of conductors having a length substantially below the shortest wavelength of signals applied on said terminals, each pair comprising a first conductor coupled at one end to one of said first terminals and a second conductor coupled at one end to said one terminal, a resistance network having n terminals and comprising n resistors, each of said terminals being coupled to the second end of one of said first and one of said second conductors of different pairs.

For a better understanding of the invention and to show how it may be put into effect, a reference will be made to the drawings accompanying the following description in which:

FIG. 1 is a diagram of a known two-input coupler;

FIG. 2 is a diagram of an n-input coupler in accordance with the invention;

FIG. 3 is an explanatory diagram; and

FIG. 4 is a diagram of another embodiment of the n-input coupler in accordance with the invention.

In FIG. 1, high frequency generators 1 and 2 respectively supply, through their respective outputs 8 and 9, the respective ends 41 and 42 of a resistor 4, through respective conductors 31 and 32 of the respective lines 6 and 7 which extend through ferrite sheaths 51 and 52, or, more generally, are each associated with a high permeability magnetic core. The ends 41 and 42 of the resistor 4 are also connected to the end 43 of a load resistor 5 through the conductors 33 and 34 of the lines 6 and 7, the other end of resistor 5 being earthed.

The arrows 11, 12, 13, 14 indicate the direction of current flow produced by the generator !, and the arrows 21, 22, 23, 24 that of the current flow produced by the generator 2, it being assumed that the generators 1 and 2 are in phase and that the lines and connections are short compared with the wavelength.

The internal impedance of the generators will preferably be identical to the characteristic impedance of the lines, the value of which will be equivalent to twice the resistance of the balancing resistor 4, and of the load resistor 5. The characteristic impedance of the lines may obviously be matched to the other impedances of the circuit, the less strictly the shorter the lines are in relation to the wavelength.

The ferrite sheaths 51 and 52, or other similar arrangements, have the effect of insulating the lines from the high frequency point of view, vis-a-vis the exterior, and of ensuring symmetry of the currents in each conductor, this in particular if the line is of the coaxial type.

The resistors 4 and 5 have an ohmic resistance equivalent to half the characteristic impedance of the lines 6 and 7, this insuring the matching since these resistors can be considered as formed by two parallel resistors of twice their resistance, associated with each of the lines.

This kind of coupler is well known and where high frequencies are involved will advantageously replace the more conventional arrangement based on transformers whose interwinding capacitances set an upward limit on the operating frequency of the system. As so line systems, they are aperiodic, if loaded by a characteristic impedance.

It is easy to see from the figure, that this design exhibits the conventional properties of couplers:

when the currents produced by the generators 1 and 2 as respectively illustrated by the arrows 11, 12, 13, 14 and 21, 22, 23, 24, are equal and in phase, the power is entirely dissipated in the resistor 5 and is zero in the resistor 4 where the currents are equal and opposite;

if the currents are equal and in antiphase, the power distribution is reversed, being zero in the resistor 5 and entirely dissipated in resistor 4;

if one of the generators, for example the generator 2, delivers no signal, it does not receive any power since the voltage developed across the terminals of the resistor 4 by the generator 1 appears across the terminals of the line 7 and is equal and opposite in sign to the voltage developed across the terminals of resistor 5 since the resistors 4 and 5 are identical and pass the same current in opposite directions. No voltage is developed between point 9 and earth so that no current flows through the line 7 and the impedance at point 9 has no effect whatsoever on the distribution of the power produced by the generator 1 which is split equally between the two resistors 4 and 5 showing that the two generators are truly decoupled;

if the function of the coupler is reversed and it is made to operate as a power splitter, that is to say if 1 and 2 become power receivers of the same impedance as the generators, and a generator is substituted for the resistor 4, this generator having the same impedance as the resistor 5, then the current distribution is identical and the same decoupling will be achieved between the receivers 1 and 2.

The coupler in accordance with the invention has the same properties but may have any number n of inputs.

The arrangement of FIG. 2, comprises n two-wire lines, identical to those of FIG. 1. For the sake of clarity, only the two first ones L_1 and L_2, the two last ones L_n and L_{n11} and one of the intermediate ones L_j, have been shown. In each l'ne a first conductor connects one of the generator G_1, G_2...G_j...G_n G_{n11} to one end of the n respective balance resistors R_1 to R_n, and a second conductor connects the other ends of said resistors to one and the same load resistor R_c. The n resistors R_1 to R_n form a closed loop arrangement 15 in which they are connected in series.

The matching conditions, the decoupling of the generators from each other and the energy dissipated in the balance resistors will be determined under the assumption that each of the generators G_1 to G_n produces a current I whose direction is indicated by an arrow and which splits into a current I_1 flowing through the corresponding resistor R_1, R_2, R_{n11}, R_n and a current i (not indicated) flowing in the opposite direction in the sum of the (n−1) other resistors, all this with the exception of the generator G_j which produces a current I′ which splits into a current I'_1 in R_j and i' in the (n−1) other resistors. Thus, one has:

$$i=(I/n) \qquad i'=(I'/n)$$

and

$$I_1=(I(n-1)/n) \quad \text{and} \quad I'_1=(I'(n-1)/n)$$

The arrow **10** illustrates the direction in which the sum of the currents i and i' flows, namely:

$(n-1)i$ in the resistor R_j

and

$(n-2)i+i'$

in the resistors R_1 to R_n, with the exception of R_j.

It follows that if $I=I'$ and consequently $i=i'$, in each of the balance resistors the current $I=I\ (n-1)/n$ is equal to the reverse current $(n-1)i$ and the dissipation is nil on the condition that the generators G_1 to G_n supply in phase high frequency signals and have the same internal impedance, each line and the associated connections having a total length substantially less than the wavelength of the signals.

R being the internal impedance the same for all the generators, the resistance r, common to the resistors R_1 to R_n, and that of the load resistor R_c, should be such that each generator is matched and decoupled from the others.

The matching condition is satisfied if the sum of the impedances as seen from the generator, is equal to R, that is to say if:

(1) $R_c+(r(n-1)/n=R$

The decoupling condition can be written in a number of ways, and in particular by arranging that the voltage supplied to the terminals of the generator G_j by the other sources, is zero, making $I'=0$.

This voltage is the sum of the voltage U_c, which appears across the load resistor terminals, and the voltage U_j, of opposite sign, which appears across the terminals of R_j; obviously, one then has

$$U_c=(n-1)I\ R_c$$

and

$$U_j=(n-1)\ ir.$$

Decoupling will be achieved if $U_c=U_j$,

that is to say: $I\ R_c=ir$

but $i=I/n$

(2) from which $R_c=r/n$

which means, from (1) that:

(3) $r=R.$

The conditions (2) and (3) being satisfied, one can examine the power distribution between the load resistors R_c and the n balance resistors R_1 to R_n.

The total power P_A supplied by the n generators G_1 to G_n, is given by

$$P_A=(n-1)I^2R+I'^2R.$$

The power, P_c, across the load is given by

$$P_c=[(n-1)I+I']^2R/n$$

The total dissipated power D_T in the balance resistors can be calculated by summing the powers dissipated in each of these resistors on the basis of the resultant current across them or more simply by writing:

$$D_T=P_A-P_o=\frac{n-1}{n}(I-I')^2R.$$

It will thus be seen that the total power supplied is dissipated in the load if $I'=I$, that is to say if the generators all produce the name power.

It is interesting to know what the power loss p_o will be if a generator fails, that is to say if $I'=0$.

One has:

$$p_0=10\,lg\frac{P_A}{P_o}=10\,lg\frac{(n-1)I^2Rn}{(n-1)^2I^2R}=10\,lg\frac{n}{n-1}$$

In FIG. 3, a graph **16** has been plotted representing the power loss p_o as a function of the number of inputs n, in accordance with the above equation. Also shown are the graphs **17** and **18** showing the overall power loss p_j against the power P_j supplied by the generator G_j when it is producing a current I' less than I, in the ratio of $a=I'/I$ namely for $a=0.8$ and $a=0.7$, these factors corresponding respectively to powers equal to around a third and a half of the nominal power. These curves have as assymptotes the straight lines **19** and **20** respectively.

They have been drawn making the assumption:

$$P_j=(P_j/P_j-D_T),$$

where

$$P_j=I'^2R=a^2I^2R$$

and

$$D_T=(I^2(1-a)^2(n-1)R),$$

from which

$$p_j=(na^2/n(2a-1)+(1-a)^2)$$

Graph **16** shows that the overall power loss p_o is limited to a maximum of 1 db. if one source is out of service, where the number of inputs is at least five.

The graphs **17** and **18** show that if one of the generators is producing a power less than the nominal power, the power loss measured in decibels in relation to the power produced by said single generator, is less than 1 db. if the faulty generator G_j is producing about half its rated power; it is negligible if the faulty generator is producing at least two-thirds of the rated power.

The result is that the discrepancies of between 10 and 20 percent which can exist in practice between the various sources do not produce any appreciable insertion loss in a coupler of this kind.

The same properties can be obtained by replacing the closed-loop arrangement of the resistors R_1 to R_n, by a star network.

In FIG. **4**, all the elements are identical to those of FIG. **3** with the exception of the arrangement **15**, formed by the star-connected resistors R_1 to R_n with the common point A.

Only resistors R_1, R_2, R_{j11}, R_j, R_{n12}, R_{n11} and R_n have been shown. The free ends of these resistors are connected in such fashion that the line L_1 is loaded by R_n+R_1, the line L_2 by R_1+R_2, the line L_j by $R_{j11}+R_j$, the line L_{n11} by $R_{n12}+R_{n11}$ and the line L_n by $R_{n11}+R_n$.

Making the same assumptions which were made in relation to the circuit of FIG. **3**, the matching condition can be written as:

(4) $R_c+2r=R$

and the new decoupling condition is again obtained by writing

$U_c=U_j$, but this time:

$$U_c=(n-1)I\ R_c$$

$$U_j=Ir;$$

(5) from which $(n-1)R_c=2r$

and it therefore follows, from (4) and (5), that:

$$R_c=R/n$$

(6) $r=(R(n-1)/2n)$

It will be seen that R_c retains the same value as in the preceding circuit, but r is different.

This device has exactly the same properties as the preceding circuit, as far as the energy balance is concerned.

It goes without saying that the dissipated power will be zero in the resistors R_1 to R_n, if the n generators produce in phase the same current (i.e. if $I'=I$), since each resistor carries the sum of two currents I which are equal and opposite.

If I' I, only the resistors R_j and R_{j11} will dissipate a power D'_T other than zero, and this is given by:

$$D'_T=2(I-I')^2r$$

From (6), it follows that:

$$D'_T=\frac{n-1}{n}(I-I')^2R$$

Therefore $D'_T=D_T$ and the graphs of FIG. **3** are valid likewise for this circuit.

In the two embodiments described, it has been assumed that the sources have the same impedance R, this in order to simplify the calculations and also since this kind of condition is frequently encountered in practice. But it goes without saying that the coupler can be designed to cope with the situation where all the input impedances, either transmitting or receiving power, are different. In this case, the balance resistors will likewise be different and, for n inputs, n corresponding values will be obtained by using a system of equations of n unknowns.

Thus far, it has been assumed that all the sources were operating cophasally; however, by altering their relative phases, various applications can be considered; in particular, a variation between 0 and π in the phase of each generator makes it possible to produce in the load $N+1$ different power values, ranging from 0 to nP, P being the common power of each generator.

The variable power thus dissipated in the balance resistors, can be used in relation to earth by arranging between each of them and their points of connection, an isolating line similar to the lines L_1 to L_n.

As in the case of FIG. 1, this coupler can be used as a splitter, the same possibilities being retained, since the distribution of current remains unchanged and is controlled by the same relationships albeit between different quantities.

The lines can be formed by coaxial cable, strip-lines or twisted wires, and they may be wound on separate ferrite rings, or upon a single ring, or again be encased in sheaths of the same material.

In trails with a variety of prototypes, insertion losses at the most equal to some tenths of decibels and decoupling between the inputs of better than 30 db., have been measured, this within a range of 5 octaves.

These performance figures are virtually independent of the frequency, provided that the lines used are short-vis-a-vis the wavelength.

Of course, the invention is not limited to the embodiments described and shown which were given solely by way of example.

What I claim is:

1. An aperiodic hybrid coupler for coupling together a number n, greater than two, of first energy providing or receiving terminals with one energy receiving or providing terminal, said coupler comprising: n pairs of conductors having a length substantially below the shortest operating wavelength of said coupler, each pair comprising a first conductor having first and second ends and a second conductor having first and second ends, the first ends of said first conductors being respectively coupled to said n first terminals, the first ends of said second conductors being coupled to said one terminal, magnetic means for ensuring symmetry of the currents in the two conductors of each of said pairs of conductors, and a resistance network having n terminals and comprising n resistors, said n network terminals being on the one hand respectively coupled to said second ends of said n first conductors and on the other hand respectively coupled to said second ends of said n second conductors, each of said network terminals being coupled to the second ends of two conductors belonging to two different pairs.

2. A coupler as claimed in claim 1, wherein said resistors are star connected.

3. A coupler as claimed in claim 1, wherein said resistors are connected in series and form a closed circuit.

4. A coupler as claimed in claim 2, wherein each of said n first terminals are connected respectively to an energy providing or receiving device and said one terminal to an energy receiving or providing device, said n energy providing or receiving devices having an identical impedance equivalent to a resistance R, said receiving or providing device having an impedance equal to (R/n), said resistors having a value equal to $(R(n-1)/n)$.

5. A coupler as claimed in claim 3, wherein each of said n first terminals are connected respectively to an energy providing or receiving device and said one terminal to an energy receiving or providing device, said n energy providing or receiving device having an identical impedance equivalent to resistance R, said receiving or providing device having an impedance equal to R/n, said resistors having a value equal to R.

6. A coupler as claimed in claim 1, wherein said magnetic means are n sheaths respectively surrounding said n pairs of conductors.

7. A coupler as claimed in claim 1, wherein said magnetic means comprise n toroidal cores on which said n pairs of conductors are respectively wound.

8. A coupler as claim in claim 7, wherein said magnetic means comprise a single toroidal core on which said n pairs of conductors are wound.