NEW METHOD OF IMPEDANCE MATCHING IN RADIO-FREQUENCY CIRCUITS.

A new transformer method is described which is suitable both for matching circuits of unequal impedance and coupling symmetrical and unsymmetrical radio-frequency circuits. In contradistinction to conventional methods of impedance matching the frequency of the oscillations being transmitted can be varied over a wide range without the necessity of re-tuning.

THE impedances of the individual circuits of radio-frequency equipment are frequently unequal. In order to obviate the reflections and losses involved by mismatching, special matching devices have to be inserted between such dissimilar circuits for the transmission of energy. For instance, matching is necessary between the tubes of a transmitter output stage with high load resistance and the low-impedance antenna transmission line or feeder system. In the case of low frequencies transformers with a corresponding turns ratio can be employed. By reason of the unavoidable leakage inductance of the coupled transformer coils, high frequencies generally involve tuning by means of additional condensers, and should the frequency be varied, corresponding re-tuning is therefore entailed.

For impedance matching purposes a quarter-wave Lecher wire system having a surge impedance which is the geometric mean between the two impedances to be matched can likewise be employed. Such matching sections must naturally also be re-tuned in the event of the frequency being altered, to correspond to the changed wave-length. Small frequency deviations are, however, permissible when the impedance transformation takes place in several steps adjusted to the mean frequency. — Another method of matching, the line with exponential taper, permits large frequency variations without re-tuning, but has amongst other things the drawback of taking up a large amount of space.

Special couplers are also necessary for transition from symmetrical to unsymmetrical circuits, e.g. between the symmetrical output of a push-pull transmitter stage and a coaxial antenna cable with earthed sheathing. Here, too, variation of the frequency generally involves re-tuning.

A new coupler which obviates re-tuning is shown in Fig. 1a. It comprises two superposed windings \( W_1 \) and \( W_2 \) separated by an insulating tube \( R \). Given symmetrical currents \( i_1 \) (full-lined arrows) the magnetic fields produced by two closely-spaced superposed sections of conductor practically neutralize each other, i.e. the mutual-inductance of two successive turns of a coil can be neglected, while it is possible to replace the two windings by two straight conductors having the same cross-section, length, and spacing as the two developed windings. This Lecher wire system is represented in the equivalent diagram (Fig. 1b) by the equivalent line \( \mathcal{A} \).

On the other hand, with unsymmetrical currents \( i_2 \) (dotted arrows), the field vectors produced by two superposed sections of the conductors are added together, with the result that the mutual inductance between the individual turns of the coil becomes an important factor. The double-wire coil system behaves here like a conventional choke coil, represented in the equivalent diagram by \( \mathcal{B} \). In this diagram the symmetrical and unsymmetrical currents \( i_1 \) and \( i_2 \), respectively, are segregated by centre-tapped ideal transformers \( T \). Given an adequate number of turns on the windings \( W_1 \) and \( W_2 \) the impedance of the equivalent choke coil \( B \) becomes so high that, even assuming unequal potentials between the centre tapings of the input and output coils, the unsymmetrical current \( i_2 \) can be neglected. In this case the described coil system forms an ideal transformer combined with an ideal line.

In view of the effect of this ideal transformer such a system \( S \) can now be employed, as shown for example in Fig. 2a, to couple a physically symmetrical circuit (connected to terminals 1 and 2) to a load resistance \( R_2 \) having one pole earthed. By making
the coil of suitable dimensions the surge impedance 
$Z_0$ of the matching line (A in the equivalent diagram 
Fig. 1 b) represented by the coil system can be adapted 
to the pure load resistance $R_a$. In this case the input 
impedance $R_a$ occurring between terminals 1 and 2 
is equal to the surge impedance $Z_0$ and in consequence 
also to the load resistance $R_a$, immaterial of 
the actual working frequency.

The curves in Fig. 3 give the input impedance 
computed from the coil dimensions for conditions 
of short circuit and no-load. The measured impedance 
values are also given and agree with the curves to 
a high degree. These measurements, which demand 
great care, were made by a method specially deve-
loped for the purpose (cf. Fig. 1, page 293). The 
characteristic surge impedance can be determined from

$$R_1 = \frac{1}{2} Z_0$$

By series-parallel connection of two or more coil 
systems impedance matching is now also possible in 
a simple manner, independent of the frequency. Fig. 
2 b shows by way of example the input terminals of 
two systems of coils $S$ connected in series and the 
output terminals in parallel. No objections can be 
raised to this practice provided the series inductance 
($B$ in the equivalent diagram in Fig. 1 b) is large 
enough. The load resistance $R_a = \frac{1}{2} Z_0$ is thus 
transformed to the input impedance $2 Z_0$. Analogously, 
with $n$ coil systems impedance transformation in the 
ratio $1 : n^2$ can be achieved.

In Fig. 2 c, for instance, four coil systems are shown 
connected between a transmitter output stage and 
the high-frequency antenna cable $K$, the resulting 
impedance transformation being in the ratio $4^2 : 1 = 16 : 1$.

With a coil system having a surge impedance $Z_0 = 240 \Omega$, 
for example, a transmitter output stage with a load 
impedance of $4 \times Z_0 = 960 \Omega$ can be coupled to an 
antenna cable of $Z_0 : 4 = 60 \Omega$. The coupled coil 
systems have the same effect as a transformer with 
separate windings, i.e. the symmetry of the anode 
circuit at the input end is not affected by single-
pole earthing of the cable connected to the other 
end. Furthermore, the coupled coil systems behave 
like a Lecher wire system, i.e. the input impedance 
must follow a tangential function of the frequency 
when the terminals at the other end are open or 
short-circuited.

The matching unit comprises four double wire coils in series-parallel 
connection. The computed and measured primary impedances are plotted 
as a function of the frequency with the secondary terminals open or 
short-circuited.
impedance being slightly lower than the theoretical value, as well as to the inherent capacitance of the circuit.

Fig. 4. — Theoretical and measured input impedance of a matching unit with a pure resistive load.

The matching unit comprises four double-wire coils in series-parallel connection. A surge impedance of 240 Ω was computed from the coil data and the measurements in Fig. 3, whence, assuming a pure resistive load of 60 Ω, the theoretical value of the input impedance is 960 Ω. The measured values of the input impedance are somewhat lower owing to the load impedance having been somewhat lower than theoretically assumed.

Theoretical value of \( R_a = \frac{L}{Z_0} \), o. Test points for \( R_a = 53 \) Ω.
Impedance transformation ratio 16:1.

The described method of matching is particularly suitable for application in the ultra-short-wave field, where it represents a big simplification compared to conventional tuned matching devices. Fig. 5 shows the external appearance of an impedance transformer with four coils, employed as antenna coupler in a medium-power transmitter. It requires little space and its losses are very low. This new component greatly simplifies the construction and operation of the equipment marketed by the Company.

Fig. 5. — Matching unit with double-wire coils.
The system contains four double-wire coils for impedance transformation from 60 Ω to about 1000 Ω in the case of meter waves. With a power of over 100 W the losses are negligible.

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