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ELECTRICAL COMMUNICATIONS TECHNIQUE
AND ITS APPLICATIONS IN ALLIED FIELDS

IMPEDANCE MATCHING

ONE of the first and best learned lessons in communication-system design is that, to obtain the greatest possible transfer of energy from one circuit to another, the impedances of the two circuits must be matched. So straightforward is the concept that the lesson may have been overlearned. In very many cases the reason for the use of transformers as impedance-matching devices is not so much to gain in power transfer as to reduce distortion, frequency discrimination, and other common defects in voice-transmission circuits.

It is very easy to fall into the error of exaggerating the amount of reflection loss that occurs due to mismatched circuits. From the single consideration of power loss a surprising amount of mismatch can be tolerated. To arrive at a figure for reflection loss, the simplest example is the case of a resistive power source connected to a resistive load. In actual practice it is not often that pure resistances will be found in radio- or audio-frequency circuits, but in most cases the phase angle is so slight that for purposes of practical demonstration it may be considered to be zero. In Figure 1 a generator producing a voltage E_G and with an internal resistance R_G is shown connected to a load R_L. The current that will flow in the circuit is

$$I = \frac{E_G}{R_L + R_G}.$$

When $R_L = R_G$, that is, in the case where the generator and load impedances are matched, the current, $I = \frac{E}{2R_G}$, and the power in the load is

$$I^2R_L = I^2R_G = \left(\frac{E_G}{2R_G}\right)^2 R_G = \frac{E^2_G}{4R_G}.$$

When the impedances are not matched the current in the load $I' = \dfrac{E_G}{R_G + R_L}$

and the power is

$$I'^2R_L = \left(\frac{E_G}{R_G + R_L}\right)^2 R_L.$$

The ratio of the power in the load for the matched condition to the power for the mismatched condition expressed in decibels is the mismatch or the reflection loss. That is

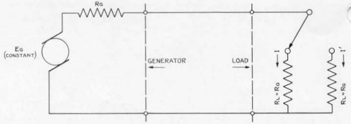


FIGURE 1. Circuit on which to base calculations of the reflection loss at a single junction

$$N_{db} = \frac{I^2 R_L}{I'^2 R_L} = 10 \log_{10} \frac{(R_G + R_L)^2}{4 R_G R_L}$$

or

$$N_{db} = 20 \log_{10} \frac{R_G + R_L}{\sqrt{4 R_G R_L}}.$$

From this formula can be calculated the reflection loss that occurs due to connecting together any two impedances having small phase angles. For instance, if a 5000-ohm vacuum tube were connected directly to a 500-ohm line, the impedance mismatch of 10 to 1 would calculate to cause a loss of 4.8 decibels. The losses calculated for a number of different impedance mismatches are shown in the chart in Figure 2. For phase angles of less than 45° the loss curve is practically the same, but the mismatch loss is always less when either circuit has a reactive component.*

It is obvious, therefore, that in many cases the actual power loss due to operating between mismatched impedances is not serious. If "ideal" or no-loss transformers could be realized, it would certainly be worth while to use them where every milliwatt of the available power must be utilized. However, well-designed and carefully made audio-frequency transformers of the usual types may have an inherent copper and iron loss of about 20%, or 2 decibels. When it is considered that small power transformers have efficiencies in the neighborhood of 85%, an efficiency of 80% for audio-frequency transformers is quite good in view of the many other problems involved in their design, such as frequency characteristic, freedom from distortion, etc.

The real value, however, of audio-frequency transformers and the reason why their use is so essential is to keep the circuit impedances at the correct operating values. For example, the design of a transformer to operate from a low-impedance line to the grid of an amplifier is not a simple job, and the successful operation of this sort of transformer depends upon its operation from the impedance for which it is designed. A line-to-grid transformer designed to operate from 500 ohms is apt to show frequency discrimination if operated from a line of 200-ohms impedance. Thus, a designer of a voice-input circuit finding that the output impedance of his mixer panel is 200 ohms, which has probably been determined by the

*"Transmission Networks and Wave Filters," by T. E. Shea, contains a complete discussion of this question.

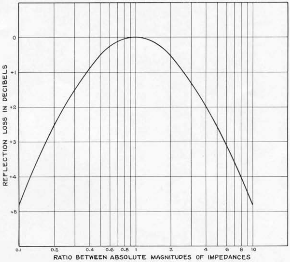


FIGURE 2. Reflection loss at a single junction in decibels as a function of the ratio between the absolute magnitudes of the two impedances. This curve is for a phase difference of 0°

microphone impedances, would certainly insert a 200- to 500-ohm transformer between the mixer and the input of his amplifier, if its input transformer were designed to operate from 500 ohms. The use of the transformer is dictated not by the consideration of the reflection loss between the 200- and the 500-ohm circuit, which is less than one decibel, but by the fact that the impedances must be kept to their correct value to maintain proper frequency characteristics.

Another example of the necessity for correct impedance matching is in the familiar case of output transformers from vacuum tubes. The distortion introduced by a three-element tube is a function, among other things, of the impedance into which it works. Ordinarily, the distortion is a minimum when the tube is worked into an impedance equal to approximately twice the plate resistance of the tube. In the case of the 2A3 tube the plate resistance is about 800 ohms and for two tubes in push-pull is 1600 ohms. The General Radio TYPE 541-D Transformer is designed to couple this system into dynamic speakers. When operating at a fixed bias potential, it is recommended that these tubes in push-pull work into 3000 ohms, which is approximately twice the plate resistance. From a consideration of the power loss due to mismatch the tubes could be worked into

TWO views of the "Variac"; right, complete; above with enclosures removed for panel mounting. It is used for light-control and for testing household appliances and radio receivers

Well-Designed Adjustable AUTO-TRANSFORMER

This adjustable transformer is made by the General Radio Company and represents a striking advance both in electrical and physical design.

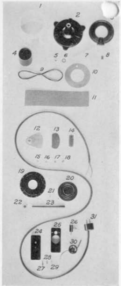
It is a toroidal auto-transformer whose output is varied from 0 to 130 volts (5 amp. maximum) by means of a sliding carbon brush. The input is 115 volts at 60 cycles.

From the design viewpoint the use of molded insulation, circular punched transformer laminations and the spun aluminum case are interesting. The member which carries the carb[illegible] brush has a fin to dissipate heat.

Materials and Parts Entering Into the Auto-Transformer

Part No.	No. Req'd	Name of Part	Material
1	1	Cover	Spun Aluminum
2	1	Mounting base	Cast iron
3	2	Winding form—end	Phenolic, molded
4	1	Winding form—tube	Phenolic, tubing
5	2	Clamping nut	Iron, cadmium plated
6	1	Lock washer	Phosphor bronze
7	1	Clamping bolt	Iron, cadmium plated
8	2	Supporting piece	Mica composition
9		Wire	Enameled copper
10	130	Lamination	Silicon steel punching
11	1	Insulating strip	Fish paper
12	1	Blade	Phosphor bronze
	1	Collar	Brass
13	1	Radiation fin	Copper, black oxidized
14	1	Label	Decalcomania transfer
15	1	Machine screw	Brass
16	1	Washer	Brass
17	1	Lock washer	Phosphor bronze
18	1	Brush holder	Brass
	1	Brush	Carbon
19	1	Dial	Photo-etched nickel silver
20	1	Knob	Phenolic, molded
21	3	Machine screws	Brass
22	2	Collar and setscrews	Brass
23	1	Shaft	Phenolic, tubing
24	1	Terminal box	Phenolic, molded
25	1	Cover	Phenolic, molded
26	1	Toggle switch	
27	2	Machine screws	Brass
28	2	Machine screws	Brass
29	4	Machine screws	Brass
30	1	Convenience outlet	
31	6 ft.	2-Conductor cord	
	1	Attachment plug	

NOTE the variety of materials used. Each has been selected for its exact uitability for the part



THE VARIAC — A "knockdown" view. This photographic parts list showing the construction of the TYPE 200-CM Variac was prepared by the editors of *Electrical Manufacturing* and published in their July, 1934, issue impedances varying widely from 3000 ohms, but the distortion would become a serious factor. This is one of the reasons why the selection of the correct output transformer is so important.

The impedance of ribbon and velocity microphones averages between 25 and 40 ohms. The customary volume control used with these microphones has an impedance of 50 ohms. An inspection of the chart in Figure 2 will show that the reflection loss due to coupling a 25- to 40-ohm generator and a 50-ohm load is negligible. The frequency characteristic of these microphones is not affected by such a small impedance mismatch. Therefore, it is sound practice to operate them into the regular 50-ohm mixer. If a transformer were used to couple these two circuits together, it would introduce a loss approximating 2 decibels which would be entirely unnecessary. Similarly, 500-ohm and 600-ohm lines can be connected together without trouble, unless special balancing or isolating problems are present. Impedance-matching transformers play a very important part in the circuits where these questions are serious. Generally, telephone lines are well balanced, particularly high-quality lines of the sort used to connect remote pickup points with the broadcasting studio. If these lines are connected directly to an unbalanced amplifier, which is one without a balanced and shielded input transformer, the resulting unbalance would affect the line and might introduce cross-talk. The customary cure for such a condition is to insert a 1-to-1 transformer between the line and the amplifier input transformer. The General Radio Type 585-R Transformer is an example of this. It has balanced windings and an electrostatic shield between the primary and secondary circuits so that a balanced line connected to its primary will remain balanced even though the secondary be connected to an unbalanced circuit. On short lines running around a studio or a laboratory, the question of unbalance is not usually so serious, but it is surprising the amount of pickup difficulties that have been encountered due to the fact that some part of a short link between a mixer panel and a speech amplifier or some other short local circuit is unbalanced. In the case of larger studios where several voice channels are running parallel through patch boards, relays, or other switching mechanisms, it is always considered good practice to run the wires in the form of twisted pair, shielded by flexible copper braid. This type of connector maintains a capacity balance to ground, and if well-balanced transformers are used most of the cross-talk difficulties are eliminated.

—A. E. Thiessen

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AMPLIFIERS FOR ALTERNATING-CURRENT BRIDGES

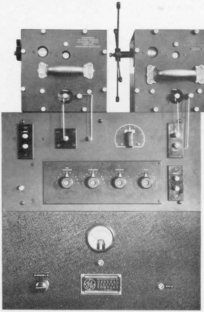

FIGURE 1. View of an audio-frequency amplifier unit with two standards (General Radio Type 222), the bridge unit in the center, and the amplifier at the bottom

Courtesy General Electric *Review*

UNDER this title W. A. Ford* and H. W. Bousman* describe two audio-frequency bridge amplifiers in the May, 1934, issue of the General Electric *Review*. After discussing the effect of stray admittances between the bridge elements and to ground, the amplifiers shown in the two accompanying photographs are described.

The complete bridge of Figure 1 has an amplifier for the detector circuit with an iron-cored input transformer between it and the bridge, an arrangement that was subject to interference induced in the transformer by power-frequency magnetic fields.

The details are given of another amplifier of high gain in which resistance-capacitance coupling between bridge and amplifier is used. This, combined with suitable multiple shielding and a self-contained galvanometer, has minimized and rendered fixed and definite many of the variable stray capaci-

*General Engineering Laboratory, General Electric Co.

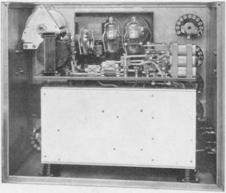

FIGURE 2. Behind the panel of a completely shielded Schering bridge. The shielded amplifier is supported on porcelain insulators inside the grounded case of the complete bridge

Courtesy General Electric *Review*

tances that often cause elusive errors in precision measurements.

Figure 2 shows the interior of a Schering bridge containing this second amplifier inside a shielded case, with the entire amplifier unit supported on porcelain insulators within the shield for the entire bridge.

Readers possessing an eye for detail will notice the liberal use of General Radio laboratory accessories, *e.g.*, TYPE 222 Precision Condensers, TYPE 539 Variable Air Condensers, TYPE 510 Decade-Resistance Units, etc.

—JOHN D. CRAWFORD

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