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Mahmoud Kandil
Associate Professor., Electrical Systems and Machines Engineering Department., Faculty of Engineering., El-Mansoura University., Mansoura., Egypt.

Mohamed Tantawy
Associate Professor., Electrical Systems and Machines Engineering Department., Faculty of Engineering., El-Mansoura University., Mansoura., Egypt., mtantawi@mans.edu.eg

R. El-Dewieny
Electrical Systems and Machines Engineering Department., Faculty of Engineering., El-Mansoura University., Mansoura., Egypt.

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EXPERIMENTAL INVESTIGATION OF CARRIER PERFORMANCE ON 66 kV O.H.P.T.L.

By

M.S. Kandil, M.A. Tantawy and R.M.K. El-Dewieny

ABSTRACT:

This paper presents experimental investigations for the main characteristics (attenuation and noise) of PLC on an O.H.T.L. The specifications of TALKHA - TANTA O.H.T.L. of the unified Egyptian grid are considered for building up a model for the T.L. and PLC equipment. Experiments are carried out on the model under normal operation and under faulty conditions on the transmission line. Attenuation and noise are measured and results are plotted as functions of the type and position of faults.

Consideration is also given to the conditions of mismatching in the matching transformer, as well as of untuning in wave trap circuits.

The authors are with the Department of Electrical Systems and Machines Engineering, Faculty of Engineering, University of El-Mansoura, El-Mansoura, A. R. Egypt.

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1.0 INTRODUCTION:

Carrier systems have long become of increasing importance and are now indispensable to the operation of power system networks with an attendant increase of network stability limits and permissible line loading[1,2].

Power line carrier (PLC) channels having frequency spectrum in the range 30 to 500 kHz, have since been used on overhead transmission lines (O.H.T.L.) for different purposes. Among these are voice communication, telemetring and supervisory control, as well as for protective relaying[2].

For voice communications, simplex and duplex systems of carrier frequency bands of about 300 to 2600 Hz are now in use between different interconnected points in almost every power system network.

The quantities often telemetred by carrier channels on power systems are usually electrical and include kilowatts, kilovars, tap-changer position, etc. Telemetring systems which use carrier channels[3,4] are based on the principle of converting the informations to be telemetred into pulse trains. These trains are well suited to operation over low and high frequency channel equipment, using modulating and filtering devices.

In PLC protection schemes, the relay signals take the form of high frequency signals, with a certain band, on which the protection informations are transmitted from one end of the protected zone to the other. This signal transmission is usually performed in different ways, according to the type of protection involved.

The application of carrier equipment for the transmission of high-frequency signals over 50 Hz power transmission systems, to perform any of the above mentioned duties, involve some problems that must be overcome. Most important of which are the attenuation[5,6] and noise[3], which take place during transmission.

This paper expermintally investigates the problems of attenuation and noise of PLC signals on a 66-kV O.H.T.L. The investigation is carried out under normal and faulty operating conditions of the power transmission line.

Before proceeding, however, a brief description of carrier systems on power transmission lines is given.

2.0 CARRIER SYSTEMS IN O.H.T.L.:

Carrier frequency band channels which contain all informations, are transmitted on O.H.P.T.L. through coupling equipment. There exist a number of cuopling methods which are now in practical use. As an example, Fig.1 shows a simplified scheme for the application of carrier system on a power transmission line, using a phase-to-ground coupling.

2.1 Carrier Frequency Bands:

The width of a carrier frequency band used for transmitting a given amount of informations is proportional to the size of these informations. A certain frequency band is obtained by resonating a network containing tuning circuits made of prescribed shunt capacitors and series inductors. The breaking of a frequency band into a number of sections is obtained by the use of more complicated resonating elements. These sections may be located as desired anywhere in the frequency spectrum. The relation between the lower and upper frequency limits f_1 and f_2 of every section and the cut-off frequency, f_{co}, is given by Reference 7 as;

$$\frac{1}{f_{co}} = \sum \left(\frac{1}{f_1} - \frac{1}{f_2}\right)$$

For one section only, the band-width (B) is given[7] by

$$B = \frac{1}{2\pi}(f_2 - f_1) = \frac{f_o^2}{2\pi f_{co}}$$

where f_o is the geometric mean of f_1 and f_2 and is called the mid-band frequency.

By time division or frequency deviation, starting from f_o=420 Hz, audio frequency channels may be selected in conformity with the frequency allocation. For example, group A of Fig.2 consists of 12 channels, separated by a frequency deviation of 120 Hz between every two neighbouring channels. Groups B, C, etc, of Fig.2, are obtained by the modulation of group A using a suitable carrier frequency.

2.1 PLC Frequency Mode of Operation:

In control systems, the informations are transmitted by one mode of operation, namely, frequency code or pulse code systems.

In the frequency code system telemetred information is transmitted to the central station as analogue or digital processing, or as complete on-off control instructions from central to out stations. This mode of operation is well suited to small or medium size stations because of its relatively long transmission time.

The information with pulse code systems are transmitted in the form of coded pulse train with the speed of a telegraph, e.g. 50 - 600 bouds. This system is more suited for transmitting large number of messages with rapid operations, since the time needed to transmit one message is 0.65 seconds at 50 bouds.

2.3 Power Line Carrier Coupling Methods:

There are many practical methods of PLC couplings in which the transmission line is used as the main part of PLC channels. The most known methods are briefly discussed below.

(i) Single-phase coupling: In single-phase coupling[1,8] carrier signals are transmitted on one power phase, with ground as the return path. Fig.3(a) shows a schematic diagram of this type of coupling. The main disadvantage of this method is its high attenuation.

(ii) Phase-to-phase coupling: This method of coupling[1] requires two traps and two coupling capacitors connected to two phases, on the same power line circuit, as shown in Fig.3(b). The attenuation and interference levels are lower in this method than in single-phase coupling.

(iii) Inter-circuit coupling: In this coupling, connection is made between two different phases on a double-circuit transmission line, as shown in Fig.3(c). This method of coupling has the advantage of somewhat lower attenuation level with increasing reliability of carrier channels under abnormal conditions.

(iv) Double-circuit ground-return coupling: With this method of coupling, the carrier channel is coupled to the same phases of the two circuits to oprate in parallel under normal conditions, as shown in Fig.3(d). In this type of coupling, either circuit can be taken out of service without interrupting the carrier channel but with the normal attenuation level.

(v) Bundle subconductor carrier coupling: As shown in Fig.3(e), the transmitter of the carrier system is connected to a twin-conductor bundle. With this method of coupling, the insulated bundle subconductors (Ibs) must be used to increase the number of carrier channels. The Ibs carrier coupling improves the blocking attenuation across the station busbar[9] and rejects the station and corona noise. In addition, this type of method has relatively low cost of coupling equipment.

(vi) Directional coupler: A directional coupler is a device that combines electric and magnetic couplings, so that the transfer of energy is unidirectional such as long been used in microwaves. A practical coupler of this type is shown in Fig.3(f) in which the two short lines or coupling elements are about 1500 ft in length, and running along the power T.L. with 12 ft spacing[10]. The directional coupler has no tuning coupling equipment and therefore, it is characterised by higher attenuation level when compared with phase-to-phase couplers. In Fig.3(f), the condition for directionality is given by $L_{12}/C_{12} = Z_L \cdot Z_2$.

(vii) Insulated skywire carrier coupling: This method of coupling, Fig.3 (g), is used for carrier systems to reduce the cost of E.H.V. coupling equipment and to provide new frequencies on an overcrowded transmission systems[2]. Under normal operating conditions, the channel attenuation is somewhat greater than for the phase-to-ground coupling having the same transmission line length.

3.0 SYSTEM MODEL:

Consideration is given to one circuit of the 60-MVA, 66-kV, 3-phase, double-circuit line which interconnects the generating station of TALKHA and the main transformer station of TANTA. This line is an important element in the Egyptian Unified Power Network which is equipped by carrier systems. The line is 53 km in length and is subdivided into three main sections of lengths 20 km, 6 km and 27 km respectively. The intermediate stations are at SAMANOUD and EL-MEHALLA. Each circuit phase consists of a single copper conductor with a cross-section area of 150 square millimeter.

3.1 Transmission Line Model:

Based on a voltage scale of 1 : 1100 V and a current scale of 1 : 300 A, the impedance scale of the transmission line model is 1 : 3.7 ohm and the power scale is 1 : 330 kVA.

For our study, each section of the transmission circuit is represented by one single-phase T-section. The three T-section model line is shown in Fig.4. The values given on the various elements are calculated according to the length of each section, together with the scales mentioned above.

3.2 Carrier System Model:

For PLC system modeling, frequencies of 204 kHz and 284 kHz are chosen as the lower and upper limits of the carrier band. The coupling method used in the investigation is that of phase-to-ground.

Fig.5 shows a complete representation of the system model. The values given for the different elements of the model are those obtained by calculations and then verified by measurements. These values are, of course, based on the above mentioned carrier frequency band. Fig.6 shows the characteristics of both the wave trap and the matching and tuning circuits. It can be seen that, within the carrier frequency band both equipment are functioning satisfactorily.

4.0 RESULTS AND DISCUSSIONS:

In all cases of attenuation measurements, the signal produced by the frequency generator is of voltage 1.505 volt with power level of +6 dB. This signal is transmitted via the coupling equipment, through the transmission line and received by the level meter at the receiving end of the line (Fig.5).

4.1 Normal Operation Conditions:

The total attenuation through the whole carrier route is given by;

$$att_{route} = dB_1 - dB_2 = 20 \log \frac{V_1}{V_2} \quad dB$$

where dB_1 and V_1 are the level and voltage of the signal at the frequency generator, and dB_2 and V_2 are the signal level and voltage as measured by the level meter, respectively. This total attenuation may also be written as the summation of attenuation caused by individual carrier system components. Thus;

$$att_{route} = att_{line} + \sum att_{trap} + \sum att_{coup.cap.} + \dots \text{ etc}$$

Measuring of attenuation is obtained at the carrier frequencies 200, 220, 240, 260 and 280 kHz, which all but the first lie within the chosen band. Table 1 gives the attenuation results under different normal operating conditions.

Table 1. Attenuation results under normal operating conditions (dB)

Carrier frequency (kHz)	Line Load (3226 Ω)		No Load (O/C)	Line earthed at both ends (maintenance)
	line energised	line de-energised		
200	42	33	28.3	39.5
220	40.2	30	23.6	38.9
240	40	30.2	23.5	39.2
260	40.2	30.1	23.7	40
280	41.6	32.6	28.6	38.7

From the table above, it can be seen that the highst attenuation with the P.T.L. de-energised is obtained when the line is earthed at both ends. With the a.c. power voltage applied to the line and the line is loaded by a 3226 ohm, the attenuation is higher than that obtained with the line de-energised. The increase varies between 9 dB and 10 dB, and therefore the increase may be considered to be constant over the whole frequency band.

The results also show that minimum attenuation in the transmitted signal is obtained when the line is energised but open-circuited at the receiving end.

The effects of changing the load values as well as the load power factors are also investigated under normal operating conditions. Fig.7 shows the relation between the level of the received carrier signal and the change in load power factor with the load ohmic value taken as a parameter. (The values given on the curves are system values and not model values.) It can be seen from the curves of Fig.7 that, best receiving of carrier signals occurs when the load is inductive. This is expected since an inductive load adds to the blocking effect of the wave trap. Also, decreasing the load impedance values results in better receiving

In carrier systems, the level of noise is as important to the operation of such systems as the level of attenuation. Thus, in improving the signal-to-noise ratio (S/N), better reception is obtained for the carrier signals. The noise in a PLC system is caused by both circuits of the P.T.L. and the carrier system equipment. The level of noise depends on the value of the carrier frequency as well as on the power transmission voltage. Fig.8 shows the experimental results obtained for inpulse noise level as a function of carrier frequency, with normal operation of P.T.L. It can be seen that within the carrier band, the noise level increases as the carrier frequency is increased.

4.2 Abnormal Operating Conditions:

(i) Mis-matching conditions: The matching transformer is used with carrier systems to match the surge impedance of the P.T.L. with that of the high frequency (h.f.) cable impedance to avoid any reflections of the carrier waves. The degree of matching depends upon the transformer turns ratio. Mismatching is therefore obtained by changing this ratio. Fig.9 shows the results obtained with mismatching at the transmitting side, at the receiving side, and at both sides. The attenuation with full matching is also included for comparison purposes. It can be seen that, highest attenuation levels are obtained with mismatching at both ends of the carrier system.

(ii) Faulty wave trap: In case of faulty or untuned wave traps the results of Fig.10 are obtained and show that, the worst case is obtained when untuning occurs at both ends of the carrier system.

(iii) Broken P.T.L. conductor: With the power conductor carrying the signal broken, there is no carrier signal at the receiving side. However, with the increase in carrier frequency towards the higher limit of the band and beyond, there is a signal arriving at the receiving side but with high attenuation. It also appears that the level of attenuation depends on the position of fault. Fig.4 shews the different fault positions and Table 2 gives the results obtained under these conditions and under the conditions of normal operation for comparison purposes. The propagation of carrier waves through air, across the break, accounts for the reception of carrier signals at the receiving side.

Table 2. Attenuation results with broken P.T.L. conductor (dB).

Fault position	Carrier frequency (kHz)						
	200	220	240	260	280	300	340
At a point between D and wave trap	39	39.5	38	38.5	40	40	42
At point D	none	none	none	68	67	66	66
At point C	none	none	none	none	none	69	67
At point A	no received signal			no received signal			

(iv) Phase-to-ground fault on the power line: Under the conditions of phase-to-ground fault on the P.T.L., there is a signal arriving at the receiving end but with higher attenuation than with normal operation conditions. The positions of faults are at points B, C and D of Fig.4. The results obtained with and without impedance present in the fault path, are given in Table 3. The value of the impedance is kept constant and equals 0.62 ohm; measured on model scale. It can be seen that, there are some improvements in attenuation levels due to the presence of impedance in the fault path. As may be expected, the attenuation level decreases with the increase in impedance value. Fig.11 shews the effect of increasing the impedance value and indicates that, the decrease in attenuation level is linear. The attenuation level continues to decrease with increasing values of fault impedance; the extreme condition is that without fault on the P.T.L.

Table 3. Attenuation results with phase-to-ground fault, with and without fault impedance (dB).

Position of fault	Carrier frequency (kHz)	Attenuation	
		with fault impedance	no fault impedance
At point B (Fig.4)	200	56.7	64.1
	240	56	63.3
	280	56	63.3
	300	55.5	64
At point C (Fig.4)	200	53.5	61.2
	240	53	61.1
	280	52.8	61
	300	53	61.6
At point D (Fig.4)	200	50.2	57
	240	50	56
	280	49.8	56
	300	50	57.5
No faults (normal operation)	200	32	
	240	30	
	280	30.1	
	300	32.6	

Referring to Fig.4, it can be seen from the results above that the attenuation level decreases as the point of fault is moved closer to the receiving side of the carrier system. This is true whether there is a fault impedance or not. It can also be seen that, for each fault point the attenuation level remains almost constant over the whole range of carrier frequency.

5.0 CONCLUSIONS:

The paper considers the performance of PLC system on one of the important O.H.T.L. in the Unified Egyption Grid. A model is built up to simulate the carrier system on the transmission line. Attenuation and noise levels are measured and results obtained under the conditions of normal operation and faults in the line and in the carrier equipment. The main conclusions are summarised below.

(a) Normal operating conditions:

- With the power line loaded, higher values of attenuation (about 40 dB) result with the line energised than with the line de-energised. The difference is about 10 dB and constant over the whole band.
- Smaller attenuation values (average 25 dB) are obtained when the line is energised but open-circuited at the receiving end.
- With the line isolated and earthed for maintenance, high values of attenuation are obtained. The values are of the order of 40 dB.
- Inductive loads improve the signal reception because of their blocking effect which adds to that of the wave traps. Further improvements are obtained with smaller values of load impedances.
- Noise level increases as the carrier frequency is increased.

(b) Abnormal operating conditions:

- With mismatching in matching transformers, lower signal levels are obtained when mismatching occurs at both ends of the system.
- Similar results are obtained with faulty wave traps at both ends.
- Almost no signals arrive at the receiving end when the line conductor is broken.
- The presence of an impedance in the path of a phase-to-ground fault causes a reduction in the attenuation level below that obtained with solid phase-to-ground fault. The reduction is increased as the impedance value is increased. Generally, however, attenuation levels are high (of the order of 50 to 65 dB) in such cases. The attenuation level remains almost constant over the whole range of carrier frequency band.

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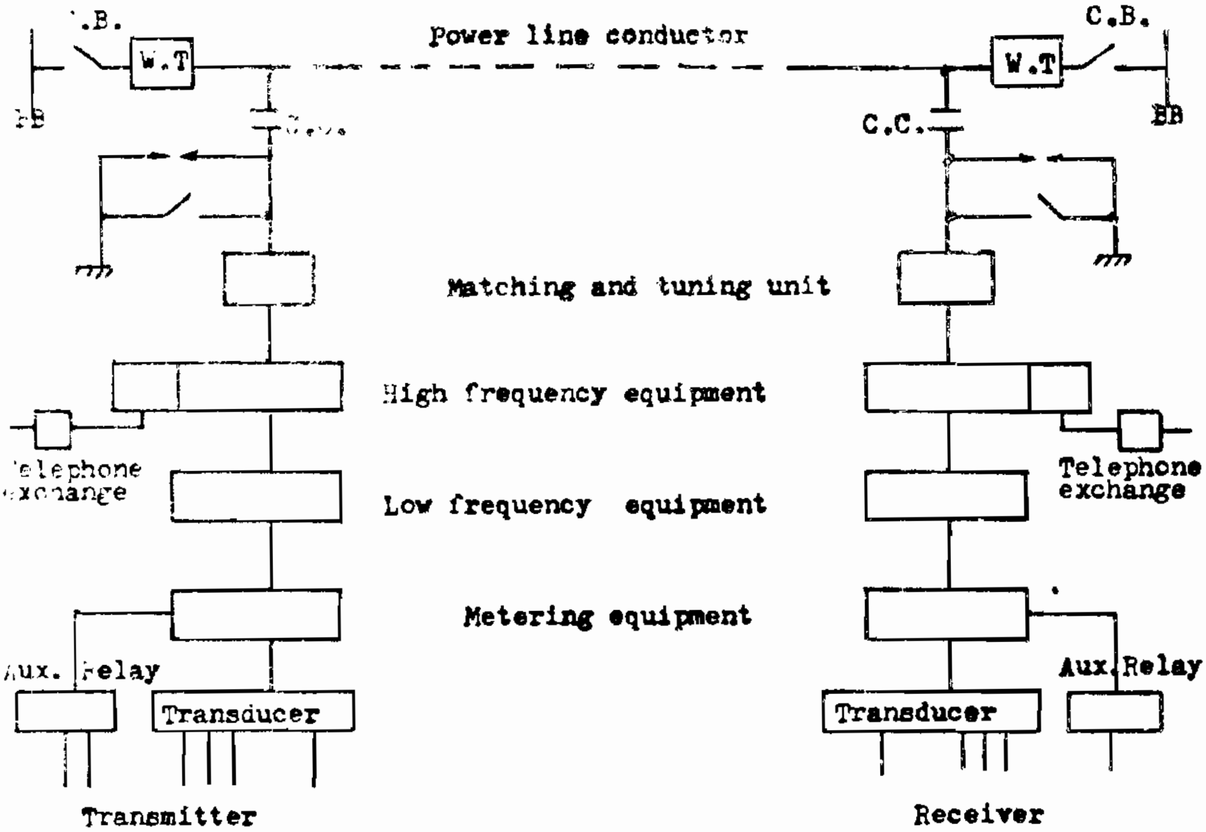

Fig.1. A schematic diagram of a PLC system using single phase coupling method.

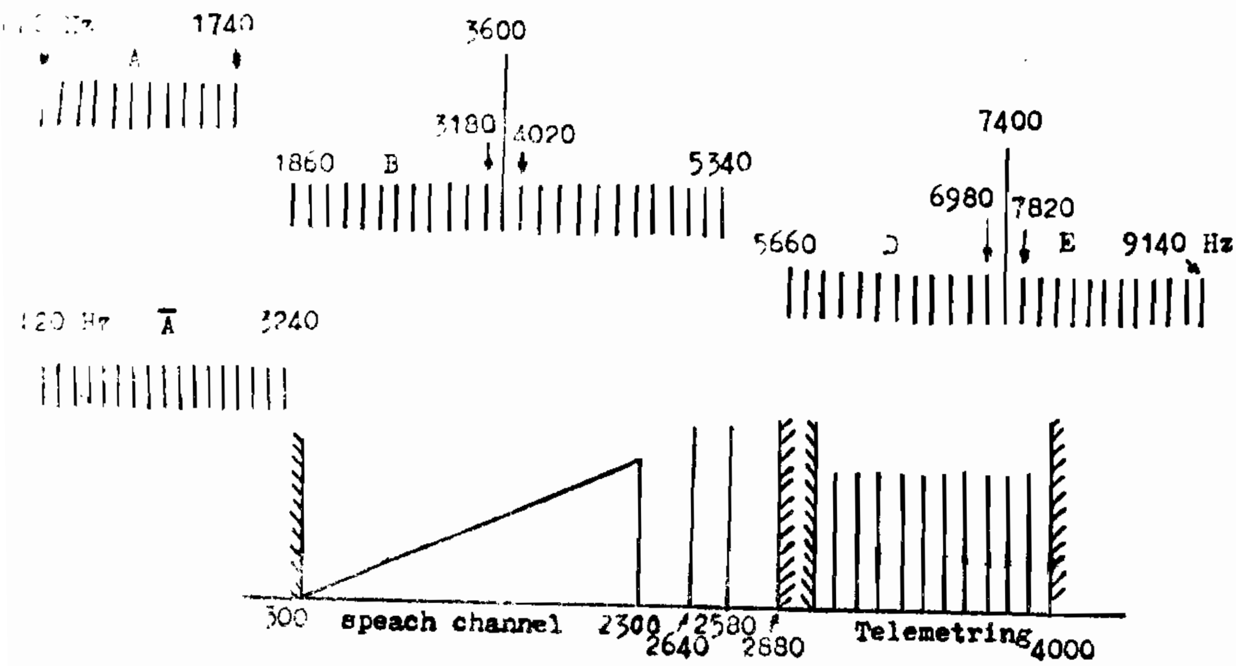

Fig.2. Channel groups and audio-frequency band channels.

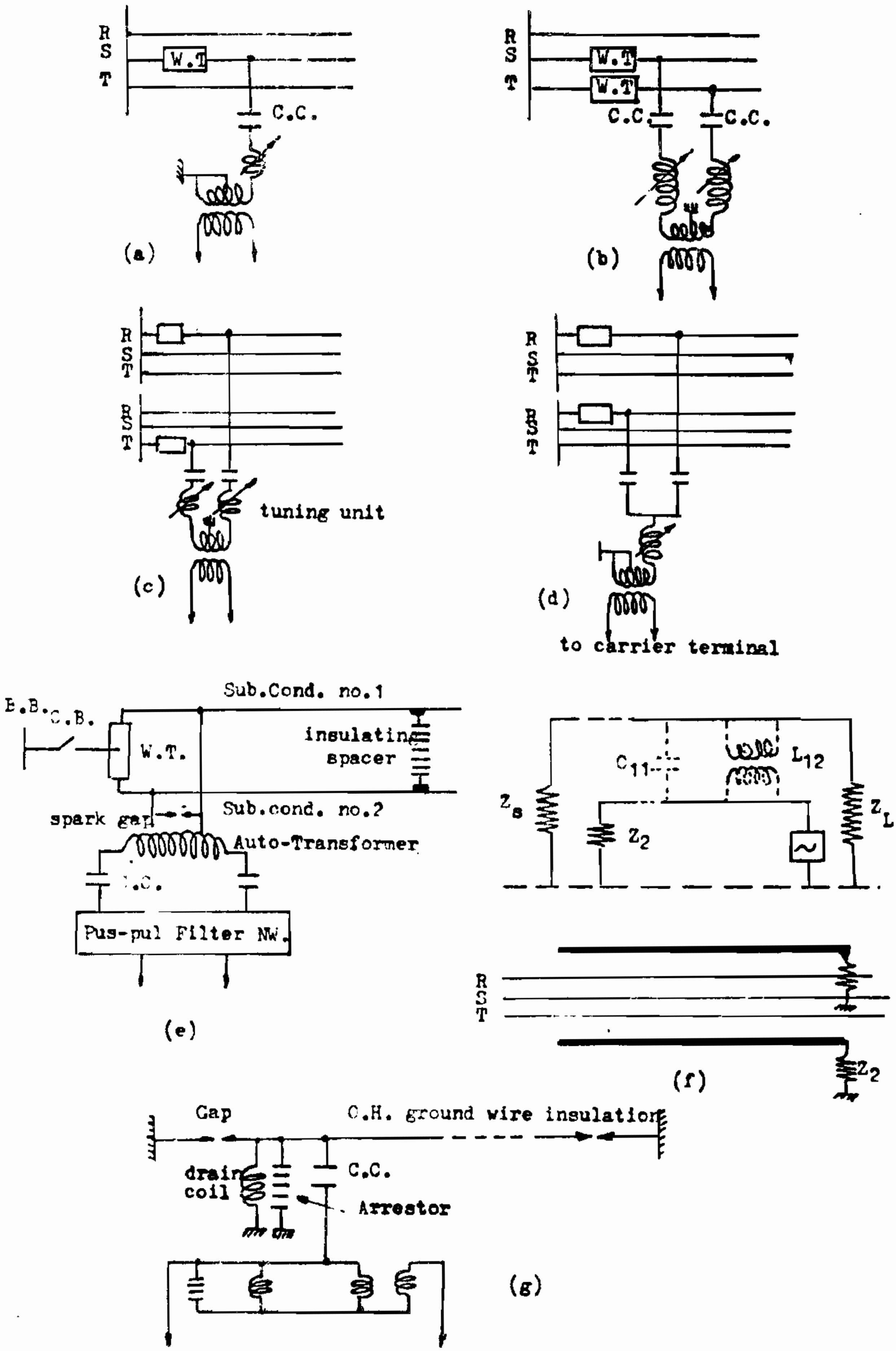

Fig.3. Power line carrier coupling methods.

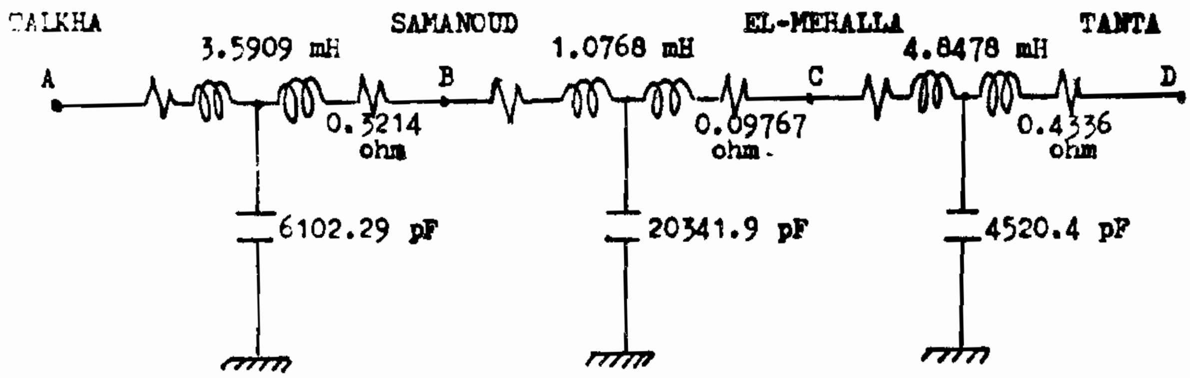

Fig.4. Single phase representation of the 3 T-section line model

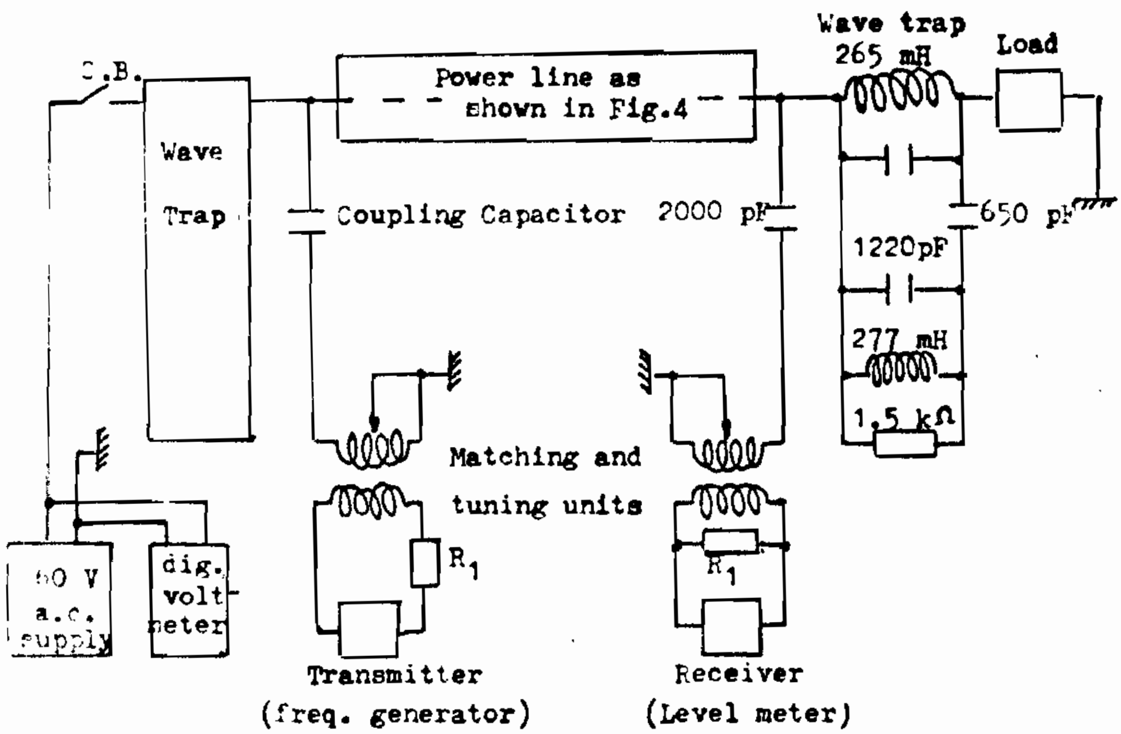

Fig.5. Power line carrier model with phase-to-ground coupling.

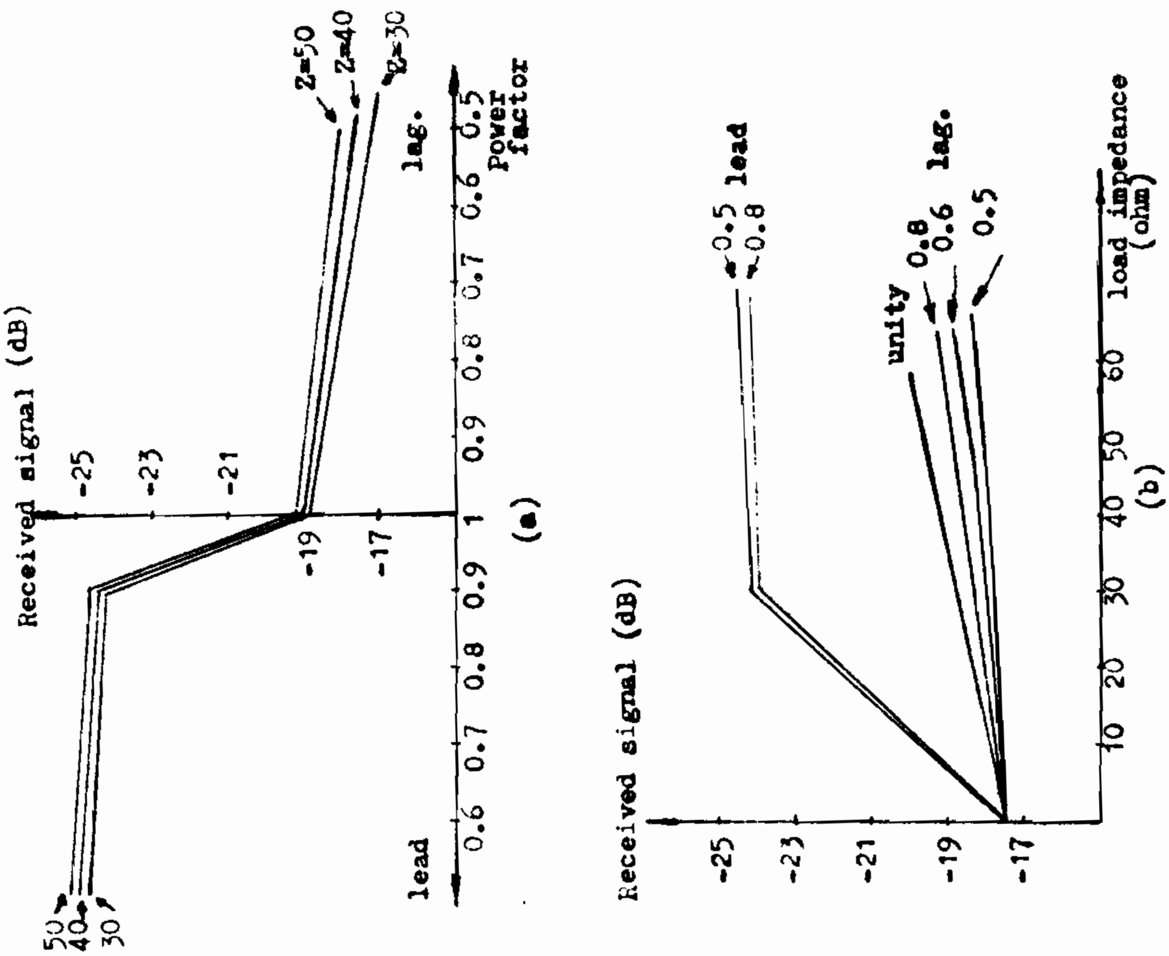

Fig.7. Effect of load P.F. and impedance on carrier received signal.

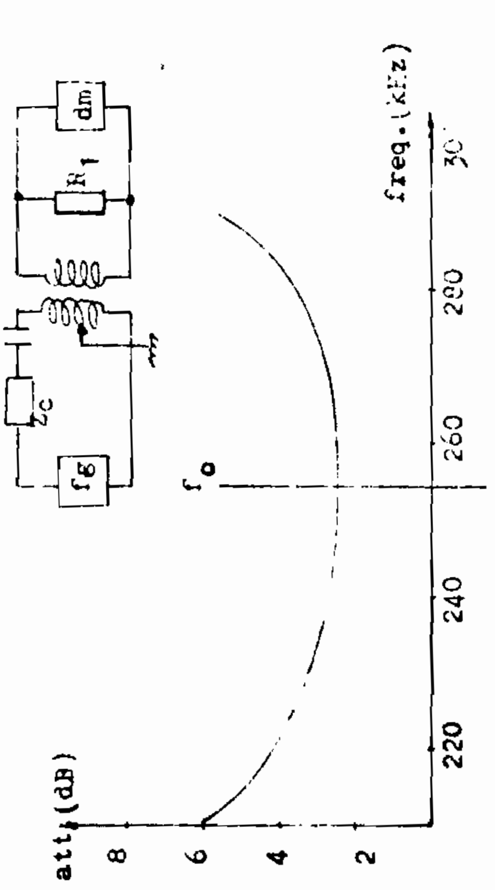

Fig.6(a) Characteristics of matching and tuning unit.

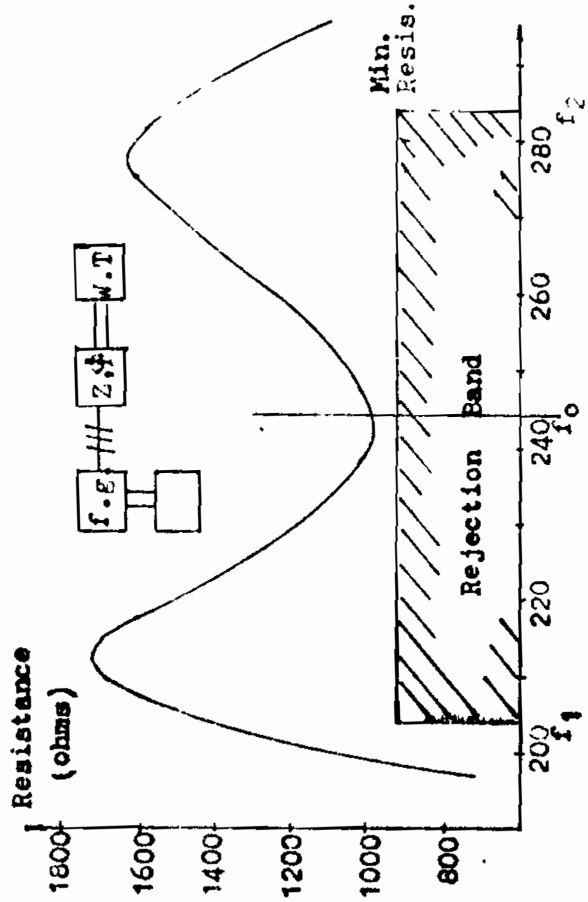

Fig.6(b) Wave trap minimum resistance.

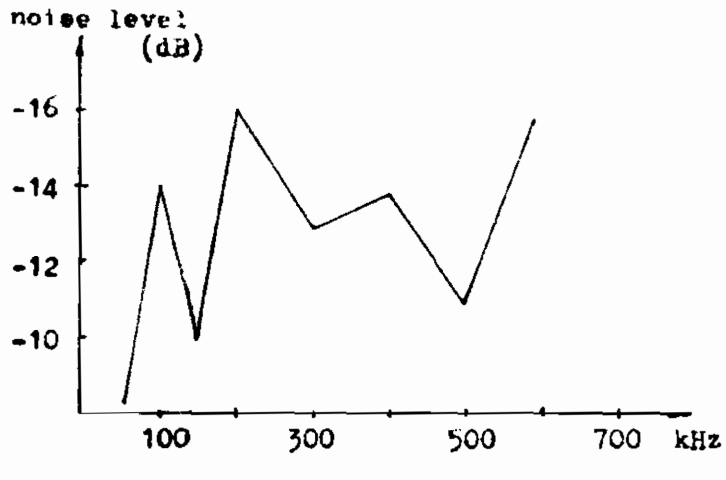

Fig.8. Noise level under normal operating conditions.

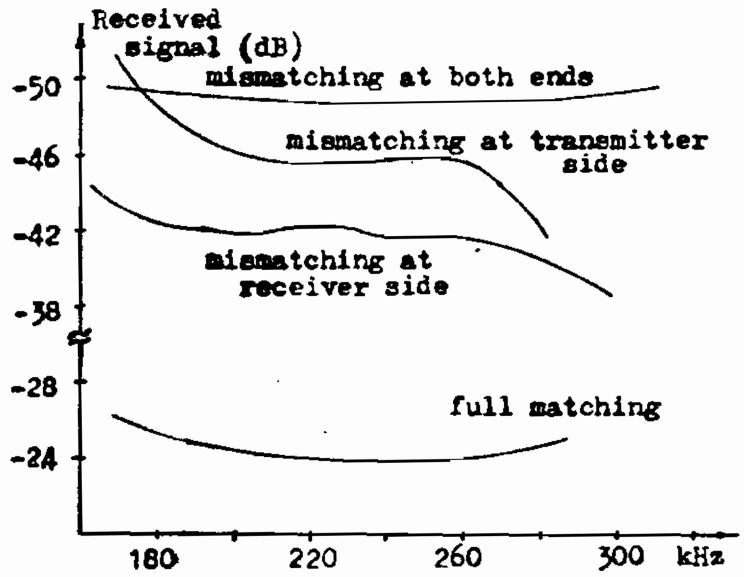

Fig.9. Effect of mismatching on received carrier signal.

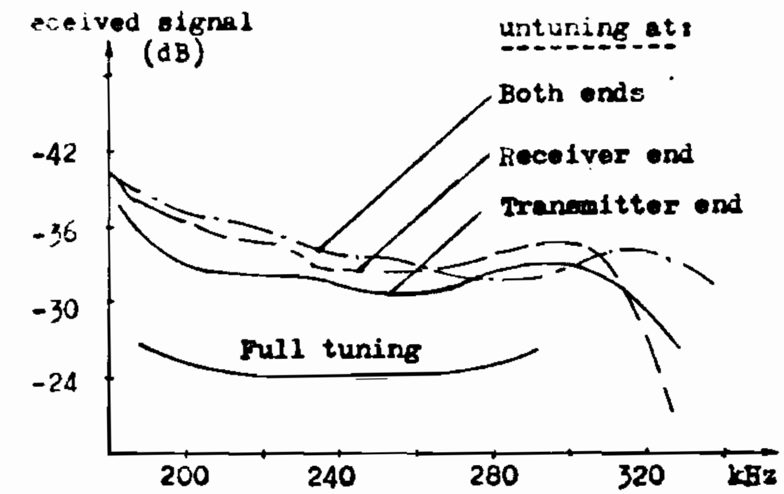

Fig.10. Carrier received signal with untuned wave trap.

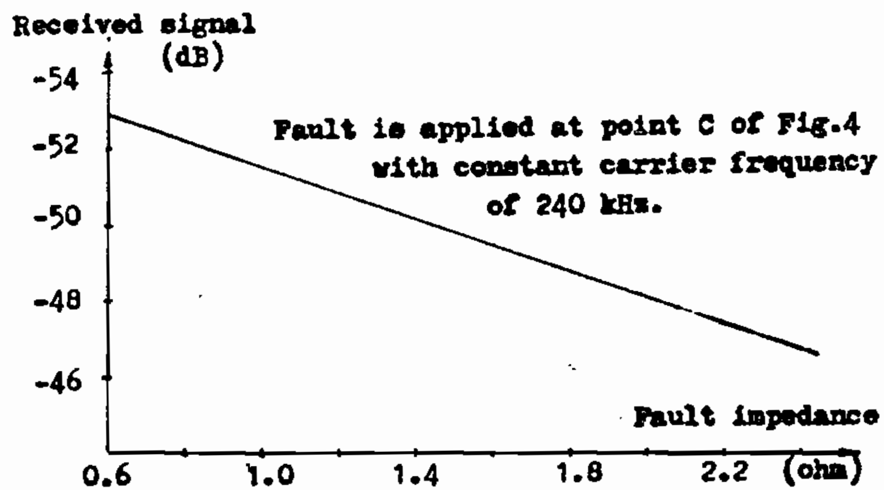

Fig.11. Effect of fault impedance value on the level of received carrier signal.