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CARRIER SYSTEMS ON OVERHEAD POWER LINES

By

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ABSTRACT:

This paper presents a comprehensive study into the application of carrier systems to overhead power transmission lines. The use of carrier systems for the purpose of telemetring as well as in protection schemes, is discussed. Different coupling methods are illustrated and a comparison is included.

1. INTRODUCTION:

Carrier systems have recently become of increasing importance in the operation of modern power transmission networks. Power line carrier (P.L.C.) channels of frequency bands ranging from 30 to 500 kHz, are now in use[1]. Carrier systems are used for control of generating units, telemetring of continuous load information[2], as well as for protective puposes. All these purposes are now necessary for reliable and efficient operation of power system networks.

The equipment of the carrier channels are coupled to the power lines by means of coupling equipment, which include wave traps, coupling capacitors, coupling filters and matching transformers.

The application of P.L.C. in telemetring and protection, as well as the different coupling methods are discussed in this paper.

2. CARRIER SYSTEM APPLICATIONS:

2.1 Power line carrier in telemetering:

The operation of measuring electrical quantities such as power, voltage, current, transformer tap-changer positions, etc, at a remote end of a transmission line, is known as telemetering. The electrical informations can be transmitted to the near end of the line on a carrier signal within certain frequency bands by a transmitter/receiver channels, the number of which depends upon the number of quantities transmitted.

Fig.1 shows a simple schematic diagram of a carrier
transmission line (P.T.L.), using phase-to-ground coupl

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the analog a.c. metering values from the remote station is fed into the primary transducer in which the metering values are converted into signal form with d.c. output of ± 6 mA. At the same time, the appropriate signal is fed through auxieliary relays into the remote-metering and signalling equipment. In the latter, the informations are translated into a pulse train having the waveform shown in Fig.2, with d.c. level of 20 ± 4 mA and having the speed of a telegraph. The pulse train is then fed into the low frequency channel equipment, which comprises a frequency modulator and a filter system having a pass-band of oudio frequency channels, Fig.3. The frequency modulated output of the low-frequency equipment is fed into the high frequency equipment. Inside the high-frequency equipment two stages of amplitude modulation are performed on the low frequency band channels. These two stages are intermediate and high frequency modulations (referred to as IFM and HFM) with frequency range 11.8 to 15 kHz for the first stage, and from 30 to 500 kHz for the second.

The modulated signals may be transmitted through a wide band amplifier to the high voltage P.T.L. via coupling equipment to the receiving end of the line. At this end, the same equipment and units exist, as for the far end, in order to receive all transmitted signals from the remote end.

2.2 Power line carrier in protection:

For maintaining the stability of the power system, a high speed P.L.C. current channel protection is intended for medium and long transmission lines. In this case, a high frequency is injected into one or two conductors (according to the protection scheme used) of the O.H.T.L. whose ends are equipped by high frequency coupling equipment[3,4].

Fig.4 shows one protection zone of a protected transmission line[5]. For each zone, the transmitter/receiver (T/R) and the two traps are tuned to operate at the same frequency. For example, the equipment of zone A are tuned to frequency f_1, those of zone B to f_2, etc. This is so to avoid any interferance between the different zones.

The protection information to be conveyed from one end to the other is superimposed on a basic carrier signal. This is done in different ways, according to the type of protection involved. In the directional protection[2], the system responds to the direction and type of fault conditions, and by comparing these directions at the ends of the protected zone, the fault point can be determined and the protection groups therefore operate by sending a blocking carrier signal to the receiving end, Fig.5.

But in phase comparison carrier protection, the phase (angle) of line current is transmitted to the remote end over carrier link, by modulated carrier signal in blocks corresponding to half-cycles of the 50 Hz wave. This transmitted signal is then compared with the phase of the current at the receiving side of the protected zone. Fig.6 shows a block diagram for the equipment used in such cases.

3. P.L.C. COUPLING METHODS:

Different coupling methods are used in P.L.C. systems. The main of which are discussed below.

3.1 Phase-to-ground coupling:

In this method[2,6], the carrier signals are transmitted on one phase of the power line with the ground as the return path. The equipment required here are; wave trap and one coupling capacitor. This results in minimum cost. The phase-to-ground method has, however, an appreciable coupling to the other phases with high interference level. Fig.7 shows a simple wiring of this coupling.

3.2 Phase-to-phase coupling:

This method of coupling[5] requires two traps and two coupling capacitors connected to two phases of the T.L., as seen in Fig.8. It has the advantage of low coupling to other phases, and the earth wire is not essential. Also, the attenuation and interference levels are lower in this method than in the phase-to-ground coupling. Inspite of its high cost, the phase-to-phase coupling method has been in use in the parts of many transmission networks in order to avoid interrupting the continuity of the carrier channels, if any phase is grounded.

3.3 Inter-circuit coupling:

This coupling method[2] is applied on two phases of a double-circuit transmission line, Fig.9. With this method, either circuit of the T.L. can be taken out of service and all three phases can be grounded at any point without interrupting the continuity of carrier transmitted signal. The inter-circuit coupling method therefore, has the advantage of increasing the reliability of carrier channels under abnormal conditions.

3.4 Double-circuit ground return coupling:

As shown in Fig.10, the carrier system is coupled to the same phases of the two circuits with ground return to operate in parallel under normal conditions. Also, either circuit can be taken out of service without interrupting carrier channels but with normal attenuation level.

3.5 Bundle sub-conductor P.L.C. coupling:

The insulated bundle sub-conductors (I.B.S.)[7] are used in carrier systems to increase the number of carrier channels. The I.B.S. carrier system presents some attractive features not to be expected in conventional P.L.C. installations and its tuning supplement on E.H.V. transmission lines.

As shown in Fig.11, the transmitter is connected to a duplex-subconductor bundle, which is energised from the station bus through a center-tapped wave trap. In this method, the carrier signal from a push-pull matching filter network is fed through a balanced step-up auto-transformer and coupling capacitors.

The I.B.S. carrier coupling improves the blocking attenuation across the station bus. This is so because the carrier voltages at the terminals of the trap are balanced to ground and the center tap is at zero radio-frequency potential. This coupling also rejects the station and corona noise and causes a reduction in current rating of the wave trap (because the center tapped trap carries only half the current carried by the trap in conventional P.L.C. coupling). Also, in I.B.S. coupling, the capacitance requirements are small, resulting in low cost of coupling capacitor.

3.6 P.L.C. directional coupler:

A directional coupler[8] is a device that combines electric and magnetic couplings so that the transfer of energy is unidirectional. Such a device has long been used in microwave applications. A practical coupler (Fig.12) has two short lines, or coupling elements, of 1500 ft long approximately, running parallel to, but 12 ft apart from, the power three-phase conductors. The feeding point on the directional coupler is at the far end, but at the near end the coupler would be terminated by a resistor.

The coupled carrier signal is resolved into two components. One component is capacitive and the other is inductive. These are added in one direction and oppose in the other to produce directionality with $L_{12}/C_{12} = Z_L Z_2$. The directional coupler has no tuning equipment losses and the relative loss may be of value 8 dB compared to phase-to-phase couplers. This is so because the capacitor coupler transfers most of the carrier power.

3.7 Insulated skywire carrier coupling:

The insulated overhead ground-wires (skywires) have successfully been used for carrier systems[1] to reduce the cost of E.H.V. coupling equipment and to provide new frequencies on an overcrowded transmission systems, without interferring with the existing coupling tuning. The simplified circuit diagram of this coupling method is shown in Fig.13.

Under normal operating conditions, the channel attenuation may be somewhat greater than for a practical phase-to-ground channel having the same legth.But, with this coupling method, the noise from the power line will be less so that better signal-to-noise ratio (SNR) is obtained. However, the main problem is that the channel reliability decreases during system disturbances (e.g. lightning storms, flashovers, etc).

The insulated skywire carrier coupling uses a simplified wave trap and a 25-kV capacitor, to obtain a simple broad band of coupling. The carrier maintenance problem is greatly reduced with this method of coupling.

4. POWER LINE CARRIER FREQUENCIES:

4.1 Carrier frequency band-width:

The remote informations are transmitted to the near end over carrier communication channels. These channels lie, of course, within the carrier band. The amount of informations is proportional to the frequency bandwidth which is obtained by resonating the resonating network. The resonating network has a frequency response which is higher than that at the cut-off frequency. The upper limit of the frequency band is limited by the connection of prescribed series inductors and shunt capacitors.

To break the pass band into a number of sections, more complicated resonating networks are used. These sections can be located anywhere as desired in the frequency spectrum. For each section, there will be a cut-off frequency associated with it.

For the complete band width, the fundamental restriction of the spectrum which is created by series inductors and shunt capacitors is;

$$F_{co} = \sum (F_2 - F_1) \qquad ......(1)$$

where F_1 and F_2 are the lower and upper frequencies of the various section bands respectively, and F_{co} is the cut-off frequency of the network in its natural state. (The cut-off frequency is defined as the frequency at which the capacitive and the reactive reactances of the frequency limiting element are equal.) When using shunt inductors and series capacitors, the principle of conservation of network band width is given by:

$$\frac{1}{F_{co}} = \sum \left(\frac{1}{F_1} - \frac{1}{F_2}\right) \qquad \ldots\ldots(2)$$

For each section, the band width B is given by:

$$B = \frac{1}{2\pi} (F_2 - F_1) = \frac{f_o^2}{2\pi F_{co}} \quad \text{Hz} \qquad \ldots\ldots(3)$$

where f_o is the geometric mean of F_1 and F_2 and is called "the mid-band frequency".

In the case of shunt inductors and series capacitors the frequency band is proportional in its width to the square of the mid-band frequency.

4.2 P.L.C. channels:

The audio frequency channels with carrier frequencies may be selected, in conformity with the frequency allocation, by time division or frequency division starting from f_o = 420 Hz. Such frequency division is in the range of 30 to 120 Hz. Fig.14, shows a group (A) of 12 channels with frequency from 420 Hz to 1740 Hz. By modulating this group by a carrier frequency of 3600 Hz, groups B and C are obtained. Groups D and E are obtained when the modulating frequency is increased to 7400 Hz, etc. With the extension of group A to 17 channels (frequency from 420 to 2340 Hz), group Á is obtained which can be used for transmission over two wires. Again, a frequency division of 120 Hz is used to separate the 17 channels from each other.

In a (multiplex system) frequency division[9], there exists a variation in the received signal level and also the attenuation is not constant. Thus, a low frequency amplifier and a line attenuation equalizer are fitted with this system to overcome the above mentioned problems.

To avoid undesirable cross-channel interference[9], a spectrum guard band is provided in the frequency division system. But in time division systems, the pulse repetition rate must be kept as low as possible to avoid this interference.

In frequency division system, a separate portion of the available frequency spectrum is reserved for each channel by using subcarriers and resonant narrow band filters. In time division system, however, the entire available spectrum is allocated to all channels.

When carrier circuits are operated with suppressed carrier frequency, there is a risk of the frequency division exceeding the channel limit. To avoid this risk, the system must be provided with an additional automatic frequency control (AFC) unit facility, to ensure frequency faithfulness of the transmitted signals.

In the above, the frequency division and the time division have been discussed. However, the frequency division system is simpler and more flexible than time division system[9]. Yet, the equipment required in the frequency-division system is often bulky and expensive. Both systems, however, are limited in their spectrum efficiency by the phenomenon of crosstalk, or interaction between channels.

4.3 Carrier frequency mode operation:

The carrier informations data in control systems are transmitted by either frequency or pulse code systems

4.3.1 Frequency code system: By this mode, the informations are transmitted to the central station as analogue or digital processing. They can also be transmitted from the central station to the out-stations as complete on-off central instructions in the form of two tones with audio signal bands. In addition, the mode connection is the same as an ordinary 2-pair telephone connection. This method of operation is well suited to small and medium size stations with time from 1 to 3 seconds needed for transmitting carrier signals.

4.3.2 Pulse code system: The informations in this mode are transmitted in the form of coded pulse trains with telegraph speed ranging from 50 to 600 bouds. This pulse train includes, in addition to the information, both pulse position and pulse check. This system is basically intended for transmitting large numbers of messages with rapid operation, and thee time needed to transmit one message is 0.65 seconds at 50 bouds.

Also, the quantities telemetered can be transmitted by either simplex or duplex system[10]:

(a) In case of simplex system, the signals between the two stations are transmitted on a single frequency channel. Therefore, the transmission and reception between the stations can take place simultaneously on the same frequency. This is so because the transmitter of one station blocks the local receiver. The use of single frequency automatic simplex system, however, permits a single conversation among several stations on the channel, and it permits operation with two-wire telephone extensions and through private board exchange (PBX).

(b) In case of duplex system, the transmission takes place from both stations simultaneously by the use of two frequencies. For example, if one station uses the frequency f_1 for transmitting and f_2 for receiving, the other station uses f_2 for transmitting and f_1 for receiving. Also in this system, up to 5 stations may be interconnected on the same line by using frequency inversion, or by changing the frequencies. These frequency modes of operation in communication circuits are illustrated in Fig.15.

5. CONCLUSIONS:

From the forgoing study, the importance of carrier system application on overhead transmission lines , for the purpose of telemetring and protection, is clarified. The advantages and disadvantages of different coupling methods, regarding the attenuation and noise, are pointed out. Also, the carrier frequency mode of operation (as frequency code and pulse code systems) are illustrated.

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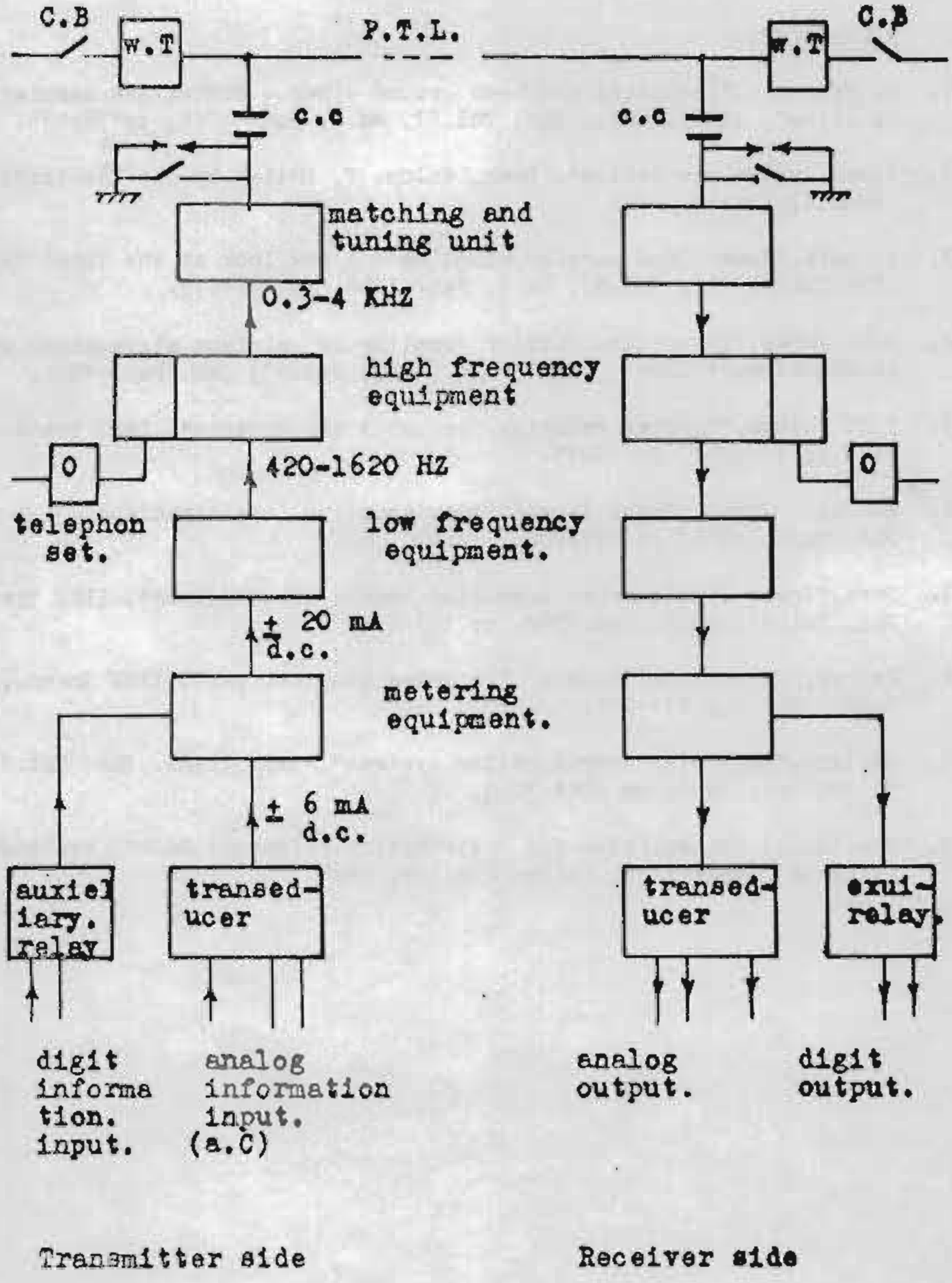
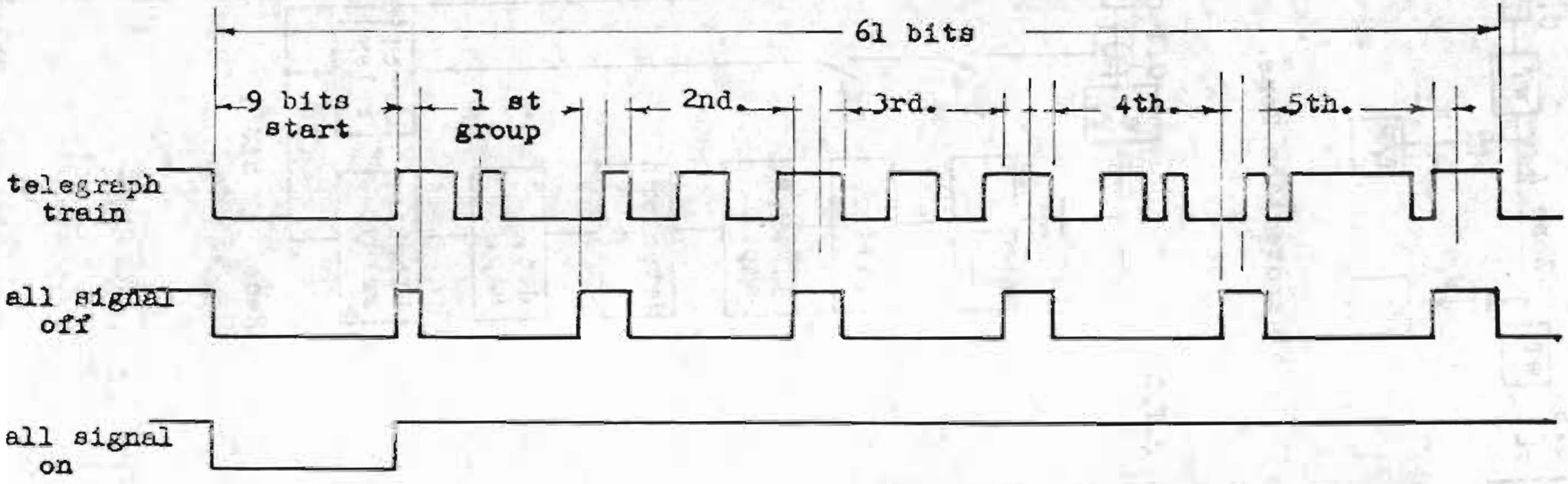


Fig. 1. A block diagram of a carrier system for telemetering.



O1 : separating pulse , Z_1 : check pulse

Fig. 2. Out-put pulse train of the metering equipment.

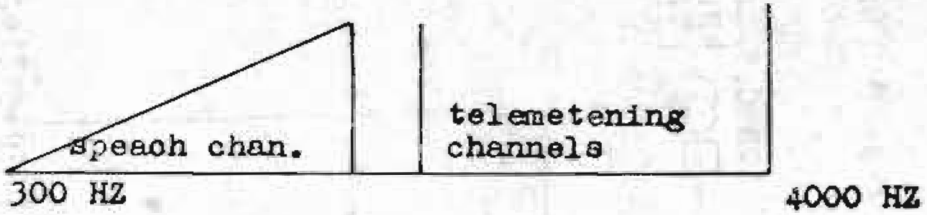


Fig. 3. Audio frequiency channels.

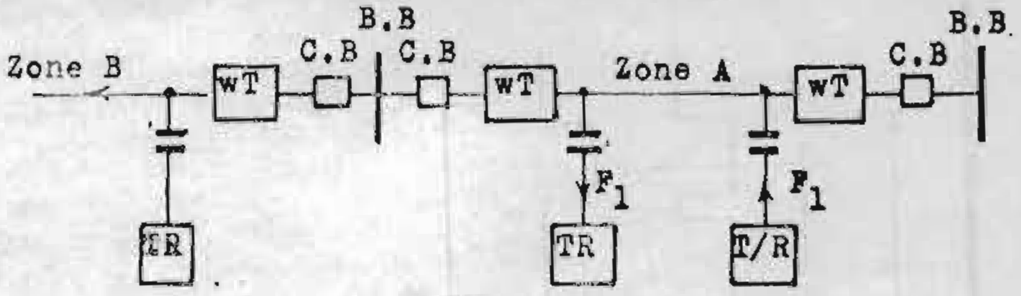


Fig. 4. Operating frequency of protection Zone.

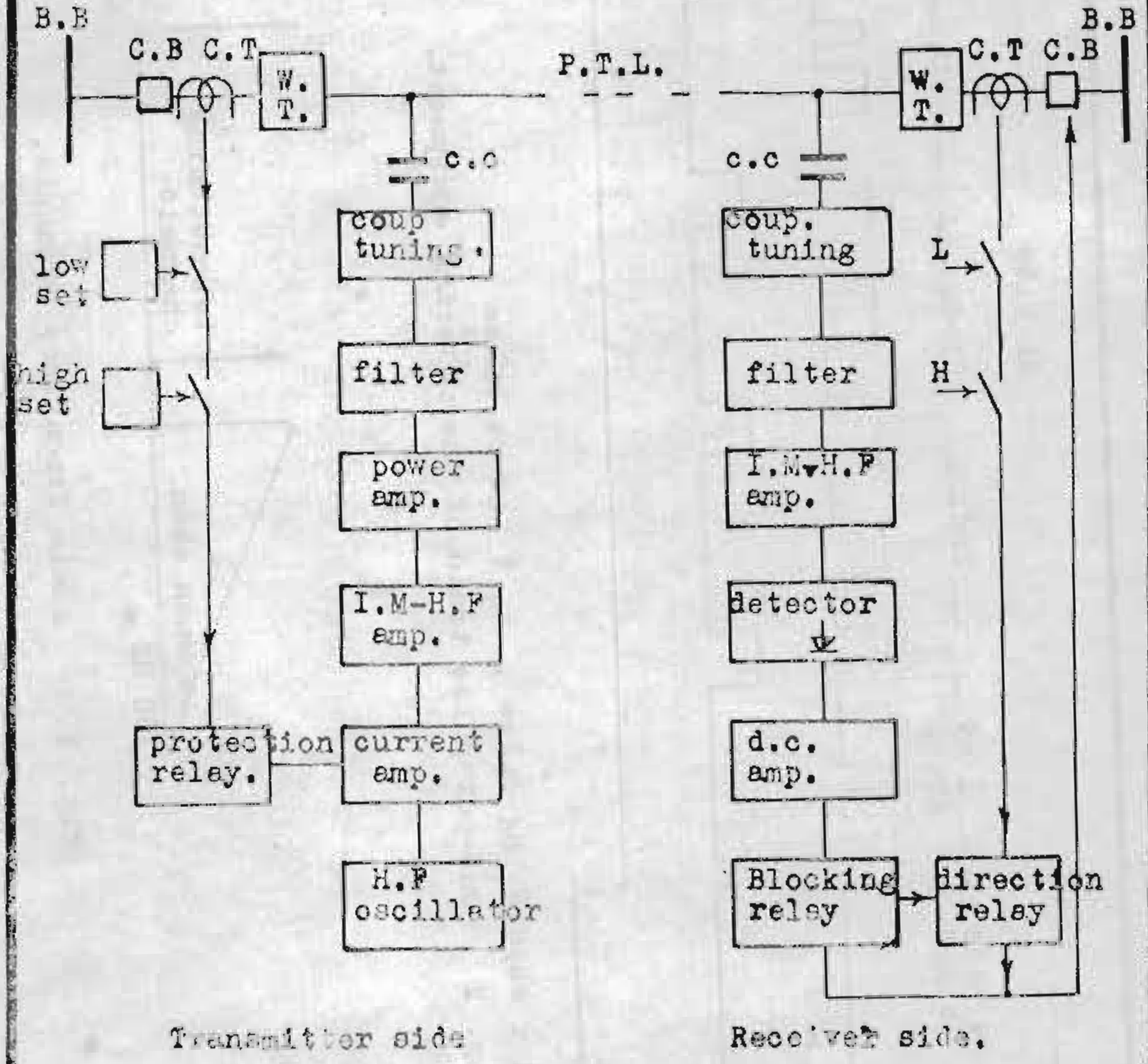


Fig. 5. Block diagram of directional-comparison as a carrier-current channel.

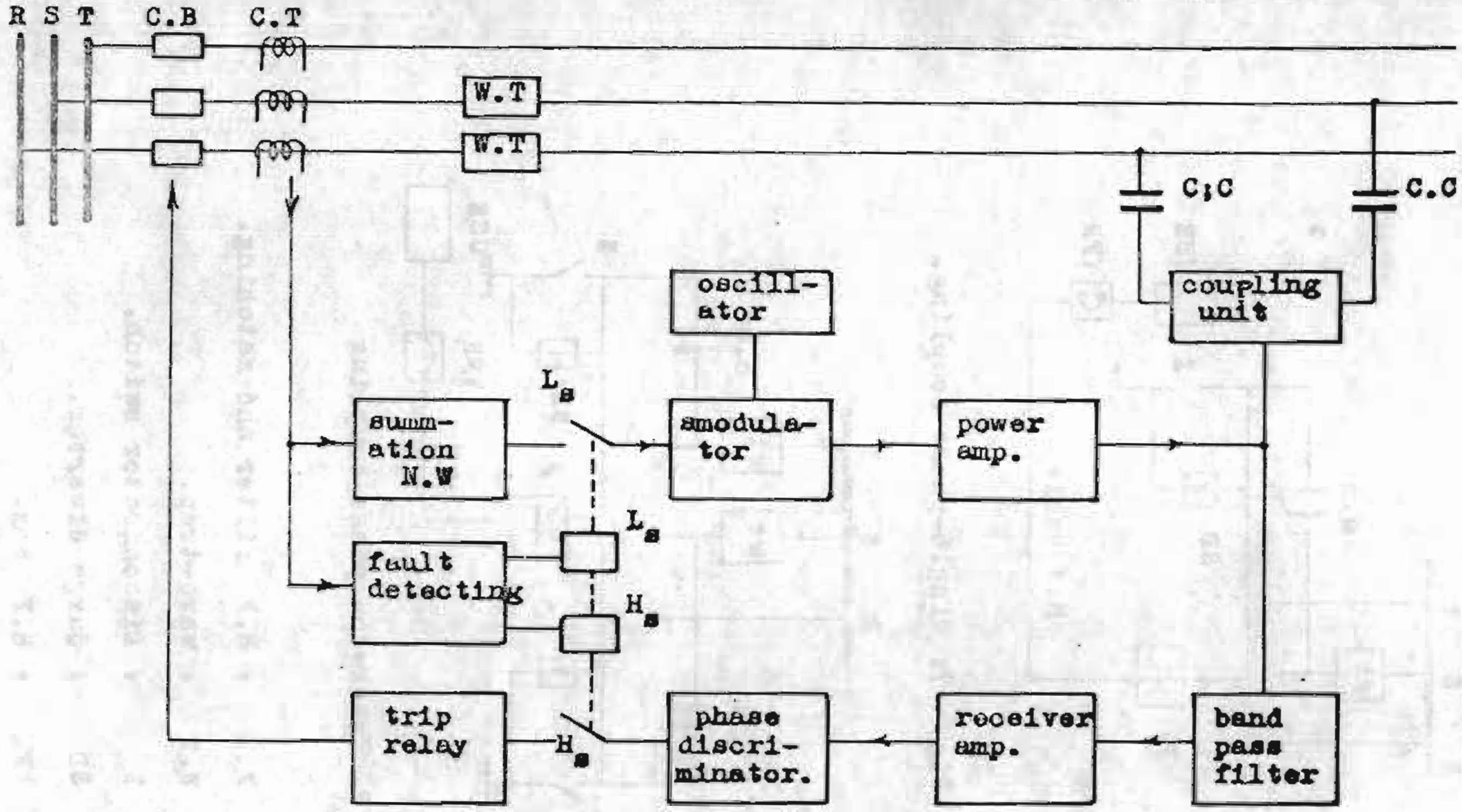


Fig. 6. Block diagram of phase comparison-carrier-current as phase-to-phase coupling on 3-phase.

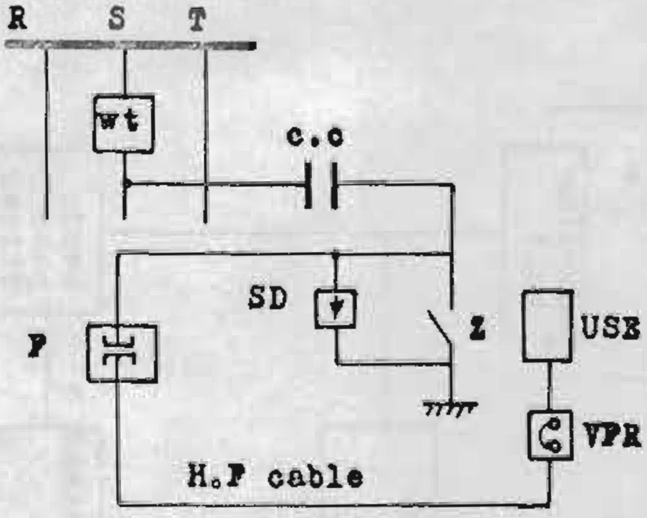


Fig. 7. Single-phase coupling.

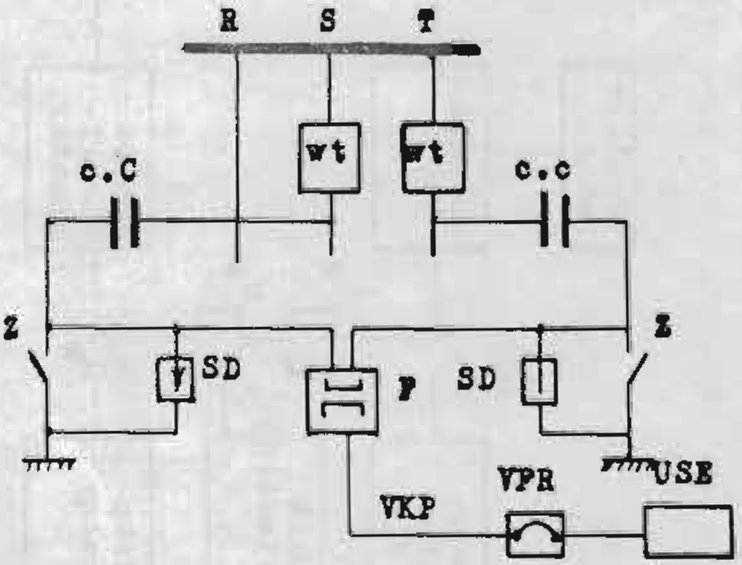


Fig. 8. Phase-to- phase coupling

F : H.F filter and matching.

W.T : wave-trap.

Z : Disconnector switch.

SD : Surge diverter.

VFR : H.F box.

VKP : H.F cable.

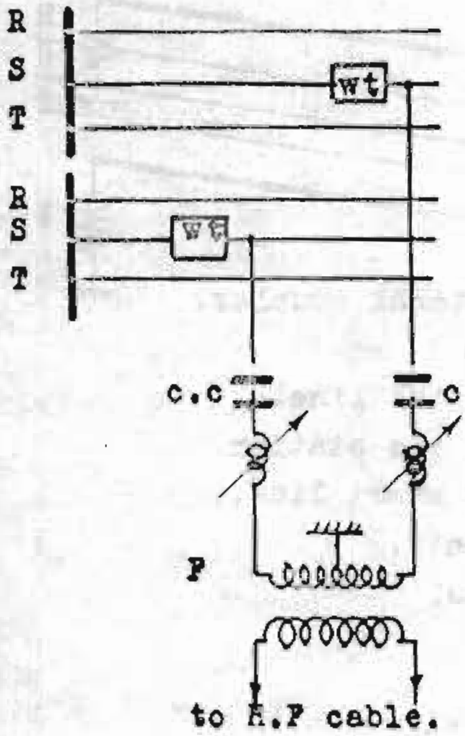


Fig. 9. Inter circuit coupling

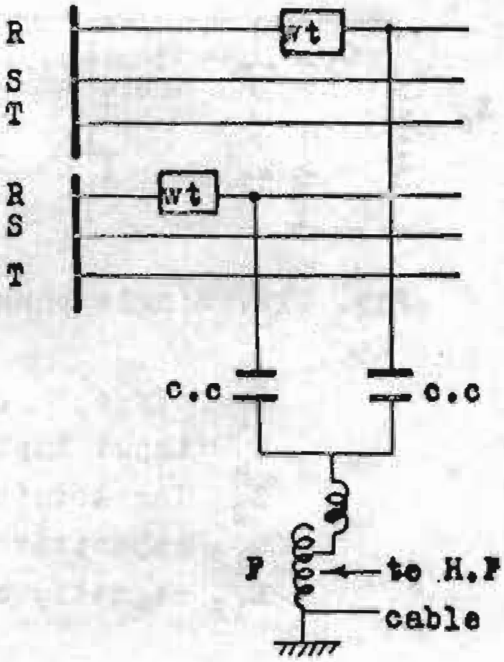


Fig. 10. Double-circ. ground return coup.

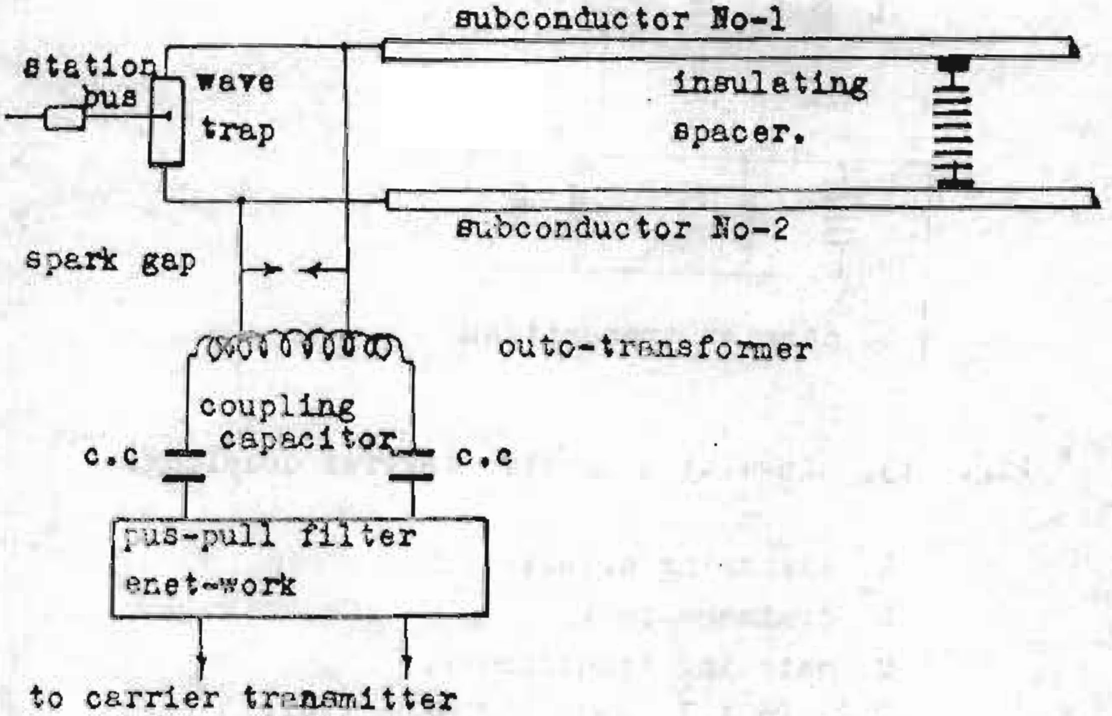


Fig. 11. Simplified circuit diagram of Ibs carrier coupling

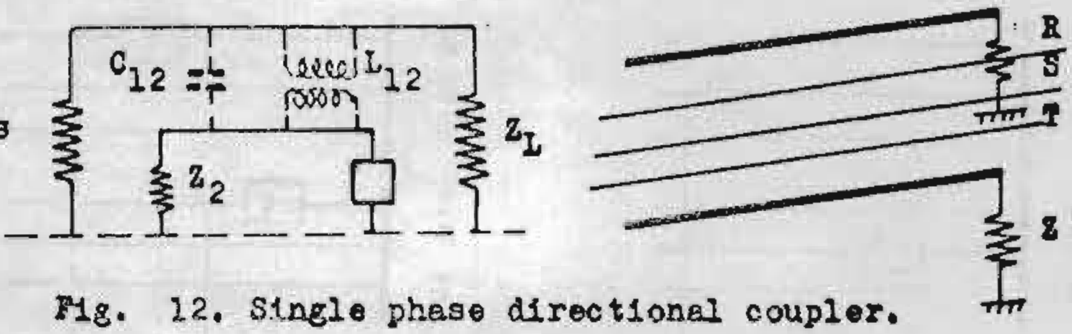


Fig. 12. Single phase directional coupler.

Z_L	surge impedance of the line.
Z_s	input impedance of the station.
Z_2	The termination of short line.
C_{12}	capacitive components.
L_{12}	magnetic components.

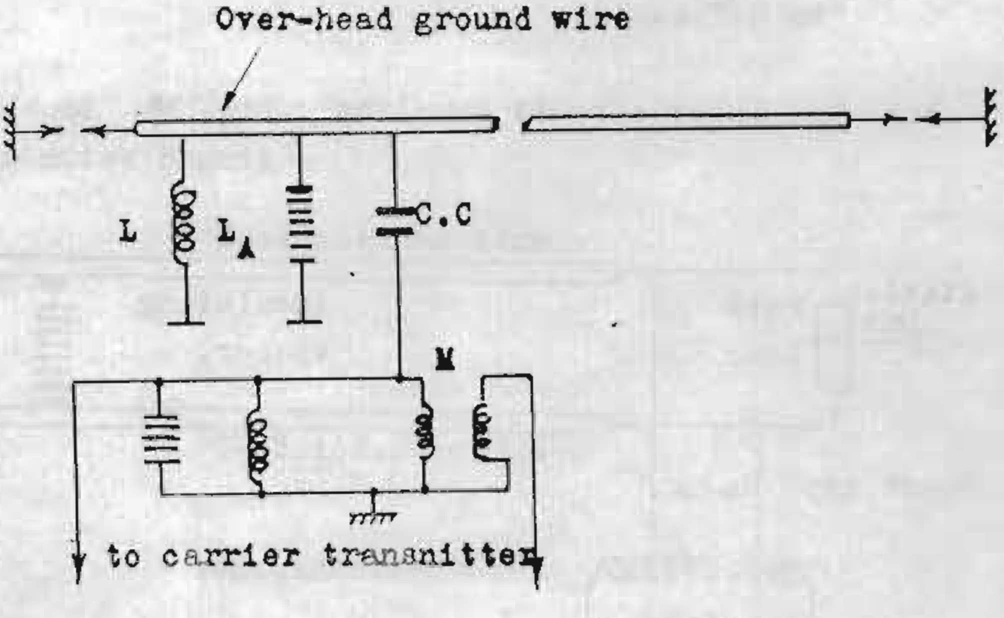


Fig. 13. Insulated skywire carrier coupling.

L_A	lighthing arresters.
L	drainage coil.
M	matching transformer.
C.C	25 K.V coupling capacitor.

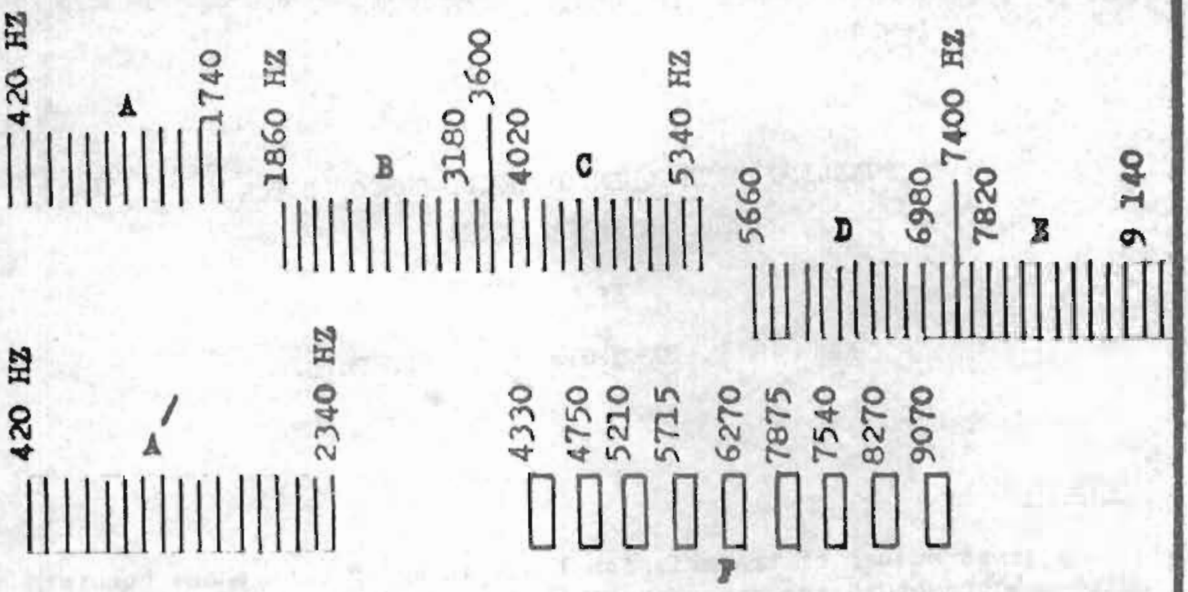
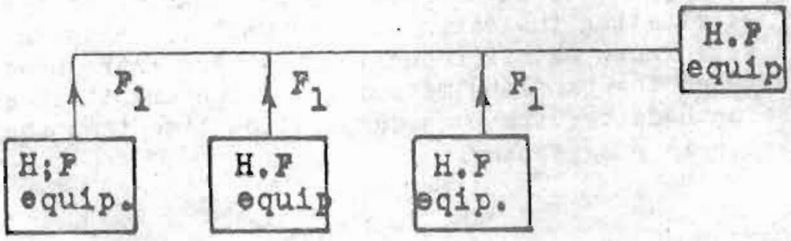
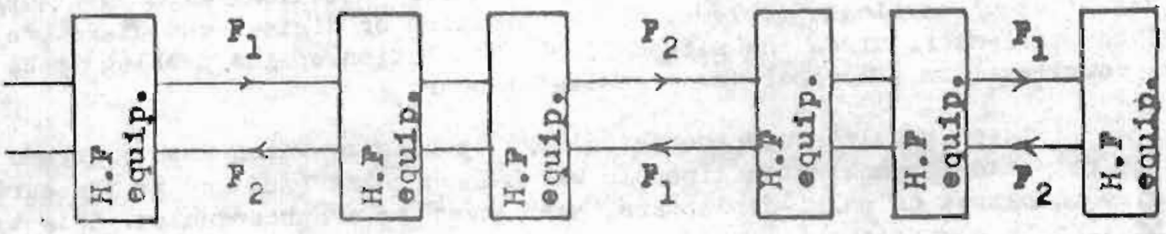


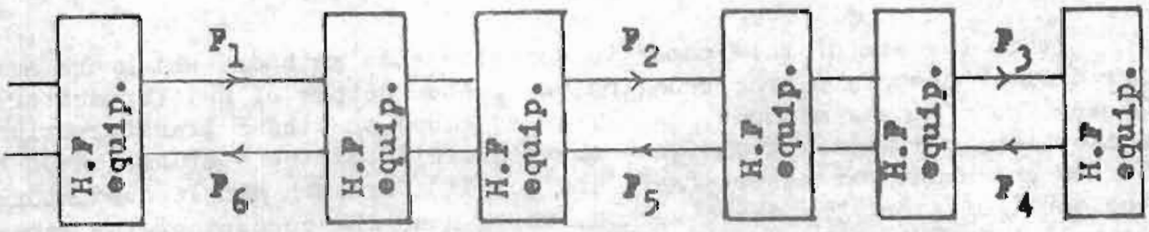
Fig.14. Low-frequency allocation plan.



(a) simplex star operation.



(b) duplex line operation with frequency inversion.



(C) duplex line operation with frequency change.

Fig. 15. Frequency mode operation.