Bi-Directional Amplification in Communication Lines

by Lloyd Butler VK5BR

Basic Amplifiers are made to amplify signal, such as speech, in a single Direction. For two way communication on a single line, or other single bearer, amplification needed is applied separately to the signal travelling in each direction. To maintain stability in the system, feedback from the output of a directional amplifier into the input of the other, must be reduced. Starting from the early days of the telephone trunk, this has been done using Balancing Networks coupled through Hybrid Coils, part of the Voice Frequency Repeater.

Introduction to the basic Voice Frequency Repeater

The basic system of two way amplification is shown in Figure 1. Picture the amplifier as being located somewhere in the trunk line installed from East to West. Both of the lines running East or West terminate at the amplifier in a Hybrid Coil. Each coil feeds a Balancing Network which hopefully duplicates an impedance close to that of the associated line (east or west). I say hopefully because whilst the equal impedance can be achieved at one frequency, it is virtually impossible to precisely achieve at all frequencies over the voice spectrum. So the balancing impedance has to be a compromise.

Following through from the East line, it can be seen that a winding of the East Hybrid couples signal from the east into the input of the West going amplifier whose output couples signal via the West Hybrid into the West line. And vice-versa, signal from the West via the West Hybrid couples into the East going amplifier which feeds output via the East Hybrid into the East line.

If you now carefully examine the fields developed in the Hybrid Coil and coupled from the amplifier outputs and also assume that the Network's impedances exactly balance those of the lines, it can be determined that the potentials across the lead pair feeding the amplifier inputs are zero. As such, there will be no back feed around the amplifiers.

But I have already said that a perfect balance in the networks is not possible. In practice, it is a question of how much gain is possible in the amplifiers that can be achieved for a given balance in the networks. I will say a little more about this further on.

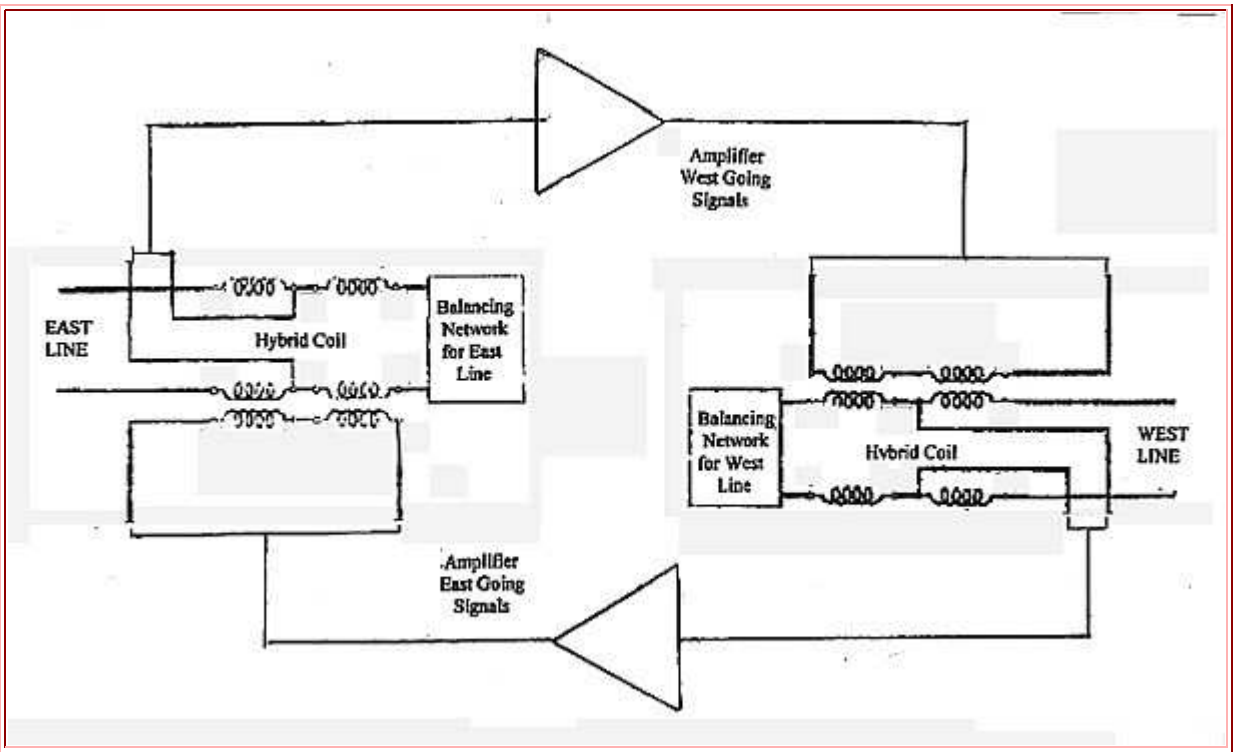


Figure 1
Basic Voice Frequency (VF) Repeater with the two Hybrid Coils and associated Balancing Networks

A typical Voice Frequency Repeater

Let's now look at a real VF Repeater, the circuit (figure 2), which I found on the Web. The Hybrid Coils as shown in Figure 1 are repeated except that there is an additional winding for monitoring and probably connected to a test jack somewhere. Amplifier gain controls at the amplifier inputs are clearly shown and needed for the installing technician to set. There are low pass filters in amplifier plate circuit, possibly provided to prevent interference to higher frequency carrier channels which might have been installed on the same line pair used by the VF Repeater.

I gained some experience with these repeaters soon after starting with the PMG in 1942. Our Transmission Laboratory had a number of these commercially made VF Repeaters in for modification. They had large round TMC16 triode valves with glass tips used for evacuation on the glass top. Apparently they were having difficulty getting hold of these early valves for replacement and I was given a job to replace the valve sockets with octal types and fit 6J7G valves connected as triodes.

Glass valve outer construction similar to valves removed from VF Repeaters

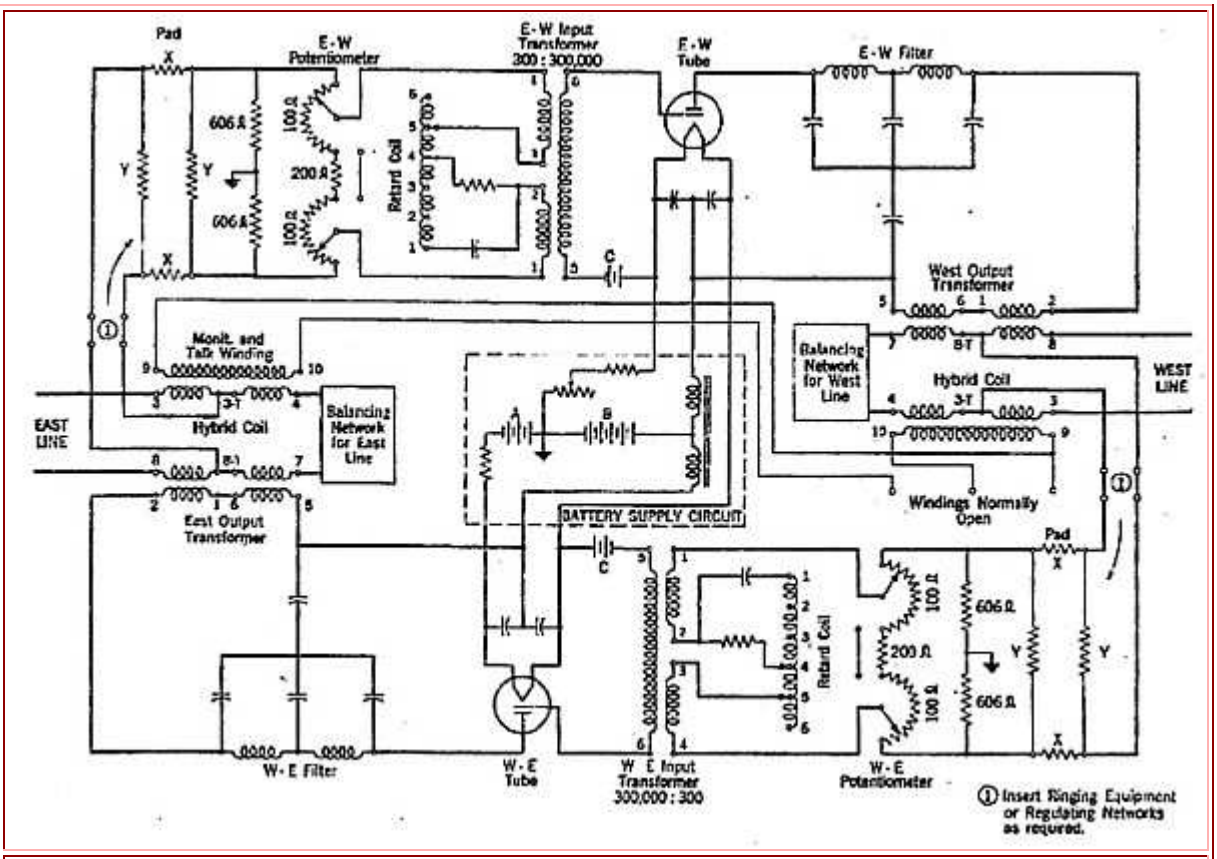
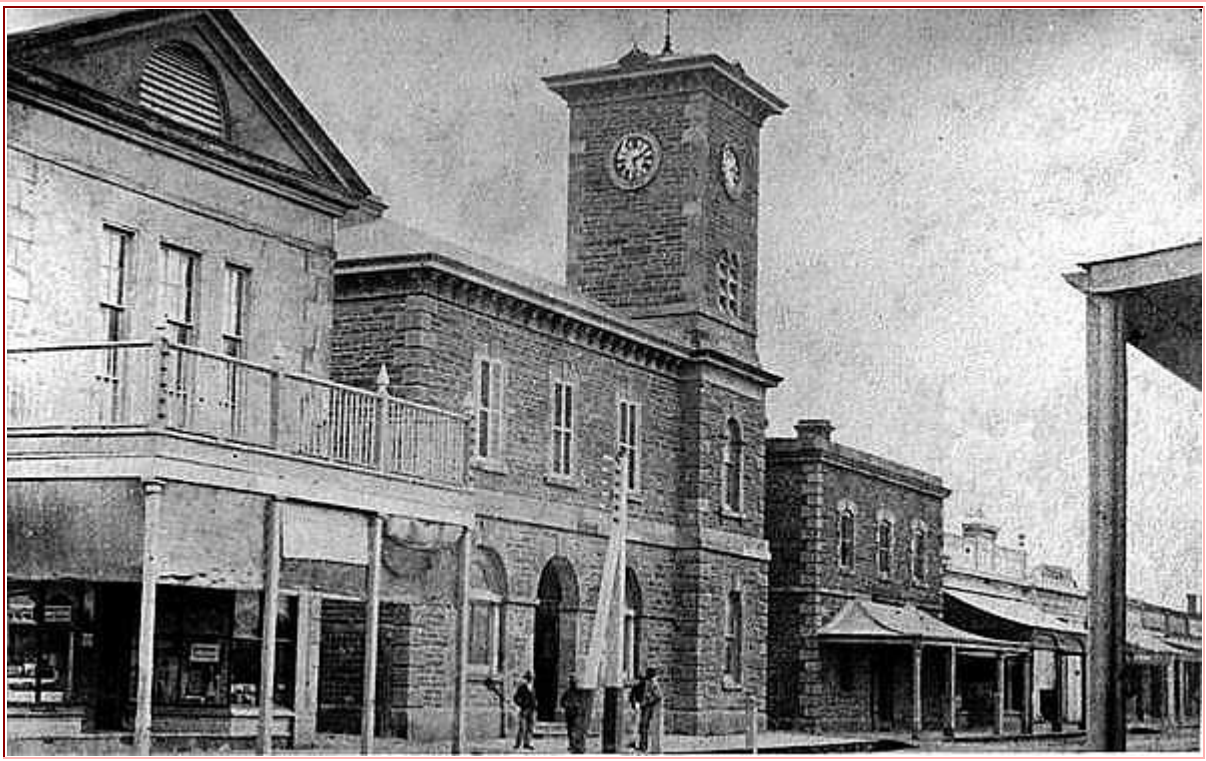


Figure 2
A Typical Voice Frequency Repeater using a Single Valve Amplifier for each signal direction and inserted in series with the Trunk Line labelled East to West. Note that each amplifier has a control to set the amplifier gain

Ultimately, with another member of the technical staff, we put in time at regional town Gawler, re-installing a number of the modified repeaters and adjusting balancing networks and amplifier gains. Some of the repeaters sat between the trunk line end and the Gawler manual telephone exchange. With the one line end of each of these repeaters terminated in an open jack in the exchange jackfield, it was difficult achieve stability in the repeater. My workmate, more experienced with these things than myself, got stability by connecting a 600 ohm resistor across the normally made contact terminals of each relevant jack. Insertion of the switch operators plug into the jack, disconnected the resistor and reconnected the repeater to the plugged in line (with its inherent line impedance).



In early days, the old Post Office building in Gawler and the oldest surviving public building in the town. With Clock Tower, it was built around 1866-1867 and sourced from local stone. It was the principal Gaw1er Post Office and Communications Centre between 1878 and 1973. When visited in the 1940's, the Telephone Repeaters were housed in a building at the rear of the post office building.

Hybrid Coil Circuit in the Telephone

Perhaps the fact that an ordinary telephone includes a hybrid circuit to reduce feedback between the carbon microphone transmitter and the receiving headphone, might not be well known. For a telephone with separated headpiece, it is an interesting experiment to place the headpiece against the carbon microphone and experience the oscillatory feedback squeal. Without that hybrid circuit, feedback could be experienced across the acoustic path between the finite distance between transmit and receive units of a handset.

Figure 3 illustrates the simple hybrid circuit commonly found in a telephone. It can be seen that if the matching network impedance were the same as that of the connecting line, the current generated from the microphone in the line winding of the transformer would be of opposite phase to that in balancing network winding. So the field coupling into the the earpiece winding would be cancelled out and the earpiece would receive no signal. In practice, some mismatch is allowed for a small amount of feedback as this effect is natural to human hearing.

Figure 4 is a complete circuit of an early central battery system telephone. You may find it a little more difficult to track down the elements of the hybrid circuit and the balancing network. Of course, the transformer has at least one other function as well as setting up the hybrid circuit. It also provides an impedance match between the low impedance carbon microphone circuit and the higher line impedance, usually assumed as a nominal 600 ohms.

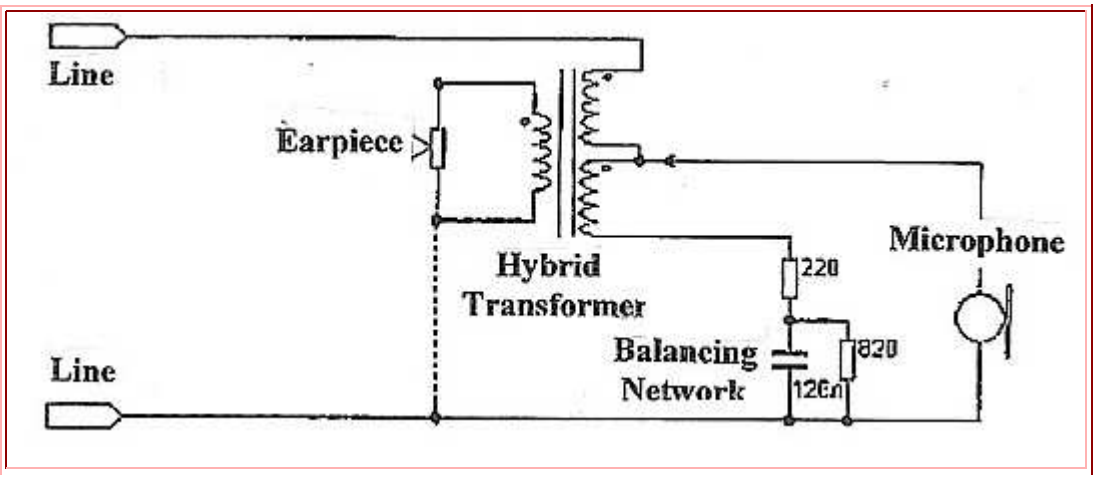


Figure 3
Simple Hybrid Coil with Balancing Network such as used in a Telephone.

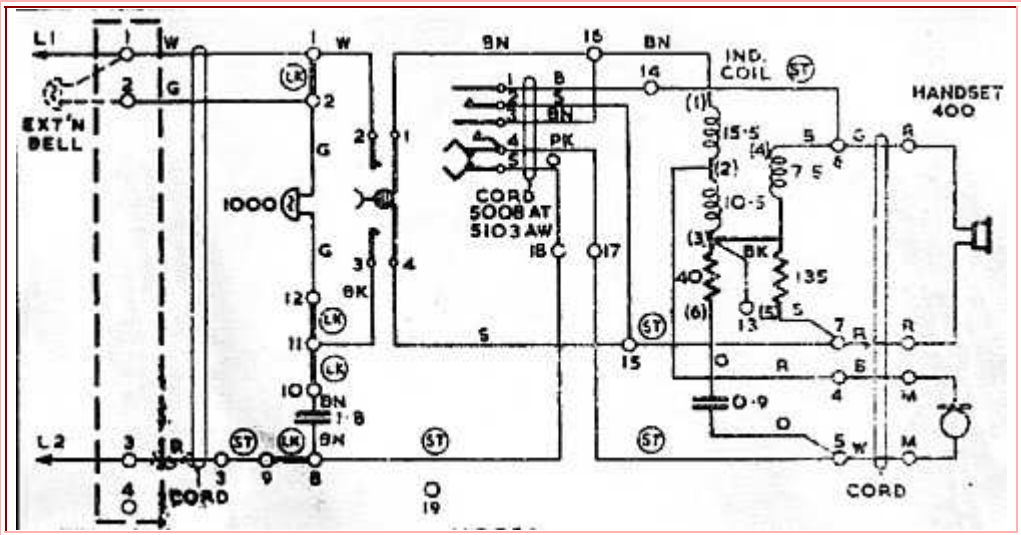


Figure 4 - An Early Telephone Circuit
The Hybrid balance winding is marked 10.5. and the Balance Network is resistor 40 and capacitor 0.9.

To Conclude

The technology described in this article, concerning bi-directional communications, centres around the 1940's and the technology of the day when I was a member of the staff of the PMG Transmission Section. In those days, long distance communication (apart from radio) was achieved using open wire line pairs mounted on poles. Travel anywhere in the country and the main roads were lined with these pole routes. But these days, the signal bearers are more commonly fibre optic cables, microwave radio links or satellite channels.

And these days, communication circuits are likely to be separated into two directional channels, (probably each via analogue or digital carriers), with their channel losses in series with one way amplifiers, correcting for that loss. Received line level could then be expected to be similar to that sent.

If the circuit were connected to the general Australian telephone system, encoding of the received VF channel to carrier and decoding of the received carrier to VF would be required at each end of the circuit. Some means (such as the hybrid coil and balancing network) would be required to prevent the gain of the looped around directional channels circuit becoming positive, and causing circuit instability.

For the separated directional channels system, I am inclined to think that correcting for loss in the transmission path, with an amplifier directly in series with the loss, would allow for much higher levels of correction. More so than outside the loss path, as applied in the early trunk circuits using the VF Repeaters. Particularly note that in the first case, the line or system loss is applied within the feed around loop. In the second case with the VF Repeater, the line loss is applied outside of the feed around loop. Perhaps further discussion on this subject can be left for another day.

In the later chapters of the article, I have discussed the use of the hybrid coil with balancing network in the ordinary telephone. This seemed to be another useful application of the circuit worth including.

References

(1) Transmission Section , PMG - Lloyd Butler, OTN March 2011

(2) The Hybrid Coil http://www.vias.org/albert_ecomm/aec11_telephone_toll_service_011.html

(3) Hybrid Coil https://en.wikipedia.org/wiki/Hybrid_coil

(4) 2-4 Wire Converters - Rod Elliot - http://sound.whsites.net/appnotes/an010.htm