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A new approach to modem design

Summary

A data communication equipment suitable for public or private telephone circuits has been designed to meet the stringent requirements of the Post Office Corporation.

Using modern technology, a 300 bit/s modem with full automatic answering facilities has been contained within one printed circuit board. The modem can be connected directly to a public network and be fitted either in a desk top case or with others in a rackside shelf.

A line interface unit provides connexion to a 2W or 4W dedicated circuit and a telephone. Other ancillary modules facilitate tone or d.c signalling over a private network.

Power consumption has been reduced to a minimum, some modules being powered by line current only. Problems with heat dissipation are thus minimized.

The system offers a comprehensive range of facilities both to the user with a single terminal and to the computer bureau operator with multiple line connexions.

Introduction

Data modems are an integral part of any data communication system using voice grade circuits. Their prime function is to convert the binary data into a modulated signal that can be transmitted within the bandwidth of a telephone channel, having due regard for the amplitude and phase distortions introduced by the telephone network.

Recognizing the need for international standards both for the line signal and the interfaces to data terminal equipment (d.t.e) CCITT have issued the 'V' series of recommendations which reflect the requirements of those wishing to transmit data and also recognize the constraints of national and international telephone systems. By complying with these recommendations, both data terminal and modem manufacturers have been able to create products which can be used world-wide without fear of incompatibility. The principal recommendations that will be referred to or are relevant to this article are:

V21 Defines the parameters of a 300 bit/s asynchronous, duplex modem for two-wire circuits.

V23 Defines the parameters or a 600/1200 bit/s asynchronous modem with a backward channel of 75/150 bit/s on two-wire circuits of 600/1200 bit/s on four-wire circuits.

V28 Defines the electrical parameters of the V24 circuits.

V24 Defines the interface circuits between a modem and a data terminal equipment.

V25 Defines the automatic answering sequence for use over international public telephone networks.

Other recommendations define modems for rates up to 9600 bit/s which are not discussed here.

In the United Kingdom the Post Office Corporation (POC) retains responsibility for all modems connected to the public switched telephone network (PSTN) and their specifications reflect the relevant CCITT recommendations. The modem system described has been designed to meet POC specifications for their third generation equipments. Whereas previous generations of POC modems have been self-contained and operated over only one speed range, this system by the selection of suitable plug-in modem modules, eventually can accommodate all the recommended ranges of data rates. The modules can be assembled as a single terminal to be used, for example, with a remote computer terminal. Alternatively, they can be grouped together to form a multi-terminal installation for use in a computer centre or bureau.

Significant reductions in physical size and power consumption compared to earlier equipments have been made possible by the application of contemporary integrated circuit component and manufacturing technologies.

The Marconi U1106 modem system is recognized within the POC as Datel Modem 21 and will be introduced into their Datel 300 service in 1979. With the alternative 600/1200 bit/s modem module fitted, the system becomes the U1107, equivalent to the POC Datel Modem 22 specified for the Datel 600 service and complying with CCITT Rec. V23.

System configurations

Figure 1 shows in block schematic form all the elements of the system and how they inter-relate in the two principal configurations.

Single terminal

The simplest arrangement is that of a single terminal connected to the PSTN with a local telephone to dial up calls (see figure 2). Within the case, which can be either, table-top or wall mounted, is housed the plug-in modem module, the fixed power supply unit and means of connecting to the d.t.e, the telephone and the line.

A private wire (PW) connexion may differ from that to the PSTN in a number of ways. The line may be four

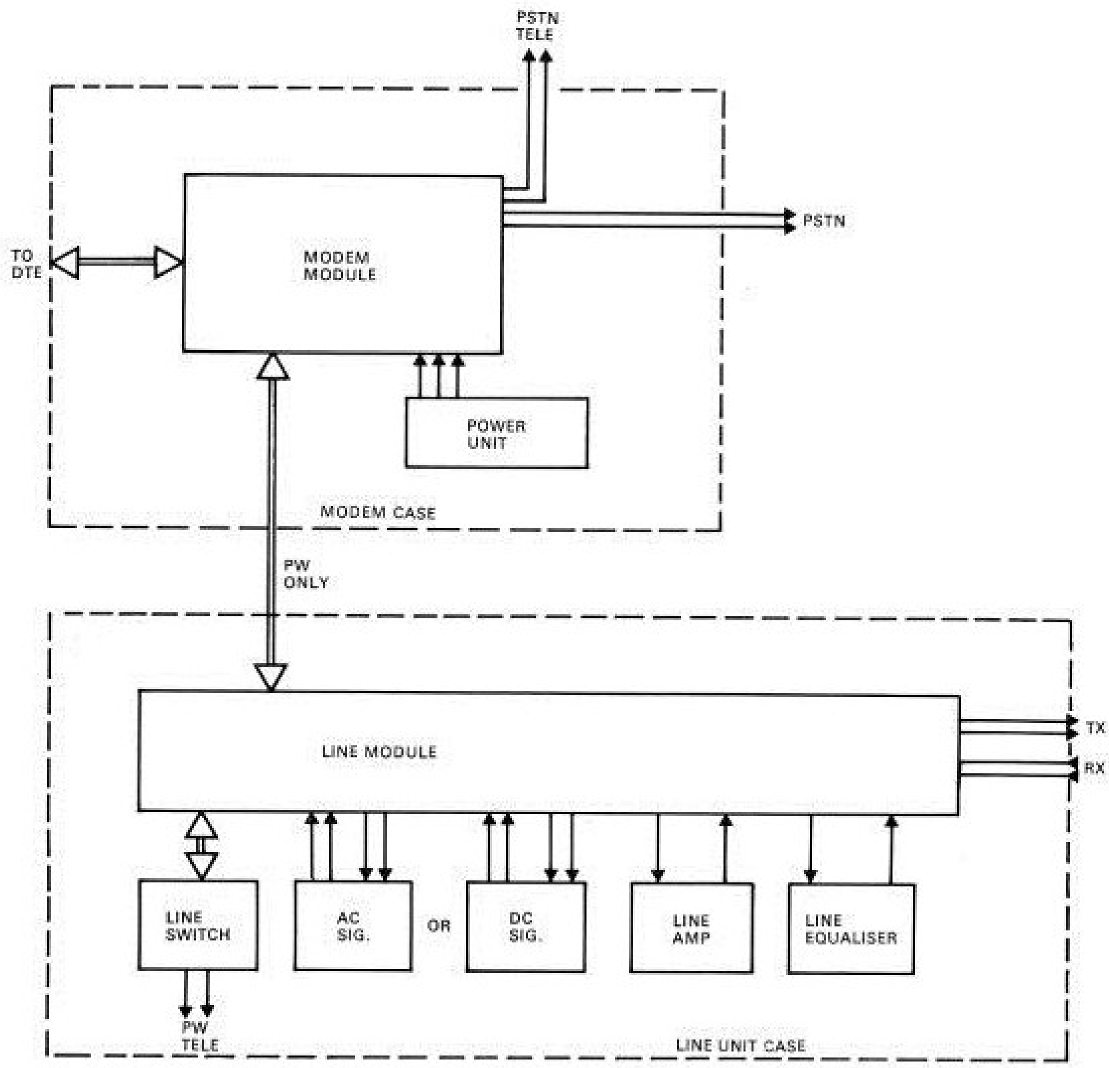

Figure 1. Single terminal PW or PSTN

wire (2Tx, 2Rx) and be either 600 or 1200Ω impedance making additional matching transformers necessary. As calls cannot be set up by dialling, a signalling system must be provided unless modems are to be permanently connected. These extra facilities are incorporated in the line module. The module fits into a case identical to that housing the modem module. Means are prescribed for inter-connecting to the modem case, the PW line and the PW telephone.

In its basic form the line module comprises line matching transformers, level setting attenuators, loop test and line monitoring facilities. Further sub-modules may be fitted; the line switching unit for connecting the PW telephone, the d.c signalling unit to generate and detect current loops or the a.c signalling unit to generate and detect two-tone signals. Additionally a line amplifier and a line equalizer can be fitted where the line characteristics so demand.

Multi-terminal

In computer bureaux or similar situations where a number of modems are required it has been customary to stack a number of table top units, each self-contained

Figure 2. Modem 21 with front panel open, showing controls and power unit.

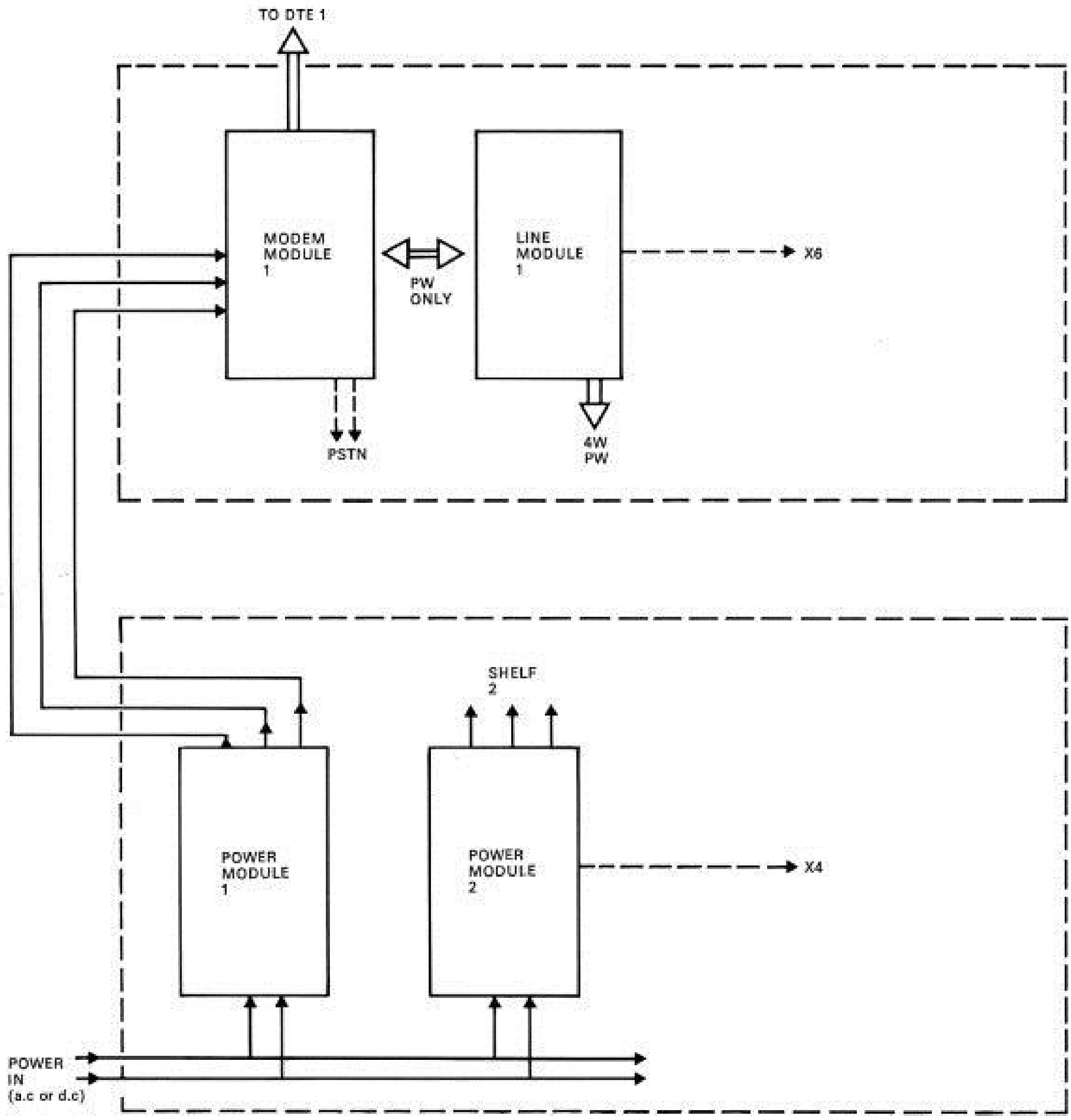

Figure 3. Rack mounted system (PW)

with its own power supply. With the modem module and the line module each reduced to a single plug-in card, it is now possible to mount up to twelve modems or six modem/line module pairs in a single shelf. Up to four shelves may be mounted in a rack with a further shelf containing their bulk power supply units. Into the same rack may be added control, test and monitoring units (see figure 3).

The modules

In summary, the system can be described as having one primary module – the modem, transmitting and receiving data to the d.t.e, with a number of ancillary modules enabling it to function over public or private circuits, in single or multiple installations. Within the modem are the modulator, demodulator and control circuits which determine the essential parameters of a data service; modulation rate and method, channel frequencies, d.t.e interfaces and protocol.

Modem module

The modem module designed for the 300 bit/s service will be described as it typifies the approach to lower speed, synchronous, f.m modem design. A block diagram of the modem is shown in figure 4.

A feature of the V21 duplex system is that the modem should transmit or receive on either of two channels: Channel A centred at 1080Hz, Channel B at 1750Hz. The recognized procedure is that a calling modem transmits on Channel A, the called modem on Channel B. To limit the amount of hardware it is desirable that each channel filter can function in the transmit path or

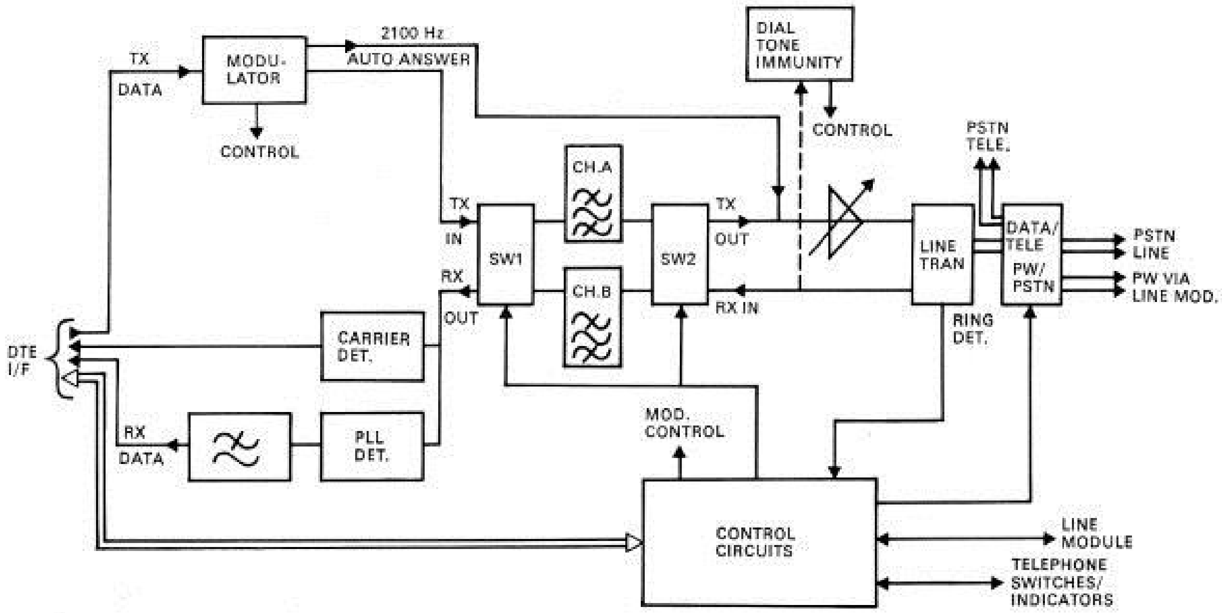

Figure 4. Modem

the receive path, although the characteristics needed for each path are not necessarily the same. In the receive path it is essential to have an amplitude response with good rejection of the high level transmitted signal and its sidebands. In the transmit path an emphasis is placed on minimizing the variation in group delay across the passband in order not to distort the transmitted signal. These two requirements conflict with each other in filter design, but by careful use of computer aided design methods it has been possible to achieve responses which do not compromise overall performance (see graphs figure 5).

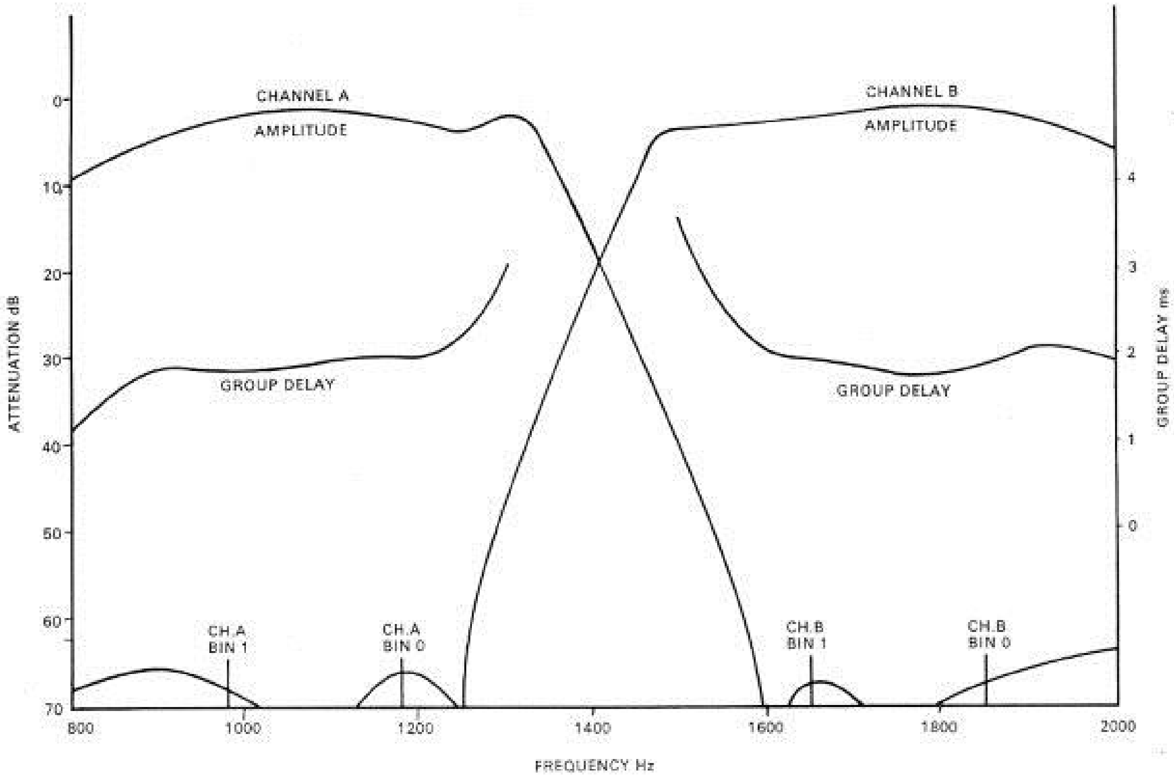

Figure 5. Channel filter characteristics

The filters take the form of passive networks. Using modern 'tower-block' polystyrene capacitors and 'R' series inductors these filters occupy little more area than they would in an active configuration, particularly as the input-output impedances are kept high. Passive filters have the added advantages of zero noise and power consumption plus ease of adjustment in the factory.

Channel filter switching (SW1, SW2) (figure 4) is by MOSFET analogue switches. These devices, in the form of integrated circuits, provide 70dB of isolation, 150 Ω forward resistance but consume negligible power and board area compared to a conventional relay and transistor drive stage.

In either channel the modulator is required to generate an f.s.k signal with 100Hz deviation. Additionally a 2100Hz tone burst is generated as part of the V25 automatic answering sequence. The requirement that these frequencies remain within ±5Hz over a period of five years indicated the need for crystal accuracy and stability. The solution has been to combine a high frequency crystal oscillator with a binary divider whose division ratio is determined by a binary address. The address is in two parts, the channel frequency set by the control circuits and the incoming data controlling the keying of the f.s.k tones. The complete divider chain is contained in an MOS microcircuit.

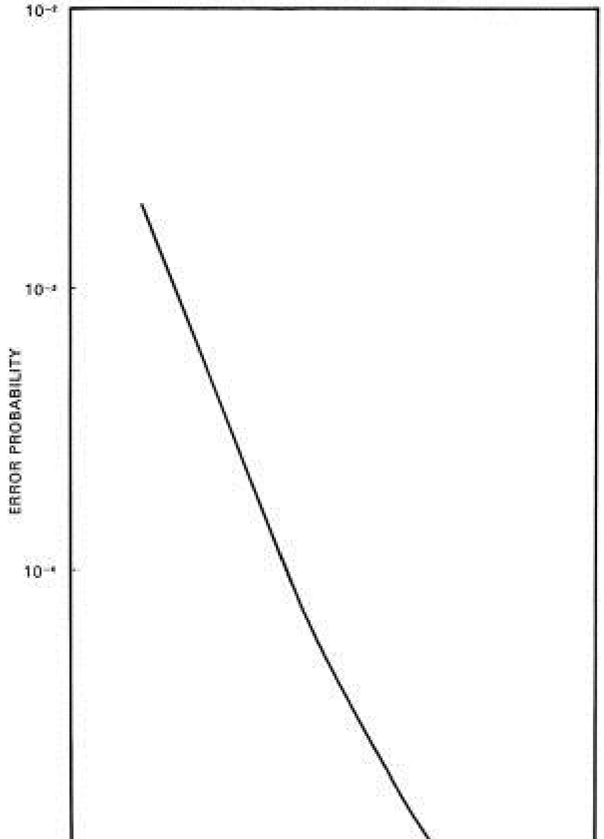

Figure 6. Typical error rate curve

Received signals are demodulated by an SL652 phase-locked-loop integrated circuit, a device found to have good performance particularly in poor signal/noise ratio conditions. The performance of the complete demodulator is shown in figure 6.

The post-detector filter is a fifth order, Bessel, low pass filter, realized in active form with two operational amplifiers. Its 3dB cut-off point is at 200Hz and at 1200Hz there is 60dB of attenuation. This performance allows some relaxation of channel filter response down to 500Hz.

At the line interface a relay controls the connexion to line of modem or telephone. A transistor with d.c negative feedback provides the d.c line hold loop necessary for PSTN working without lowering the impedance across the line. The centre-tapped line transformer provides the mandatory d.c isolation between line and modem circuits and, as a hybrid, gives some isolation between transmit and receive paths. The degree of isolation is dependent upon the match to 600Ω presented by the line and in the worst case may only amount to 2–3dB. Lightning strike protection at the line terminals is provided by high voltage zener diodes.

A feature of a data modem is its complete lack of manual controls except for test purposes. It must initiate and respond to calls under the control of signals from the d.t.e, the data/tele switch of the telephone, received signals or a combination of all three. Within the modem, the modulator must be turned on at the correct operating frequency and connected to line. Externally, signals are exchanged with the d.t.e after defined time intervals. Whereas in previous designs of modem, control circuits to perform these functions have been implemented by a combination of discrete logic, monostable timers and relays; in this modem the power and space constraints demanded an all solid-state solution. It has been found in the use of the Ferranti Uncommitted Logic Array (ULA). This integrated circuit comprises an array of cells, each in the form of a three-input NOR gate, whose interconnexion mask is customized to create the desired logic circuits. Most conventional logic functions, bistables, shift registers, divide, etc, can be formed with the cells and also some analogue functions such as the clock oscillator, used to drive the counters which measure time intervals. Using the ULA it has been possible to contain all the control circuits for the modem within a 40 pin DIL package consuming only 200mW of power.

Ten V24 interface circuits are provided between the modem and the d.t.e, five transmit and five receive plus the common return. Their electrical parameters are as defined by V28 and connect via the ISO defined 25-way 'D' connector mounted in the case.

Each line driver circuit uses a type 747 operational amplifier, chosen for its low drive current requirement and power consumption. For the line receive circuits a discrete transistor circuit is chosen in preference to an integrated circuit line receiver to give economy in price and power consumption.

There are two main reasons for keeping the overall power dissipation of the modem module down to a few watts. First, the compact table-top case could not accommodate a large power supply transformer nor could ventilation be provided. Secondly, a maximum of 48 modems with power supplies and control units have to be accommodated in an enclosed cabinet without forced ventilation. Using the design techniques described the power consumption of the modem is only 3 watts, although when the line hold circuit operates on the PSTN the dissipation can be increased by a further 1.6 watts.

Dial-tone immunity circuit

Dial-tone generators operate at frequencies below 500Hz but commonly their outputs have a high harmonic content. These harmonics can fall within the calling channel (A) and trigger the received signal detector of the modem. To prevent this, an immunity circuit can be provided on modem modules for PSTN installations. This circuit detects dial tone and inhibits the received signal detector during the tones presence.

Line module

When operating on a PW circuit the modem line circuits are connected to the line module (figure 7).

The principal components on the basic line module are the two line transformers, providing impedance matching and d.c isolation in the transmit and receive paths between the modem and the PW line. When the line is only two-wire, the convention is that the transmit path carries both transmit and receive signals.

Because the transformers should not introduce significant attenuation or non-linearities in the signal paths their electrical parameters were tightly specified. By careful design the transformer can have up to 65mA passing through the primary and maintain an insertion loss of less than 1dB and a good match to the 600Ω line impedance across the channel bandwidth. To achieve this performance in a volume of $35\times41\times27$mm it is necessary to use a laminated iron core, as ferrite cores would saturate when the d.c is applied to the primary. Provision is made on the transformers to tap off the d.c line current to power some of the ancillary modules that may be fitted.

A loop test switch on the module permits either the transmit and receive lines or the transmit and receive paths from the modem to be looped together to facilitate back-to-back testing. Monitor points are also provided on the front panel.

Line switching module

Connexion from the four-wire PW line to the two-wire PW telephone is made via two line transformers cross-connected to form a hybrid. Much the same constraints are placed on the performance of these transformers as on those for the line module and similar laminated core transformers were designed. A relay, controlled by the connect-to-line signal from the modem, is used to switch from data to telephone communications.

Signalling modules

One of the new aspects of this modem system is the incorporation of PW signalling circuits. The d.c signalling module is used in conjunction with a tone

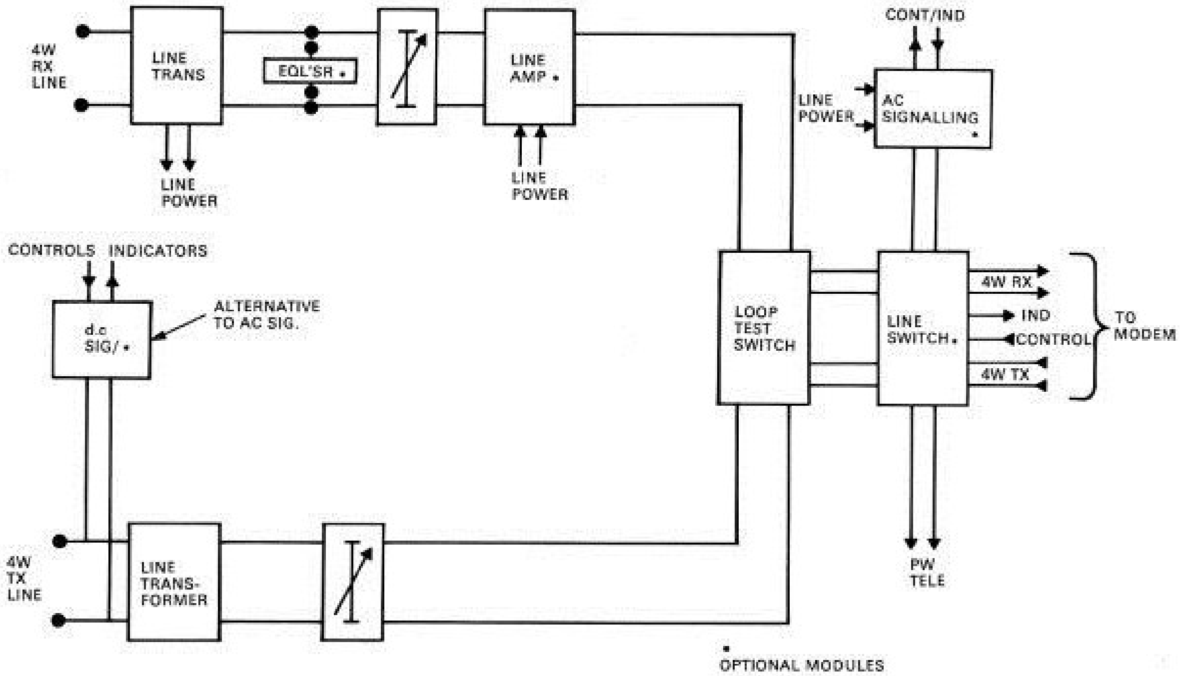

Figure 7. Line module

signalling system at a local exchange and in the transmit mode, a voltage from a local battery is applied to the line creating a current loop to the distant signal set. In the receive mode, the current loop energizes a relay, the contacts of which provide an external indication or complete a buzzer drive circuit. The system will operate over lines of up to 1 000Ω resistance.

Direct tone signalling between data terminals can be implemented by the alternative a.c signalling module which generates or detects the two signalling tones of 750Hz and 2550Hz. The transmit section operates when power is applied via an external call key and comprises two LC oscillators which were chosen for their high stability and simplicity compared to RC types. Long term frequency stability of $\pm 1.4\%$ is achieved with these oscillators.

In order that the receive section is not activated by speech or random tone signals, received tones are subjected to a number of validity checks before acceptance:

(a) The frequency of each tone must be within their transmit tolerance and no more than $\pm$6Hz offset due to f.d.m translation tolerance.
(b) The level of the 750Hz tone must exceed −34 dBm.
(c) The difference in level between the two tones should not exceed 12.5dB.
(d) The signals should persist for more than 0.6 sec.
(e) The signal/noise ratio should be better than 6dB where noise is either white noise or interfering tones at 50, 1 200 or 1 800Hz.

To meet these criteria the received tones pass through two narrow band, active LC filters and their outputs are combined in such a way that three voltages are derived, two which represent the level of each tone and a third which represents the overall level in the channel less that at the two tone frequencies. Comparators then make the checks b, c and e above, with the persistence check d. If all conditions are satisfied an output signal drives either the buzzer or a relay for external indication. To prove the immunity of the receiver to speech it has been subjected to a series of tape recorded telephone conversations with voices having a range of characteristics. None of these triggered the receiver.

The module may be powered by the modem power supply or by line current derived from the line module transformer. To accommodate the range of line voltages that result from loop resistances varying between 400 and 1 400Ω it is necessary to provide a simple voltage regulator using zener diodes.

Line amplifier

This optional module provides up to 20dB gain, flat to within 0.5dB across the telephone bandwidth, with unbalanced input and balanced output.

To ensure that it does not distort the received signal the maximum group delay variation across the channel must not exceed 50 microseconds and the total power of all harmonics produced must not exceed −40dB. These parameter are maintained using a Type 741 operational amplifier.

The amplifier is powered by line current but must have good immunity to line voice. For this reason a d.c–d.c convertor is used to convert the line current into an isolated supply for the amplifier; this also maintains the balanced output.

A PO Equalizer Type 77 is a further optional module that may be fitted to the line module.

Bulk power units

Two types of power unit were required for the multiple terminal system rack: one type powered from a.c mains, the other from a 50V exchange battery. The output specification was identical for both, demanding good regulation on the three output rails, +5V, +12V, −12V, where either rail may be supplying its minimum or maximum load independently. Higher than 60% efficiency was necessary to limit the total dissipation in a rack for reasons explained earlier.

A switching regulator circuit operating at 25kHz, provides the main regulation and is common to both types of unit. A supplementary series regulator on each rail minimizes the interaction due to differential loading.

Input circuits to the two types of unit are of course different. The a.c version has a mains transformer, bridge rectifier and smoothing circuits to give the d.c input to the regulator. The d.c version has only a filter to prevent switching noise appearing on the battery lines.

Mechanical construction

The mechanical design of the system is based on the Post Office Type 62 equipment practice. The two principal units, the modem and the line module are standard 62 type plug-in modules, 40mm (1.6in) wide enabling either 12 modems or 6 modem/line module pairs to be accommodated in a 62 type shelf. The modem module comprises one full size printed circuit card with three small sub-boards, edge mounted, each accommodating up to eight small resistors and diodes. The optional dial tone immunity circuit is contained on a separate p.c board mounted by pillars from the main board.

The basic line module comprises only a small p.c board plus front panel components and edge connector. This leaves some 200mm (8in) of card frame on which the optional signalling, line switching, equalizer and amplifier modules may be mounted and interconnected by cable.

The table-top cases for the two modules are of rugged construction and measure 420 × 230 × 65mm. Connexion between the internal and external connectors is by flexible printed wiring, a technique that allows rapid and accurate assembly.

The two types of bulk power supply unit are of identical construction; a 62 type chassis unit 110mm (4.8in) wide allowing four to be fitted in the 62 shelf. A printed circuit board containing all the common circuits is fitted to both units while sub-boards accommodate the items unique to each type.

Conclusion

A modem system has been designed which represents a radical departure in concept from its predecessors. It allows more versatility in the configuration of data transmission systems and potential for future expansion without major redesign. Application of contemporary techniques in the fields of integrated circuits, passive components and production engineering has allowed a significant reduction both in physical size and in power consumption making possible more compact installations.