QEX
32
October
1984
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The ARRL Experimenters' Exchange

Digital Committee Completes Work on Packet Protocol

The ARRL Ad Hoc Committee on Amateur Radio Digital Communication agreed on the wording of the AX.25 packet-radio link-layer protocol definition document at their September 15-16 meeting. The final step for this specification is to go to the ARRL Board of Directors at their October 25-26, 1984 meeting for adoption as an ARRL standard. As soon as this happens, the document will be printed so to make it available for sale as a League publication.

Also at the September 15-16 meeting, the Digital Committee began work on network- and transport-layer protocols. First, Wally Linstruth, WA6JPR, initiated discussion on network objectives, which led to committee agreement on a set of goals for network development. Then they discussed various protocol alternatives, principally virtual-connection and datagram approaches. Terry Fox, WB4JFI, presented details of virtual-connection protocols based on the International Telegraph and Telephone Consultative Committee (CCITT) X.25 packet-layer protocol. Phil Karn, KA9Q, explained the operation of Defense Advanced Research Projects Agency (DARPA) Transport Control Protocol/Internet Protocol (TCP/IP) which uses datagrams. Den Connors, KD2S, mentioned a third alternative, that of SOFTNET, which is being developed at the University of Linköping, Sweden. Eric Scace, K3NA, broke down the functions of the various stations within the network.

There was no agreement on the best approach, so the committee decided to go into a period of coordinated experimentation with network and transport protocols. Spokesmen from different areas indicated that they would like to experiment with simplified versions of X.25 and TCP/IP.

For the experimentation phase, the group favored the Xerox 820 board as the network-development hardware and Aztec C as the program-development language. Lyle Johnson, WA7GXD, said that the Tucson Amateur Radio Packet Radio (TAPR) group would take on the job of producing an I/O modification to the Xerox 820 board and offering it to network experimenters in kit form.

The committee reviewed the latest 23- and 33-cm band plans developed by the VHF/UHF Advisory Committee and agreed that they provided adequate spectrum space for development of packet-radio networking in the forseeable future. The committee also noted that there was also adequate digital communications space in the 23-cm plan developed by the Southern California Repeater and Remote Base Association (SCRBBA). Both 23-cm band plans provide space for digital links running data rates up to 1.5 megabauds. The 1 1/4-m, 70- and 33-cm bands are to be used for digital communications at speeds up to 56 kilobauds.

European observers at the meeting were: Ian Wade, G3NRW, of the British Amateur Radio Teleprinter Group (BARTG); John Sager, G8ONH, representing the Radio Society of Great Britain (RSGB); Alan Jones, G8WJM, of the Cambridge University Computer Laboratory; and, Hanspeter Kuhlen, DK1YQ, of AMSAT-DL. They left the meeting with a fairly complete understanding of North American packet-radio developments to date. They anticipate rapid growth of packet radio in Europe.

Packets in the Southeast

Gwyn Reedy, W1BEL, who attended the digital committee meeting as an observer, mentioned that there will be a major packet-radio forum at the Southeast Division Convention now being planned for February 2-3, 1985, in Miami.

The packeteers in Georgia are getting organized. A new club, Georgia Amateur Radio Packet Enthusiasts (GRAPES) was formed on September 14, 1984. They have picked a name for their network: GRAPEVINE, what else? For more information, contact: Dennis Barrow, WB4GQX, Route 7 Heard Road, Cumming, GA 30130.

Contest Contact Simulation

If you haven't seen/heard the Advanced Electronic Applications, Inc. DOCTOR DX, you're in for a treat. Check the October issue of QST for the AEA advertisement. Basically, it lets you simulate a DX contest using a Commodore 64 computer.

Hey, wait a minute. What does DOCTOR DX have to do with QEX, the experimenters' newsletter? A lot! It certainly raises the expectations of radio amateurs on what simulation software should be able to do. It should serve as a challenge for other programmers to match, or exceed, DOCTOR DX's level of sophistication. Also, it should help to free up some of the HF bands for experimenters to get on the air. Encourage your DX-contester friends to play DOCTOR DX on their computers and help decongest the airwaves. - W4RI

Correspondence

In This Issue

Many new technological products on the market today have a built-in liquid-crystal display. Better known as LCDs, they can be seen in your new Amateur Radio equipment, calculators, or the watch worn on your wrist. Have you ever wondered what is taking place within the display area?

This issue of QEX is proud to reprint an article from the October 1983 issue of IEE PROCEEDINGS-I on Molecular Electronics. Starting on page 3, Dr. I. A. Shanks, formerly with the Royal Signals and Radar Establishment, answers questions on the methods of LCD construction, their operation and use. His article, "Liquid-Crystal Displays: An Established Example of Molecular Electronics," will be divided into two parts because of its length. The November issue will feature Part 2. If you have ever questioned how an LCD is constructed, from its molecular structure to the display area, this technical article should be examined.

Robert J. Carpenter, W3OTC, shares his experiences of making routine packet-radio meteor burst contacts between Iowa and Maryland on six meters. Information on equipment in use at his station and Ralph Wallio's, W0RPK, and a comparison table of estimated system performance enhance his report starting on page 9.

Rounding out the issue, John S. Davis, WB4KOH, offers advice on how to add "A Remote Terminal to Your Micro." Photos and a schematic diagram of how to install your own at low cost accompany this article.

Keeping Cool

Heat and overvoltage are the greatest enemies of transistors. Because I live in Brazil, I read with great interest, "Keeping Cool," in the June 1984 issue of QST. I would like to make an observation here on footnote 10.

I use two small block fans, one four inches in diameter for the transceiver heatsink, the other a five-inch diameter for the heatsink of the power supply. Both have two-pole shaded pole motors which make some noise. Because of this, I installed a reactor (ballast) normally used for fluorescent lamps in series with the fans. In my case, the two fans are fed from one 20 W, 220 V, 60 Hz, 0.38 Amp ballast, and the voltage is reduced from 220 to 140 V. This permits the fans to operate quietly.

I think this solution is more convenient than a series capacitor that is not dependable (I tried this, too), or a series resistor that generates heat. I placed the fans on half-inch thick foam pads to avoid transmission of vibration. My equipment always runs cool and fortunately, I have never experienced any trouble. — Dietrich Kulhlmann, PY3DK, Box 248, 95670 Gramado, RS.

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Liquid-crystal displays: an established example of molecular electronics

I.A. Shanks, B.Sc., Ph.D., C.Eng., M.I.E.E.

Indexing terms: *Reviews of progress, Optoelectronics, Electro-optical effects, Molecular-electronics devices, Liquid-crystal displays*

Abstract: Displays using electro-optical effects in liquid crystals are now well established and have permitted the manufacture of many new or improved products. This review examines the underlying physics and chemistry which underpins their use as molecular-electronics devices, describes how they operate and looks at a number of recent applications and possible future developments.

1 Introduction

The remarkable increase in the performance/cost ratio of micro-electronic components has made it highly desirable to introduce their sophisticated signal-processing capabilities into traditionally non-electronic products. In many cases, however, micro-electronics alone does not suffice to accomplish this. Such cases frequently also require the availability of new sensors, actuators and displays, having comparable performance/cost ratios, in order to interface with the non-electronic world. It is arguable, for instance, that the radical impact of micro-electronics on the previously non-electronic watch and calculator markets would not have been possible without the liquid-crystal display (LCD) technology which has been developed over the last ten years. These LCD devices do not manipulate electrons in the manner of semiconductor micro-electronic components, but rather employ electrical signals from such micro-electronic components to influence the behaviour of complete molecules in order to achieve their function. They are therefore, in this sense at least, more correctly described as examples of molecular electronics. There is also, however, a second sense in which they fit this description. Their development has required the synthesis and screening of a wide range of chemical molecules in order that the required levels of performance/cost ratio could be achieved for their application. Thus their operating performance, as well as their operating principles, are encompassed by the concept of molecular electronics.

This point is emphasized by the historical perspective that, although liquid-crystal behaviour has been known since 1888 [1], it is only since the discovery of the first usable display effect in 1968 [2] that the required materials have been developed. The liquid-crystal materials of 1968 were chemically unstable, impure and had to be used at temperatures well above ambient (e.g. 160°C) in order to function. Initial, subsequent research identified materials which could be used at room temperature, but these were still highly unstable. Their existence, nevertheless, opened the way to the discovery of a number of new display effects in the early 1970s, and this, in turn, added momentum to the quest for new materials.

A most significant turning point was the discovery in 1973, by workers at Hull University and RRE (now RSRE), of a new family of liquid-crystal materials [3] which were extremely stable and could be mixed to give wide operating temperature ranges. Even today, over ten years later, more than half of all the liquid-crystal displays manufactured across the world incorporate these materials. Taken together, these new display effects and materials provided the 'critical mass' required to attract high-calibre scientists to the field, to make liquid-crystal displays commercially viable and to achieve the rapid progress which has been obtained to date. Let us now review this progress, starting with a consideration of the characteristics of liquid crystals generally.

2 Liquid crystals

Liquid crystals constitute a fourth state of matter frequently encountered in the phase diagrams of organic materials having somewhat asymmetric molecules. The molecules may, for example, be in the form of rods or discs (e.g. Billard [4]) and are held together by the highly anisotropic van der Waals forces due to dipole and quadrupole interactions. These anisotropic intermolecular forces, taken together with the asymmetric shape of the molecules, can give a turbid, mobile liquid exhibiting some degree of long-range orientational or translational molecular ordering not present in an ordinary isotropic liquid.

Liquid crystals can be divided into two distinct types, known as lyotropic and thermotropic liquid crystals. Lyotropic liquid-crystal phases are of great importance in the large-scale manufacture of certain organic compounds and in the bodily functions of living organisms (e.g. Small [5]), from single cells to human beings. Their detailed treatment is, however, beyond the scope of this review and the interested reader is referred to Helfrich and Heppke [6].

Thermotropic liquid crystals are obtained within certain ranges of temperature and may occur in single-component systems. Most frequently the solid material melts on heating to give a mobile liquid, which possesses long-range molecular ordering and is stable up to some temperature where it transforms to a normal isotropic liquid.

Friedel [7] recognised three main classes of thermotropic liquid crystals known as smectic, nematic and cholesteric mesophases. A representation of the molecular structure in each of these is shown in Fig. 1. They are distinguished from each other by their differing degree of translational and/or orientational molecular ordering, and the smectic classification has now been divided into additional sub-classes A–H to take account of further variations in ordering within and between the layers.

In all cases, the time-averaged preferred orientation of the molecules in any small volume is described by a unit vector (of arbitrary sign) called the director and this is shown for each of the classes. In the cholesteric class the director rotates continuously about a helical axis with a characteristic pitch due to the presence of one, or more, chiral centres within the molecules. Examples of typical

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Paper 2603I, received 1st March 1983

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molecular structures, their chemical names and, in two cases, their colloquial names are also shown.

It is emphasised that these are only representations of possible forms of the three main classes in the absence of external forces. The exact form of molecular alignment obtained in any case will depend on boundary conditions and on any applied fields, and these may give rise to a number of different molecular arrangements within each class. These arrangements are known as textures (e.g. Gray [8]). In any case, the long-range ordering of the anisotropic molecules in the liquid crystal results in it exhibiting, on a macroscopic scale, anisotropy in many of its properties such as its viscosity, magnetic susceptibility, electrical conductivity, refractive index and dielectric constant.

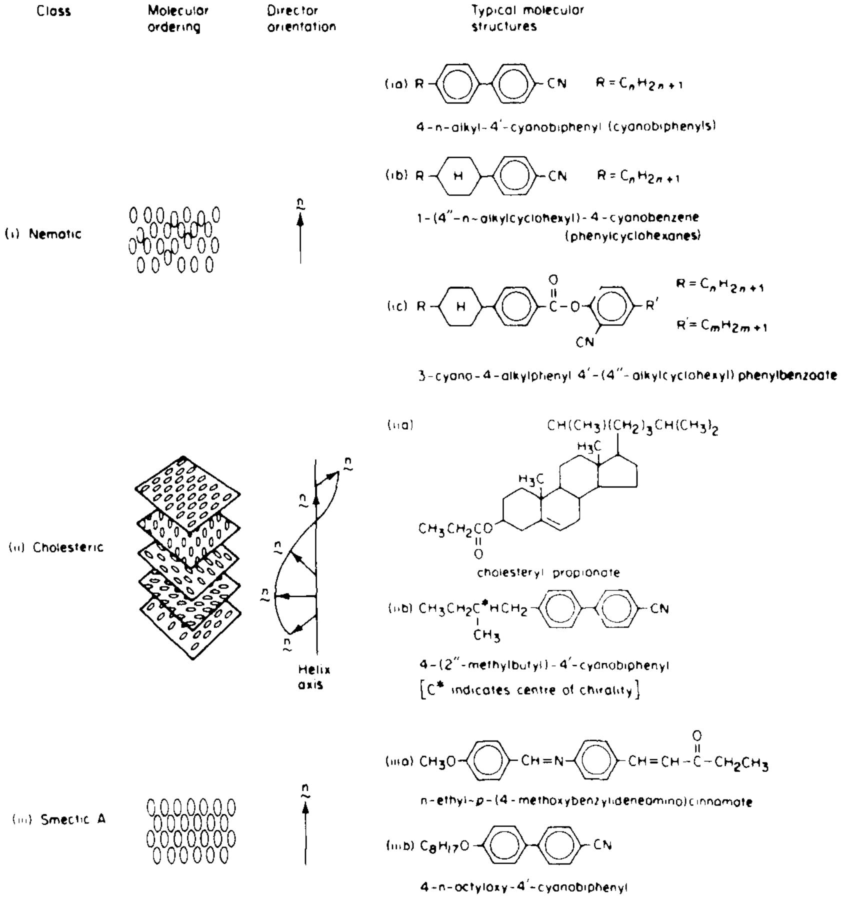


Fig. 1 *Classification of thermotropic liquid crystals*

Thermotropic liquid crystals are divided into three classes, distinguished by their differing degrees of orientational and translational long range molecular ordering. The nematic (i) and cholesteric (ii) classes possess only orientational ordering and the molecules are randomly distributed as to the positions of their centres of mass. The smectic class (iii) possesses both orientational ordering and at least one degree of translational ordering so that the time-averaged positions of the centres of mass of the molecules give rise to the layered structure shown. Further subclasses A H are known, depending on the ordering within and between the layers. In all cases, the time-averaged preferred orientation of the molecules in any small volume is described by a unit vector (of arbitrary sign) called the director, and this is shown for each of the classes. In the cholesteric class, the director rotates continuously about a helical axis with a characteristic pitch. It should be noted that the planes shown in the representation of the cholesteric class merely represent imaginary cross-sections through the continuum of randomly distributed molecules.

The molecular ordering representations of Fig. 1 are time-averaged pictures of the molecular orientations. The individual liquid-crystal molecules will, of course, be subject to random thermal fluctuations in their position and orientation. The orientational fluctuations and, in smectics, the translational fluctuations will, however, tend to interact co-operatively between molecules over much larger areas. The smaller are these molecular fluctuations, the more highly ordered the liquid crystal is said to be. The orientational fluctuations have been analysed using the molecular-interaction theory [9, 10, 11] with mean field approximation methods, and this has led to their characterisation by an order parameter

$$S = \tfrac{1}{2}(3\,\overline{\cos^2\theta} - 1)$$

where $0 < S < 1$ for most known materials, θ is the instantaneous deviation of the long molecular axis from the preferred average direction and $\overline{\cos^2\theta}$ is the time average of $\cos^2\theta$.

The positional fluctuations in a smectic crystal are characterised by a density wave [12] whose amplitude is related to a positional order parameter.

3 Continuum theory of liquid crystals

The continuum theory [13, 14] ignores the existence of the molecules and their thermal fluctuations and deals only with the time-averaged direction of orientation of the molecules. It defines a unit vector (of arbitrary sign) called the 'director' which lies along the preferred direction of alignment of the long axes of the molecules in any small region of the liquid. The orientation of the director in smectic, nematic and cholesteric mesophases is shown in Fig. 1.

Three fundamental distortion modes called splay, twist and bend are known and these are associated with the elastic constants K_{11} (splay), K_{22} (twist) and K_{33} (bend). Examples of these are shown in Fig. 2. The elastic constants all have similar values ($\sim 10^{-11}$ Nm^{-2}) with ratios in the ranges

$$0.5 < K_{22}/K_{11} < 1.2$$

$$0.5 < K_{33}/K_{11} < 4.0$$

4 Electro-optical effects in liquid crystals

The anisotropy of the dielectric constant of liquid crystals allows them to be aligned by an applied electric field acting on their induced and permanent dipole moments. Thus, if $\Delta\varepsilon = \varepsilon_{\parallel} - \varepsilon_{\perp}$ is the anisotropy of the dielectric constant, where $\varepsilon_{\parallel}$ and $\varepsilon_{\perp}$ are, respectively, the values of the dielectric constant measured with the applied electric field parallel and perpendicular to the director, materials which have $\Delta\varepsilon > 0$ will align with the director parallel to an applied electric field and those with $\Delta\varepsilon < 0$ will align with the director orthogonal to it. This is illustrated in Fig.

3. The direction of the dipole is mainly decided by the influence of the permanent dipoles such as cyano groups (CN) within the molecule. For example, the compounds (*ia*) and (*ib*) in Fig. 1 have $\Delta\varepsilon$ values of 10–15 and 8–11, respectively and compounds (*ic*) have $\Delta\varepsilon \simeq -4$. In the absence of such permanent dipoles $|\Delta\varepsilon|$ is small (~ 0.2). The anisotropy in the electrical conductivity of these materials coupled with the presence of ionic species in the liquid can result in space-charge effects which can give rise to electrohydrodynamic flow in the liquid (e.g. de Gennes [15]). This flow may correspond to lamellar or turbulent flow conditions, depending on the magnitude of the applied electric field and the existence, or non-existence, of a space charge instability condition.

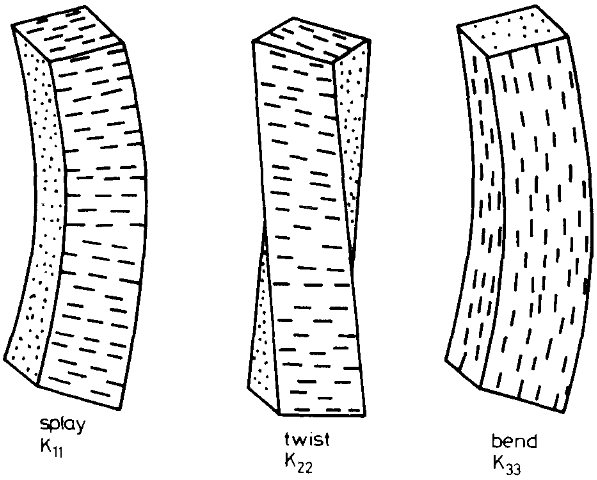


Fig. 2 *Schematic diagram illustrating the three possible modes of distorting the orientation of a liquid crystal*

The torques and the increases in free energy involved in producing these are associated with the curvature elastic constants K_{11} (splay), K_{22} (twist) and K_{33} (bend)

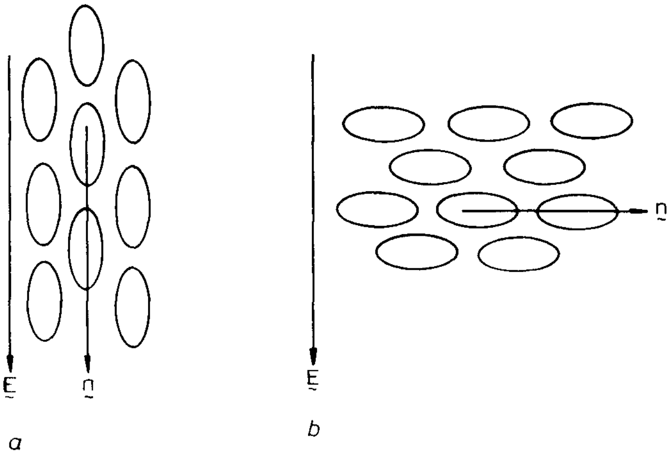


Fig. 3 *Alignment of the director in an applied field* **E** *for nematic liquid crystals*

a with positive dielectric anisotropy ($\Delta\varepsilon > 0$)
b with negative dielectric anisotropy ($\Delta\varepsilon < 0$)
Similar behaviour is exhibited in a magnetic **H** according to whether the anisotropy in the diamagnetic susceptibility, $\Delta\chi$ is positive or negative

In the absence of an electric field, a thin film of liquid crystal, say 6–50 μm thick, may be held in single crystalline alignment by suitable physical or chemical treatment of the surfaces which contain the film. These surfaces are usually transparent, electrically conductive coatings of SnO_2 or indium tin oxide which have been deposited on a glass substrate and which may have been etched to give a desired electrode pattern. This alignment may be with the director uniformly perpendicular to the bounding surface, homeotropic alignment, achieved, for example, by chemically cleaning the surface or by coating the surfaces with a thin surfactant layer such as a chromium complex or lecithin. The alignment may, alternatively, have the director coplanar with, or tilted to, the surface and pointing along a specific direction, parallel homogeneous alignment. This may be achieved, for example, by coating the surfaces with a layer of polymer, for example polyvinyl alcohol or polyimide, and rubbing unidirectionally with tissue paper, for example, or by vacuum evaporating MgF_2 or SiO obliquely onto the bounding surfaces prior to bringing them into contact with the liquid crystal. The construction of a typical liquid-crystal cell is shown in Fig. 4.

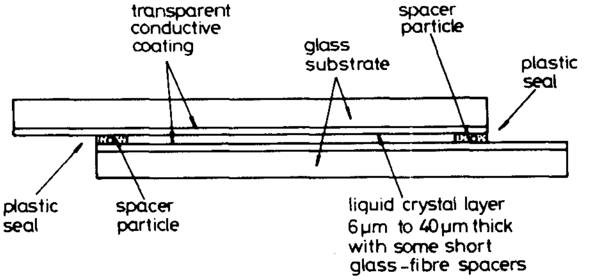


Fig. 4 *Cross-section showing the construction of a typical liquid crystal display cell*

The transparent electrodes are usually a layer of SnO_2 or In_2O_3 and are etched to give a desired electrode pattern. Alignment layers (not shown) are invariably used adjacent to the liquid-crystal layer to define its orientation in the absence of an applied voltage, and a dielectric barrier layer (SiO_2 or polyimide, not shown) is frequently used between this and the electrodes to prevent direct voltages being applied to the liquid crystal

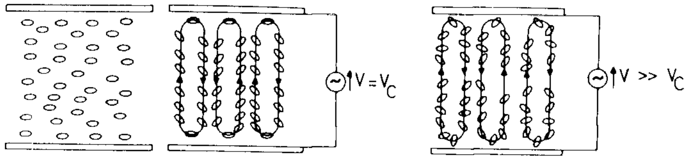
The reorientation of the director, which may be achieved by applying a voltage between the electrodes, can result in a change in the optical properties of the cell due to the birefringence (the anisotropy in the refractive index) of the liquid crystal. Such changes may be obtained as a scattering, colour or transmission modulation phenomenon. The thin layers of liquid crystal used can allow these effects to be obtained with voltages as low as 2–3 V. This has resulted in considerable interest in such liquid crystal cells as optical-display devices (LCDs) which modulate light.

Many liquid crystal electro-optic effects are now known, but only the three most widely used in liquid-crystal displays will be considered here. The effects almost invariably exhibit a threshold voltage or field below which no optical change is obtained and the reasons for this will be considered later. AC drive is generally preferred so that electrolysis effects are avoided. The first display effect to be considered is that of dynamic scattering. The twisted nematic effect and the guest-host interaction effect will then be reviewed.

4.1 Dynamic-scattering displays

Dynamic-scattering displays [16] were the first generation of liquid-crystal displays and are still commercially available. They use a nematic liquid crystal having a negative dielectric anisotropy and usually doped with an ionic solute to increase its conductivity. The displays are transparent in the 'off' state and change to give a milky white, scattering appearance in the regions where a voltage of greater than about 8 V is applied. This is due to turbulent, electrohydrodynamic, vortex-like flow in the energised regions of the liquid, arising from the effects of the applied field on the space charges formed in the liquid layer as a result of the conductivity anisotropy (Fig. 5). This causes a spatial variation in the effective refractive index on a distance scale which causes the scattering of incident light.

Most of the incident light is scattered forward, and it is usual to employ a metallic or dielectric mirror behind the display, so that one sees the scattering areas as white against the specular reflection of the mirror in the unenergised areas. This gives rise to viewing angle and legibility problems, as the reflected light from the transparent regions of the display may equal or exceed that from the scattering regions, giving total illegibility or contrast inversion on the display under certain viewing conditions. This situation can be avoided, with the constraint of a somewhat restricted viewing angle, by suitably hooding the display or by more sophisticated optical arrangements. These, however, mean added complication and expense and give rise to a bulky display.



cell transparent *a* cell weakly scattering *b* cell strongly scattering *c*

Fig. 5 *Molecular alignment in a dynamic scattering cell*

a with no applied voltage

b an applied voltage equal to the threshold value V_c required to produce a space-charge instability, results in lamellar, vortex-like, flow loops in the liquid-crystal layer

c an applied voltage V much greater than V_c causes turbulent electrohydrodynamic flow loops in the crystal layer

The problems of illegibility and contrast inversion can also arise when such displays are used in transmission, although more complex optical arrangements can give good legibility over a wide angle of view. This, once again, means added cost and complication. The operating characteristics of a typical reflective dynamic-scattering display are given in Table 1. These problems and the fact that the necessary ionic conductivity tends to be deleterious to the lifetime of the display have led to its replacement by field-effect displays, principal amongst which are the twisted nematic LCD and the guest-host LCD.

4.2 Twisted nematic displays

Twisted nematic displays [17] are the second and present generation of display devices. They employ a nematic liquid crystal having a positive dielectric anisotropy and utilise a pure dielectric reorientation, so that they are true field-effect displays needing no charge flow in the liquid crystal.

The cell walls are treated so that the director at the surfaces lies in the plane of the device and along a specific direction at each surface. The cell is assembled in such a way that these directions are at an angle to each other, usually $\pi/2$ rad; this gives a twisted molecular structure as shown in Fig. 6. This structure will rotate the plane of polarisation of incident linearly polarised light through the twist angle of the cell, provided that its plane of polarisa-

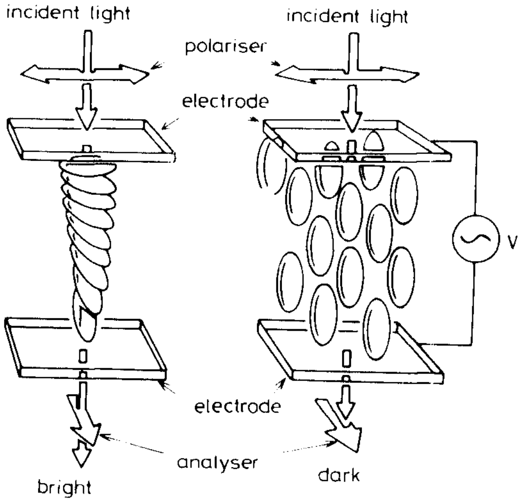


Fig. 6 *Twisted and untwisted molecular alignments in a twisted nematic liquid-crystal cell and their effect between crossed linear polarisers*

Table 1: Typical operating characteristics of current reflective displays using dynamic scattering, twisted-nematic and dyed-phase-change effects

	Dynamic-scattering display	Twisted nematic display	Dyed-phase-change display
Commercial availability	yes	yes	yes
Threshold voltage, V_c, at 50 Hz	5–8	1–2	3–30
Approximate operating voltage, V (and frequency range)	15–60 (50–600 Hz)	3–20 (50 Hz–100 kHz)	5–35 (50 Hz–100 kHz)
Approximate power consumption, μW/cm^2 of active area	100–1000	1–10	2–100
Turn-on time at 20°C	depends on applied voltage, 10 ms typical	depends on applied voltage, 0.2–100 ms	depends on applied voltage, 0.2–100 ms
Turn-off time at 20°C	100–200 ms	30–100 ms	1–100 ms, depending on cholesteric concentration
Operating temperature range	−10 to +80°C	−30 to +80°C	−30 to +80°C
Multiplexibility	20 lines or digits	60 lines or digits	2 lines or digits
Legibility	zero to excellent, depending on viewing conditions	good	excellent
Viewing angle	poor	poor, ±40°	excellent, ±80°
Brightness	good	modest	excellent
Lifetime in hours	>10000	>50000	>50000

tion is parallel or orthogonal to the director alignment at the surface through which it enters the liquid-crystal layer and that $\Delta n\, p \gg 8\lambda$ where $\Delta n = (n_e - n_0)$, λ is the light wavelength and p is the pitch associated with the cell twist. Thus, for a $\pi/2$ twist cell, light is transmitted through a sandwich containing the cell between crossed linear polarisers (Fig. 6).

If an alternating voltage, somewhat larger than the threshold value of about 1–2 V, is applied to the cell, the director is reoriented to lie parallel to the applied field, that is, normal to the cell walls. This causes the rotatory power of the cell to be lost, so that extinction is now obtained with the cell between crossed polarisers. Thus the transmission of the display can be changed by applying an appropriate voltage.

The cells may be used transmissively, or reflectively utilising a diffuse reflector, e.g. brushed aluminium, which conserves polarisation. Their contrast is excellent and their power consumption minimal, typically 1–10 $\mu W/cm^2$ of active area. Typical operating characteristics for a twisted nematic display are given in Table 1.

Early twisted nematic displays often had an unsightly, patchy appearance when viewed at an angle. The mechanisms responsible for this have now been identified [18, 19], and the construction techniques used in the manufacture of current twisted nematic cells permit this problem to be avoided completely. Considerable thought has gone into the optimisation of the types of polarising filters and the reflectors used in current displays. Although this has given a noticeable improvement in the brightness of these displays, the brightness is still far from ideal and the bright areas in a good, reflective twisted nematic display will only reflect about 25–30% of the intensity of the unpolarised incident light. Other problems associated with the polarisers are their susceptibility to high humidities and temperatures, their costs and the yields involved in attaching them to the displays.

One interesting variation of the twisted nematic effect is the production of large-area electro-optic colour switches by making one of the polarisers a coloured dichroic type or by incorporating a retardation plate, or other birefringent plastic sheet, into the polariser/twisted-nematic-cell/analyser sandwich. These colour switches have been used to produce a 2-colour, frame-sequential picture on a monochrome CRT display using a 2-frequency switching method to give the required switching speeds [20, 21].

4.3 Guest-host displays

Newer types of field-effect LCD, such as the dyed phase-change [22] variety, make use of the guest-host interaction effect. Such devices usually employ a nematic or cholesteric liquid crystal containing about 1% by weight of a dissolved pleochroic dye, and the various forms of such devices have been reviewed by Uchida [23]. LCDs containing dyed smectic liquid crystals have also been reported (e.g. Reference 61)

The pleochroic dye used possesses the property that it will absorb some or all of the spectrum of white light whose $\boldsymbol{E}$ vector lies along the direction of its transition moment (usually along the direction of the long molecular axis) and will not absorb light whose $\boldsymbol{E}$ vector lies in a plane orthogonal to this, as illustrated in Fig. 7.

The 'guest' pleochroic dye molecules are aligned by the 'host' liquid crystal so that, on average, their long axes are parallel to the director at every point in the liquid. This co-operative alignment mechanism is the guest-host interaction effect referred to above.

As the $\boldsymbol{E}$ vector of incident unpolarised white light will always have a component along the axis of some of the dye molecules in a twisted nematic or cholesteric layer of liquid crystal, the emerging light will be both coloured and linearly polarised, provided that the twist angle of the layer is not too great, say between 0 and 2π rad. A schematic illustration of this is shown in Fig. 8. The intensity of this colour may be greatly enhanced by combining such a cell with a linearly polarising sheet. This is particularly useful in enhancing the coloured absorption of transmissive displays where the light passes only once through the dyed liquid-crystal layer. In other cells having much more highly twisted layers of cholesteric liquid crystal, such as the dyed-phase-change devices referred to above, all the vibration components of unpolarised light may be absorbed giving a naturally greater intensity of colour so that a polariser is no longer needed for a reflective display and a simple white reflector may be used. The application of a voltage above the threshold value for such a layer of liquid crystal which has a positive dielectric anisotropy causes the director, and hence the dye molecules, to realign as shown in Fig. 8. As the dye molecules now have their long axis along the direction of propagation of normally incident light, the $\boldsymbol{E}$ vector of the light can now have no component in this direction. Thus the light can pass through the display with only a little absorption (due to the thermal fluctuations of the dye molecules) and the ON areas will be colourless and transparent. Therefore, the display goes essentially from being coloured or black to being colourless or white, on the application of an appropriate voltage. Alternative versions employing a homeotropically aligned nematic or long-pitch cholesteric material, having a negative dielectric anisotropy, can be made to give a coloured or black on white presentation, and displays having two layers of liquid crystal have been made with both types of appearance.

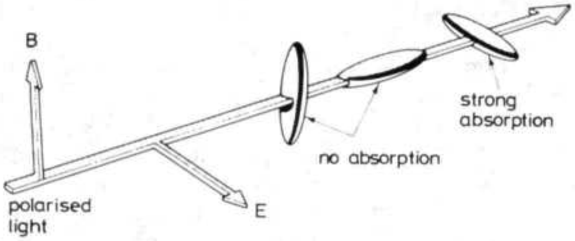


Fig. 7 *Optical properties of a pleochroic dye molecule*

Light is selectively absorbed, to give the colour of the dye, only when the electric field vector $\boldsymbol{E}$ of the incident light has a component along the transition moment, usually along the long axis, of the dye molecule. More complex forms of this anisotropy in the dye absorbance are also known

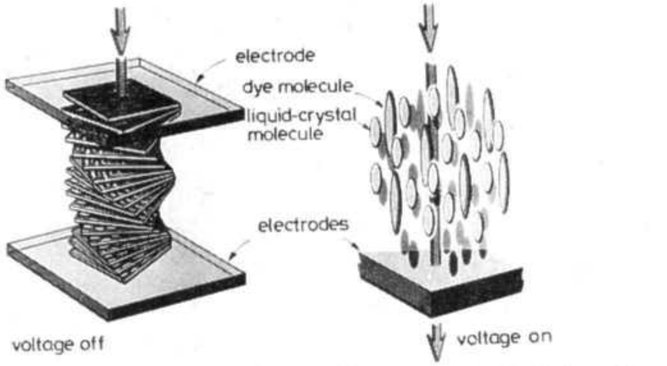


Fig. 8 *Schematic view of one implementation of a dyed phase-change cell showing the alignments of the director and of the pleochroic dye molecules, oriented by the guest-host interaction effect, in the liquid-crystal layer*

a no applied field E or E less than a threshold field E_c and applied to the cell
b $E \gg E_c$, nematic ON state
In other implementations, the helical axis of the cholesteric may be in the plane of the cell (focal-conic texture) in the OFF state

Most types of guest-host displays require the use of a single polariser to provide adequate contrast. This significantly reduces the brightness of reflective versions, however, and provides other limitations associated with the polariser.

The exception to this is the dyed-phase-change display which can provide reflective displays of adequate contrast without this restriction. They can therefore give significantly brighter reflective displays and their somewhat higher operating voltage may be offset by more rapid response times. Their excellent legibility may be further improved by incorporating a roughened metallic reflecting layer inside the cell, and this may be used to form the rear electrode layer. Their properties are summarised in Table 1.

4.4 Threshold and realignment mechanisms

The true field effects almost invariably exhibit a threshold voltage or field, owing to the fact that the electric field cannot exert a torque on the director in the centre of the layer if the director is strictly orthogonal to the direction in which the field would wish to align it. There are, however, cooperative thermal fluctuations of the molecular alignment and account must be taken of them. They mean that the molecules in any small area and, hence, the director, are not instantaneously always strictly orthogonal to the field preferred alignment direction. Thus an applied electric field can exert a torque on the molecules when they are at an angle to this orthogonal direction. When the angular rate of increase in this torque equals that of the restoring elastic torque on the director, the threshold condition is obtained. A field-induced reorientation occurs gradually as the field is increased above its threshold value. This arises because the orientation of the director cannot be changed at the bounding surfaces and an elastic deformation occurs between the field-oriented centre of the cell and the walls, which opposes exactly the body torque exerted by the field on the molecules due to their dielectric anisotropy. It should be stated that, in the case of cholesteric liquid crystal, the elastic torques due to the bounding surfaces may be far exceeded by those due to the field attempting to distort the helical cholesteric structure. This is reflected in the fact that short-pitch cholesterics generally exhibit a threshold field rather than a threshold voltage; i.e. the measured threshold voltage varies with cell thickness. This contrasts with nematics where both the field and elastic torques scale with thickness to give a constant threshold voltage.

In the case of dynamic scattering there is again a threshold voltage, but this is due to the voltage required to create a space-charge instability and hence electrohydrodynamic flow in the material.

5 Dynamics of liquid-crystal displays

The dynamical behaviour which defines the response times of liquid-crystal displays is extremely complex and beyond the scope of this paper. It is generally observed, however, that the response times of such cells may be approximately described by the relation [24] (this holds both for cells having threshold voltages or threshold fields)

$$\tau_{on} = \frac{\eta d^2}{\varepsilon_0 \, \Delta\varepsilon(V^2 - V_c^2)}$$

where η is some average of the viscosity coefficients (usually taken as the value measured using a capillary viscometer or a rotating cone viscometer), d is the layer thickness of the liquid crystal, V is the applied voltage and V_c is the threshold voltage measured for the cell. In the case where $V = 0$ the turn-off time τ_{off} is given approximately (suppressing the negative sign) as

$$\tau_{off} = \frac{\eta d^2}{\varepsilon_0 \, \Delta\varepsilon(V_c^2)}$$

Note the implication that thin cells with high threshold voltages have shorter turn-off times in general.

6 Liquid-crystal materials

The performance of liquid-crystal displays depends heavily on the properties of the liquid-crystal materials used in them. Individual compounds may have relatively restricted temperature ranges over which they exhibit the required liquid-crystal phase. This is overcome by the intelligent mixing of different compounds, perhaps up to 10 of these being used, so that a eutectic mixture is obtained whose components will not segregate at low temperatures. Nematic mixtures having temperature ranges extending from −30 to +90°C have been made in this way. The phase diagram of a simple 2-component system, compounds (*ia*) ($n = 5$) and (iii*b*) in Fig. 1, is shown in Fig. 9 which also indicates the eutectic composition. The increased nematic temperature range of the eutectic mixture can clearly be seen.

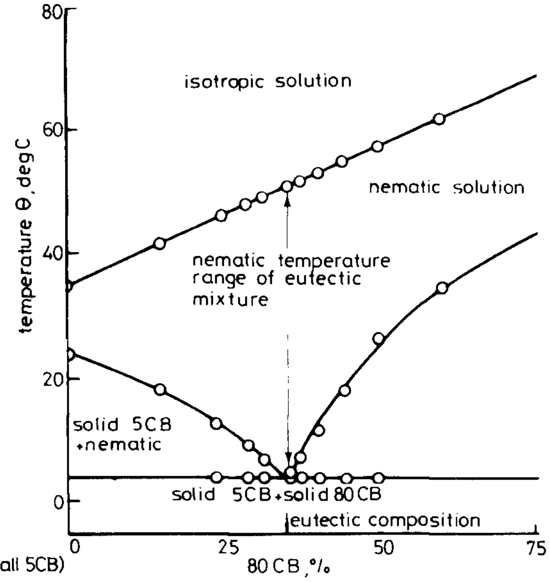


Fig. 9 *Part of the phase diagram of two cyanobiphenyl liquid-crystal materials 5CB (compound (ia) in Fig. 1) and 8O CB (compound (iiib) in Fig. 1) showing the composition and temperature range of the eutectic nematic mixture*

The optimisation of other aspects of display performance may also directly relate to the choice of material used, and frequently this choice is a compromise between conflicting options. It is generally required, however, that the materials must be of exceptionally high purity and highly resistant to chemical, electrochemical, photochemical or thermal decomposition or alteration. Not all liquid-crystal materials fulfil these requirements, but the application of some clever chemistry has resulted in classes of compounds which do. Examples of these would be the alkyl-cyanobiphenyls, the alkyl-cyanophenylcyclohexanes shown in Fig. 1 and various types of phenyl esters.

Another prime requirement of such materials is that they should be safe. They should not be toxic or carcinogenic nor should they be irritants. Other parameters which may be taken account of when selecting components or designing a mixture could be as follows:

Routine Packet-Radio Meteor Burst Contacts on Six Meters

By Robert J. Carpenter,* W3OTC

I have been making routine contacts from Rockville, MD, by six-meter meteor-burst propagation to Ralph Wallio, W0RPK, of Indianola, IA. Thanks to the use of packet-radio techniques, these contacts have been 100% error free. Other than the use of TAPR (Tucson Amateur Packet Radio) packet-radio boards and computer terminals, conventional Amateur Radio equipment has been used.

W0RPK uses an unmodified 250-W Motorola FM base station, and a 5-element beam. My station consists of a modern all-mode rig, a 150-W solid-state amplifier, and a 6-element beam. Packets are limited to 30 or 40 information characters, plus about 20 overhead characters (calls, error detection characters, and so on). This totals to about 320 to 380 ms. Acknowledgement packets are about 20 characters long (128 ms). Because of the slow change-over of the old FM rig, as much as 100 ms of fill has been allowed before acknowledgement. Thus, a burst would have to be about 610 ms long to transmit a 60 character long packet and get an acknowledgement. Shorter times are now in successful use.

Table 1 presents a comparison with an earlier experimental meteor-burst communication system. [1] The system reported in 1959 operated over a 1277 km east-west path, about the same length as the current 1300 km path. In the ham setup, the two stations alternate transmitting so that the complex filters for full-duplex operation are not required. The 1959 system had relatively poor receiver performance because of filter losses and transmitter noise, a common problem with full-duplex operation.

With our present protocol, perhaps 80% of the possible transmission time is lost. Little improvement is likely from improved antenna gain, since a high-gain antenna illuminates fewer meteor trails, but better. The frequency dependence of burst duration and signal strength are taken from, "Ionospheric Radio Propagation," by Davies (NBS Monograph 80, 1965). The effectiveness of the TAPR FM-AFSK modulation is a rough estimate.

It can be seen that our six meter results are close to the predictions. Our 1 bps results were obtained during the Perseid meteor shower. The estimate that 50 MHz throughput should be about fifty times better than at 145 MHz is borne out by the fact that W0RPK could only complete a minimal two-meter packet contact with K1HTV (to Maryland, requiring over two hours), while his six-meter station was simultaneously transmitting hundreds of characters of a file to W3OTC.

Work is now under way to get better throughput. Possible improvements are a modulation scheme such as phase shift keying, a protocol better suited to the characteristics of meteor-burst propagation, and higher output power. Eight-phase keying, three bits coded at once, should give from 10 to 15 dB improvement.

Anticipated Improvements:

Modulation (PSK)	10-15 dB	(10 to 32 x data rate)
Protocol	3 dB	(2 x data rate)
Power (500 W)	4 dB	(2.5 x data rate)

An expected 6-meter data rate of 7.5 to 24 bps is not bad for 100% perfect copy at a distance of 1300 km on a "dead" band.

Reference

[1] "The NBS Meteor Burst Communication System," IRE Trans P G Comm Sys, v. CS-7, No. 4, Dec. 1959, pp. 263-271.

[On August 13, 1984, K1HTV forwarded the following message to W0RPK: Two-meter packet meteor-scatter experiment results what is believed to be the first two-way packet-radio meteor scatter contact by radio amateurs utilizing the 2-m amateur band. The contact was made by W0RPK in IA and Rich Zwirko, K1HTV, in Glenn Dale, MD. This occurred during the peak of the Perseids meteor shower the day before. K1HTV transmitted information about the Perseids and using packet radio on M/S until his rig failed.

The packet transmissions of W0RPK were captured and saved on a disk file by K1HTV. Both stations were using TAPR terminal node controllers (TNCs) and operation was in the unconnected mode. Using the TAPR's UNPROTO command, either a call sign or a signal report was put in the TO address field of each packet...This report is incomplete as W3OTC dismissed himself from his station to go to work. -- Ed.]

(Continued on page 12)

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* 12708 Circle Drive, Rockville, MD 20850

Remote Terminal for your Micro

By John S. Davis, WB4KOH

This article tells how to remote a terminal to your microcomputer for about $50, or at least that's what it cost me. At the same time, I added several features to the remote keyboard. Whoops! I just gave away the secret of my project -- a remote keyboard.

I added 17 extra keys in a numeric style keyboard to my TI-99/4a. Features include MULTIPLY (*), PLUS (+), and SUBTRACT (-) keys in use without employing the FUNCTION KEY, a SHIFT and FUNCTION LOCK switch with indicator LEDs, the use of standard DB-25 connectors and cable for the remote (not in RS-232 configuration, however). This eliminated the mess of cables on the remote keyboard to only one. Two keyboards may be in use at the same time for educational, game or business use. Plenty of extra space and spare connections for future expansion in the remote keyboard were an added plus. If the remote is to be used in another room, video or RF may be taken from a "Y" connector to another TV or monitor. With the use of audio cables, a cassette may also be remoted.

If you do not have a TI-99/4a, some of these ideas may be applied to other micros. If you are afraid of harming the resale value of the computer, the cable may be removed within minutes. TVI or RFI has been checked with a six-ft cable on TV channel 3 and 145.50 MHz without increased interference. On long runs to the remote, I recommend the use of shielded wire for all cables, to be on the safe side.

The remote keyboard I obtained from a department store for $20 was a discontinued demonstrator. All other parts were collected from a local hamfest and Radio Shack, or whatever my junkbox was able to donate.

Construction

The added keypad was mounted in front of the game slot to the right of the main keyboard. Just behind this is the FUNCTION and SHIFT LOCK switches and their indicator LEDs. Reference the accompanying photos for parts placement.

The circuit uses six miniature reed relays for the SHIFT, *, +, and - keys from the added keypad. Five volts is taken from the host computer to power the relays and LEDs. Power consumption for these devices should be very small.

The reason for six relays is that the SHIFT key must be in the upper case or closed before any of the *, +, or - keys (switches) can make contact. This is why two relays must be used for each of these keys. See the schematic for details.

I used 1N4001s across the relay coils to take care of any glitches on the 5-V line. Other glitch or RF problems can be handled by passing this supply with a 10 and 0.1 uF capacitor.

The pin connections for the DB-25 are as follows: Pin no. 1 to 15 are for the main keyboard connections of pin 1 to 15 (Pin 1 to 1, 2 to 2, and so on). Both keyboards are in parallel! Pin no. 16 is for -5 V, pins no. 17 to 24 are for the frame ground, and pin no. 25 is the +5-V feed.

I connected the frame ground (pins no. 17 to 24) to the metal frames of the remote keyboards. This line is also used as a "tug" line to take any pull from the other connections. The placement of this line can be seen in the photographs.

Double-stick tape is used to hold the relays in place. All of the other keys on the keypad are in parallel with the main keyboard(s). More than one remote may be added for this reason. Keyboards may also be upgraded as long as the same circuit is used. I used the same keyboard and case as in the 99/4a computer and did not have to worry about the difference in keyboards.

*3929-4 Winterfield Place, Charlotte, NC 28205

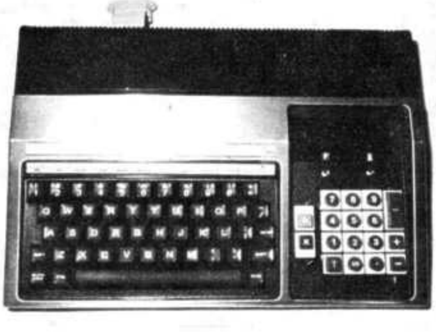
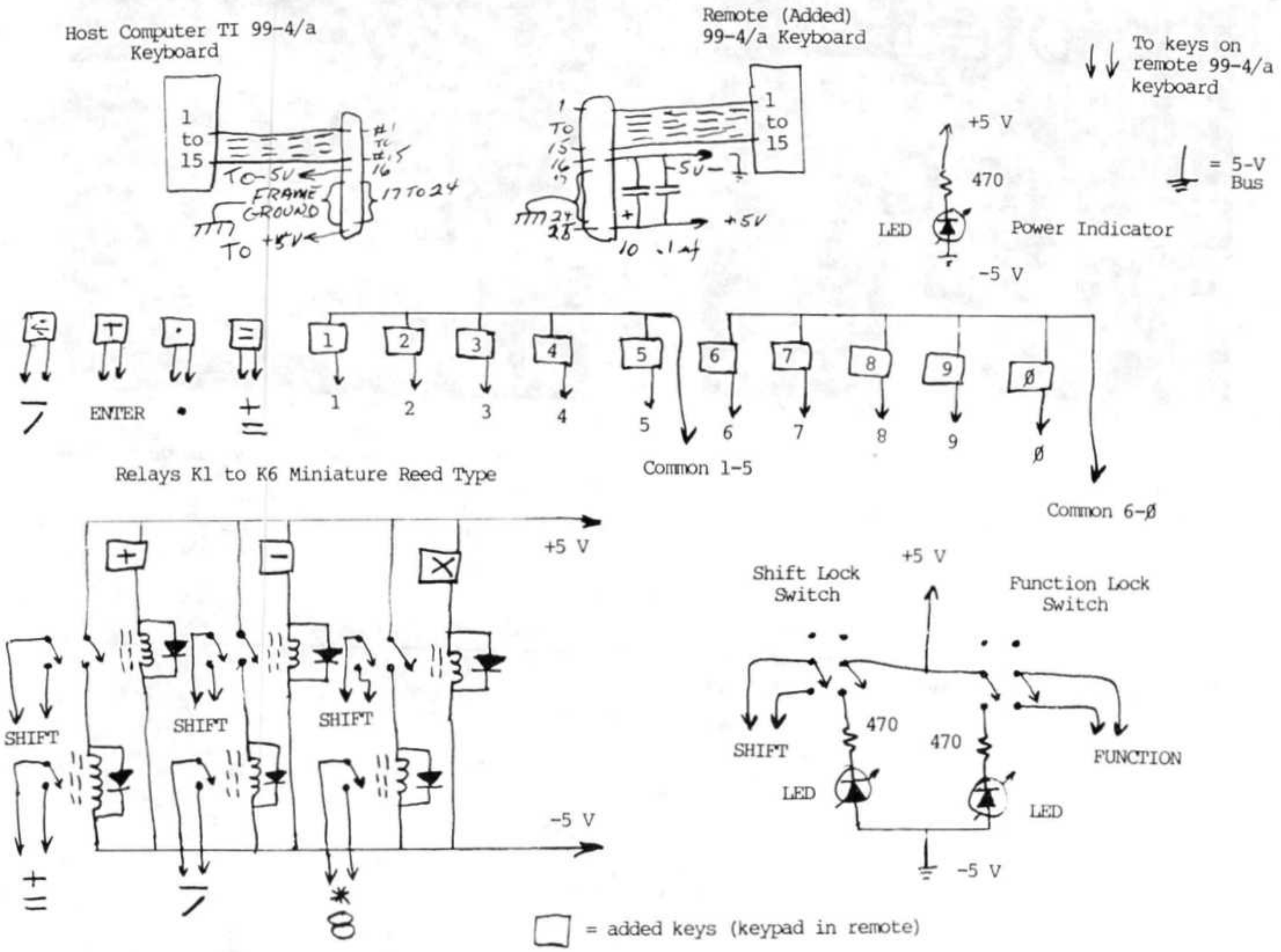


Fig. 1 — Completed Remote Keyboard.



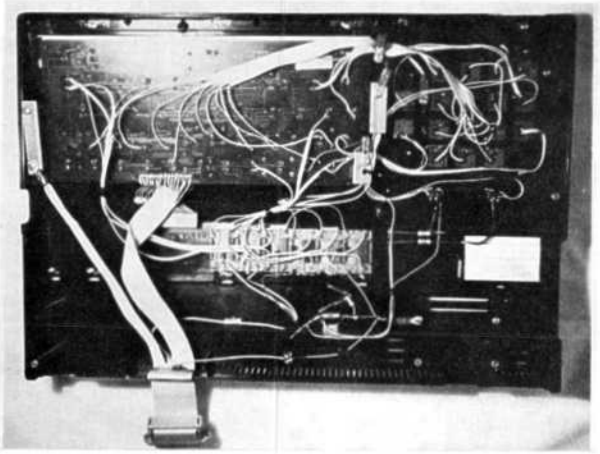


Fig. 2 -- View showing wiring. You can see the added keypad in the lower left, and the six reed relays in the center.

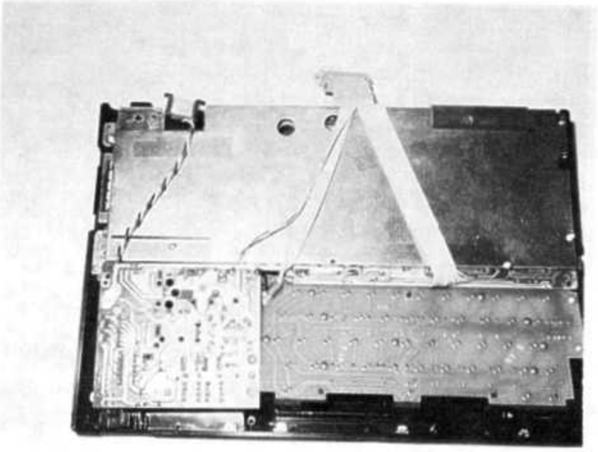


Fig. 3 -- This view shows the added wiring inside computer.

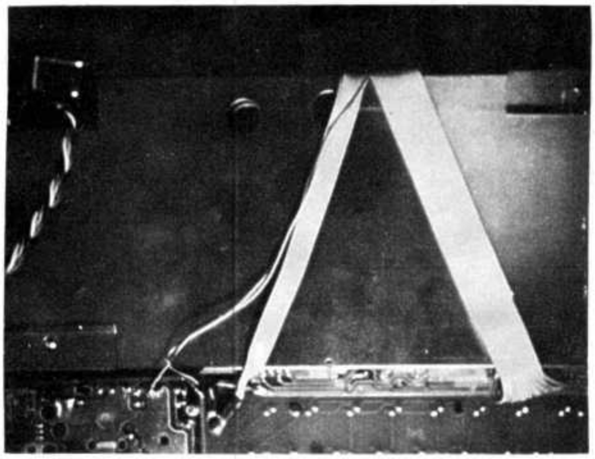


Fig. 4 -- Closer view of added wiring.

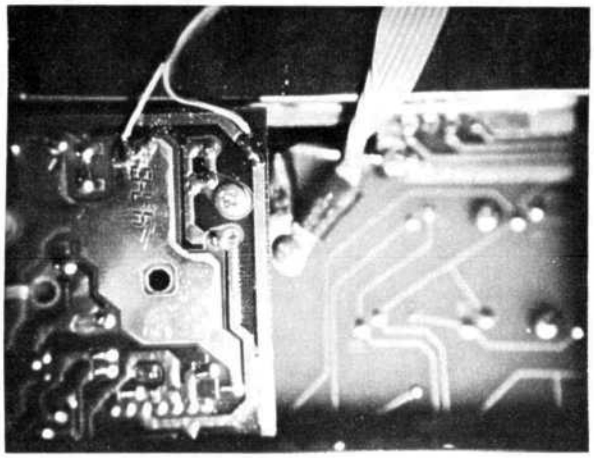


Fig. 5 -- This photo displays the power hookup and frame ground. Negative 5 V can be seen at the far left, and the power supply board contains the +5 V on the outer foil. The frame ground and short jumper to ground pad on the computer board is seen on the far right.

(Meteor-Burst Communication System Comparison Table continued from page 9)

Table 1
Comparison of Estimated System Performance

		Six Meters		Two Meters	
Parameter	1959 Report	W0RPK W3OTC	Ham/ Report	Typical Ham	Ham/ Report
Transmitter Output, W	2000	200	-10 dB	200	-10 dB
Antenna	10 el	5 & 6 el	-2 dB	beams	+2 dB
Duty Cycle, available	100%	20%	-7 dB	20%	-7 dB
Receiving Sensitivity			+4 dB		+6 dB
Frequency Effects, freq	49 MHz	50.5 MHz		145 MHz	
Burst Duration Ratio (f1/f2)**2		0.94	-0.3 dB	0.11	-9.6 dB
Signal Strength Ratio (f1/f2)**3		0.91	-0.4 dB	0.04	-14.4 dB
Modulation	FSK	FM-AFSK	-7 dB	FM-AFSK	-7 dB
Amateur Radio Disadvantage with Current Equipment.			22.7 dB		40 dB
Observed bit rate	30 bps	0.2-1.0 bps*			
Expected bit rate		0.16 bps			0.003 bps

*0.2 bps on 12 and about 1 bps on 15 August 1984; apparently the Perseid meteor shower helped.

Bits

Midway Amateur Radio Club to Assume Management of the North American Teleconference Radio Net

On September 15, 1984, the Midway Amateur Radio Club of Kearney, Nebraska, took over sponsorship of the North American Teleconference Radio Net (TRN). "Mert" Feikert, WB0USW, President, announced that Timothy Loewenstein, WA0IVW will be the new Net Manager.

TRN links together over 150 gateway stations (mostly VHF/UHF repeaters) across the U.S. and Canada to present high-quality technical and informational programs of interest to radio amateurs. When available for uplinking from the U.S., the OSCAR 10 satellite also transmits the net to one-third of the earth's hemisphere. It is estimated that a single TRN has had as many as 75,000 amateurs tuned in plus uncounted scanner listeners. Past speakers on TRN have included the late Vic Clark, W4KFC, and Senator Barry Goldwater, K7UGA. A fact not generally realized is that the technology behind TRN allows any of the amateurs tuned in, whether in Alaska, Florida or New Brunswick, in their car, home or walking down the street with a hand-held radio, to talk to each other or to the featured speaker.

TRN is "amateurs learning to serve." The featured speakers provide state-of-the-art information to amateurs to inform and inspire. While behind the scenes, amateurs perfect their skills to provide ad hoc radio/interconnect networks to serve the public in times of emergency or disaster.

The idea for TRN began with the work of Ed Piller, W2KPQ, and Charlie Kosman, WB2NQV. In the early 80's, Ed and Charlie began linking repeaters by telephone to provide technical presentations to amateurs as a joint project of the Long Island Mobile Amateur Radio Corps (LIMARC) and the Long Island Chapter of IEEE. However, with the telephone bridging equipment readily available to them, it was difficult to provide high quality audio to and from all participating repeaters. In later 1982, Rich Whiting, W0TN, became net manager. A telecommunications engineer with extensive experience in developing teleconference capabilities for Honeywell, he was an early participant in the IEEE/LIMARC technical nets. Rick made arrangements with Lou Appel, K0IUQ, of Darome, Inc., to use Darome's highly sophisticated multipoint teleconference bridges to provide the "land line" links for repeaters (note that many of the repeaters are, in turn, linked by radio). The result was superb audio quality and a rapid growth in the number and distribution of gateway stations in the net. Lou will continue to be the bridge engineer behind the scenes in TRNs under the new net manager.

Steve Bauer, KC0UF, a highly talented and dedicated ham in Wichita, Kansas, conducts interviews on the pre-net audio on many TRNs. A highlight of Steve's pre-net programs was his interview with astronaut Owen Garriot, W5LFL, for the March 1984 TRN.

Located midway between Boston and San Francisco, (1,733 miles either way), the Midway Amateur Radio Club is the ongoing host of the annual Kearney Spring Amateur/Family Convention held the last weekend of March. This event draws amateurs and their families from throughout the midwest. The Midway Amateur Radio Club hosted the Nebraska State ARRL Convention and the 1984 Midwest ARRL Convention.

"Packet Radio Overview and Prospective" will be the subject on the first TRN presented under the sponsorship of the Midway Club, Sunday December 2, 1984, at 6:00 P.M. CST (local nets may begin earlier). The speakers will be Lyle Johnson, WA7GXD, and Harold Price, NK6K, both highly respected authorities and pioneers in packet radio technology.

Correspondence and requests for TRN information should be sent to: TRN Manager, c/o Midway Amateur Radio Club, P. O. Box 1231, Kearney, NE 68847-1231 (s.a.s.e. please, Canada excepted).

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For technical personnel from telephone and power companies, broadcasters and others engaged in radio and cable communications, the University is offering a course on "Lightning Protection." Classes run November 29 and 30, 1984 and the fee is $625. Again, Shirley Forlenzo can be of assistance in this area. A brochure may be obtained by writing The George Washington University, Continuing Engineering Education Program, Washington, D.C. 20052.

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American Radio Relay League
225 Main Street
Newington, CT 06111 USA
telephone 203-666-1541

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