INTRODUCTION
The familiar shape of the magnetic tape transport has undergone a dramatic change. As a result, space age television shows may have to find convincing replacements for madly spinning banks of vertically placed reels. The imagination of the public may suffer, but the industry is provided with a new peripheral having a most exciting future.

Details of a multistation Magnetic Tape Cluster are presented in this paper to provide an insight into how it was conceived, how it is built, and its capabilities.

The Cluster concept
If we reflect for a moment to consider the scheme generally used in digital tape drive design, one common characteristic becomes apparent; the tape path formed by the reels, the transducer and the tape buffers lies in the same plane. This is the simplest and most direct way to accomplish the objectives of a single station machine. Of all the transports on the market today, perhaps 80% are designed around the formal vertical plane tape path as shown in Figure 1a.

Another popular method places the tape path in a horizontal plane such as shown in Figure 1b. This design is advantageous in many respects and offers convenient table height operation. Some forward thinking designers have combined the two ideas to provide two transports in the same box (Figure 1c).

Our earliest considerations for designing the multistation Cluster Unit contained several features which have remained throughout the entire development. These requisites included a four station package which shared electronic and mechanical features to achieve the best possible combination of performance, reliability and low manufacturing cost.

Naturally, the development group first took a hard look at the commonly used vertical plane geometry. It was found that some improvement was possible by rearranging reel positions similar to those shown in Figure 2a. This arrangement could share electronics very nicely but the ability to share mechanical components was questionable. Figure 2b shows a folded version of the above arrangement which improved the possibility of sharing mechanical features.

An original design, Figure 2c, having a multiplicity of vertical tape paths but with horizontal tape buffers, received attention during the early development period. It was apparent, however, that a “sandwich” machine such as this would be plagued with severe accessibility problems.

For each of the above designs there were advantages which could be cited, but one fact remained abundantly clear: none of the arrangements represented the major step forward we were seeking. We realized that the point had been reached where additional time spent in simply rearranging tape path components was not justified, and a clear departure from established custom was a “must” if our objectives were to be met.

What then could be done to break this impasse? We were confident that the reels themselves were the key factor and, since a simple rearrangement did not fulfill our needs, the logical remaining possibility was to stack the reels and operate them on a common axis. This possibility proved to be the turning point and has since become the foundation of the multistation Cluster design.

Stacked reels, in themselves, are certainly not original with this design. They have been used in the field of music reproduction and, to some extent, in the digital field at very low or incremental tape speeds. What is original with us is the design associated with making the philosophy work on a multistation tape transport operating at relatively high tape speeds and recording densities.

Once the general approach had been determined, the next step was to examine tape path configurations capable of transporting tape which terminated at two levels of spooling. Refinements came rapidly,
Figure 2 - Conventional tape path geometry for coplanar multiple station units.

1 (a) Single station units

2 (a) Multiple station units

1 (b) Single station units

2 (b) Multiple station units

1 (c) Single station units

2 (c) Multiple station units
and one particular path emerged which seemed to have superior characteristics over all others.

A series of preliminary layouts was made and, much to our delight, the various pieces began to fit together with remarkable solidarity. Within a month we felt that sufficient understanding had been obtained to proceed with a full-fledged development program, and management gave its unqualified approval.

Thus, the multistation coaxial reel concept was born. Three months later, a hurriedly constructed experimental model, Figure 3, was providing operational data. It is gratifying to note that the tape path shown here has stood the test of time and basically is the same as that used in the machine as it exists today. The current design is shown by Figure 4. It is a four-station Cluster which operates at a tape speed of 45 inches/sec. The Cluster is now in production and will be available to industry within the next several months.

**Geometric relationships**

Before proceeding with a discussion of the finished product, let us examine some of the geometric relationships associated with nonplanar tape paths.

We begin by considering two coplanar reels as shown by Figure 5A. This condition requires that the reels be in a spaced-apart relationship and that the axes of rotation be parallel. Desired convolutions of the tape between the two reels are a function of judiciously placed pivot points which are installed normal to a plane of reference.

The plane of reference, for our needs, may be defined as a plane which passes through one edge of the tape and is normal to the tape surface. It is particularly desirable to consider the tape as lying in the plane of reference between the point of entry into the supply reel buffer and the point of emergence from the take-up reel buffer. For purposes of our discussion, this condition will be assumed for all cases.

We next introduce a modified condition which retains the parallel relationship of the reel axes but repositions the reels such that they are no longer coplanar. This condition is illustrated by Figure 5B. As can be seen, the pivot points now assume an angular relationship to the reel axes. Convolutions of the tape within the plane of reference (between pivot points A and B) are removed from the scope of our discussion by definition.

We continue our space relationships by repositioning one reel such that its axis becomes an extension of the axis of the second reel as shown in Figure 5C. This move is for convenience only and no significant geometric changes are introduced when compared with Figure 5B. However, a comparison of Figures 5A and 5C leads to several important observations.
1. If the pivot points are cylindrical and fixed, they will perform their intended function under either condition. The relationship between the tape and a fixed pivot is one of sliding contact between the two surfaces but a variation in the contact length of the tape as it proceeds around the pivot will have no ill effects in guiding the tape.

2. If the pivot points are cylindrical and rotatable, they will perform properly under condition 5A only. Under condition 5C, we observe that a variation in the contact length of the tape as it proceeds around the roller must introduce relative motion between the two surfaces. The roller will therefore migrate along its axis or, if restrained, an undesirable slippage is introduced between the tape and roller.

To summarize our position at this stage, we find that rotatable pivots cannot be used in conjunction with coaxial reels unless some type of relationship is established which prevents an angular contact between the direction of tape travel and the rotation of the roller. Since rotatable pivots are highly desirable for maintaining a low frictional drag, and perhaps even more important, to keep the drag forces constant, it is imperative that such a relationship be found.

To accomplish this, we introduce an angularity between the axis of reel rotation and a plane of reference as illustrated by Figure 6A.

Now, consider the tape as it proceeds from the supply reel to rotatable pivot point A. Upon contact, the tape proceeds around the roller without sliding contact. If $180^\circ$ were selected as the arc of contact, the tape would simply be returned to the reel. Under this condition the bottom edge of the tape would make a "point" contact with the plane of reference.

Suppose we wish the tape to depart from the roller in such a fashion that its lower edge were to continuously lie in the plane of reference. This is accomplished with the aid of an additional rotatable pivot point C, which must be precisely located. The location must be such that a line drawn between pivots A and C must lie on the intersection of the plane passing through the bottom edge of the spooled tape and the plane of reference.

Since by definition we must position the tape surface normal to the plane of reference, we install pivot point C such that its axis is normal to the plane of reference rather than simply parallel to the axis of pivot point A. Under these conditions, a small twist is introduced in the tape over the distance "L". Note, however, that the rule stating that no relative motion is permissible as the tape travels around a rotatable pivot point has not been violated.

To illustrate this, we introduce an angularity between the axis of reel rotation and a plane of reference as illustrated by Figure 6A. 

Now, consider the tape as it proceeds from the supply reel to rotatable pivot point A. Upon contact, the tape proceeds around the roller without sliding contact. If $180^\circ$ were selected as the arc of contact, the tape would simply be returned to the reel. Under this condition the bottom edge of the tape would make a "point" contact with the plane of reference.

Suppose we wish the tape to depart from the roller in such a fashion that its lower edge were to continuously lie in the plane of reference. This is accomplished with the aid of an additional rotatable pivot point C, which must be precisely located. The location must be such that a line drawn between pivots A and C must lie on the intersection of the plane passing through the bottom edge of the spooled tape and the plane of reference.

Since by definition we must position the tape surface normal to the plane of reference, we install pivot point C such that its axis is normal to the plane of reference rather than simply parallel to the axis of pivot point A. Under these conditions, a small twist is introduced in the tape over the distance "L". Note, however, that the rule stating that no relative motion is permissible as the tape travels around a rotatable pivot point has not been violated.
All that now remains to accomplish our geometric objectives for coaxial reels and rotatable pivot points is to reposition the two reels in a stacked attitude, such as illustrated by Figure 6B. We know from the foregoing discussion that this can be done without introducing any significant change to previously established relationships.

We find that for small values of $(a)$, a reasonably short distance “L” can be tolerated without difficulty. The magnitude of $(a)$ is a function of the spacing between reels and the distance from the reel axis to the location of pivot point A (or B). These relationships, as expressed in actual Cluster values, result in a stress of approximately 40 psi at the outermost fibre of the tape. This figure is very low when compared with the proportional limit of the mylar material and a more meaningful comparison may be made in terms of the strain profile introduced across the width of the tape. Tension forces acting on the tape will desirably approximate 9 ounces and the 40 psi fibre stress is found to be equivalent to 0.3 oz. of tension. This results in a profile which has a variance of about 3% across the tape width.

**Geometric implementation**

At this point it would be well to examine the hardware and see how the geometrics have been reduced to practice. Figure 7 shows the structural relationship between the frame and an unusual looking weldment called the spider. The spider is supported at four points by vibration isolators to damp spurious frame or floor oscillations which might be detrimental to reliable operation. The pads on each arm of the spider provide bearing surfaces for the coaxial reel drive assembly.

One of the four coaxial reel drives is shown in mounted position on the spider. The deck assembly is also shown in mounted position attached to the face of the tubular hub of the spider.

A close look will reveal the angularity $(a)$ which exists between the reel drive and the vacuum columns (plane of reference). This angular relationship is obtained by machining the mounting pads of the reel drive housing at precisely the proper angle. A vertical adjustment is provided in the reel drive to correctly align the height of the reels with the plane of reference.

Figure 8 shows the top of the four station Cluster without covers. This provides a view of the various component parts which lie in the plane of reference. For purposes of clarity, Figure 9 has been prepared to enable us to examine the elements which comprise a single station. Beginning with the supply reel, we trace the tape path as follows:

1. Tape from the supply reel passes around rotatable pivot A (remembering the axis of pivot A is parallel to the reel axis).
2. Between pivot A and rotatable pivot C the tape undergoes a slight twist of about 3°.
3. Since the axes of pivots C and D are normal to the plane of reference, the tape lies in the same
Figure 8 – Deck assembly showing quad configuration

plane at every point in the path between these two extremes.

4. The tape now proceeds in a fairly conventional manner from the supply buffer, past the reverse pinch roller driver, and over the left hand cleaner guide. Here, the reference edge of the tape is precisely aligned for passage over the head and any loose oxide particles are scraped off and vacuumed away.

5. Prior to reaching the read/write head, the tape passes through the end of tape/beginning of tape sensor. This sensor is also used to fix the exact position of the tape leader latch when the tape is to be unloaded.

6. As the tape passes over the read/write head, it is held in close contact by a magnetic shield supported by the lift-off arm. The shield not only assures an optimum flux path but effectively damps any vibrations which might be introduced during startup. The lift-off arm rotates to lift the tape completely off the head during rewind, thereby preventing unnecessary wear.

7. The tape continues past the right hand cleaner guide, past the forward pinch roller driver, and into the take-up buffer. A slight twist of the tape is again introduced between rotatable pivot points D and B. At pivot B, the tape is realigned in the plane of the tape reel (remembering that the axis of pivot B is parallel to the reel axis) and finally is spooled onto the take-up reel.

Cluster design features

Speed, size and weight

Each station of the Cluster operates independently at a tape speed of 45 inches per second (forward or reverse). The four stations are packaged in a single box 43" high, 36" wide and 30" deep. This compactness is further exemplified by the weight of the unit which approximates 800 pounds.

Tape is moved by means of sealed pinch roller drive modules which are extremely positive and quiet in operation. Much of the clackety-clack is gone and, once the internal adjustments have been correctly made, further adjustment becomes essentially nonexistent. This condition arises from the fact that metal-to-metal contact found in most electromagnetic clapper devices has been eliminated by means of a cushioning device of a proprietary nature.

The capstans for all four stations operate continuously at a synchronous speed of 900 RPM. Power is supplied by a single motor, and heavy flywheels provide sufficient inertia to maintain tape fluctuations at a minimum regardless of pinch roller activity.

Tape guides are located on either side of the head in the conventional manner. The design of the tape
The "Cluster" — Four Tape Stations In A Single Package

guides serves a dual function since the guides also provide for efficient cleaning action. Particles removed by the cleaning action are not allowed to accumulate but are swept away in a high velocity air stream.

The vacuum columns are assembled in the form of a cross and receive vacuum pressure from a single source. Vacuum pressure to each station is isolated by means of a fail-safe check valve which closes should tape failure occur. Other stations are thus protected against loss of vacuum pressure and remain operational.

Of particular significance is the fact that the entire tape chamber is a sealed compartment which maintains this critical area dust free. Air within the chamber is recycled 30 times per minute and passes through a micronic filter element on each cycle. The air temperature within the chamber is continuously sensed and compared with room ambient temperature by means of a differential thermostat. A small cooling unit maintains the temperature of the recycled air within ± 1°C of the ambient temperature at all times.

Cluster logic is a hybrid combination of discrete components and integrated circuit chips. Normal input power is approximately 2 KW at 208/230 V, single phase, 50/60 cycle.

The read/write electronics accept either seven or nine channels of information in any code combination.
The external control (Central System) is switched to any one of the four stations by an appropriate exchange within the Cluster. Reading or writing at bit densities of 200, 556 and 800 bits per inch (NRZ1) is provided as standard. At 800 bpi, the transfer rate is 36KB. This capability can be extended to 72KB by installing the Phase Encoding option which is presently being offered at a density of 1600 bpi.

Terminology for a machine composed of one set of read/write electronics, four active stations and nine channel R/W heads is 1×4×9. Under these conditions, any one of the four stations can be independently reading or writing at any given period of time under the direction of a single external control.

Provision is made to install a second set of read/write electronics if desired. In this case, the above terminology becomes 2×4×9. Under these conditions, any two of the four stations can be simultaneously and independently operating under the direction of two external controls.

If a user plans to use the Cluster with Burroughs’ B2000 systems, the ability to fully utilize its multi-processing capability is a highly desirable feature. Since multi-processing will generally require more than four tape stations, the Cluster can also be obtained as a slave unit and will be equipped with two, three or four stations to exactly respond to a user’s needs. The slave unit is identical in design to the master unit except for unneeded electronics.

The terminology 2×8×9 is used to define a master and slave combination where any two of the eight available stations are under the independent and simultaneous direction of two external controls.

SUMMARY
The multistation coaxial reel concept is believed to be a significant advance in the art of digital tape transport design. In support of this belief are the many new features of the 45 ips Cluster which have been discussed in this paper. However, today’s technology is a hard task master and technical advances without appropriate economic advances are likely to be lost in the shuffle. As most of us have learned, it is no longer sufficient for the engineer to develop “something better”; that “something better” must also cost less.

Economic studies of the Cluster’s design are most encouraging in this respect and major cost reductions have accrued by sharing certain portions of the machine’s makeup. This condition is also the result of a program where assigned target costs have accompanied each design element almost from its inception.

Consider the two machines shown in Figure 10. The upright unit is typical of many single station tape transports on the market today.

Externally, we note that a four to one savings is directly applicable to the frame, skins, trim and covers. Internally, the ventilation and vacuum subsystems represent the same four to one savings potential. The power supply and capstan drive elements can be considered as a three to one savings. Perhaps the most outstanding single factor of all is the electronics themselves, here a savings of three to one can be conservatively applied.

What does this all add up to? Although a direct cost comparison between the two machines is not completely fair, we do know that the Cluster not only represents something better, but that it also satisfies the corollary that it must cost less.

We look forward to continued refinement of the Cluster concept and foresee its advantages extended to higher speed machines operating reliably at even greater packing densities than heretofore considered practical.

Figure 10—Multistation Cluster and conventional single station transport