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A COMPARATIVE ASSESSMENT OF SOVIET OPTICAL COMMUNICATIONS CAPABILITIES (U)

Draft Report No. M2012 ✓

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ABSTRACT

The purpose of this report is to indicate whether or not the Soviets have the capability to deploy 5 Mb/s fiber optic communication systems to support an ABM system.

The evidence provided by the literature search seems to indicate that the Russians can deploy such a system without importing technology from the West. They demonstrated a short distance system capable of transmitting 114 Mb/s as long ago as 1977. Since that time, they have demonstrated a system as long a18 Kb; and they have demonstrated a 5 Km long link utilizing both wavelength division multiplexing and duplex transmission. They have also done a number of studies on the radiation hardness of optical fibers and components.

More important than the systems actually exhibited by the Soviets, are the capabilities of the components that they have developed. They are working on distributed feedback lasers and Schottky barrier photodetectors which are capable of multi-Ghz emission and detection, respectively. Additionally, they have demonstrated the ability to produce single mode fibers. it would therefore seem that the Soviets may already be able to transmit data in the low Gb/s range.

For comparison, the West has demonstrated the following capabilities:

1. 2 Gb/s transmission for 130 Kb unrepeatered.
2. 400 Mb/s transmission for 250 Km unrepeatered.
3. Laser modulation rates above 20 Gb/s.

4. Schottky barrier detectors with bandwidths near 20 GHz.

Most, if not all, the systems described in the Russian literature seem to have been assembled from domestically produced components; and, in fact, several of those components were described as having been mass produced. It seems doubtful that Russia can routinely manufacture components as capable as those described in its literature since the West cannot do so, but there is a large gap between the prototypes exhibited and a 5 Mb/s system. This gap is large enough that it seems likely that a 5 Mb/s system can be deployed.

Section 1

(U) INTRODUCTION

The basic question to be answered by this report is whether or not the Soviet Bloc can produce fiber optic transmission systems by utilizing only their domestic technology. Stated specifically, can the Soviets produce systems with a capacity of 5 Mbps without importing technology from the West?

Beyond simply answering whether the Soviets can build systems of a certain data capacity, this report will address the broader question of where the Eastern Bloc stands in this particular technology. To do this, it is necessary to review the state-of-the-art, review the state of Soviet art, and estimate what lag , if any, exists between the two. The method used to accomplish this task is outlined in the following paragraphs.

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To review the state-of-the-art it was only necessary to update the author's own knowledge of the field. This was accomplished by reading a number of recent review articles. If the review articles spoke of areas in which the author's knowledge was not current, specific articles in those areas were obtained. In this manner, it was possible to ascertain both where the industry stands at this time, and where it is likely to go in the next decade.

To review the state of Soviet art was more difficult because their review articles heavily reference Western sources. Thus, unless a Russian review article has a preponderance of Russian references, it is difficult to ascertain the Soviet contribution. Therefore, Soviet review articles may simply restate for a Russian audience the content of Western review articles. It was therefore necessary to read a number of Russian papers in each specific area of interest. Theoretical papers were ignored because we must acknowledge that Soviet theoretical knowledge is on the par with the West's, if for no other reason that that they continually reference Western literature. Experimental papers, on the other hand, can often tell one more than the result of a particular experiment; often, the sources of components and equipment can be determined. Similarly, if a paper describes the development of a dispersion measuring instrument capable of sweeping to a GHz, one can be sure that its authors have access to lasers and detectors with response times on the order of 1 ns.

To estimate the lag between Soviet and Western technology one must correlate a development's first appearance in Western literature with similar developments in Soviet literature. This requires that the history of the development of fiber optics in both the Eastern and Western blocs be researched and compared. But even such a comparison does not give the entire picture, because the open literature does not give one an indication of Soviet manufacturing capabilities.

It therefore seems that one is confronted with two choices when trying to estimate Soviet capabilities in any particular field. One can assume that the worst case always prevails; thus, if the Russians demonstrate a prototype system, one assumes that they can manufacture such systems in quantity. The other method of estimating Soviet capabilities depends on knowledge of their historical lag between prototype and production, but such knowledge is likely only to be available to the intelligence community. Without this specialized information, the author reverts to the first scheme and assumes that the Soviets' ability to deploy rests at the level of the most advanced prototype demonstrated.

The evidence provided by the literature search indicates that the Soviets can deploy a fiber optics system without importing technology from the west. This assessment is based on the fact that the Soviets have demonstrated prototypes of systems with the required technology and does not consider whether they can reliably manufacture all of the components of a demonstrated system in quantities necessary for widespread deployment. They demonstrated a short distance system capable of transmitting 114 Mb/second as long ago as 1977. Since that time they have demonstrated a system as long as 8 kilometers; and they have demonstrated a 5 kilometer long link utilizing both wavelength division multiplexing and duplex transmission. They have also done a number of studies on the radiation hardness of optical fibers and components.

Section 2

(U) STATE-OF-THE-ART

2.1 Fibers

Since the development of the first 20 dB/Km fiber in 1970, the losses in high silica fibers have dropped to the point where they rival their theoretical limits. These losses for single mode fibers are 0.16 dB/Km at 1550 nm (1) and 0.27 dB/Km at 1300 nm (2). For multimode fibers, the losses are somewhat higher, 0.31 dB/Km at 1550 nm (3), due to higher concentrations of dopants and consequently higher Rayleigh scattering. However, even though not much improvement in either silica fiber type is expected, there are a number of materials which potentially have losses in the range .001-.01 dB/Km. These materials will be discussed in the section of future projections.

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Just as the losses in optical fibers continued to drop through the decade of the seventies, bandwidths continued to climb with the evolution in fiber designs. The highest bandwidth multimode fiber mentioned to date has a bandwidth of 9.7 Ghz Km at 1310 nm (4). However, it must be mentioned that the peak bandwidth for this fiber was maintained only in a small spectral range of about 1310 nm. It must also be mentioned that production fibers have much lower bandwidths. For example, a recent mass production run yielded an average of 1.83 Ghz Km at 1300 nm (5).

In contrast to multimode fibers, which show sharply peaked dispersion vs. wavelength characteristics, single mode fibers are capable of maintaining low values of dispersion over wide wavelength ranges. The best fiber so far maintains less than 2 ps/Km-nm over the range 1280 - 1650 nm (6). These numbers were achieved with a multiply-clad (depressed-cladding, W, or index-well) fiber and indicate that: 1. The practical limits to data transmission over optical fibers may be as high as 100 Gbn/s over a 100 Km span (7); 2. We eventually may be able to wavelength division multiplex (WDM) a large number of channels into this low dispersion band; 3. Material dispersion is so small in certain fibers that fast systems can be built even with light emitting diodes (LED).

Because the loss minimum of silica fibers occurs at about 1550 nm and the dispersion minimum occurs at about 1300 nm, a class of fibers with the dispersion minimum shifted to the lowest loss region was developed. Best results reported are 0.24 dB/Km at 1550 nm where the dispersion minimum also occurs. For the sake of completeness, I will add that the best values obtained at the shorter wavelength of 850 nm are approximately 2.5 dB/Km and several hundred MHz Km (9). Cabling adds about 0.2 dB/Km to the values recorded for raw fiber.

In addition to their optical properties, fibers have also been continually improved in terms of their mechanical properties. The best strength thus far reported is 5×10^5 psi (10), which is comparable to steel strands of the same size. Because of these increases in strength, the lengths of fiber that can be continuously drawn has also been increasing. A continuous fiber of 100 Km in length has been drawn (11).

2.2 Components

Besides the fiber, the other key components of a fiber optic transmission system are the transmitter and the receiver. Admittedly, other components such as connectors, couplers, and multiplexers are important, but the fact remains that a point-to-point system can be built with just a transmitter, a fiber, a receiver, and a means of splicing fibers. Consequently, the concurrent development of devices compatible with the evolving fibers has been mandatory.

Sources, both LEDs and lasers, that are compatible with optical fibers have experienced the same progression through the wavelengths as have the fibers, themselves. The initial devices were made of AlGaAs and had peak emission wavelengths in the 800-900 nm range, corresponding well with the first low loss window of silica fibers. For the 1.3 micron and 1.55 micron windows, devices made of InGaAsP, which can be made to emit in the 1.1-1.65 micron range depending on exact composition, are most often used.

Although some work is being done on the development of high output and/or low threshold, AlGaAs injection laser diodes (ILDs), the state-of-the-art is generally represented by InGaAsP devices. Before going on to discuss the longwave devices, however, the best performances from AlGaAs should be summarized. Shortwave lasers with thresholds as low as 21.5 ma and output powers as high as 50 MW in a single mode have been demonstrated (2). In fact, an AlGaAs laser with an output of 200 mw CW is commercially available from Spectra Diode. Reliability studies (12) indicate that mean life times for AlGaAs LEDs are greater than 10^6 hours while ILDs made from the same material show mean life times ranging from 6.7×10^4–5×10^5 hours. Reference 2, however, mentioned that AlGaAs ILDs had projected life times of 10^6 hours. The difference between the two values cited may simply depend on differences in specified operating conditions; generally, the lower the power output and the operating temperature, the longer the diodes will last.

The following information about InGaAsp lasers and light emitting diodes is freely abstracted from references 2 and 5, which are themselves review articles.

As with their shorter wavelength cousins, longwave LEDs sometimes offer a cheaper, easier to use, and more reliable alternative to longwave ILDs. Since LEDs normally couple on 50-100 microwatts into a 50 micron multimode core, they were initially thought unsuitable for use with single mode fibers. Recent studies, however, have shown that not necessarily to be the case. By increasing the dopant density, the carrier lifetime can be reduced to about 2 ns, thus increasing the LED's speed; this increase in speed, unfortunately, comes at the expense of output power. Modulation frequency can thus be extended to about 1 Ghz, but the useful frequency range is considerably lower. Modulation frequency and coupled power are not the only parameters limiting the applicability of LEDs to single mode systems because spectral width is another limiter. Surface emitting LEDs at 1300 nm have spectral widths of 120 nm, while at 1600 nm the width is 140 nm. Used at the wavelength of zero chromatic dispersion (1300 nm), a surface emitting diode therefore has a maximum gain-bandwidth product of 2.4 Ghz-Km. On the other hand, edge emitting LEDs have spectral widths of only about 70 nm at 1300 nm. This implies that their maximum gain-bandwidth product is approximately 7 Ghz-Km; they also couple 2-3 times more power into fibers than surface emitters. Projected mean life times for surface emitters are on the order of 109 hours (2) while values for edge emitters are expected to be at least several hundred thousand hours (12)

The best performance to date for an IGaAsP edge emitting LED used in a single mode systems is 180 Mb/s for a distance of 35 Km (13). Such performance indicates that there are likely to be a number of potential applications for single mode-LED systems in the future. Longwave LEDs are commercially available from a number of Western vendors.

Multimode InGaAsP/InP lasers with peak wave lengths in the 1300 nm range have been commercially available for several years. More recently, lasers emitting at 15509 nm and lasers emitting in a single mode have become available, but they are very expensive. These single mode lasers emit a single transverse, or spatial, mode but they do not emit in a single longitudinal mode. This means that although they have narrow beam widths and can be efficiently coupled to single mode fibers, they do not emit a single wavelength. The single frequency ILD is therefore the hottest topic in emitter research.

As mentioned, single mode lasers for both short and long wavelengths have been produced, but they both share certain deficiencies. At high modulation rates, there is a tendency for their spectral outputs to broaden and to hop around. In such characteristics were also shared by the single frequency lasers, they would completely destroy its single frequency characteristic at high speed. The spectral spreading, also called chirp, and hopping of the output would increase the chromatic dispersion experienced by pulses, and limit the ultimate data rate achievable with these lasers. Consequently, single frequency lasers must maintain their single frequency output not only when run in the CW mode but also when pulsed rapidly. Such lasers exist in the research labs and are called dynamic single mode lasers.

Many types of dynamic single mode (DSM) lasers are being developed, but they can be broadly grouped into four families (14): coupled cavity, frequency selective feedback, injection locked, and geometry controlled. All these different lasers are designed to achieve the same goal, selecting one frequency, and one frequency only, for lasing action. Coupled cavity lasers work by allowing the light to pass through an additional cavity. Thus only the frequency that is resonant in both cavities is allowed to propagate. The difficulties in tuning the frequencies of cavity lasers was cause for the development of the frequency selective lasers. Frequency selective lasers use either external diffraction gratings or integral Bragg reflectors to select the output wavelength. The internal Bragg reflectors are formed directly under or above the laser cavity by integrated optics techniques; this type of laser is also called a distributed feedback laser (DFB). In injection locked lasers, the diode laser's output is forced to contain a single frequency by coupling it to another single frequency laser such as a HeNe. The principal geometry controlled DSM laser is the short cavity laser. The geometry of this laser forces adjacent modes to be spaced by about 20 angstroms rather than nearly overlapping each other. High reflectivity coatings or filters can then be used to enhance the wavelength of interest. Hybrids of the various families are also being investigated.

DSM lasers have been demonstrated that produce spectral lines as narrow as one millionth of an angstrom (14) and that have maintained narrow linewidths even when pulsed at several Gb/s. Which type will eventually be most popular will probably depend on which is most easily manufactured, although manufacturers are leaning toward the DFB laser. British Telecom Research Labs, AT&T Bell Labs and NTT Labs in Japan have traded the world record for data rate-distance numerous times as a means of displaying the superiority of their designs. Commercial realization, however, remains at least a year or two in the future.

Silicon is an ideal detector material for the short wavelength fiber optic systems because its bandgap nearly matches the systems' 800-900 nm operating range. Commercial silicon PIN (positive intrinsic negative) diodes are therefore highly developed and can be expected to provide the following characteristics: quantum efficiencies above 90%, response times below 1 ns, and dark currents about 1010 amps. Likewise, silicon APDs (avalanche photodiodes) are commercially available with the following parameters: quantum efficiencies near 100% response times about 1 ns, current amplification factors of about 100, noise factors of about 5, and primary dark currents around 1011 amps (2).

The first detector used for the 1300 nm wavelength was germanium, but devices constructed from silicon suffer from larger dark currents and noise factors than do comparable silicon devices. Germanium APDs also suffer from decreased high frequency response at 1550 nm has recently described (15). These problems with germanium are caused by its physics and therefore cannot be solved by improving manufacturing techniques; new materials must be found.

Before detailing the work being done on alternatives to germanium, the best results reported for germanium should be detailed. The best report found for a Ge APD described a device with the following parameters: excess noise factor of

7 at a gain of 10, a risetime of 150 ps, a frequency response of 2 GHz, a quantum efficiency of about .8, and a total dark current of 1 microamp (2, 5). Ge APDs are commercially available with somewhat poorer specifications.

Another device that has been commercially available for several years is the InGaAsP/InP PIN diode with integral GaAs FET (field effect transistor) amplifier. This device can be used from several megahertz to several hundred megahertz, and it theoretically will exhibit lower noise than a Ge APD at all frequencies below 1 GHz. However, what is really needed is a better APD; and that is the area in which detector research is currently focussed.

Other than germanium, the most developed technologies for longwave detection are InGaAsP and InGaAs. PIN diodes made from these materials have been commercially available for a number of years; APDs of two different types, planar and mesa, have been demonstrated. The mesa is the more developed of the two types, and the best device found described in the literature had a noise factor of 5 at a gain of 10 with a primary dark current of 3 nanoamps (2). Its noise factor if already better than germanium APDs, but further work will be needed before commercialization.

Other materials have been used to produce long wavelength detectors, among these are HgCdTe, and AlGaSb or AlGaAsSb/GaSb systems have already been demonstrated in both PIN diodes and APDs. The APDs have displayed efficiencies in the .9-.9 range, gains in the 40-100 range, and bandwidths above 1 GHz. Unfortunately, their dark currents are high. In HgCdTe, a photodiode with dark current of 1 nanoamp, bandwidth of 850 MHz, and responsitivity of .8 at 1300 nm has been demonstrated. However, commercial development of any of these detector systems seems to lie sometime in the future.

In addition to PIN diodes and avalanche photodiodes, two other devices are being researched. InGaAs/InP has been used to produce phototransistors (16), and there is hope that these may in the future be developed into high speed devices with the capability to measure very low light levels. For ultra speed detection, although only at short wavelengths so far, the GaAs Schottky barrier photodiode is being developed. Thus far, a device with 18 GHz bandwidth has been demonstrated (17).

2.3 Systems

The pushers of the state-of-the-art in optical fiber communications have been the world's phone companies, not its military organizations; and the phone companies have been shattering the records so rapidly that it is hard to report exactly what those records are. As an example, between June of 1983 and September of 1984, seven records were set. The players in this competition were: AT&T Bell Labs, Nippon Telephone and Telegraph, and British Telecom Research Labs. Although it is possible that the record has since changed hands, as of early this year, Bell Labs had both ends of the record (18). The record for bandwidth-distance was achieved with a system that transmitted for 130 Km unrepeatered at a data rate of 2 Gb/s. As for sheer unrepeatered distance, a 420 MHz signal was sent 203 Km. Performance curves of typical fiber optic systems are shown in Figure 1.

Besides these "hero" experiments, much research is being done on optical multiplexing and heterodyning. The reason that the hero experiments are receiving so much attention is that they push the major systems components to their limitsexciting. To illustrate this point, one need only look at the components used to produce these records. All seven systems used 1500 nm light to take advantage of the fiber's absorption minimum; fiber losses including splices average only .25 dB/Km for all systems. All seven systems used single frequency lasers; five used DFB lasers, one used a cleaved-coupled-cavity, and one used both injection locking and distributed feedback. As for receivers, only one system used a PIN diode while three others used GeAPDs. The other three systems used a new APD invented by Bell Labs. Made of InGaAsP, this device is called a separate absorption, grading, and multiplication region (SAGM) APD., Sensitivity for the SAGM APD is claimed to be 7 dB greater than a PIN-FET, and 4 dB greater than a GeAPD (18).

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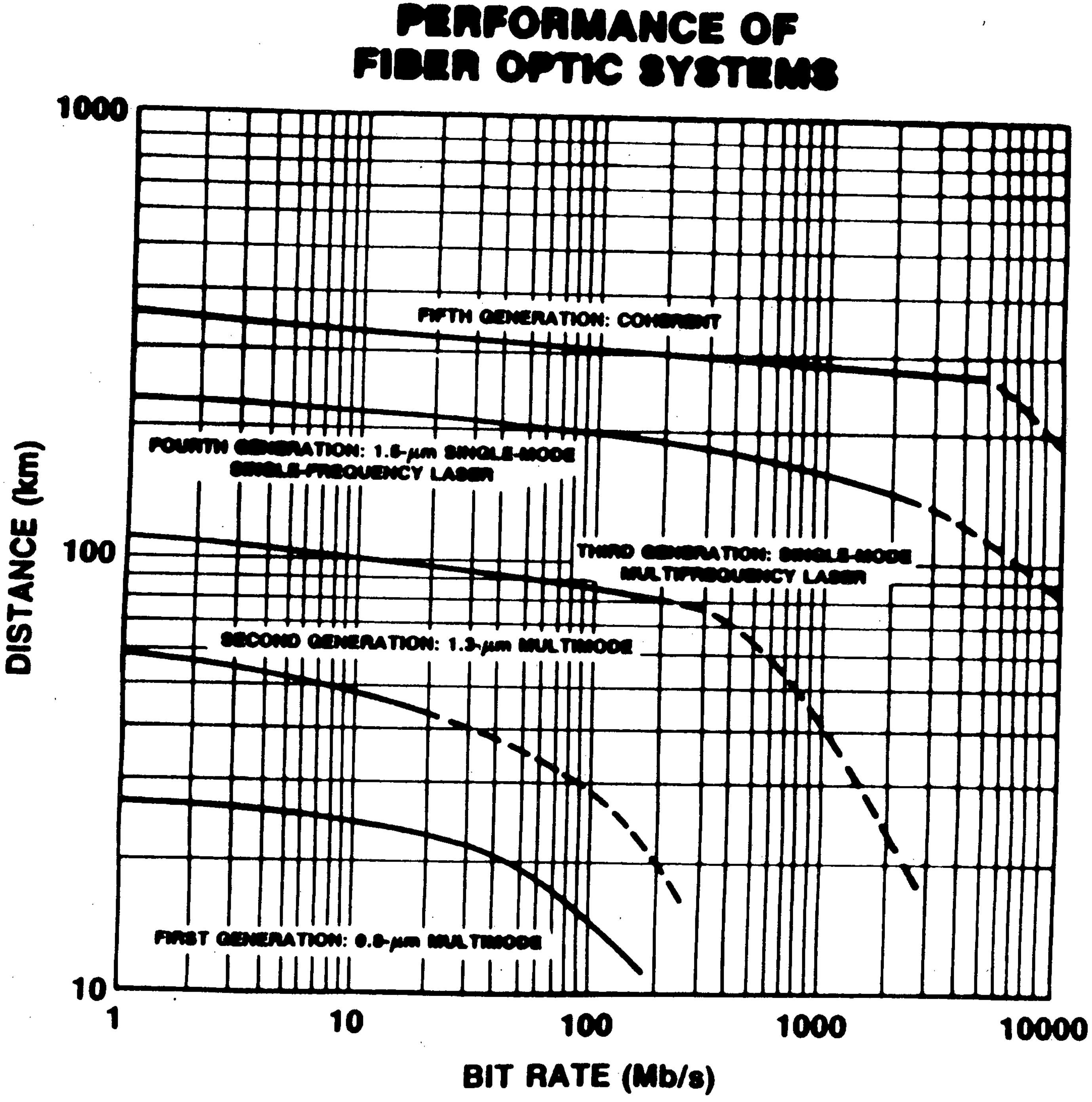

Figure 1.

Section 3

(U) SOVIET TECHNOLOGY

3.1 Fibers

Although Soviet fiber optic technology does seem to lag the West by several years, the gap is not large, and the Soviets are thus able to demonstrate very capable systems. This fact can be illustrated by tracing some of the evolution of the Soviet fiber optic capability.

As long ago as 1977, the Russians had demonstrated the ability to produce fibers with losses below 1 dB/Km (19); the reported values for that fiber were: .7 dB/Km at 1600 nm, 1 dB/Km at 1Km at 1200 nm, and 5 dB/Km at 820 nm. Additionally, it was clear that the Russians were well aware of the military potential of optical fibers because the authors of reference 19 proposed building systems in the 110-1700 nm range. Their proposal was based not only on the lower losses that they had achieved at the longer wavelengths but also on referenced articles both Western and Russian, indicating that fibers had greater radiation resistance at wavelengths greater than 1 micron. Simultaneously with the proposal to build systems at the longer wavelengths, a system capable of transmitting data for .5 Km at 1540 nm was demonstrated (20).

By 1978, the Soviets had produced their first strengthened fiber optic cable (21). Reported losses for ten fiber cable were 5 dB/Km at 1060 nm and 8 dB/Km at 900 nm.

By the following year, a load bearing cable was announced (22). Although designed for oil well logging, the high hydrostatic pressures and high loads that this cable had to withstand indicate that with perhaps minor modifications, it could have been adapted for use under the sea. Excess losses in this cable were reported as 2 dB/Km above those of the raw fibers.

In addition to their work on various types of cables, the Russians have duplicated virtually every type of fiber being produced by the West. In 1980, they announced their first single mode fiber (23). It exhibited losses below 5 dB/Km over the range 870-1020 nm, and maintained 99% single polarization for a kilometer. In that same year the Russians also demonstrated a fairly low loss, silicone clad fiber (PCS) with losses of 20 dB/Km at 980 nm (24). The developers of that 200 micron fiber thought that the observed losses were due to high losses in the silicone rather than the silica, so they retested the fiber by exiciting only lower order modes (modes less likely to encounter the core-cladding interface). Losses consequently dropped to 8 dB/Km at both 860 and 980 nm. The authors therefore concluded that by purifying their silicone, production runs of 10 dB/Km could be achieved. Since one of the main attributes of PCS fiber is its radiation resistance, it was not surprising to see these authors also speaking of increased radiation resistance at the longer wavelengths.

Because the standard two layer, single mode fiber has a very small core, it is difficult to produce interconnection devices for this type of fiber. Consequently, much effort has been expended in trying to produce fiber designs that propagate a single mode yet have larger core sizes. Among these fiber types are the already mentioned W fiber and the ring fiber. Thus in 1981, the Russians introduced a ring fiber (25) and a W fiber (26). The best results obtained with the ring structure were 4.6 dB/Km at 1020 nm. On the other hand, losses for the W fiber were 3.2 dB/Km at 1200 nm, and single mode propagation was achieved with a 13.5 micron core as opposed to the 8 micron core that would have characterized an equivalent two layer fiber.

Another area of interest in both the East and the West is the application of optical fibers to data communications. Since this field often involves much shorter fiber runs that does telecommunications, larger core fibers with lower bandwidths are acceptable. In turn, larger core fibers mean less expensive sources and connectors can be used. Thus, it was in the Russians interest to develop larger core fibers, And they have done so. A 1982 paper described an all glass fiber, as opposed to PCS, with a 100 micron core (27). This fiber had a graded index and showed both larger effective numerical apperture and higher bandwidth than a comparably sized PCS fiber. Its reported parameters were an NA of .4, modal dispersion of 2.5 ns/Km, and a loss of 6 dB/Km at 850 nm. The material dispersion was also measured and found to be approximately 100 ps/Km-nm at 850 nm. The dispersion minima was shifted to the 1350-1400 nm range. Another 1982 paper (28) reviewed work on all polymer fibers, which have some potential short run applications. Of interest in this article were the facts that the Russians are paralleling Western efforts in this area and that "Polymer fiber waveguides subjected to gamma rays or neutrons in doses of 5 x 10^5 rad have been found to recover their properties after 50 msec".

The latest document pertaining to silica waveguides should serve as an indicator of where the Russians stand with respect to the West. That paper (29), dated 1984, reported on a graded index, multimode fiber that was obviously developed for long haul applications. The reported losses were .25 dB/Km at 1550 nm, .50 dB/Km at 1300 nm, and 2.45 dB/Km at 850 nm. These values can be constrasted with the theoretical limits predicted for the materials used, these limits were: .20 dB/Km at 1550 nm, .40 dB/Km at 1300 nm and 2.43 dB/Km at 850 nm. The bandwidth was measured at 870 nm and was 900 MHz-Km.

As previously mentioned, the Russians are just as interested in the effects of ionizing radiation on optical fiber systems as is the West. And although it is likely that some papers were classified, a number of these articles were published in the open literature (30-35). The last of these references is a review article that draws on both Russian and

Western sources. One reference on the effect of radiation on light emitting diodes was also found (36).

The final question that one might ask about current Soviet capabilities in fiber optics is where do they get their fibers? An auxiliary question is, "Can we deny them access to optical fibers?". It has become apparent in the courses of performing this search that the Soviets are developing their own capabilities in parallel with the West. It is true that they do seem to lag somewhat, but they also seem to eventually match our accomplishments. Thus, there appears to be no way to embargo anything tangible, and the restriction of research results would most likely slow development in the West. Besides, there is at least one fiber company in Yugoslavia, ISKRA>

3.2 Components

In the development of semiconductor lasers, the West has a lead over the Soviets, but the lead is by no means enormous. In 1980, the Russians demonstrated InGaAsP/InP lasers that could run CW at room temperature (37). These lasers had threshold currents as low as 30 milliamps, and output powers as high as 10 milliwatts in the 1240-1280 nm rnage. Additionally, they were claimed to be kink-free and to emit a single transverse mode when strongly pumped. More reliable single mode operation at 1300 nm seems to have been achieved with a design termed a three-layer waveguide laser (38).

By 1982, the range of continuous wave (CW) operation had been extended to the 1500-1600 nm range (39, 40). The output powers for these lasers were 2-3 nm, and threshold currents were as low as 23 mA. Some of the lasers were also claimed to have single frequency outputs, although it is likely that their outputs were only single frequency in the CW mode.

The Soviets have also been interested in the various aspects of ILD behavior. Among the areas being investigated are the following: laser to fiber coupling efficiency (41, 42), threshold current reduction (43, 44), and the temperature sensitivity of InGaAsP lasers (45). Their results in terms of coupling efficiency have been quite good with claimed efficiencies of 90%, or 16 mW, into multimode fiber and 36% into single mode fiber. In addition to these studies of laser properties, the Soviets have also been working on different laser materials. Lasers have been fabricated from GaSb/GaAlAsSb (46) for use at 1600 nm. While achievements with GaSb are not impressive when compared with what has been achieved with InGaAsP lasers, the mention of this research serves to illustrate the breadth of the Soviet program.

The Russians have also been experimenting with the use of optical feedback to produce single longitudinal mode outputs and ultrashort pulses. A diffraction grating has been coupled to a 1300 nm laser to produce a single frequency output with up to 4 mW output power tunable over a 24 nm range (47). However, this laser cannot be termed a dynamic single model laser because its frequencies above 20 MHz. Optical feedback by an external mirror also has been used to produce tunability in a short wavelength laser (48), but mode hopping could not be suppressed with that design. In addition to its use in producing single frequency outputs, feedback by diffraction grating has been used to produce pulse trains of very narrow pulses (49, 50). The best results reported in these experiments were 2.7 ps pulses at a repetition rate of 660 MHz.

The first laser displayed by the Soviets that appears to be true dynamic single mode laser made its appearance in 1984. This laser apparently used a holographic diffraction grating to select the frequency. It also used a second diode laser as a modulator and travelling wave amplifier. The results achieved included both modulation at up to 2 GHz and reduction in the optical spectral width (51). With this laser, the Russians can be said to have entered the fourth gneeration of optoelectronic systems research. However, they are not yet world class competitors.

Before addressing the Soviet capabilities in the field of photodetedctors, it should be mentioned that they have also been doing resesearch into light emitting diodes. As long ago as 1978, they produced long wavelength LEDs made by liquid phase epitaxy (52). These InGaAsP/InP LEDs were very efficient, and yielded output power of 15 mW at 50 mA. They would thus be suitable replacements for lasers in some applications.

In the field of detector research, the Russians also seem to lag. They seem to have mastered silicon because their Si research is on such advanced topics as enhancing spectral range and producing sub-nanosecond response times (53-55). They are also working with germanium photodiodes (56) and Schottky barrier diodes (57). In fact, they claim to be the first to combine an integrated optic waveguide with a Schottky barrier to produce a detector with enhanced responsivitity. Several combinations of materials were tried including gold with GaAsP on a GaP substrate and silver with GaAsP/GaP. It was mentioned that Schottky barrier detectors would be operable at microwave frequencies; the authors estimated time constants of less than .5 ns.

Despite their activity in other areas of detector development, the Soviets definitely seem to be lagging the West in the area of longwave APDs constructed from alloys of groups III and V of the Periodic Table (III-V). This statement is based on analysis of a 1983 Russian review article on the subject (58). In that review, Russian references were used but only when referring to research on III-V materials. When articles pertaining to the actual construction of prototype APDs were used, they had all been written by Western authors. Thus, it appears likely that Soviet research into the subject dates back, not much more than two years.

3.3 Systems

This section contains the essence of the entire study, since it will attempt to answer whether or not the Russians can deploy a 5 Mb/s fiber optic system.

The Soviets undoubtedly lag the West in fiber optics; however, the gap is not as large as one would normally be inclined to assume. Since they have access to our literature, it would be naive to assume that they could not at some point duplicate our achievements. On some developments, the delay between attainment in the East and the West seems to be four or five years, while other developments are duplicated within a year or two. In fact, the estimation of the exact lag between the two blocs could in itself be the subject of a study. By correlating, on a one for one basis, the development in the two blocs of the principal milestones in the field, it should be possible to achieve a good estimate of the exact lag between the blocs. However, that is not the subject of this report; so we will here concentrate on building evidence to support the contention that the Soviets long ago achieved the capability in question.

The Russians cannot necessarily match the West's technology in elegance, but they can often achieve the same results through brute force. In a 1977 study designed to study the dispersive properties of fibers, the Soviets displayed the ability to send signals modulated beetween 800 and 940 MHz through 25 meters of high loss (600-700 dB/Km) fiber (59). The system consisted of a HeNe laser beam modulated by an external modulator, the fiber was high loss, and the detector was a photomultiplier coupled to a microwave resonator; the setup was designed as a measurement system, not a communications link, but it did demonstrate some capability. That capability was displayed in the very same journal issue as Reference 59. In an article about using fiber optics to communicate between two computers, an eight fiber link that could transmit 64 Mb/s was demonstrated (60). Therefore, the actual optical signal on each channel was transferring data at 8 Mb/s for 20 meters over high loss fibers. Thus, by 1977 the Soviets had already exceed the speed in which we are interested, so what remains to be seen is whether they have improved their distance capability.

Later in 1977, the Russians improved the speed of their systems by demonstrating two new systems: a 8.5 Mb/s system designed to transmit 120 phone calls, and a 114 Mb/s system designed to transmit either digital color TV or 1440 telephone circuits (61). However, the fibers used still had losses of 500 dB/Km. Several months later the first system to use low loss fibers was demonstrated (62). The data transfer rate between two computers was only 11 KB/s, but notable were the introduction of a mass producible LED and fibers with 10-20 dB/Km losses, both Russian designs. The transmission distance was .75 Km.

1978 saw the introduction of 1300 nm systems in Russia. A 2 Km long telecommunications line was demonstrated, and the stated system margins indicated that the system could actually operate in the 10-20 Km range (63). The data rate was 10 Mb/s, and specifically stated as an advantage of 1300 nm transmission in addition to the greater transmission distances was the improved radiation resistance. This is not normally of concern in civilian telecommunications.

The following year, radiation resistance was again mentioned as an impetus in the development of a 1300 nm system demonstrating wavelength division multiplexing (64). Although only .5 Km long and unidirectional, this system was notable for several reasons. It demonstrated the use of fiber optic couplers and claimed single mode laser emission was made possible by proper control of the pumping current. With this control of the spectral output, the researchers were able to multiplex two signals separated by only 10 nm and still maintain crosstalk to less than -20 dB. However, the fact that spectral output of standard ILDs cannot always be controlled by controlling the pump current was illustrated in a 1982 paper by the same authors, when they extended their 1300 nm WDM system to 5 Km and introduced duplex transmission (65). Two signals were multiplexed in each direction (although the system was claimed to be capable of handling 10 channels in each direction) with a separation of 17 ns between channels. However, the lasers could not produce single frequency outputs so their spectral widths had to be narrowed t4o 8 nm by filtering, not by current control. Also interesting was the fact that the couplers used had rather high losses, but they were serviceable and they were Russian manufactured. The system's pass band was 5 MHz for its 5 Km length mostly because it was intended as a demonstration of multiplexing capability not data transfer capability. The researchers had used step index fiber, but they noted that the pass band could be greatly increased simply by installing graded index fiber.

The authors of reference 65 made an interesting point about the need for single frequency lasers. It has been mentioned that fibers are being developed that will allow the wavelength division multiplexing of hundreds or thousand of channels. Similarly, WDM components have been developed and are commercially available for this purpose. However, systems demonstrating WDM have invariably transmitted relatively few channels. This is because the close spacing of channels requires sources that are both spectrally narrow and drift-free; DSM lasers are needed.

The longest system found in the Soviet literature was an 8 Km system with a pass band of 6.5 MHz (66). This must have been a short wavelength system because the source used was AlGaAs laser, and 8 Km at that wavelength is not bad. As with many of the other Russian systems found in the literature, the purpose of this system was not to display the system's capabilities but rather to experiment with mode coupling in step index fibers. All the Russian papers seem to concentrate on demonstrating one achievement, be it 1300 nm transmission, high speed, WDM, or long distance. Not one paper followed the Western penchant for pushing a system to its limit in bandwidth-distance product. Perhaps the reporting of research into such areas is prescribed for military reasons, perhaps the authors simply want to avoid unfavorable comparisons with Western results, or perhaps the proper literature was simply not discovered. However, the factors remain that the Soviets have displayed high speed short distance systems, low speed long distance systems, low loss-high bandwidth fibers, and high speed sources and detectors. It therefore seems fairly reasonable to assume that there is nothing preventing the assembly of the various components into a high speed long distance system. To further support this statement, it is only necessary to point out that the Poles, who because of their political situation do not share the latest in Soviet technology, have independently demonstrated an 8 Mb/s fiber optic system and the ability to produce their own fiber (67).

EMP, as a propagated signal, can damage equipment or cause RF interference. In the case of fiber optics transmission systems, the concern is more with damaged equipment. A surface burst generates an EMP due to the rapid ionizing radiation effects. The EMP can be divided into two regions: a source region which is associated with the air volume and ground current returns where the EMP is generated, and the radiated region. Detonations ranging from about 70 miles altitude to several hundred miles altitude give rise to high altitude EMP. This is the dominant EMP survivability concern for most systems. The source of the HEMP is ionization at the top of the atmosphere cause by X-Rays and GAMMA rays moving downward from the nuclear burst points. Residual GAMMA radiation can travel over 2000 miles.

Within the source region, which extends to 3-5 kilometers from the source, electric fields may exceed 100 kV/meter. The EMP energy coupled to a system must be treated as a survivability issue because permanent damage may result. Beyond this 3 to 5 kilometer distance, the radiated fields are less intense, and less than high altitude EMP fields. The latter field strength is generally specified at 50 kV/meter as a system survival requirement. While fiber optics are attractive for use in High Altitude EMP (HEMP) mitigation programs, any such application must include protection against radiation damage.

As mentioned before, degradation of fiber optics systems due to nuclear radiation is of major concern. Nuclear radiation could cause damage to the transmitters, receivers, and repeaters of fiber optic systems. Prompt radiation and fallout could cause darkening of the fiber optic cable, which might result in loss of transmission. The darkening of the fiber optic cable is caused by the formation of "charge traps" that absorb and scatter the incident light. This produces an induced attenuation in the fibers which progressively decreases after the source of radiation is removed. The state of the cable may or may not return to the original state in the absence of the radiated field. Radiation experiments have lead to two interesting observations. First, a correlation seems to exist between the level of radiation-induced loss and the intrinsic material loss. Fibers with higher loss have a higher radiation sensitivity, which probably is due to the higher impurity concentration. Second, after a certain dose, polymer-coated fused silica fibers become extremely saturated; other fibers tend not to saturate and show a fairly linear behavior. The magnitude of the induced loss effect at a given time depends on the nature of the radiation, its total level and rate of application, the wavelength of observation, the composition of the glass, the temperature and, in some cases, the previous history of the material and the optical power fed to the fiber.

Reference 100 defines the level of increased earth potential as a function of the magnetic disturbance (which could be created from EMP) and the type of earth structure. Typically, a fiber optics link connects two sets of terminal equipment together via wideband fiber optic cable through wideband repeater amplifiers. A secondary copper line is run in parallel with the fiber optic line to provide monitoring control of the repeaters. There are two possible failure modes that can occur from this increased potential:

a. The power supplies for the repeaters (or regenerators) distributed along the line can fail and/or;

b. The monitor and control units that regulate the signal amplitude along the link can fail.

Either or both failures noted above would increase the susceptibility of the fiber optic link to EMP.

Section 4

(U) PROJECTIONS-WESTERN

4.1 Fibers

It has already been mentioned that high silica fibers have already attained their theoretically predicted minimum losses. Further improvements, therefore, can only be expected in entirely different glass systems. A number of materials are potential candidates for the optical fibers of the future. Among these candidates are certain crystalline materials, such as KRS-5, and several families of glasses: heavy metal fluorides (HMF), heavy metal oxides, and chalcogenides. In the past five years, much work in both the East and the West has been done on these materials because they promise: transparency from the near UV (.2-.3 microns) to the mid-IR (7-8 microns), losses a factor of 10 to 100 lower than the best silica, and less susceptibility to ionizing radiation in the mid-IR (68).

Little work, either theoretical or experimental, has been done on the heavy metal oxide glasses with the exception of germanium oxide. There also seems to be more research being performed on glasses than is being performed on crystals, even though there are indications that certain crystals, KC1 for example, may ultimately exhibit the lowest losses of all the materials being considered (69). On the other hand, the chalcogenide and HMF glasses are being widely studied.

Perhaps one of the reasons that glass research has been given such impetus was a paper published in 1981 that predicted ultimate losses of .001 dB/km for certain HMF glasses and .01 dB/km for chalcogenide glasses (70). If losses this low can actually be achieved, it may be possible to span oceans without using repeaters. Another reason for the interest in mid-IR fibers was another 1981 paper that reported on the effects of gamma rays on bulk samples of a HMF glass. The researchers found increased losses at both the high and low ends of the spectral range, but found no incremental losses in the range 2.5-4 microns (71). No effects were recorded even of doses of 45 Mrad, and the region where there appears to be no radiation damage overlaps the region of the lowest loss; these glasses therefore show promise for military applications.

One of the reasons that the authors of reference 70 predicted such low losses for the HMF and chalcogenide glasses was that Rayleigh scattering was viewed as one of the most important loss mechanisms in low loss fibers; and because Rayleigh scattering is predicted to be lower in the low melting point glasses, such as HMF and chalcogenide. However, when the initial predictions were made, losses in the 300-500 dB/km range were the state-of-the-art. Since that time, losses have dropped considerably; and the projections, at least for chalcogenide glasses, may have changed. The latest paper published by some of the same people who authored reference 70, reports on the development of three different chalcogenide glasses (72). The best results reported in reference 72 were for a glass made of 40% As and 60% S. Lowest losses for this glass were 35 dB/km at 2.44 microns. While both reporting improved performance and reiterating that chalcogenides are less prone to crystallization than HMF glasses, the authors nevertheless also mentioned a "weak absorption tail". This tail is evidently caused by a loss mechanism not originally included in the estimates of the ultimate losses of chalcogenides. It now appears that chalcogenide glasses may never exhibit losses below about 10 dB/km. If that is the case, the only application for these glasses may be the short distance transmission of energy from a CO_2 laser.

As already mentioned, the only heavy metal oxide given extensive notice appears to be germanium oxide. The latest results for this glass are 4 dB/km at 2.0 microns and 15 dB/km at 2.4 microns (73). The low losses thus far achieved are due in part to the ability to apply techniques developed for silica fibers directly to Ge fibers. Unfortunately, this similarity with silica extends to the Rayleigh scattering coefficient of germanium oxide fibers; these fibers are likely to have ultimate losses very nearly equal to those of high silicate fibers. If that turns out to be the case, then Ge based fibers will face two difficulties when compared with Si based fibers. First, germanium oxide does not transmit very far into the IR (only to about 2.6 microns), and second, Ge is expensive when compared to Si. The authors of reference 73 therefore suggest that one of the realistic uses for germanium oxide fibers might be the construction of optical signal amplifiers for ultra long distance communications systems.

The glasses with the best chance of exceeding the performance of silica fibers is therefore the heavy metal fluorides, and work in this area is proceeding rapidly. Leaders in this field are the United States, France, and Japan.

There are two distinct categories of glass in the HMF family. Most development efforts seem to be concentrating on one of these categories, the glasses based on either fluorozirconate or fluorohafnate. An excellent review article (74) has summarized the achievements to date. Drawing freely from that paper, the following summary of properties can be offered.

The best losses reported are 8.5 dB/km at 2.1 micron and 6.8 dB/km at 2.55 micron. Material dispersion zero is in the range 1.6-1.7 microns while the lowest losses are expected to be in the range 3-4 microns. However, waveguide dispersion can be used to offset the material dispersion and shift the zero toward the region of lowest loss. Doping with chlorine or bromine can achieve the same goal. Additionally, the material dispersion is low (several ps/km-nm) over a wide wavelength range, so even without offset from waveguide dispersion, the overall dispersion will be low over a wide range. Coupled with the wide spectral transparency, this means that WDM of very many channels may be possible.

The strengths of HMF fibers are currently running about 1/3 that of silica fibers, but their theoretical limits are closer to those of silica. Strengths reported to date are in the range 10 E4-10 E5 lb./sq-in., but theoretical limits may be 5x10 E5 lb./sq-in. The practical limits may be in the range of 3x10 E5 lb./sq-in.

The ultimate fracture toughness of HMF glasses is expected to be 1/2 to 2/3 that of silica, but silica's values are high. Therefore, the attainment of a sizable fraction of silica's toughness will yield acceptable fiber strengths. One of the main barriers to attainment of high strengths in fluoride glasses is their susceptibility to attack by water. In fact, there has been some talk about the possibility of having to hermetically seal HMF fibers. This may not be necessary, however, because Corning has just announced a newly developed HMF with an order of magnitude less solubility in water. So far this glass has only been prepared in bulk form and has not been drawn into fiber, but future prospects are good.

It therefore seems that within the next ten years some form of mid-IR fiber will be in use. At this point in time, it appears that the most likely candidates for the production of these developed fibers are the HMF glasses. These glasses have already been developed at a more rapid rate than were silica fibers. And considering that silica fibers went from a breakthrough 20 dB/km to their theoretical limits in ten years or less, low loss, mid-IR fibers are likely to appear by about 1990 unless fundamental problems hinder development.

4.2 Components

Articles written just a few years ago claimed that the maximum rate at which a laser diode could be directly modulated was about 2 GHz, yet this limit has already been exceeded. By using such schemes as combining high drive currents with low modulation depths, lasers are now being modulated at greater than 20 GHz in research laboratories. In fact, lasers are commercially available with bandwidths of 6 GHz (from Ortel in California). Over the next several years, we should therefore see higher and higher speed lasers become widely available. Similarly, Schottky barrier photodetectors with bandwidths near 20 GHz have also been demonstrated in the laboratory. These too may eventually prove commercially viable.

One thing that was noticed was that the older papers listed lower values of the theoretical limit for system bandwidth-distance product than did the newer papers, and the limits have invariably been exceeded. The author would therefore compound these errors by stating speed limits which devices will never exceed. The fibers themselves may set the ultimate limits.

However, to push the fibers' data handling capacity to the limits, the most sensitive detectors must be used with lasers that emit pulses that will suffer neither modal nor chromatic dispersion. Thus, the devices most necessary for the attainment of fiber limited bandwidth-distance products are single frequency lasers and long wavelength APDs. And, as has already been mentioned, both devices are being hastily pursued in the world's top laboratories. Some shakeout in terms of device designs should occur in the next several years with commercialization of the devices following shortly afterward. With the widespread availability of such devices, heterodyne detection may become a reality. Figure 2 shows performance characteristics of long wavelength and single frequency devices.

LONG-WAVELENGTH PERFORMANCE OF CONVENTIONAL AND DISPERSION-SHIFTED FIBER

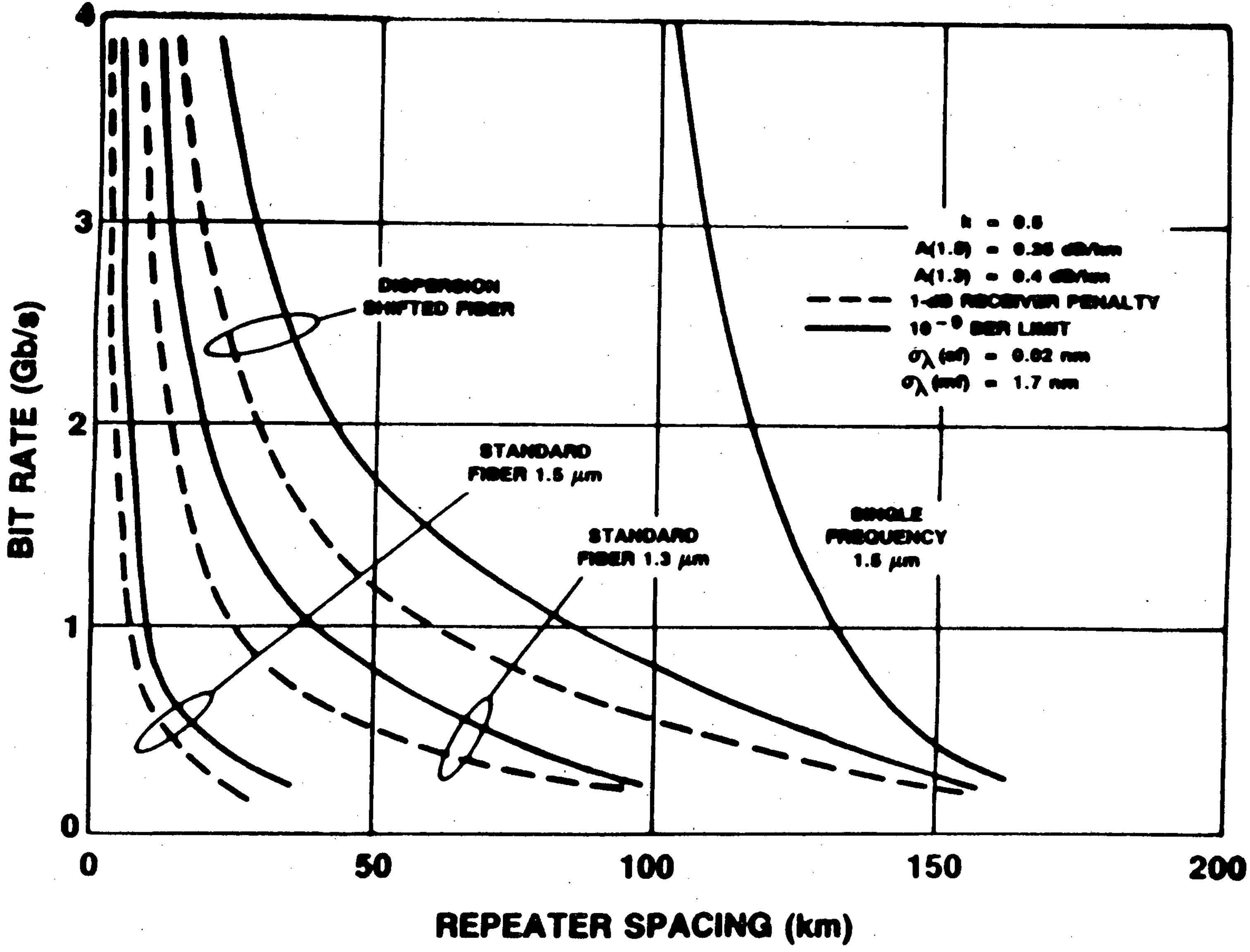

Figure 2.

4.3 Systems

By combining the components and the fibers previously discussed with some of the devices mentioned only in passing, such as WDMs and integrated optics, future systems will have much more capacity than is currently exhibited. In the near-term (2-5 years), we can expect to see higher power and smaller spectral widths from single frequency lasers, lower noise from long wavelength APDs, the introduction of some integrated optical devices, and coherent transmission and detection. In the longer term, ultra low loss mid-IR fibers may be developed as well as purely optical repeaters; research on these items is currently in a more preliminary stage.

Of the topics just mentioned, integrated optics and coherent transmission show great promise in the near-term. Therefore, accomplishments to date in those areas will be briefly summarized in the following paragraphs.

A number of discrete components such as couplers, modulators, and switches have already been demonstrated in integrated form. Through the use of integrated circuit techniques, waveguides and other structures can be formed from optically active materials. The parameters of the structures can then be varied by varying some external parameter, usually an electrical field, thereby controlling the amplitude, phase, or direction of a light beam traversing the structure. To date, the main achievement of this technology is the miniaturization of fiber components; but eventually whole systems comprised of emitters and/or detectors, modulators, directional couplers, and optical switches may be formed on a single substrate.

The other technology already showing considerable promise is that of coherent transmission. There are two main advantages to this technology: first, a 10 to 20 dB improvement over direct detection is possible, and second, the 50,000 GHz of bandwidth between 1250 nm and 1600 nm can be effectively utilized. Coherent systems can employ either homodyne detection or heterodyne detection. In both systems, the incoming signal is mixed with a local oscillator (i.e., laser) thereby improving the signal to noise ratio. In a heterodyne system, the local oscillator is not at the same frequency as the signal, while in a homodyne system, the frequencies of local oscillator and signal are the same. The homodyne system is harder to implement, but it does enjoy a 3 dB advantage over heterodyning.

The performance of a coherent system depends on the modulation scheme, be it phase (PSK), amplitude (ASK), or frequency shift keying (FSK). PSK provides the best performance, but imposes the most stringent requirements on the components. The local oscillator's output must be polarization matched to the incoming signal, which means that either the more expensive polarization maintaining fibers must be used or that the oscillator's polarization must be adjusted by an integrated optical device. Also, the laser linewidth must be very narrow. The typical multimode laser has an output about 3 nm or 500 GHz wide, far too broad for coherent transmission. Even distributed feedback lasers with linewidths of tens of MHz can only be used for ASk and FSK transmission. Even so, the best coherent results are comparable with the best results for direct detection. For PSK, injection locked lasers with linewidths of 10 KHz must be used to generate the light. The signal must then be phase modulated by an external modulator, usually an integrated optical device made from the electro-optically active material lithium niobate.

The best results in heterodyning to date were just announced several months ago in Venice (ECOC/IOOC '85). There, Bell Labs talked about two coherent systems, 400 Mb/s over 150 km and 1 Gb/s over 148 km. Also presented at that conference were results from Japan. NTT announced that they had achieved 400 Mb/s over 250 km, while NEC talked of transmitting 140 Mb/s over 234 km.

Section 5

(U) PROJECTIONS - SOVIET

5.1 Fibers

The Soviets are also pursuing research on mid-IR fibers, and for the same reasons that the West is pursuing such research. In fact, one of the Russian papers mentioned something that should have been obvious, but that did not seem to be covered in the Western literature surveyed. Another reason for wanting to shift into the mid-IR is that single mode fibers for that region could have core sizes of several tens of microns, thereby reducing the difficulty of coupling fibers together. The fact that this was mentioned in a Russian article may be significant, because it may indicate a deficiency in their manufacturing capabilities. Producing low loss connectors for single mode fibers is perhaps one of the most demanding manufacturing jobs currently on the horizon. It is difficult in the West, and perhaps more difficult in the Eastern Bloc.

As mentioned earlier, the materials presently showing the most potential for development into ultra low loss optical fibers are the HMF glasses, and the Russians are not among the leaders in this field of research. They are, however, pursuing research in low loss crystals, and have been doing so since at least 1980. A paper (75) written in that year reported that losses of 13-21 dB/km had been achieved in bulk samples of polycrystalline TIC1, KRS-5, and KRS-6.

The Russians have tried to extrude fibers from the crystals mentioned and from T1Br, but have been unable to maintain the low losses achieved in bulk samples. A 1981 paper (76) reported on the results obtained with polycrystalline fibers and found that the best losses that could be attained were about 1300 dB/km at 5-6 microns and 10.6 microns. Since these wavelengths correspond to the outputs of carbon monoxide and carbon dioxide lasers respectively, the researchers tested the fibers' power handling capability and found no damage at 1 kw/sq. cm. They also calculated the material dispersion for KRS-5 and KRS-6 and report zero dispersion at 6.5 and 5 microns, respectively. Material dispersion was found to be low (below 10 ps/km-nm) over wide spectral ranges for both crystals, making the materials attractive for communications if lower losses can be achieved. For comparison, at the time the Russians were reporting 1300 dB/km, they were referencing Western sources that had achieved 430 dB/km 2-3 years earlier.

In addition to extruding polycrystalline fibers, the Soviets have also tried to grow single crystal fibers from a melt (77). Results were obtained for the following materials: T1C1, T1Br, KRS-5, KRS-6, AgC1, AgBr, KBr, and CsI. Lowest losses were achieved with T1C1, and were 3000 dB/km at 10.6 microns. This was about an order of magnitude above the best Western results at the time and two orders of magnitude above the values recorded for bulk materials. Both pieces of information indicate that the researchers are having trouble with their fiber production process.

The Soviets also are active in research into chalcogenide glasses (78-81), and, in fact, claim to have originated the field of study in 1954. The materials that they are using are mostly sulfides and selenides of arsenic. They are making progress with these materials, as witnessed by the fact that during a one and half year period between 1981 and 1983 reported losses dropped from about 8000 dB/km (78) to 580 dB/km (80). The authors of reference 80 also calculated the material dispersion from their glass' measurable properties, and found a zero at 4.89 microns and values not exceeding 20 ps/km-nm over a wide spectral range.

In addition to the fact that these materials are transparent over the range of 1-11 microns, the Soviets have reported other properties that may be extremely useful.

The Soviets report discovering a photoinduced optical absorption in the fibers that they were testing (79). The absorption of the fibers could be increased by exposing them to light from a He-Ne laser, but they were not affected by higher power densities of longer wave radiation. The reseachers therefore suggested several possible applications for this phenomenon. They suggested that fibers could be graded with complex profiles simply by exposing them to properly shaped laser beams; this grading would only be good for short distances, however, because 630 nm light does not propagate very far in these fibers. The technique thus might be applicable to the grading of integrated optical devices. Another suggestion from the researchers was that He-Ne laser beams could be imaged on the beveled ends of fibers to create phase diffraction gratings. If the fibers are exposed to 630 nm light long enough, a permanent structural transformation seems to occur. This change, however, is apparently permanent only at normal temperatures. The annealing of the fibers by heating almost to the softening point apparently erases the induced changes. Further work on this phenomenon (81) has led to the modulation of a beam at 1150 nm by a beam at 630 nm. In this case, the shorter wavelength light was pulsed into the fibers, and the changes apparently were thus not permanent. Since the absorption of 630 nm light was a factor of 100 times higher than the absorption of the 1150 nm light, the modulating beam did not propagate to the detector.

The Soviets are apparently making good progress in the development of low loss crystals and chalcogenide glasses, and even appear to be making some initial discoveries. Overall, however, their efforts in the development of mid-IR glasses appear to lag the West's by several years.

5.2 Components

It appears that in the future the Soviets will continue to duplicate Western achievements in the area of component development, but with a several year lag. They are already working on fourth generation optoelectronic devices such as single frequency lasers. Also, they have probably also begun research on type III-V avalanche photodiodes by now; but in that technology they undoubtedly lag the West by quite a few years. Without these components, they can forget about producing such advanced systems as those employing heterodyne detection or multiple channel multiplexing.

Because of time constraints, the author was unable to cover a number of topics. The Soviets are actually pursuing research in such advanced subjects as integrated optics and optical amplification, and they can be expected to match our accomplishments in these areas in the future. Therefore, several references on these subjects are offered for the sake of completeness.

We have already mentioned optical amplification with respect to some of the Soviet single frequency laser research, but for the interested reader, reference 82 is offered. Integrated optical devices are covered in references 83 through 87. Multiplexers and couplers are covered in references 88 through 91. Optically bistable devices (i.e., the potential building blocks of optical computers) are covered in references 92, 93 and 94.

5.3 Systems

If the Soviets can eventually duplicate our efforts in terms of fiber and component development, it seems clear that they can eventually match our systems capability. Thus, we can expect that as our systems become faster and more efficient, their's will also. Since Western research papers almost never reference Soviet sources and since Russian papers heavily reference Western sources, it must be admitted that they seem to feed off of our technology. However, since the Soviets are acknowledged to have an extensive intelligence network in the West, censorship of Western research might have a greater slowing effect on Western progress than it does on Eastern progress.

As has been mentioned repeatedly, this report details the capabilities the Soviets have thus far demonstrated, it does not say anything about what the Soviets can reliably manufacture. It may be entirely true that the Soviets possess a number of talented individuals, who are concentrated in a very few research institutes; and it may also be true that the Russian manufacturing capabilities lag several technological generations behind these scientists. But it must be emphasized that at least some Russians are working on fourth generation fiber systems, while a 5 Mb/s system lies well within the capabilities of first generation fiber optics. Thus, it is quite likely that they can deploy a 5 Mb/s system.

Section 6

(U) LOCAL AREA, LONG DISTANCE F.O. SYSTEMS

The use of fibers are much more advanced in Local Area Networks and User Networks than in long distance carrier networks because of the ease of installation and the bandwidths they provide. Fibers are being used for building, campus and public subscriber networks [95,96]. Existing western technology is sufficient to permit the use of fibers and related digital modems and multiplexers to be used for present users' requirements. Even in the bloc countries fiber is being employed in these user networks, but advanced networks are limited by the lack of adequate microchips for the modems and multiplexers.

Whether or not fiber optics is used in long distance carrier networks is primarily a cost issue. If there is an installed base of other types of media such as radio or coaxial cable, then the tendency is to upgrade those first before installing fibers. Within the United States there is a major move to install fibers. The developing countries are using more fiber than radio because they do not have a basic investment in many major toll systems. Radio systems are favored in some countries that have remote or mountainous regions due to the problems of maintaining long cable or fiber routes. However, the costs of installing fiber is dropping and by the early 1990s most all new toll transmission systems will be fiber, with radio and satellite systems confined to specialized markets [97,98]. There are presently few, if any, new long distance cable systems being installed except in the bloc countries. In the bloc countries new long distance fiber systems will likely start appearing by 1990 as they develop the capacity to produce the high data rate electronics required by the fiber systems. [99].

Section 7

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