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I. INTRODUCTION

The present telecommunications study was sponsored by the United States Agency for International Development, Department of State, at the request of the Chad Basin Commission. The member countries of the Commission include Cameroon, Chad, Niger and Nigeria, all of whom have a part of their national territories within the geographical region of the Lake Chad Basin. All four of these countries share common interests in this region, one of which is telecommunications.

This final report of a Chad Basin Regional Telecommunications Study is submitted in accordance with the requirements of Task Order No. 1 of the Basic Ordering Agreement Contract AID/csd-2243 between the Agency for International Development and MORCOM Systems, Inc.

The government of Nigeria is presently engaged in expanding and improving its national telecommunications system. As part of this program, it is constructing a countrywide interurban microwave and VHF radio network. One branch of the microwave network terminates at Maiduguri in the northeast part of the country. This termination is about 140 miles from Fort Lamy in Chad. Maiduguri will be connected via six intermediate relay points, with the existing microwave system at Ibadan. The present microwave system connects Lagos, Ibadan, Benin, Onitsha, Enugu, and Port Harcourt. A radio link or links from Fort Lamy to Maiduguri would thus tie the Chad

Telecommunications System into the Nigerian System and allow intercommunication from Fort Lamy to all points in Nigeria.

The government of Cameroon is also expanding its telecommunication system, and construction is about to be started of a microwave system linking Yaoundé to Fort Foureau, which is located just across the river-border from Fort Lamy in Chad. A link between Fort Lamy and Fort Foureau would thus provide access to the entire Cameroon telecommunication system upon completion of the Cameroon construction program.

The purpose of the present study is to determine the economic feasibility of a telecommunication connection between Fort Lamy and Maiduguri as a means of access from points in Chad to the Nigerian Telecommunication System. Similarly, the study is also aimed at a determination of the feasibility of a link between Fort Lamy and Fort Foureau which would provide access from Chad to the Cameroon Telecommunications Network. In addition, the study is designed to determine the optimum type of connection for each of the above from both the technical and economic viewpoints.

II. CONCLUSIONS AND RECOMMENDATIONS

The following section summarizes the principal conclusions of each part of the study and recommendations are presented concerning system selection and implementation.

1. Traffic Estimates: -- The estimates of traffic for the proposed Fort Lamy-Fort Foureau telecommunication link, to interconnect with the new Cameroon microwave system, were based on the actual traffic data for 1968 over the HF radio link between Fort Lamy and Douala. It was assumed that this traffic will be diverted to the microwave system that will link Fort Foureau with Yaoundé and Douala. The annual traffic volume originating in Fort Lamy for this route was very conservatively estimated to consist of 1, 682 telephone calls, 5, 825 telegraph messages, and 4, 793 telex calls.

The estimates of traffic for the proposed Fort Lamy-Maiduguri telecommunication system cover the period from 1971 through 1980. The estimates of telephone traffic show an increase from 22, 700 calls in 1971 to 48, 200 calls in 1980. This projected increase of more than 100% is paralled by a corresponding planned increase of telephone lines in these two cities. The telegraph estimates follow a different pattern because of the present tendency of telephone to supplant telegraph service. This is reflected in an estimated decline from 48, 200 messages in 1971 to 32, 800

messages in 1980. Telex service, on the other hand, is expected to increase from an initial 1000 calls in 1971 to 7,500 calls in 1980, largely because traffic between the two cities is expected to be chiefly business in character rather than social.

2. Circuit Requirements: -- The estimated volume of traffic for the Fort Lamy-Fort Foureau link would require only one or two voice channels. However, for only a modest additional cost, many more channels can be provided. This would be particularly true of a multi-pair cable link which could easily provide 50 voice or telegraph channels. Such a number would be desirable to accommodate local traffic that might develop between Fort Lamy and Fort Foureau as well as to handle transit traffic between Cameroon and Nigeria that might be transmitted over the proposed Fort Lamy-Maiduguri route.

The channel requirements for the proposed Fort Lamy-Maiduguri telecommunication system will total 12 voice channels by 1980. Initial telephone requirements are five channels in 1971, increasing to eight in 1980. Telegraph and telex service would require another two voice channels by 1980, and an additional two voice channels are provided as spares.

3. System Alternatives: -- On technical and operational grounds, a 50-pair cable link was proposed for the Fort Lamy-Fort Foureau connection in preference to a VHF or microwave radio link.

A wider choice of alternatives was considered for the Fort Lamy-Maiduguri system, including HF radio, open-wire carrier, VHF radio, microwave, and troposcatter radio. All of these systems were considered feasible for meeting traffic requirements except the HF radio link. The latter, however, could provide an interim service should that be considered desirable. The two alternatives considered to best meet the technical and operational requirements were microwave and troposcatter radio.

4. System Cost Estimates: -- The estimated construction cost of the cable link between Fort Lamy and Fort Foureau was $12,000, with annual maintenance costs of $600.

The estimated construction costs of the proposed system alternatives for the Fort Lamy-Maiduguri route were $400,000 for troposcatter and $440,000 for microwave. The corresponding annual operating costs were $27,500 and $38,000, respectively.

5. System Revenues: -- System revenues accruing to the Fort Lamy-Fort Foureau cable link were estimated to be 10% of the total revenues on traffic between Fort Lamy and Douala. This would amount to $3,000 a year.

System revenues for the Fort Lamy-Maiduguri route were based on rates comparable to present Chad interurban tariffs. The figures include $40,000 of telephone revenues in 1972, increasing to $100,700 by 1980. Telegraph revenues were estimated to decrease from $27,200 in 1972 to

$24,900 in 1980. Telex revenues were estimated to increase from $2,400 in 1972 to $19,200 in 1980.

6. Financial Analysis: -- A summary analysis of the proposed cable connection between Fort Lamy and Fort Foureau showed that an internal rate of return of 16.7% could be expected for this link for the period from 1971 to 1980.

Detailed financial analyses were performed on the troposcatter and microwave system alternatives. The analysis was based on a 25-year loan amortization period and a system life of 15 years. The results showed that an internal rate of return of 16.7% could be expected for the troposcatter system and 12.5% for the microwave system for the period from 1971 to 1980.

7. System Implementation Plans and Training: -- The proposed multipair cable link between Fort Lamy and Fort Foureau could be placed in operation within six months of start of system design. No special training requirements would be required for this system.

Either the microwave or troposcatter system alternative for the Fort Lamy-Maiduguri route could be installed and operating within 18 months of the start of system engineering. Contractor training of local personnel would be provided during the construction period for either system. Subsequent training requirements should be within the capabilities of expatriate staff or existing

training programs of the PTT organizations.

8. System Recommendations: -- A 50-pair pressurized cable connection between Fort Lamy and Fort Foureau is recommended over other possible modes because of its low cost, ease of maintenance, and relatively high channel capacity.

A troposcatter radio link is recommended for the proposed Fort Lamy-Maiduguri route. The advantages of this system over the microwave system include somewhat lower investment and operating costs with consequently higher rates of return. The troposcatter system alternative obviates the need for repeater stations and the corresponding problems of third-country operating agreements. The troposcatter system performance would be equivalent to microwave performance, and the system would be expandable to handle up to 120 voice channels.

III. DESCRIPTION OF FIELD SURVEY

Preparations for the field survey included a review of available documents on telecommunications in the Chad Basin area. These documents consisted of the Checchi study on Chad Telecommunications, the Western Electric documents on the program for expansion of telecommunication facilities in Nigeria, and the General Telephone & Electronics and Teleprojects Corporation documents on the Cameroon Telecommunications System. In addition, a meeting was held with Western Electric personnel in New York to determine the current status of the Nigerian System expansion program. The best available topographic maps of the area between Fort Lamy and Maiduguri were obtained through the U. S. Coast & Geodetic Survey, and possible telecommunication routes between these points were examined.

A stop was made in Paris, enroute to Fort Lamy from Washington, to discuss with American Embassy officials the possibility of obtaining information from French sources which related to telecommunications in the Chad Basin area. A meeting was arranged for the MORCOM team with officials of France Cable & Radio (FCR) which is headquartered in Paris. FCR operates many of the international circuits in West Africa, and in particular operates HF circuits between Chad and Cameroon.

The interest of FCR was primarily to maintain the existing HF link between Fort Lamy and Douala and to implement the proposed HF link

between Fort Lamy and Lagos. They felt that the latter link would provide adequate communications capability by routing of messages for Maiduguri via Lagos. We informed the FCR people that part of our study was to evaluate this alternative for traffic between Fort Lamy and Maiduguri.

On arrival in Fort Lamy, the MORCOM team was met by officials of USAID and the Chad Basin Commission. Briefing sessions were held for the team and meetings were arranged with local agencies and businesses concerned with telecommunication requirements.

1. Discussions With Chad PTT: -- The Chad Government has submitted a loan request to the World Bank for Implementation of Telecommunication Improvements recommended in the Checchi report. A copy of the loan request document was presented to us. The loan request document provides data on Chad PTT revenues and operating expenses for the years since the Checchi report was prepared.

Data were obtained on international traffic for the years 1967 - 68, and the first five months of 1969. Included were figures on traffic to Douala and Yaoundé from Fort Lamy, and on traffic to Maiduguri via Kano. This Maiduguri traffic is Morse telegraph only, transmitted by means of an HF link from Fort Lamy to Kano. The volume of telegraph traffic on this link to Maiduguri is very low. Information was also provided on the increase in the number of telex subscribers annually since 1966.

It was learned that the HF circuit between Fort Lamy and Lagos had never been placed in operation. All traffic to Lagos was routed through Paris and London. The technical parameters of the HF circuit from Fort Lamy to Douala were provided.

At one time, an ordinary cable pair circuit provided service between Fort Lamy and Fort Foureau. This cable was run across the Chari River to Fort Foureau under water. However, the circuit never functioned effectively and eventually the cable was broken and lost. There is no telephone connection between Fort Lamy and Fort Foureau at the present time.

A copy was obtained of the convention or contractual agreement between the Chad PTT and FCR relating to telecommunication services provided by FCR.

A map showing a current listing of Chad domestic and international radio links was obtained. This listing included assigned frequencies and operating times for all circuits, both domestic and international, and schedules of rates for telephone, telegraph, and telex.

Visits were made to the HF transmitter station at Gredia and the HF receiver station at Moussouro, both on the outside of Fort Lamy. The PTT transmitter facilities at Gredia are housed in the same building with the facilities of ASECNA, the aeronautical navigation service covering most

of West Africa. The FCR transmitter facilities are located in a separate building. Similar colocation arrangements of these telecommunication services exist at the Moussouro receiving site.

Interest was also expressed by PTT officials in the possibility of investigating the feasibility of improving telecommunication services between Fort Lamy and Bol (on the northenn shore of Lake Chad) and between Fort Lamy and Zinder in Niger.

2. Discussions With Fort Lamy Commerce & Trade Groups: -- Officials of the Fort Lamy Chamber of Commerce indicated a strong interest in the establishment of a communication link between Fort Lamy and Maiduguri. They estimated that the importing and exporting firms in Fort Lamy would generate 40 to 50 telephone calls a day. Any transit traffic to Lagos, Port Harcourt, Kano, or other Nigerian cities relating to transport shipments would be in addition to the above estimate. It was estimated that there is currently about 50,000 tons of freight a year shipped from the railhead at Maiduguri to Fort Lamy. With regard to a telecommunication link between Fort Lamy and Fort Foureau, it was stated that a need does exist, but no estimate of traffic was offered.

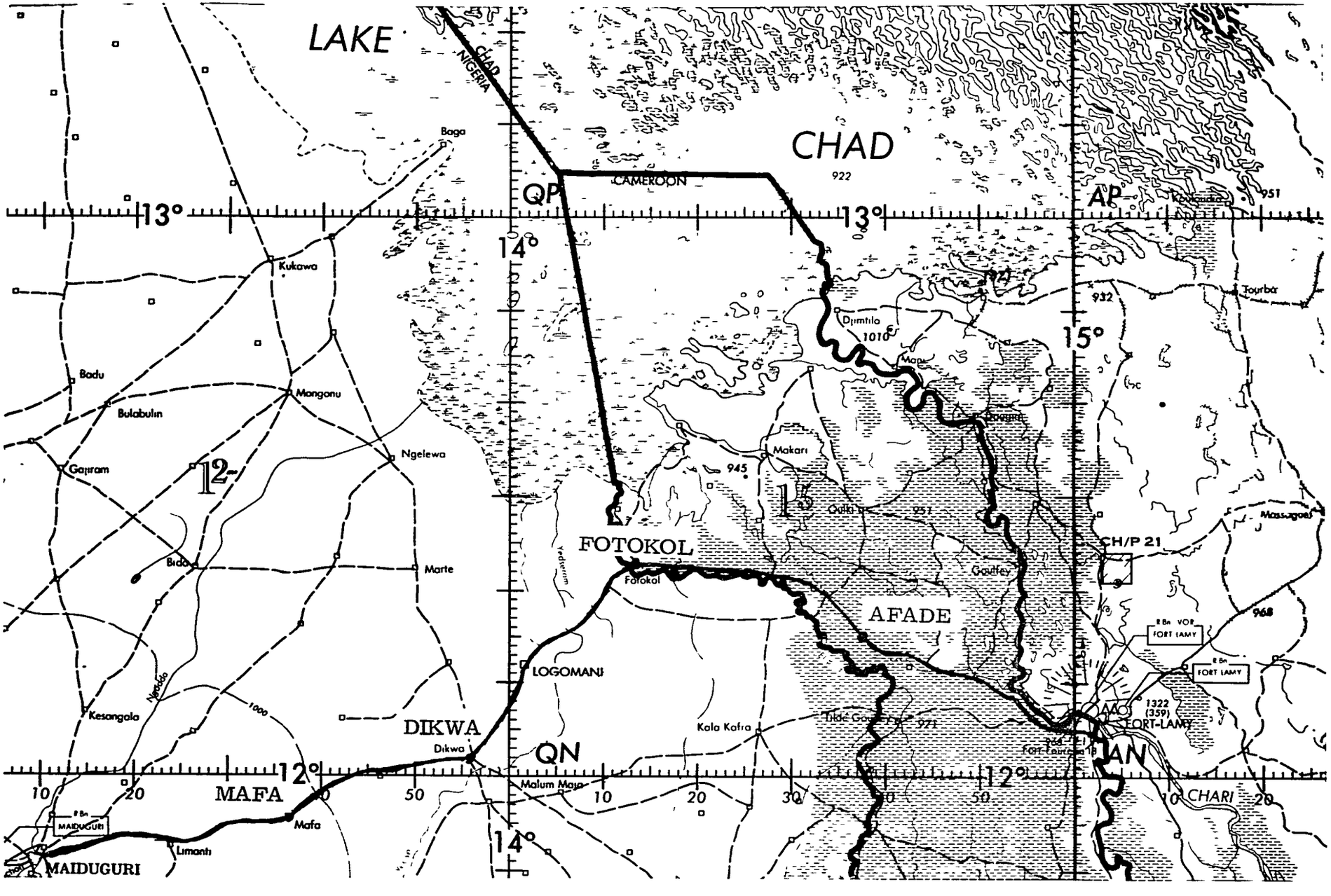
Additional meetings with shipping firms located in Fort Lamy produced similar reactions. All of them wanted telecommunication facilities between Fort Lamy and Maiduguri. At the present time, the only direct means of communication is by written instructions carried by the truck

drivers. In extreme cases, messages are sent via Paris, London and Lagos to Maiduguri. Interest was expressed in telex service as well as telephone and telegraph. There was less concern with the problem of communicating with Douala, as the existing HF link from Fort Lamy to Douala provides a means of maintaining contact with shipments on the highway between Douala and Fort Lamy.

3. Fort Lamy - Maiduguri Route Survey: -- A survey was made of a possible telecommunicatinn route between Fort Lamy and Maiduguri. Prior to actually travelling over the route, a map study was made of the area between these terminal points using the topographic maps supplied by the U. S. Coast & Geodetic Survey. These maps showed that there was essentially no variation in terrain elevation along the whole route. By means of the map study, possible radio relay sites were selected along the main highway crossing Cameroon to the Nigerian border point at Fotokol and connecting with the highway to Maiduguri. Four such relay sites were selected, each spaced about 30 miles apart. A map of the route surveyed with the locations of the four possible relay sites is shown in Figure 1.

The trip from Fort Lamy to Maiduguri was made by Land Rover, first crossing the Chari River at Fort Lamy to Fort Foureau in Cameroon by ferry. The highway was unpaved the whole distance, but little difficulty was encountered in making the round-trip in one day. However, under

FIGURE 1 -- ROUTE MAP BETWEEN
FORT LAMY AND MAIDUGURI SHOWING POSSIBLE REPEATER SITES



rainy con [illegible] closed to traffic partly to protect the roadbed from damage by heavy trucks, but also as a safety measure. When wet, the fine silty sand of the roadway becomes very slippery and maintaining traction becomes extremely difficult. During such rainy periods, it is not uncommon for the highway to be closed for 48 hours at a time.

The first of the four possible radio relay sites, which were selected from the map study, was located close to the small village of Afade in Cameroon about 31 miles from Fort Foureau. The village area itself was on a slight elevation about 20 feet above the highway level. The vegetation over this section of the route consisted generally of brush with a thin scattering of small trees. The second site was located at Fotokol in Cameroon at the border crossing point into Nigeria. The general character of the vegetation over the second section of the route was similar to that of the first, although the country was somewhat more open with fewer trees. Both sections of the route traversed low country which tended to accumulate standing water during the rainy season and the period of high water levels in Lake Chad. The road distance from Afade to Fotokol was 32 miles. The Nigerian town of Gambaru was immediately adjacent to Fotokol and a bridge connected the Cameroon highway to the Nigerian highway leading to Maiduguri. Highway markers indicated that the distance from this border point to Maiduguri was 85 miles.

The third relay point was located near the village of Dikwa in Nigeria, a distance of 31 miles from Fotokol or Gambaru. This section of the route

differed considerably from the first two sections. The country was wide and open with very few trees and resembled very much the plains country of the mid-western part of the United States. Occasionally mirages were observed on the horizon.

The fourth relay site was near the village of Mafa, about 24 miles by road from Dikwa. The vegetation had changed somewhat at this point, consisting largely of scrub underbrush. The remainder of the distance to Maiduguri, about 31 miles, was through country covered by increasingly heavy underbrush. The last 10 miles of the distance to Maiduguri passed through a forest reserve with rather low trees. This section of the highway was the roughest encountered on the whole trip. A 3-phase electric power line was observed about 1.25 miles outside of the city.

Maiduguri is a city with a population of about 140,000, and is the terminus of the Nigerian railroad. It is also the capital of the northeast province of Nigeria. English is the official language, although Hausa and Arabic appeared to be more commonly spoken. As a result of this, our driver encountered no language difficulties, as these languages are equally common in Fort Lamy.

A visit was made to the PTT headquarters in Maiduguri, but since the day was a Moslem holiday, only one technical officer was on duty. He informed us that a definite decision had been made to extend microwave rather

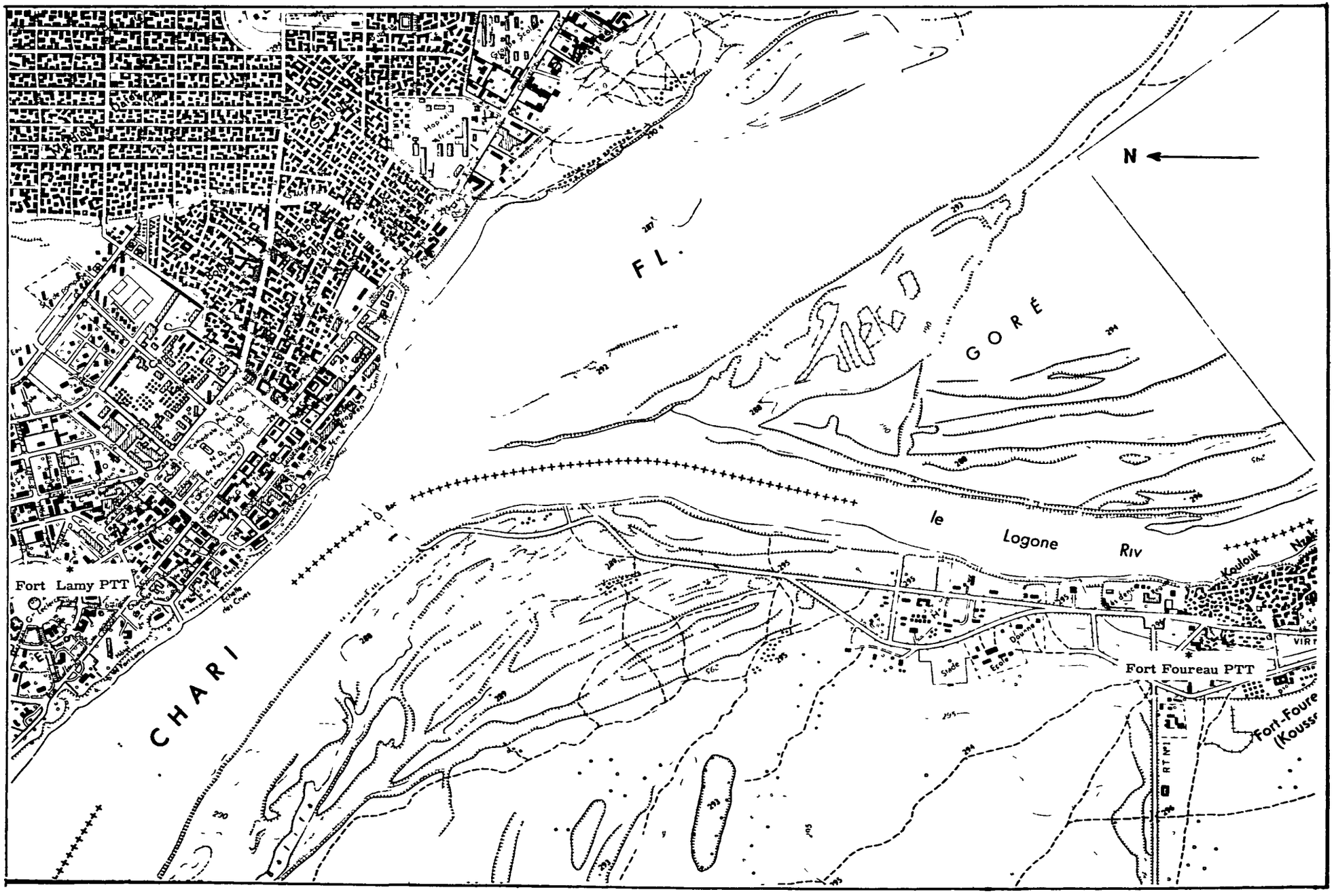
than VHF radio relay to Maiduguri from Bauchi, as part of Step III of the Nigerian Telecommunication Expansion Program. At the present time, Maiduguri is linked with Bauchi and points south and west by 17 voice channels of open-wire carrier.

Maiduguri appeared to be a comparatively modern and well developed city. Before beginning the return trip to Fort Lamy, a visit was made to the railroad terminal which seemed to be well equipped and in good repair with extensive sidings and other facilities for handling freight.

4. Fort Lamy - Fort Foureau Route Survey: -- These two towns are separated by hardly more than the Chari River, which forms the border between Chad and Cameroon at this point. The river itself is about 1,500 feet wide, but the actual distance to Fort Foureau is somewhat greater as it is located a short distance up the Logone River, as shown in Figure 2. The Logone flows from the south and joins the Chari at Fort Lamy. The airline distance from the PTT Headquarters building in Fort Lamy to the PTT building in Fort Foureau is about 2.25 miles. The two PTT buildings could be interconnected by means of a radio link or by a multipair cable. The latter alternative would involve an underwater cable crossing. However, a feasibility study about to be made of a paved highway from Fort Lamy to Maiduguri will include consideration of a bridge link across the Chari River to Fort Lamy. If the bridge were to be built, the cable could be carried across the river on the bridge.

FIGURE 2

ROUTE MAP BETWEEN FORT LAMY AND FORT FOUREAU SHOWING PTT BUILDING LOCATION



5. Discussions With Cameroon PTT: -- Meetings were held with AID officials and officers of the Cameroon PTT in Yaoundé. One member of the MORCOM team participated in advance meetings to submit requests for data which could be prepared in time for a second visit to Yaoundé by the rest of the MORCOM team. Data requested included:

(1) A schedule of domestic and international rates in Cameroon for telephone, telex, and telegraph;

(2) Traffic data on Fort Lamy - Douala HF link, showing breakdown of traffic between Douala, interior of Cameroon and transit international traffic;

(3) A further breakdown of interior Cameroon traffic from the Fort Lamy - Douala HF link and how it is divided between major cities or regions; and

(4) Technical characteristics of the HF terminal in Douala including transmitter power, antenna type and bearing, number of channels and frequency complement.

The PTT officials stated their opinion that the existing agreement between France Cable & Radio and the Government of Cameroon placed no restrictions on the PTT, with regard to the establishment of new communication links. In any case, new agreements are being discussed with FCR by which the PTT would be assuming greater responsibilities for their international communications.

The PTT officials stated that construction is scheduled to begin on the Yaoundé - Fort Foureau microwave system at the end of the rainy season, in October of 1969.

It was learned that, at the present time, there is no telecommunication link between Cameroon and Nigeria.

The planned meeting of the MORCOM team with the ITU team surveying West African Communications was not held. The ITU team had been scheduled to be in Yaoundé from the 7th to the 18th of June, but changes in their itinerary caused cancellation of the meeting.

6. Discussions With Nigerian PTT: -- Meetings were held with AID officials and officers of the Nigerian PTT, as well as personnel of the Western Electric Telecommunications Project Office.

Apparently, propagation problems have been encountered with those parts of the Nigerian microwave system now in operation. The propagation problems are largely due to the Hamadan, which are a kind of dust storm, that prevail during a part of the year. In order to overcome fading problems during the Hamadan, the Nigerians have used both space and frequency diversity, simultaneously, on the microwave circuits.

The Western Electric Project Office confirmed the information obtained in Maiduguri relating to the use of microwave rather than VHF between Bauchi and Maiduguri. The Bauchi to Maiduguri microwave link is to have 120 channel capacity and will operate in the 2 GHz range. According to the present construction schedule, the new microwave system to Maiduguri should be operational by May 1971. It was stated by the PTT that the possible

extension of the telecommunication system from Maiduguri towards Fort Lamy was an important factor in the decision to implement a 120 channel microwave system rather than a 36 channel VHF system. At the present time, there is an HF circuit from Kano in Nigeria to Fort Lamy which handles slow speed Morse telegraph traffic. This circuit is operated by the Nigerian PTT rather than NETCOM, which is the Nigerian External Telecommunications Organization. Similarly, any extension of the Nigerian microwave system towards Fort Lamy would be operated by the PTT rather than NETCOM.

7. Discussions With NETCOM: -- Requests were made for data relating to the proposed HF link between Lagos and Fort Lamy. These data included technical parameters of the proposed terminal equipment, as well as traffic projections and rates. It was stated that NETCOM was prepared to open the circuit for operation to Fort Lamy at anytime. It was also pointed out that the Africa Plan Document does show a proposed 24-voice channel telecommunication link between Fort Lamy and Maiduguri as part of a network which would cross Central Africa from East to West. A copy was obtained of the NETCOM HF operating schedule as well as rates for international circuits.

8. Discussions With AID Office of Central and West Africa Regional Activities (OCWARA): -- The purpose of this meeting in Dakar was to brief the regional office on the information obtained relating to the Chad

Basin Telecommunication requirements. In addition, a summary was prepared of the MORCOM Field Study activities to date, which could be used as background information by representatives of the Regional Office at the upcoming meeting of the Chad Basin Commission, scheduled to begin on June 17, 1969, in Yaoundé.

IV. ANALYSIS OF TRAFFIC DATA AND TRAFFIC FORECASTS

Consideration has been given to the traffic requirements for both the Fort Lamy - Fort Foureau and the Fort Lamy - Maiduguri routes. However, the Fort Lamy - Fort Foureau route is of only minor consequence, in terms of investment requirements, compared with the Fort Lamy - Maiduguri route, and the traffic considerations are correspondingly simple.

1. Fort Lamy - Fort Foureau: -- The purpose of this link would be to gain access to the new Cameroon microwave system, which will connect Fort Foureau with Yaoundé and Douala.

It is assumed that the traffic to be handled over this route is the traffic now passed over the HF radio link from Fort Lamy to Douala. The volume of this traffic in 1968 amounted to 1, 682 telephone calls (9, 864 minutes), 5, 825 telegraph messages (81, 550 words), and 4, 793 telex calls (10, 224 minutes). It is unnecessary to make future projections of this traffic, as it will be shown that the revenues which can be attributed to this traffic will more than cover the annual investment cost of the short interconnection between Fort Lamy and Fort Foureau. In addition, there will be new traffic generated consisting of local traffic between Fort Lamy and Fort Foureau and that which results from the availability of high quality microwave service to Yaoundé and Douala.

2. Fort Lamy - Maiduguri: -- The establishment of a communications link between Fort Lamy and Maiduguri is intended primarily to provide direct communication between these cities. While some of the traffic originating in these cities will have destinations in other parts of Chad and Nigeria, the bulk of the traffic is expected to be between the two cities. Therefore, estimates of anticipated traffic have been based on interurban traffic patterns. In this respect, the Checchi report accumulated useful data which has been brought up-to-date for this study.

2.1 Economic Aspects: -- An additional factor which would increase the communication between Fort Lamy, Fort Foureau and Maiduguri is the proposed highway recommended in the "Report on a Study of Projected International Road Links for the Chad Basin Commission, March, April, 1968." This study recommends an $11,396,000.00 road link between Fort Lamy and Maiduguri as the road project of greatest importance of the nine possibilities studied. The report estimates that the new road would initially carry 55,000 tons of trucking per year on approximately 5,000 trips. The movement of this freight would be facilitated through the availability of an adequate telecommunication system. In fact, interviews with the managers of the two largest import-export firms in Fort Lamy revealed that they were very interested in the prospect of telecommunications facilities, even without a new paved highway.

They indicated that they would use both telephone and telex services. The Executive Secretary of the Chamber of Commerce of Fort Lamy had surveyed the business community of Fort Lamy and stated that there would probably be an initial traffic volume of as many as 50 calls per day to Maiduguri. This does not include prospective calls from Maiduguri to Fort Lamy. Presently, there are no reliable communication facilities between these two cities. Messages are carried by the truck drivers or in unusual cases sent by radio via Kano or Paris, London, and Lagos. These are inefficient and expensive procedures when it is considered that the two cities are only 140 miles apart.

2.2 Telephone Traffic: -- The average number of interurban calls (in and out) of Fort Lamy to all of the cities of Chad where telephone service is available for the three years (1966 - 1968) were divided by the average number of subscriber lines. The result was 30.8 messages per line. These data are shown in Table 1. Figure 3 illustrates this result graphically by showing telephone lines on the horizontal axis and calls on the vertical axis. The line corresponding to a ratio of 30.8 (calls per line) also passes through the points for Abeche and Moundou. Fort Archambault has a calling rate proportionately higher in relation to its number of subscribers. The number of calls to be expected each year, 1971 through 1980, was computed by multiplying the straight line projection of Maiduguri subscriber lines by 30.8. The basic estimate of the

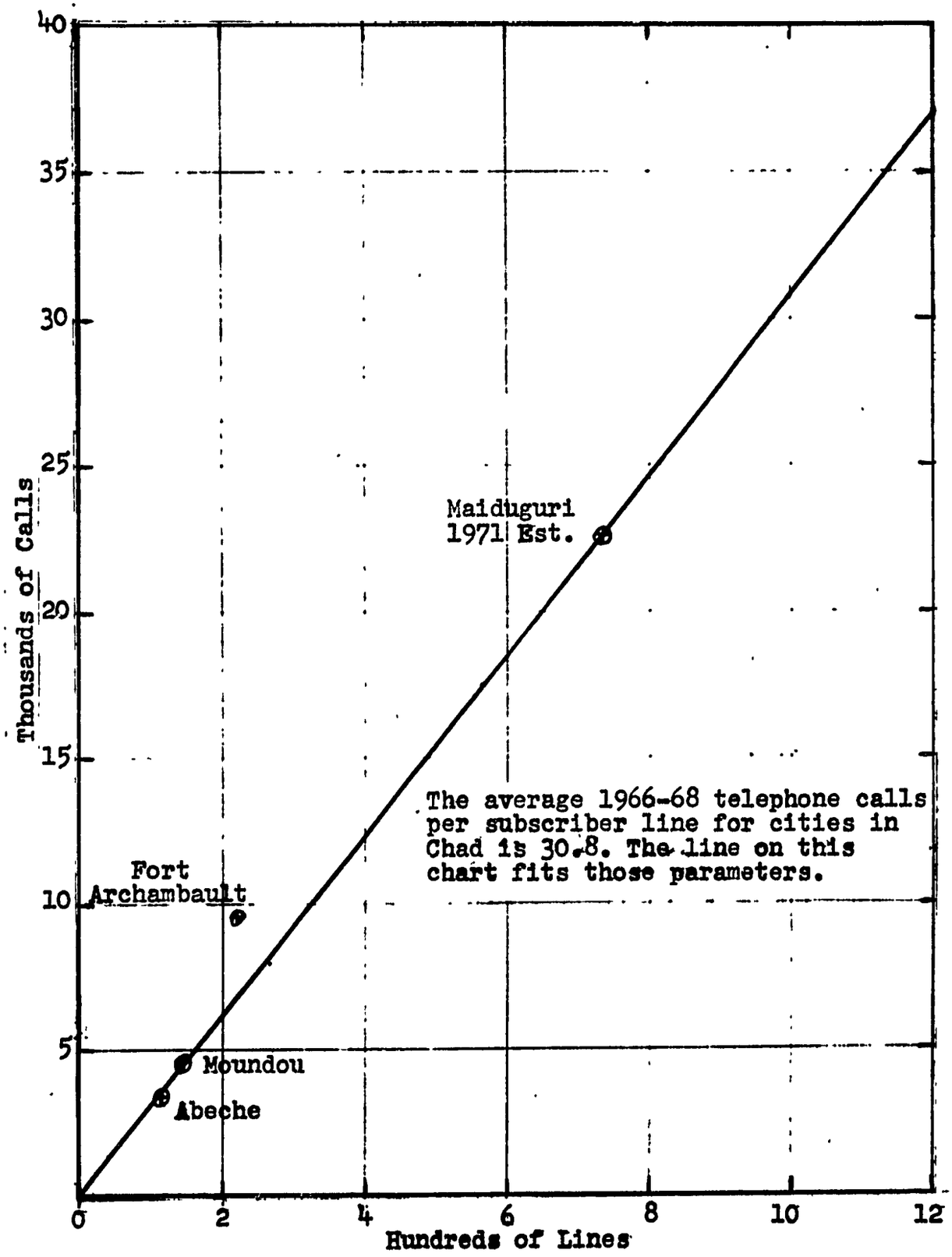
TABLE 1

FORT LAMY AND INDICATED POINTS
INTERURBAN TRAFFIC AND SUBSCRIBERS' LINES
- Telephone -

	1966		1967		1968		Total 3 years		Average		
	Calls	Lines	Calls	Lines	Calls	Lines	Calls	Lines	Calls	Lines	Per Line
Abeche	3,223	107	3,983	114	3,282	121	10,488	342	3,496	114	30.6
Am-Timan	373	18	341	19	400	20	1,114	57	371	19	19.5
Ati	966	27	1,134	28	866	30	2,966	85	989	28	35.3
Biltine	102	14	165	14	279	16	546	44	182	15	12.1
Bokoro	595	11	518	12	670	13	1,783	36	594	12	49.5
Bol	584	11	714	12	461	14	1,759	37	586	12	48.8
Bongor	516	54	1,054	62	1,132	70	2,702	186	900	62	14.5
Bousso	72	14	498	15	822	16	1,392	45	464	15	30.9
Doba	401	47	253	50	565	53	1,219	150	406	50	8.1
Fort Archambault	5,727	195	8,907	220	14,203	245	28,837	660	9,612	220	29.1
Lai	370	30	783	32	728	34	1,881	96	626	32	19.6
Mao	736	11	882	11	849	12	2,467	34	823	11	74.8
Massokory	558	14	551	15	751	16	1,860	45	619	15	41.3
Massenya	370	16	543	17	712	19	1,625	52	542	17	31.9
Mongo	508	23	673	25	696	27	1,877	75	626	25	25.0
Moundou	4,216	141	5,254	148	5,397	155	14,867	444	4,956	148	33.5
Pala	284	47	352	52	331	57	967	156	322	52	6.2
TOTAL	19,601	780	26,605	846	32,144	918	78,350	2,544	26,114	848	30.8
Average Call Per Line	25.1		31.5		35.0		30.8				

FIGURE 3

RELATIONSHIP BETWEEN NUMBER OF LINES
AND VOLUME OF INTERURBAN CALLS
FROM AND TO FORT LAMY AND OTHER CITIES



number of subscribers in Maiduguri was taken from the Western Electric Company Nigeria Telecommunications Study. This projection of telephone traffic is presented in Table 2.

It was determined that the Schaefer formula used in the Checchi report would not apply in the present case. The constant used in the formula was established for traffic between cities in Chad where the volume and growth of other than business traffic would doubtless be greater than between Fort Lamy and Maiduguri. The difference in official languages of Chad and Nigeria and the lesser extent of non-business interests would suggest that traffic will be predominately business in nature. Application of this formula in the present circumstances would result in unreasonably high estimates. Furthermore, there are no data available from which to determine a proper constant for the formula in applying it to the Fort Lamy - Maiduguri situation.

2.3 Telegraph: -- The expected volume of interurban telegraph traffic was projected as a function of telephone calls. The number of telegraph messages between Fort Lamy and all of the other cities in Chad with telephone service was compared with the number of interurban telephone calls. In 1965 there were 4.89 telegraph messages for every telephone call. By 1968 this ratio had changed to 3.12, a decline of 36 percent or 12 percent per year. Beginning with the 1968 ratio of 3.12, a decrease of 12 percent was applied to each successive year and this series

TABLE 2

ESTIMATES OF PROJECTED TRAFFIC
BETWEEN FORT LAMY AND MAIDUGURI

(Incoming and Outgoing)

MESSAGES

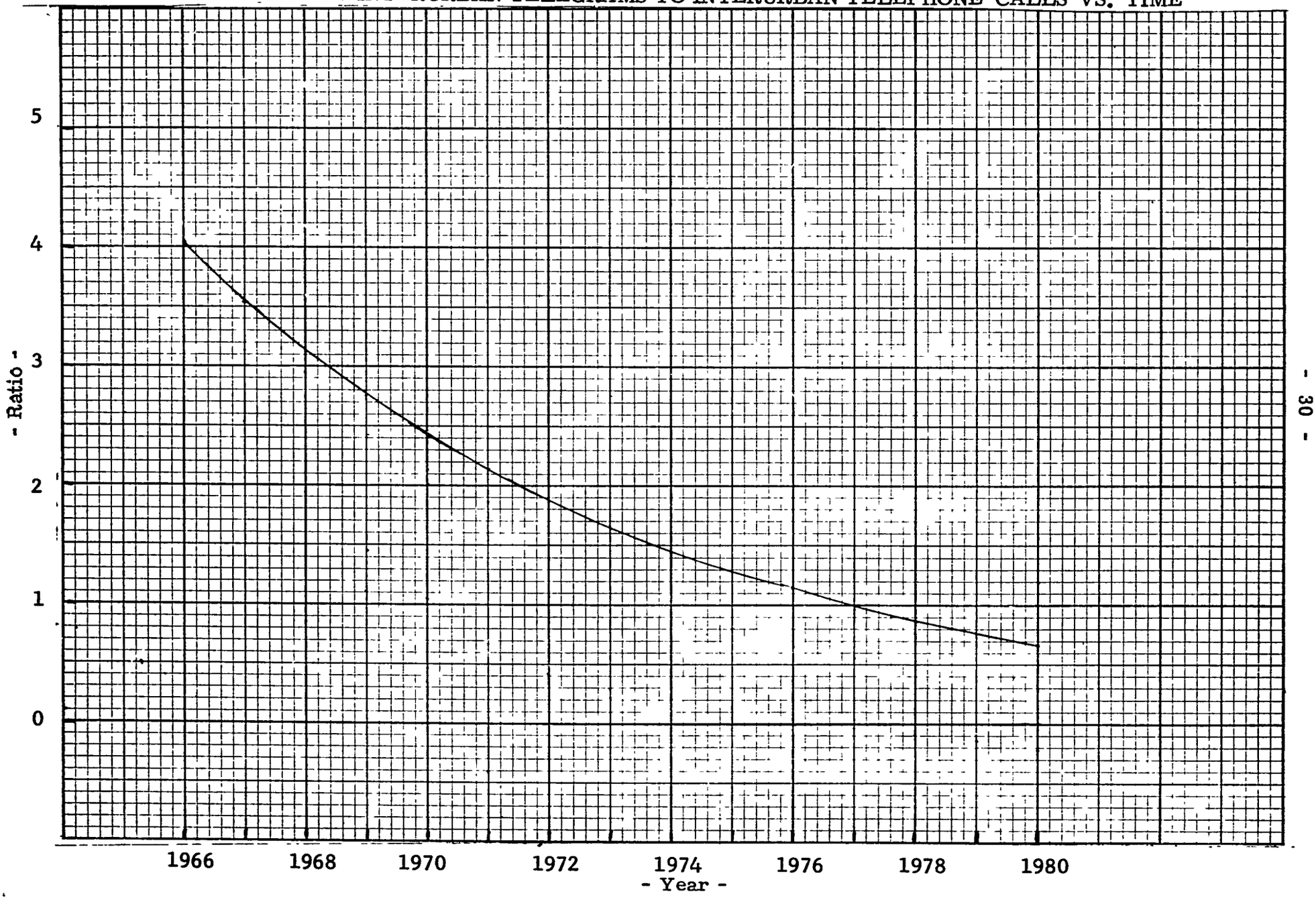
YEAR	TELEPHONE	TELEGRAPH	TELEX
1971	22,669	48,285	1,000
1972	25,502	47,689	1,250
1973	28,336	46,754	1,562
1974	31,170	45,197	1,953
1975	34,003	43,524	2,441
1976	36,670	41,625	3,051
1977	39,670	39,273	3,813
1978	42,504	36,978	4,766
1979	45,338	34,910	5,958
1980	48,171	32,756	7,447

of ratios was applied to the annual projections of interurban telephone calls between Fort Lamy and Maiduguri. As a result, 48,285 telegrams were estimated for 1971, decreasing to 32,756 in 1980, while telephone calls are expected to increase 2 1/2 times. The use of an exponential trend in this case, as shown in Figure 4, appears much more reasonable than a straight line trend. A straight line would ultimately indicate zero telegrams, which could hardly be the case. This decline appears reasonable in view of the expected increases in telephone subscribers in the two cities and the greater convenience of the two-way telephone connection. The estimates of projected telegraph traffic are also shown in Table 2.

2.4 Telex: -- In 1968, there were 30 telex subscribers in Fort Lamy and four in Fort Archambault, creating 1,184 interurban messages, or 35 messages per subscriber. The relation of telex to telephone subscribers in these two cities was 1.7 percent. Assuming the same development for Maiduguri, its estimate of 460 telephone subscribers for 1968 would equate to eight telex subscribers. Adding Fort Lamy's 30 to Maiduguri's eight and applying 35 messages per year per subscriber gives an estimate of about 1,300 messages. Allowing for a smaller number in the first year of operation, 1,000 was used for the base year of 1971. Telex is a desirable means of communication where there are any language barriers and the businessmen interviewed indicated a preference for this service. Accordingly, an annual rate of increase of 25 percent over the

FIGURE 4

RATIO OF INTERURBAN TELEGRAMS TO INTERURBAN TELEPHONE CALLS VS. TIME



base year was used in the projection. These telex traffic projections are also shown in Table 2.

V. DETERMINATION OF CHANNEL REQUIREMENTS

The channel requirements of the Fort Lamy - Fort Foureau and Fort Lamy - Maiduguri routes are based on the traffic forecasts of Section IV. and were determined in accordance with the 1967 Africa Plan recommendations of the CCITT and the CCIR.

1. Fort Lamy - Fort Foureau: -- The channel requirements on this link required to accommodate the actual traffic experienced on the Fort Lamy - Douala HF circuit in 1968 are nominal. Two or three voice channels would be more than adequate. However, if a multipair cable were to be used for this connection, it would be wise to provide a 25 - or 50 - pair cable at modest additional cost. These additional pairs would accommodate local traffic that might develop in the future between Fort Lamy and Fort Foureau, as well as transit traffic to be relayed to Nigeria over the proposed route between Fort Lamy and Maiduguri.

2. Fort Lamy - Maiduguri: -- The annual number of projected telephone calls between Fort Lamy and Maiduguri ranges from 23,000 in 1971 to 48,000 in 1980 so that an annual concentration factor of 1/175 was used. Since the calls per day would be over 60, a daily concentration factor of 1/12 was applied. These factors produce the expected daily calls during busy hours. Two multipliers of 1.3 were used, the first to secure the basis of a very busy day (10th busiest of the year) and, the second, to adjust for the difference between offered and paid

traffic and to take account of the real occupation of circuits, no-answers, disturbances, etc. These adjusted calls per hour were multiplied by the holding time of 4.75 minutes, which is the 1968 actual for interurban traffic in Chad. Multiplying this last figure by 60, converts call minutes into call seconds which when divided by 100 gives CCS (Hundred Call Seconds) units. Poisson tables were applied using a rate of three percent probability of finding all lines busy, in accordance with the Africa Plan recommendation at the 1967 Addis Ababa conference. From these compilations, it was determined that the present requirement for telephone circuits would be five, increasing to eight in 1980.

Telegraph circuit requirements were based on 300 equivalent average working days in the year, average message length of 14 words, and average transmission speed of 15 words per minute. A factor of 1.3 was applied to provide for idle operating time. The minutes were converted to CCS and the requirements taken from the Poisson tables. The circuit requirements were divided by 10 since it was assumed that one voice channel would handle 10 telegraph circuits. Three telegraph circuits will be required in 1971 and two in 1980. This appears adequate, in that ordinary telegraph traffic can be handled during slack telephone traffic periods.

Telex requirements were computed in a similar manner to that for telephone circuits, since it is a demand service corresponding to telephone

service. However, here again, 10 telex circuits can be accommodated by one telephone channel. The requirement for 1971 is two circuits and four in 1980, which means that a single voice channel would be adequate to handle all foreseeable telex traffic between Fort Lamy and Maiduguri in the next 10 years.

The total indicated requirement for the Fort Lamy - Maiduguri route is 10 voice channels. Provision of two spares would raise the total requirements to 12 voice channels.

VI. DESCRIPTION OF TELECOMMUNICATION SYSTEM ALTERNATIVES

There are a number of means by which the channel requirements for the Fort Lamy - Fort Foureau, and Fort Lamy - Maiduguri telecommunication links can be satisfied.

The Fort Lamy - Fort Foureau link presents relatively few problems because of the short distance between these terminals. The choice of a type of link is effectively limited to either a radio system or a multipair cable.

The range of choice for the Fort Lamy - Maiduguri system is much greater and includes HF radio, land-line carrier, VHF radio, microwave, and tropospheric scatter radio.

1. Fort Lamy - Fort Foureau Telecommunication Link: -- As indicated above, this link could be effected by either a radio link or a multipair cable. From a technical point of view, the multippair cable would be the simplest way to meet this requirement. The distance between the PTT telephone exchanges in the two cities is only about two miles. Consequently, the toll switchboards at the two exchanges could be connected by simple cable pairs at audio levels. A 50-pair No. 22 gage cable, with copper shielded pairs and an outer polyethylene covering, could be installed for either direct burial or as an overhead line. This cable would also be suitable for underwater crossing of the river. No carrier or repeater equipment would be required, with a consequent reduction in maintenance problems. The lack of any need for the above anciliary equipment

would be a factor in improving the reliability of a multi-pair cable link over other possible modes. If an underwater river crossing is required, the cable would be subject to damage from dragging anchors. However, a cable crossing is customarily well marked to warn shipping of its presence and, hence, the possibility of such damage would not be too great. Furthermore, the amount of water-borne traffic is not great, consisting chiefly of the ferry and other small craft. If a bridge were to be built across the Chari, and the cable was suspended from it, this possibility of damage would be eliminated completely.

An alternative means of providing for the Fort Lamy-Fort Foureau link would be by means of VHF or microwave radio. A radio link would avoid the disadvantages of the cable crossing, but would involve the need for relatively complicated terminal equipment with concomitant operational and maintenance problems.

In view of the above considerations, it appears that the preferred means of connecting Fort Lamy and Fort Foureau would be by a multi-pair cable. This method would have the additional advantage of providing a large number of spare cable pairs for meeting future expansion requirements.

2. Fort Lamy-Maiduguri Telecommunication System: -- In discussing alternatives for meeting the Fort Lamy-Maiduguri requirements, consideration will be given first to the technical and operational suitability of the

various systems. On these grounds, some systems will warrant less detailed consideration that others and the resulting discussion will be correspondingly brief.

2.1 High Frequency (HF) Radio Link: -- The advantages of an HF link are chiefly its simplicity and low cost. In fact, presently installed HF equipment (at least in Fort Lamy) might be time-shared on a proposed link with Maiduguri. However, these are about the only advantages that can be advanced in its favor. The disadvantages are more numerous. First of all, a single HF circuit would not provide the channel capacity that our traffic forecasts show to be ultimately required, although some initial requirements could probably be met. The relatively short path of a circuit between Fort Lamy and Maiduguri would call for a high incidence radio beam, which in turn would necessitate the use of frequencies in the lower part of the HF band. The use of such frequencies is particularly affected by atmospheric conditions and results in relatively inefficient operation. Furthermore, this part of the HF frequency band is heavily used in Africa and the possibility of interference between different users is very great.

In spite of the overall limitations of an HF service for the proposed route, an evaluation of such a circuit was made to determine its feasibility as a possible interim measure.

The characteristics of an HF propagation path between any two points on the earth can be predicted with reasonable accuracy by computer analysis

techniques developed by the Environmental Science Services Administration (ESSA) of the United States Department of Commerce. Using these methods, the optimum frequency and the maximum and minimum usable radio frequencies can be determined, for each hour of the day and night, for an HF communication path between the specified points. This prediction is based upon specific values of transmitter power, antenna gain, modulation bandwidth, and desired signal-to-noise ratio. The reliability of service is specified as 90% of the time for these predictions.

This ESSA service was employed to obtain information on HF path propagation conditions between Fort Lamy and Maiduguri.

The circuit parameters and the computed results are presented in tabular and graphical form in Appendix A of this report for the month of August 1969. There will be some variation for different months of the year and for different periods of the eleven-year sunspot cycle. These data show that a reliable HF path will exist generally from 0600 to 1800 hours daily (GMT) for frequencies between 4 and 10 MHz; and from 0600 to 2400 hours daily for frequencies between 4 and 7 MHz. For the hours between 0000 and 0600, frequencies below 4 MHz are most useful.

One HF channel of 6 KHz bandwidth will accommodate two voice channels, using ISB modulation. One voice channel may be used to accommodate a number of teletype channels.

Assuming that four interference-free HF channels of 6 KHz bandwidth might be available on 3000, 5000, 7000, and 9000 KHz, the useful daily operating hours obtained from the data of Appendix A would be as follows:

Frequencies (KHz)	Available Operating Times (GMT)	Total Hours
3000	0000 to 0500, 1600 to 2400	13
5000	0000 to 0300, 0500 to 2400	22
7000	0000 to 0100, 0600 to 2400	19
9000	0700 to 1900	12

The ESSA prediction data show that frequencies above 10 MHz would be unsuitable over this short path. It is apparent that a useful interim HF service could be supported over this path, but that HF service would not be adequate to meet the projected traffic requirements between Fort Lamy and Maiduguri.

2.2 Land Line Carrier System: -- A 12-channel open-wire carrier system could be designed which would meet the traffic forecasts developed earlier. This system, requiring two repeaters, would terminate at Fort Foureau, as a river crossing of the Chari to Fort Lamy with open-wire line would be extremely difficult unless a bridge crossing were to be built. Otherwise, the connection with Fort Lamy would have to be made via the multi-pair cable proposed for the Fort Lamy-Fort Foureau link. There are numerous disadvantages of the carrier system. These include the problem of reliability, as a break anywhere in the 140 mile line would

interrupt service until maintenance crews could reach the scene. Apart from more common causes of line breaks, such as falling trees and branches, the presence of large game animals such as elephants along the route would be a serious source of concern. In particular, the route passes through a game forest near Wasa, in Cameroon, which has large herds of elephant. In travelling through this area, the presence of these beasts along the route is very evident. The incidence of lightning storms along the route is also significant during the months of June through October, another factor in system reliability. During these same months, there is extensive flooding of parts of the area through which the route would pass. This would present certain problems in pole line construction and maintenance, as well as technical difficulties in the operation of a carrier system due to rain and dampness. A final point which militates against the construction of an open-wire carrier system is the fact that it would be limited in its capability of being expanded to meet future traffic requirements that are not presently envisaged. For example, it was proposed in the 1967 Addis Ababa Africa Plan that a transcontinental telecommunications network should pass through Fort Lamy and Maiduguri. This proposal called for 24 voice channels, a number which could not be accommodated by the above open-wire system.

The same general objections to the use of open-wire carrier would also apply to the use of a cable carrier system. In addition, the cable carrier system is more expensive than an open-wire system.

On the basis of the above discussion, it does not appear that land-line carrier would be the most suitable means of providing service between Fort Lamy and Maiduguri.

2.3 VHF Radio System: -- The cost advantages of a VHF radio system over a light route microwave system, such as will be discussed in the next section, are not significant. Furthermore, it does not lend itself to expansion for the accommodation of presently unforeseen traffic in the way that the microwave system does. For these reasons, a more detailed consideration of VHF systems for meeting the present requirement does not seem to be warranted.

2.4 Light Route Microwave Radio System: -- The map study and path survey of the Fort Lamy-Maiduguri route which were described earlier showed that a radio relay system between these points would require four repeater stations, as shown in Figure 1. In addition, a terminal would be required at Fort Lamy and another at Maiduguri.

The analysis of traffic requirements between Fort Lamy and Maiduguri showed that a conventional wideband microwave system for this route was both unnecessary and uneconomical. Furthermore, the relatively low density traffic projections would only provide revenues sufficient to support a light route or narrow band system which utilized a minimum of electronic equipment. Such a system would have to operate on a non-diversity basis and without redundant or hot-running standby equipment. However, this sacrifice of a certain amount of system reliability is justified

in view of the fact that service would be provided over a route where there is now no service at all. Diversity could be provided later.

A solid state narrow-band microwave system operating in the 2000 MHz band based on the above criteria and which would approximate CCIR-CCITT transmission requirements could be provided. Each of the two radio terminals would consist of a single radio transmitter and receiver combination and the necessary voice multiplex and voice-frequency telegraph (VFTG) terminations. The necessary remote monitoring, signalling, and order wire equipment would also be provided. The station terminal would also include batteries and battery charging equipment, spare equipment racks, antenna and tower, spare parts, and test equipment. It is assumed that floor space will be available in existing or planned building facilities at each terminal. The spare equipment racks would be provided to accommodate additional radio equipment, if diversity and hot-running standby operation should eventually be desired. The proposed radio equipment would have an ultimate capacity of at least 72 voice channels.

The four unattended repeater stations would utilize essentially the same radio equipment on a baseband back-to-back basis. No multiplex equipment would be provided at the repeater stations, as no need for drop channels appears necessary. However, an order wire panel at each repeater station would provide a voice channel for the use of maintenance personnel and any emergency communications. In addition to batteries and charging

equipment, a primary power source would be required as well as alarm equipment, which could be monitored at one or both of the terminal stations.

As indicated in the discussion of the Fort Lamy-Maiduguri route survey, the terrain between these points is essentially flat and no insurmountable problems affecting radio propagation should be expected. The Nigerian PTT had encountered fading problems on some of their microwave links during the Hamadan season and this effect should be given some consideration if a detailed engineering design phase should eventuate. The nominal 30-mile microwave paths which would be encountered on the proposed system could easily be accommodated as long as antenna towers of adequate height are provided.

2.5 Troposcatter Communication Link: -- A single-hop troposcatter over-the-horizon radio link could provide the necessary capabilities for handling traffic between Fort Lamy and Maiduguri. A simplified and economical tropo system approximating CCIR-CCITT transmission standards could be designed to meet the present requirements. The simplification would consist in providing a single transmitter chain at each terminal without hot-running standby equipment. This reduction in equipment reliability would be justified on the same ground as that stated for the proposed microwave alternative, namely, that a service would be provided where none now exists. However, dual space diversity would be provided

by means of two receivers and a combiner and two antennas at each terminal. Dual space diversity is considered essential to combat the short-term fading that is typical of the tropo mode of radio propagation. The diversity requirement is particularly applicable to the transmission of telegraph signals.

The proposed tropo system would operate in the 2000 MHz band and would utilize the same type of low-level equipment (receivers and transmitter exciters) as that suggested for the microwave system alternative. However, an additional element at each terminal would consist of a 1 kw power amplifier to raise the output level of the transmitter-exciter. The two antennas at each terminal would consist of 30-foot diameter parabolic dishes with pressurized dual polarization feed horns. Both antennas at each terminal would receive the signal from the distant terminal, but only one of the antennas at each terminal would be used to transmit the signal. Signal transmission and reception by a single antenna would be achieved by the provision of a duplexer-filter combination for that antenna. A block diagram of the system configuration is shown in Figure 5.

Although only 12 voice channels are required to meet the present traffic forecasts, the system would be capable of handling many more channels, possibly as high as 120 voice channels. In addition, the proposed system would be expandable to quadruple diversity and hot-running stand-by operation by doubling the number of receivers and transmitters of the proposed

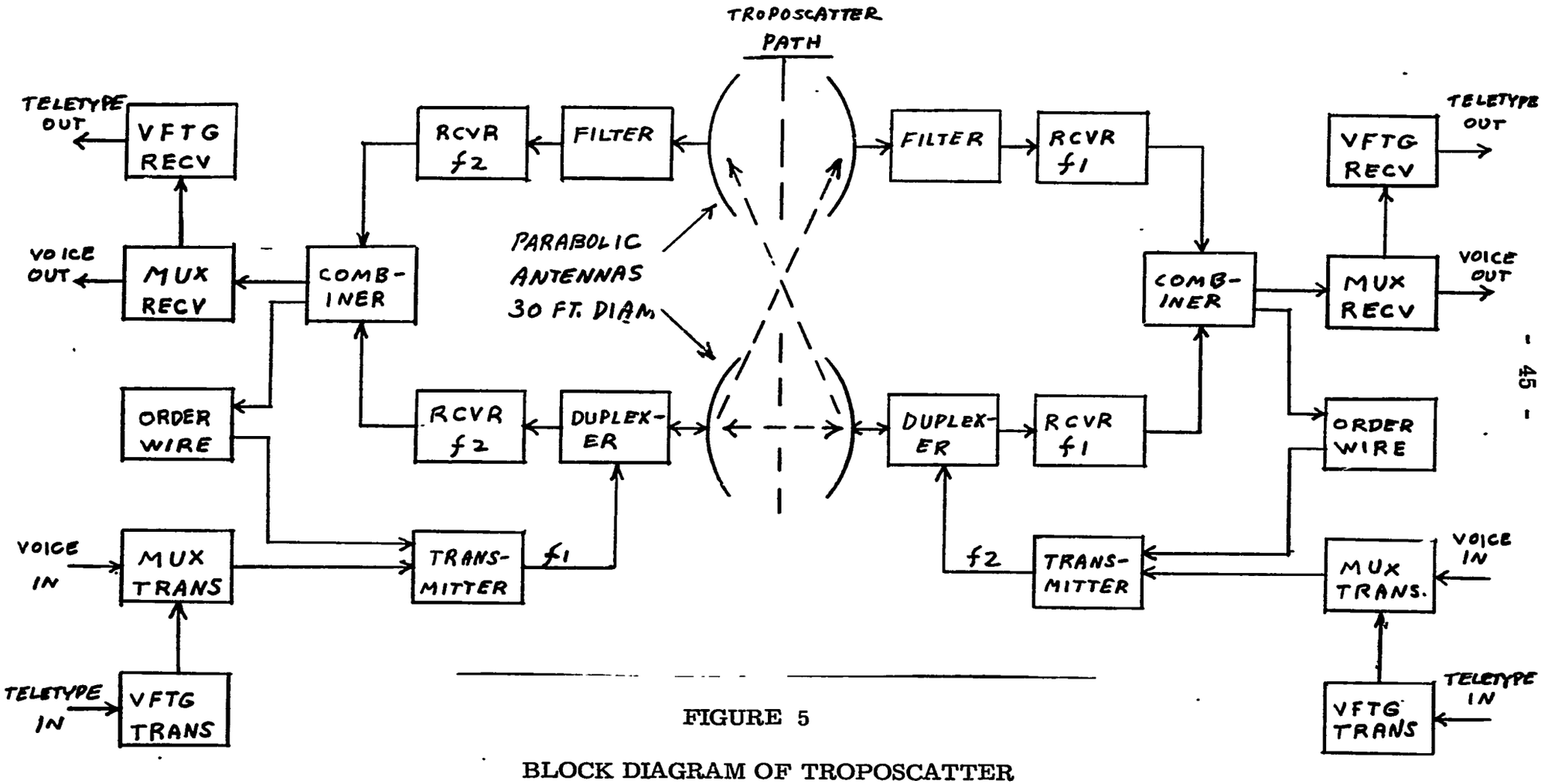


FIGURE 5

BLOCK DIAGRAM OF TROPOSCATTER

DUAL DIVERSITY COMMUNICATIONS LINK

terminal configuration. Such an expansion would improve system performance and reliability, if such should ultimately prove necessary or desirable.

The multiplex and order wire requirements for the proposed tropo system would be the same as for the two terminals of the microwave alternative. The power requirements of the tropo terminals would be greater than that of the microwave terminals because of the 1 kw power amplifiers. However, it is assumed that the tropo terminals could be co-located at existing (Fort Lamy) and planned (Maiduguri) facilities and, thus, minimize the need for separate prime and standby power sources. Similarly, the co-location of facilities would minimize building construction costs.

A propagation and system analysis of the proposed tropo link was performed and the results indicate that an acceptable system performance level can be attained. This analysis has been confirmed by the results of a programmed computer evaluation of troposcatter radiowave path losses between Fort Lamy and Maiduguri and other parameters of the proposed system. A summary of computer outputs for various combinations of equipment parameters is shown in Table 3. This summary shows an acceptable system noise performance during the month in which the worst propagation condition can be expected. The table shows that 22 dBaO median noise level and a 99.9% propagation reliability are

TABLE 3

TROPOSCATTER SYSTEM

WORST MONTH TRANSMISSION PERFORMANCE

Fort Lamy-Maiduguri Path

No. of Voice Channels *	Antenna Dia. Ft.	Transmitter Power kw	Median Rec'd. Carrier dBm	Peak Mod Index	Threshold Extension Bandwidth mHz	DUAL DIVERSITY Median Noise dBa0	DUAL DIVERSITY Outage Time %	QUADRUPLE DIVERSITY Median Noise dBa0	QUADRUPLE DIVERSITY Outage Time %
12	30	1	-81	20	0.4	22	0.1	19	0.01
12	60	1	-72	20	0.4	13	0.005	10	0.002
12	30	10	-71	20	0.4	12	0.004	9	0.0001
12	60	10	-62	20	0.4	3	0.0001	-	-
24	30	1	-81	20	1.0	23	0.4	20	0.07
24	60	1	-72	20	1.0	14	0.02	11	0.0008
24	30	10	-71	20	1.0	13	0.01	10	0.0005
24	60	10	-62	20	1.0	4	0.0005	-	-
48	30	1	-81	10	1.0	30	1.0	27	0.4
48	60	1	-72	10	1.0	21	0.1	18	0.01
48	30	10	-71	10	1.0	20	0.07	17	0.007
48	60	10	-62	10	1.0	11	0.002	-	-

*Assumptions are: 3 dB noise figures (transistor front ends), 3 dB total line loss and 8 dB monthly standard deviation of median received carrier power.

attainable with system parameters including dual diversity, 30-foot antennas, 1 kw power amplifiers, and 12-voice channel loading. A more detailed analysis of the tropo system is presented in Appendix B.

There are certain disadvantages of the tropo system compared to the microwave alternative. For example, there would be no possibility of providing future communication service to intermediate points between Fort Lamy and Maiduguri. However, the advantages of the tropo system over microwave are many. The maintenance problems of a tropo system will be less because there will be no need for maintaining four repeater stations as required by the microwave alternative. The division of responsibility for construction, maintenance, and operation of the tropo system can be made easily between two countries; one country for each terminal.

An international connection between Cameroon and Nigeria could also be provided by the tropo system. This would be achieved by means of the proposed cable connection from the Cameroon microwave system terminal at Fort Foureau to Fort Lamy.

3. <u>HF Radio Systems Between Fort Lamy-Douala and Fort Lamy-Lagos</u>: -- At the present time an HF system exists only between Fort Lamy and Douala, although an HF system has been planned but not implemented between Fort Lamy and Lagos. Consideration of the Fort Lamy-Douala HF link as an alternative connection between Chad and Cameroon

has become somewhat academic, as construction of the Yaoundé-Fort Foureau microwave system is about to begin. The only comparison that can be made now is between the HF link and the proposed cable connection between Fort Foureau and Fort Lamy. On the basis of traffic handling capability, the cable system would be superior by a 12 to 1 ratio, at least, of available voice channels. In terms of system operation and maintenance, the cable connection again has a great superiority as it is a completely passive system available 24 hours a day. However, the HF link between Fort Lamy and Douala will remain the only available communication link between Chad and Cameroon for sometime. Consequently, it has appeared desirable to present in this report an evaluation of the HF link in terms of expected performance and traffic handling capability.

The HF propagation path between Fort Lamy and Douala was analyzed in the same way as that described for the Fort Lamy-Maiduguri HF path. The data for this analysis are also included in Appendix A. There are presently three HF frequencies in use for the Fort Lamy-Douala circuit: 11608, 7650, and 5081 KHz. The ESSA data show that the reliable propagation times for these frequencies over the 1073 km path are as follows:

Frequencies (KHz)	Available Operating Times (GMT)	Total Hours
5081	0000 to 0500 & 1700 to 2400	12
7650	0000 to 1100 & 1300 to 2400	22
11608	0000 to 0100 & 0600 to 2400	19

The proposed Fort Lamy-Lagos HF link has also been suggested as an alternative means of providing service between Fort Lamy and Maiduguri, using the transiting facilities of the Nigerian PTT landline and microwave network. The most obvious objection to this alternative is that the projected 12-voice channel requirement between Fort Lamy and Maiduguri could not be accommodated by an HF system. The maximum number of voice channels that a Fort Lamy-Lagos HF link could handle would be four. Additional factors militating against this alternative would be the problems and cost of transiting traffic over the Nigerian PTT network. However, since the establishment of an HF link between Fort Lamy and Lagos might be desirable as an interim measure, an evaluation of such a link based on the ESSA techniques is also presented in terms of expected performance and traffic handling capability. The circuit analysis and data are included as part of Appendix A. If the availability of three frequencies, 7000, 9000, and 11000 KHz, is assumed, the reliable operating times over the 1421 KM path, for August 1969, can be obtained from the ESSA data and are as follows:

Frequencies (KHz)	Available Operating Times (GMT)	Total Hours
7000	0000 to 0600 & 1700 to 2400	13
9000	0000 to 0700, 0900 to 1100 and 1500 to 2400	18
11000	0000 to 0300 & 0600 to 2400	21

VII TELECOMMUNICATION SYSTEMS INVESTMENT AND OPERATING COSTS

This section includes a breakdown of investment and operating costs of those system alternatives which could be designed to most reasonably meet the technical and operating requirements of the proposed links between Fort Lamy and Fort Foureau and Fort Lamy and Maiduguri. Consideration will be given first to the cable link between Fort Lamy and Fort Foureau. The system alternatives to be considered for the Fort Lamy-Maiduguri connection include open-wire carrier, VHF radio, microwave, and troposcatter radio.

1. Fort Lamy-Fort Foureau Cable Link: -- The cost of the cable system described earlier can be broken down as follows:

Capital Investment

Three 5,000 foot reels of 50-pair #22 gage wire with copper shielded pairs and outer polyethylene sheath (at $428/thousand ft.)	$ 6,420
Cable pressurizing equipment	600
Cable terminations & installation	1,200
Installation	3,000
Packing & shipping	780
	$ 12,000

Annual Maintenance

Five percent (5%) of capital cost	$ 600

The above investment costs assume that the construction of the proposed cable connection would be carried out by the local PTT organizations.

2. Fort Lamy-Maiduguri System Alternatives: -- Of the four alternative systems to be considered for this route, our combined evaluation of technical operational characteristics and system cost in each case has resulted in a determination that only two of the system alternatives (microwave and troposcatter) should be considered for implementation. Consequently, only summary estimates of investment costs for the open-wire carrier and VHF radio systems are given.

2.1 Open-Wire Carrier System: -- An open-wire carrier system would consist of about 140 miles of pole-line, two carrier repeater stations, and two carrier terminals. The system would require twenty-five 25 ft. poles per mile with a single pair of open-wire. The capital investment costs required for such a system are tabulated as follows:

Capital Investment

One hundred - forty (140) miles of pole-line installed at $2,625/mile	$ 367,500
Two carrier terminals plus two carrier repeaters installed	80,886
Interest during construction cost	27,400
	$ 475,786

The above indicated cost of an open-wire carrier system is greater than either the microwave or troposcatter alternative.

2.2 VHF Radio System: -- The following estimates for a VHF radio system to provide service over the Fort Lamy-Maiduguri route assume solid state equipment operating in the 150 MHz band. Hot-running standby equipment

is not assumed. A breakdown of capital investment costs is presented in Table 4. The indicated total cost in rounded figures of $435,000 is only slightly less than the cost of the microwave system. Since the VHF system lacks the capabilities of the microwave system for future expansion, it is not considered suitable for further consideration.

2.3 Microwave Radio System: -- The microwave system, as described earlier would be solid state, operating in the 2000 MHz band on a non-diversity and non-hot-running standby basis. The total capital investment required for the system would amount to $440,000 in rounded figures. The details of this cost estimate are shown in Table 5. The estimate of annual operating costs for the microwave alternative amounts to $38,000. The details of this cost estimate appear in Table 6.

A detailed financial analysis of a telecommunication system connecting Fort Lamy and Maiduguri, based on the proposed microwave alternative, is presented in Section IX of this report.

2.4 Troposcatter Radio System: -- A detailed cost breakdown of capital investment requirements for the troposcatter system alternative is presented in Table 7. The total indicated cost in rounded figures is $400,000. The estimate of annual operating costs for this system is given in Table 8 and amounts to $27,500.

A detailed financial analysis of the troposcatter alternative for the Fort Lamy-Maiduguri link is also presented in Section IX of this report.

TABLE 4

VHF RADIO INVESTMENT COSTS

(In U.S. Dollars)

Fort Lamy-Maiduguri Route

Item	Foreign Currency	Local Currency	Total
VHF Radio Term. Equip.	$ 8,250	$ --	$ 8,250
Repeaters (4)	33,000	--	33,000
Voice Freq. Multiplex	22,000	--	22,000
Order Wire	3,400	--	3,400
Fault Alarms	5,700	--	5,700
Antennas & Tower Mounts	9,000	--	9,000
Coaxial Cable	7,000	--	7,000
Towers	48,000	--	48,000
Batteries & Chargers	21,000	--	21,000
TOTAL	$ 157,350	$ --	$ 157,350
Installation, Test & Training	$ 83,600	$ 48,096	$ 131,696
Power Supplies	30,000	--	30,000
Test Equipment & Spares	15,000	--	15,000
Buildings	--	20,000	20,000
Packing & Shipping	20,000	--	20,000
Engineering	35,000	--	35,000
Interest during Construction	26,100	--	26,100
GRAND TOTAL	$ 367,050	$ 68,096	$ 435,146

TABLE 5

MICROWAVE RADIO INVESTMENT COSTS

(In U.S. Dollars)

Fort Lamy-Maiduguri Route

Items	Foreign Currency	Local Currency	Total
Radio Terminal Equip.	$ 8,800	$ --	$ 8,800
Repeaters (4)	35,200	--	35,200
Voice Freq. Multiplex	22,000	--	22,000
Order Wire	3,400	--	3,400
Fault Alarms	8,200	--	8,200
Antennas & Tower Mounts	9,000	--	9,000
Wave Guide	7,000	--	7,000
Towers	48,000	--	48,000
Batteries & Chargers	21,000	--	21,000
TOTAL	$ 162,600	$ --	$ 162,600
Installation, Test & Training	$ 83,600	$ 48,096	$ 131,696
Power Supplies	30,000	--	30,000
Test Equipment & Spares	15,000	--	15,000
Buildings	--	20,000	20,000
Packing & Shipping	20,000	--	20,000
Engineering	35,000	--	35,000
Interest during Construction	26,400	--	26,400
GRANT TOTAL	$ 372,600	$ 68,096	$ 440,696

TABLE 6

MICROWAVE RADIO ANNUAL OPERATING COSTS

(In U.S. Dollars)

Fort Lamy-Maiduguri Route

Item	Foreign Currency	Local Currency	Total
Electronic Spares	$ 8,000	$ --	$ 8,000
Salaries	--	16,000	16,000
Power	--	3,000	3,000
Building & Maintenance	--	2,000	2,000
Vehicle Operation & Maintenance	--	1,500	1,500
Training	--	4,000	4,000
Traffic Expenses	--	3,500	3,500
	$ 8,000	$30,000	$38,000

TABLE 7

TROPOSCATTER RADIO INVESTMENT COSTS

(In U.S. Dollars)

Fort Lamy-Maiduguri Route

Item	Foreign Currency	Local Currency	Total
Tropo Radio Term. (2)	$ 56,800	$ --	$ 56,800
Voice Freq. Multiplex	22,000	--	22,000
Order Wire	1,000	--	1,000
Fault Alarm	1,600	--	1,600
Parabolic Antennas (4) (30 ft. dia.) with Tower Mounts	57,800	--	57,800
Wave Guide	5,000	--	5,000
TOTAL	$ 144,200	$ --	$ 144,200
Installation, Test & Training	$ 66,300	$ 44,320	$ 110,620
Power Supplies	20,000	--	20,000
Test Equipment & Spares	20,000	--	20,000
Building Floor Space	--	20,000	20,000
Packing & Shipping	25,000	--	25,000
Engineering	35,000	--	35,000
Interest during Construction	24,000	--	24,000
GRAND TOTAL	$ 334,500	$ 64,320	$ 398,820

TABLE 8

TROPOSCATTER RADIO ANNUAL OPERATING COSTS

(In U.S. Dollars)

Fort Lamy-Maiduguri Route

Item	Foreign Currency	Local Currency	Total
Electronic Spares	$ 8,000	$ --	$ 8,000
Salaries	--	8,000	8,000
Power	--	3,000	3,000
Building & Maintenance	--	1,000	1,000
Vehicle Operation & Maintenance	--	--	--
Training	--	4,000	4,000
Traffic Expenses	--	3,500	3,500
	$ 8,000	$ 19,500	$ 27,500

In the cost estimates for both the microwave and troposcatter systems, it is assumed that training of local personnel will be provided by the contractor during the period of construction and test. It is expected that the expatriate technical personnel now on the staffs of the local PTT organizations will be prepared to take over the future training requirements.

VIII. DEVELOPMENT OF REVENUES

Revenue estimates are presented for the Fort Lamy-Fort Foureau, and the Fort Lamy-Maiduguri routes. The estimate for the former route has a very simple base, while estimates for the latter are based on somewhat more complex considerations.

1. Fort Lamy-Fort Foureau: -- The revenue estimate for this link is based on actual revenues of the Fort Lamy-Douala HF link for 1968. These actual revenues amounted to about $30,000 for telephone, telegraph, and telex services. Assuming that all of the HF link traffic is diverted to the new Cameroon microwave system, and that 10 percent (10%) of the $30,000 revenue were applied to the proposed cable connection, the amount of revenue accruing to the latter would be $3,000 per year. It is unnecessary to project future revenues that would accrue to this link, as the initial $3,000 per year is more than adequate to meet annual costs.

2. Fort Lamy-Maiduguri: -- A more detailed analysis is required of the development of revenues for this route. Separate discussions are presented for telephone, telegraph, and telex.

2.1 Telephone: -- The conversion of traffic volumes into revenues was accomplished by the application of revenues per message for 1968 supplied by the PTT in Chad. It is assumed that the revenue per telephone message

between Fort Lamy and Maiduguri would be about the same as between Fort Lamy and other cities in Chad. Between Fort Lamy and Fort Archambault the rate is $1.32 for three minutes of conversation and the average length of conversation is 4.75 minutes, so that an average call would produce $2.09 of revenue. For Abeche, at a greater distance, the rate is $1.43, which is equivalent to $2.24 of revenue per call. Moundou is $1.32 or the same as for Fort Archambault. Bongor, a small city with only 70 subscribers is about the same distance from Fort Lamy as Maiduguri and the rate is $0.91 or $1.44 for an average call. Although Maiduguri is nearer to Fort Lamy than the three largest cities mentioned above, it is felt that in view of the fact that the proposed link would be relatively expensive, the rate per message of $2.09 is reasonable. This is about the average of all calls in and out of Fort Lamy to all cities in Chad. Accordingly, revenues for the years 1971 - 1980 were obtained by applying the $2.09 average to the projected estimated messages between Fort Lamy and Maiduguri. These revenue estimates appear on the proforma income statements presented in Section IX.

2.2 Telegraph: -- In 1968 Chad handled 221,000 interurban telegraph messages which produced $167,000 of revenue, or $0.76 per message. This was applied to the telegraph message projections to obtain the revenues, as shown in the proforma income statements.

2.3 Telex: -- In 1968, there were 1,184 interurban telex messages and $3,059 of revenues, or an average of $2.58 per message. This average was applied to the projected messages to obtain the revenues, which are also shown in the proforma statements of Section IX.

Assuming that these messages were of average duration of 4.75 minutes, the same as for telephone, this is 23 percent higher than the average revenue per telephone call. In the U.S., the rate for a three minute station-to-station call from Washington, D.C. to Philadelphia, Pa., 130 miles, is $0.75, while the telex rate for the same call is $0.30 per minute or $0.90 for three minutes, which is 20 percent higher than for telephone. From this it would appear that the above suggested revenue per telex call conforms to present rate practices.

Some of the traffic originating at either end of the proposed link will have destinations in other parts of Nigeria and Chad. Just how much of this is a diversion from present facilities is difficult if not impossible to ascertain. On the other hand, the existence of the new facility is almost certain to generate some new traffic of this character.

In the absence of data sufficient to develop a reliable measure of the extent of additional traffic which might be generated by the proposed new link and in the interest of conservatism in this study, nothing has been included in the revenue projections for this item.

IX. FINANCIAL ANALYSIS AND ECONOMIC FEASIBILITY

In this section of the report, the financial aspects of the proposed Fort Lamy-Fort Foureau cable link are considered, and a more detailed financial analysis is given of the Fort Lamy-Maiduguri microwave and troposcatter alternatives.

1. Fort Lamy - Fort Foureau Link: -- As noted earlier, the estimate of cost for the proposed 50-pair cable link was based on the assumption that construction and installation would be performed by the PTT organizations themselves. The nominal indicated cost of $12,000 for construction of this link is not large enough to require special financing. The cost of the link can be met out of funds from the current PTT operating budgets. However, the rate of return calculation for the proposed link has been made on the basis of estimated costs of construction and maintenance as well as the estimated revenues accruing to the link. These calculations are very conservative as they are based on static estimates of annual traffic. The internal rate of return has been determined to be 16.7%. The data involved in this analysis are shown in Table 9.

The implementation of the proposed cable link would have no adverse economic effect resulting from the displacement of existing Fort Lamy-Douala HF radio facilities, as these facilities could be profitably utilized

TABLE 9

CABLE LINK BETWEEN FORT LAMY AND FORT FOUREAU

Time Profile and Benefit Costs
(In Thousands of U.S. Dollars)

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Benefit Streams										
Revenues	- -	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Residual Value of Property	- -	- -	- -	- -	- -	- -	- -	- -	- -	4,800
TOTAL	- -	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	7,800
Cost Streams										
Capital Cost	12,000	- -	- -	- -	- -	- -	- -	- -	- -	- -
Operating Cost		600	600	600	600	600	600	600	600	600
NET BENEFITS	(12,000)	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	7,200

Internal Rate of Return: 16.7%

in providing other telecommunication services. In particular, they could be used to provide the ISB services recommended in the Checchi report for the Fort Lamy - Abeche HF radio circuit.

2. Fort Lamy - Maiduguri System Alternatives: -- On the basis of technical, operational, and cost considerations, the microwave and troposcatter system alternatives for this route have been selected for detailed financial analysis.

2.1 Financial Analysis: -- Financial statements for the Fort Lamy - Maiduguri system alternatives are shown in Tables 13 and 14. These tables present pro-forma income statements, including cash flow, and balance sheets for the troposcatter and microwave alternatives for each year from 1971 through 1980.

As shown by the statements, revenue projections are identical for the two systems but investment and expenses are somewhat lower for troposcatter. Consequently, net income from troposcatter exceeds microwave by approximately 23% in 1980. The internal rate of return for the 10-year period, as shown in paragraph 2.4, is likewise higher for the troposcatter system. By the end of 1980 the troposcatter system will have generated enough cash to exceed the original investment, whereas cash generated by the microwave system falls short of the original investment by approximately $100,000.

2.2 Depreciation: -- Both troposcatter and microwave installations were estimated to have service lives of 15 years, with a salvage value at the end of the period of five percent of original cost. Depreciation expense and accruals to the reserve were computed on a straight line basis beginning with January 1, 1972, the date estimated to begin operation.

2.3 Financing: -- Financing arrangements which have been assumed for both the troposcatter and microwave systems contemplate a 25-year loan at six percent; the entire amount to be received January 1, 1971. Repayments of debt, in equal amounts per year, are shown to begin on December 31, 1973, since there would be insufficient cash generated prior to this date to make a debt repayment while still retaining a moderate amount of cash as working capital. The accompanying Tables 10 and 11 show sources and application of funds. Table 12 shows the schedule of financing and Tables 13 and 14 show cash flow and cash balance after debt service.

2.4 Cost Benefit Analysis and Internal Rate of Return: -- Tables 15 and 16 show the cost benefit analysis for troposcatter and microwave projects. This analysis shows the amount of revenue expected for each year of the 10 year period and the residual value of the investment in the property at the end of the period. This constitutes the expected benefits to be derived from the project. To obtain the net benefit, the expenditure for the plant in the

TABLE 10

TROPOSCATTER LINK BETWEEN FORT LAMY AND MAIDUGURI

Sources and Application of Funds

January 1, 1971 to December 31, 1980

SOURCES OF FUNDS		
Net Operating Income		$ 556,580
Cash Generated by Depreciation		228,000
Loan		400,000
		$1,184,580
APPLICATION OF FUNDS		
Construction of Communications Link		
Local Currency	$65,000	
Foreign Currency	335,000	
		$ 400,000
Debt Service		
Interest	$186,784	
Repayment of Loan	139,128	
		$ 325,912
Cash Balance (working capital)		$ 458,668
		$1,184,580

TABLE 11

MICROWAVE LINK BETWEEN FORT LAMY AND MAIDUGURI

Sources and Application of Funds

January 1, 1971 to December 31, 1980

SOURCES OF FUNDS		
Net Operating Income		$ 448,280
Cash Generated by Depreciation		250,800
Loan		440,000
		$ 1,139,080
APPLICATION OF FUNDS		
Construction of Communications Link		
Local Currency	$ 68,000	
Foreign Currency	372,000	
		$ 440,000
Debt Service		
Interest	$205,461	
Repayment of Loan	153,040	
		$ 358,501
Cash Balance (working capital)		$ 340,579
		$ 1,139,080

TABLE 12

Schedule of Financing

T R O P O S C A T T E R

		Balance Unpaid	Repayment December 31 Each Year	Interest 6%	Total Debt Service	Cash Available
January 1	1971	$ 400,000	$	$	$	$
December 31	1971	400,000		24,000*		
"	1972	400,000		24,000	24,000	43,047
"	1973	382,609	17,391	24,000	41,391	71,979
"	1974	365,218	17,391	22,957	40,348	77,451
"	1975	347,827	17,391	21,913	39,304	83,081
"	1976	330,436	17,391	20,870	38,261	89,084
"	1977	313,045	17,391	19,826	37,217	94,678
"	1978	295,654	17,391	18,783	36,174	101,038
"	1979	278,263	17,391	17,739	35,130	108,187
"	1980	260,872	17,391	16,696	34,087	116,035
TOTAL		$	$ 139,128	$ 186,784	$ 325,912	$ 784,580

M I C R O W A V E

January 1	1971	$ 440,000	$	$	$	$
December 31	1971	440,000		26,400*		
"	1972	440,000		26,400	26,400	33,547
"	1973	420,870	19,130	26,400	45,530	62,479
"	1974	401,740	19,130	25,252	44,382	67,951
"	1975	382,610	19,130	24,104	43,234	73,581
"	1976	363,480	19,130	22,957	42,087	79,584
"	1977	344,350	19,130	21,809	40,939	85,178
"	1978	325,220	19,130	20,661	39,791	91,538
"	1979	306,090	19,130	19,513	38,643	98,687
"	1980	286,960	19,130	18,365	37,495	106,535
TOTAL		$	$ 153,040	$ 205,461	$ 358,501	$ 699,080

* Capitalized

TABLE 13

TROPOSCATTER LINK BETWEEN FORT LAMY AND MAIDUGURI
Proforma Income Statement and Balance Sheet
(In U.S. Dollars)

INCOME STATEMENT	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Revenues										
Telephone	--	39,974	59,222	65,145	71,066	77,196	82,910	88,833	94,756	100,677
Telegraph	--	27,182	35,533	34,350	33,078	31,635	29,847	28,103	26,532	24,895
Telex	--	2,419	4,030	5,039	6,298	7,892	9,838	12,296	15,371	19,213
Total Revenues	--	69,575	98,785	104,534	110,442	116,723	122,595	129,232	136,659	144,785
Operating Expenses										
Operation & Maint.	--	26,528	26,806	27,083	27,361	27,639	27,917	28,194	28,472	28,750
Depreciation	--	25,333	25,333	25,334	25,333	25,333	25,334	25,333	25,333	25,334
Total Oper. Exp.	--	51,861	52,139	52,417	52,694	52,972	53,251	53,527	53,805	54,084
Net Operating Income	--	17,714	46,646	52,117	57,748	63,751	69,344	75,705	82,854	90,701
Less Interest	--	24,000	24,000	22,957	21,913	20,870	19,826	18,783	17,739	16,696
Net Income	--	(6,286)	22,646	29,160	35,835	42,881	49,518	56,922	65,115	74,005
Plus Depreciation	--	25,333	25,333	25,334	25,333	25,333	25,334	25,333	25,333	25,334
Less Debt Repayment	--	--	17,391	17,391	17,391	17,391	17,391	17,391	17,391	17,391
Cash Flow	--	19,047	30,588	37,103	43,777	50,823	57,461	64,864	73,057	81,948
BALANCE SHEET										
Assets										
Plant Investment	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000
Less: Depreciation	--	25,333	50,666	76,000	101,333	126,666	152,000	177,333	202,666	228,000
Net Plant Invest.	400,000	374,667	349,334	324,000	298,667	273,334	248,000	222,667	197,334	172,000
Plus: Cash	--	19,047	49,635	86,738	130,515	181,338	238,799	303,663	376,720	458,668
Total Assets	400,000	393,714	398,969	410,738	429,182	454,672	486,799	526,330	574,054	630,668
Liabilities										
Debt	400,000	400,000	382,609	365,218	347,827	330,436	313,045	295,654	278,263	260,872
Retained Earnings	--	(6,286)	16,360	45,520	81,355	124,236	173,754	230,676	295,791	369,796
Total Liabilities	400,000	393,714	398,969	410,738	429,182	454,672	486,799	526,330	574,054	630,668

TABLE 14

MICROWAVE LINKS BETWEEN FORT LAMY AND MAIDUGURI
Proforma Income Statement and Balance Sheet
(In U.S. Dollars)

INCOME STATEMENT	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Revenues										
Telephone	--	39,974	59,222	65,145	71,066	77,196	82,910	88,833	94,756	100,677
Telegraph	--	27,182	35,533	34,350	33,078	31,635	29,847	28,103	26,532	24,895
Telex	--	2,419	4,030	5,039	6,298	7,892	9,838	12,296	15,371	19,213
Total Revenues	--	69,575	98,785	104,534	110,442	116,723	122,595	129,232	136,659	144,785
Operating Expenses										
Operation & Maint.	--	36,028	36,306	36,583	36,861	37,139	37,417	37,694	37,972	38,250
Depreciation	--	27,867	27,866	27,867	27,867	27,866	27,867	27,867	27,866	27,867
Total Oper. Exp.	--	63,895	64,172	64,450	64,728	65,005	65,284	65,561	65,838	66,117
Net Operating Income	--	5,680	34,613	40,084	45,714	51,718	57,311	63,671	70,821	78,668
Less Interest	--	26,400	26,400	25,252	24,104	22,957	21,809	20,661	19,513	18,365
Net Income	--	(20,720)	8,213	14,832	21,610	28,761	35,502	43,010	51,308	60,303
Plus Depreciation	--	27,867	27,866	27,867	27,867	27,866	27,867	27,867	27,866	27,867
Less Debt Repayment	--	--	19,130	19,130	19,130	19,130	19,130	19,130	19,130	19,130
Cash Flow	--	7,147	16,949	23,569	30,347	37,497	44,239	51,747	60,044	69,040
BALANCE SHEET										
Assets										
Plant Investment	440,000	440,000	440,000	440,000	440,000	440,000	440,000	440,000	440,000	440,000
Less: Depreciation	--	27,867	55,733	83,600	111,467	139,333	167,200	195,067	222,933	250,800
Net Plant Invest.	440,000	412,133	384,267	356,400	328,533	300,667	272,800	244,933	217,067	189,200
Plus: Cash	--	7,147	24,096	47,665	78,012	115,509	159,748	211,495	271,539	340,579
Total Assets	440,000	419,280	408,363	404,065	406,545	416,176	432,548	456,428	488,606	529,779
Liabilities										
Debt	440,000	440,000	420,870	401,740	382,610	363,480	344,350	325,220	306,090	286,960
Retained Earnings	--	(20,720)	(12,507)	2,325	23,935	52,696	88,198	131,208	182,516	242,819
Total Liabilities	440,000	419,280	408,363	404,065	406,545	416,176	432,548	456,428	488,606	529,779

TABLE 15

TROPOSCATTER LINK BETWEEN FORT LAMY AND MAIDUGURI

Time Profile and Benefit Costs
(in Thousands of U.S. Dollars)

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Benefit Streams										
Telephone Revenues	- -	39,974	59,222	65,145	71,066	77,196	82,910	88,833	94,756	100,677
Telegraph Revenues	- -	27,182	35,533	34,350	33,078	31,635	29,847	28,103	26,532	24,895
Telex Revenues	- -	2,419	4,030	5,039	6,298	7,892	9,838	12,296	15,371	19,213
Residual Value of Property	- -	--	--	--	--	--	--	--	--	172,000
TOTAL	- -	69,575	98,785	104,534	110,442	116,723	122,595	129,232	136,659	316,785
Cost Streams										
Capital Cost	400,000	--	--	--	--	--	--	--	--	--
Operating Costs	- -	26,528	26,806	27,083	27,361	27,639	27,917	28,194	28,472	28,750
Net Benefits	(400,000)	43,047	71,979	77,451	83,081	89,084	94,678	101,038	108,187	288,035

Internal Rate of Return 16.7 %

TABLE 16

MICROWAVE LINK BETWEEN FORT LAMY AND MAIDUGURI

Time Profile and Benefit Costs
(in Thousands of U.S. Dollars)

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Benefit Streams										
Telephone Revenues	- -	39,974	59,222	65,145	71,066	77,196	82,910	88,833	94,756	100,677
Telegraph Revenues	- -	27,182	35,533	34,350	33,078	31,635	29,847	28,103	26,532	24,895
Telex Revenues	- -	2,419	4,030	5,039	6,298	7,892	9,838	12,296	15,371	19,213
Residual Value of Property	- -	--	--	--	--	--	--	--	--	189,200
TOTAL	- -	69,575	98,785	104,534	110,442	116,723	122,595	129,232	136,659	333,985
Cost Streams										
Capital Cost	440,000	--	---	--	--	--	--	--	--	--
Operating Cost	- -	36,028	36,306	36,583	36,861	37,139	37,417	37,694	37,972	38,250
Net Benefits	(440,000)	33,547	62,479	67,951	73,581	79,584	85,178	91,536	98,678	295,735

Internal Rate of Return 12.5%

construction period and the cost of operation in each succeeding year are deducted from the yearly benefits. Depreciation expense is not included as a cost because the residual value is included as a benefit.

The internal rate of return computation is a device to bring all of the values to the beginning of the period in order to recognize the earning power of money over periods of time. In effect, the sum of the present values of net benefits for all of the years is compared with the present day expenditure which created these benefits. The solution resolves the interest rate which when applied to these future net benefits permits their summation to equal the original investment. The equation to be evaluated is the following:

$$\frac{b_o}{1} + \frac{b_1}{1+N} + \frac{b_2}{(1+N)^2} + \frac{b_3}{(1+N)^3} + \cdots + \frac{b_n}{(1+N)^n} = 0$$

where b_o, b_1, b_2, . . . , b_n represent the net benefits for each year, n is the number of the years in the period, and N is the internal rate of return required to satisfy the equation.

In order that the above equation be applicable to the problem, there must be an expenditure at the beginning of the series which is a negative benefit.

The above expressions were programmed for computer analysis and internal rate of return values of 16.7 and 12.5% were computed for the troposcatter and microwave systems, respectively. The computer printouts for these

two calculations are shown in Table 17.

2.5 Cost Benefit Ratios: -- The purpose of the cost benefit computation is to check the advantage of the proposed project against the opportunity investment rate of the economy where the project would be built. In the case of the troposcatter project, if the opportunity cost of investment expressed as a rate of interest is less than 16.7%, the project may be considered economical. A corresponding figure for the microwave project would be 12.5% . The cost benefit ratios for these two project alternatives over a range of interest rates are shown in Table 18.

3. Financial Commitments: -- A review was made of the convention or agreement between the Government of Chad and France Cable & Radio (FCR) concerning telecommunication services. There appear to be no restrictions in the agreement applying to the Government, which would require any payments of money to FCR if the Government should decide to establish new telecommunication facilities or alternatives to existing FCR facilities. In any case, discussions are underway between the Government of Chad and FCR for drafting a revised telecommunications agreement. The above statements apply equally to the agreement between the Government of Cameroon and FCR.

TABLE 17

COMPUTER PRINTOUT OF
INTERNAL RATE OF RETURN
CALCULATION

TROPOSCATTER

SCHEDULE OF BENEFITS IN THOUSANDS

1ST YEAR	2ND YEAR	3RD YEAR	4TH YEAR	5TH YEAR	6TH YEAR	7TH YEAR	8TH YEAR	9TH YEAR	10TH YEAR
-400.00	43.05	71.98	77.45	83.08	89.08	94.68	101.04	108.19	288.04

INTERNAL RATE OF RETURN N= 0.165

MICROWAVE

SCHEDULE OF BENEFITS IN THOUSANDS

1ST YEAR	2ND YEAR	3RD YEAR	4TH YEAR	5TH YEAR	6TH YEAR	7TH YEAR	8TH YEAR	9TH YEAR	10TH YEAR
-440.00	33.55	62.48	67.95	73.58	79.58	85.18	91.54	98.68	295.74

INTERNAL RATE OF RETURN N= 0.125

TABLE 18

COST-BENEFIT RATIOS

TROPOSCATTER

Interest Rate	Cost - Benefit Ratio
13%	1.18
14%	1.13
15%	1.08
16%	1.03
* 16.7%	1.00
17%	0.99
18%	0.95
19%	0.91
20%	0.87

MICRO WAVE

9%	1.20
10%	1.14
11%	1.08
12%	1.02
* 12.5%	1.00
13%	0.97
14%	0.92
15%	0.88
16%	0.85

*Corresponds to internal rate of return.

X. SYSTEM IMPLEMENTATION PLANS AND TRAINING

Implementation plans for the microwave and troposcatter alternatives will not be totally different. However, the training problems for the two systems will be different, not so much for technical reasons as for the fact that a microwave system will require greater coordination between PTT administrations than a troposcatter system.

1. System Implementation Plans: -- Implementation plans are proposed for the cable system and for the microwave and troposcatter alternatives. The latter two require an 18 month period from commencement of engineering to completion of final system testing. The implementation plan for the cable system is shown in Table 19, microwave system in Table 20, and the troposcatter system in Table 21. These implementation plans are based on the assumption that government or international agency administrative delays will be nominal.

2. Training: -- There should be no training requirements for the cable system. The problems of training with respect to the troposcatter system would be relatively simple. One terminal would be in Fort Lamy under the jurisdiction of the PTT of Chad, the other would be in Maiduguri and administered by the Nigerian PTT. Initial training would be provided by the contractor at each terminal during the period of construction and testing. The expatriate personnel on the staff of the PTT of Chad will be more than qualified

TABLE 19

CABLE SYSTEM IMPLEMENTATION PLAN

Fort Lamy - Fort Foureau Route

TASK	TIME IN MONTHS From Start of Project
Preparation of Cable Distribution Layout	0 - 1
Cable, Hardware, and Termating Equipment Procurement	1 - 4
Installation and Connection	4 - 5
Test	5 - 6
Operation	6

TABLE 20

MICROWAVE SYSTEM IMPLEMENTATION PLAN

Fort Lamy - Maiduguri Route

Task	Time in Months From Start of Project
Site Selection, Path-Loss Calculations and Preparation of Specifications	0 - 3
Evaluation of Proposals and Contract Negotiations	3 - 6
Land Acquisition	0 - 6
Equipment Fabrication and Delivery	6 - 12
Building Plans	6 - 8
Construction of Buildings and Towers	8 - 12
Installation of Equipment	14 - 17
Testing	17 - 18
Operation	19

TABLE 21

TROPOSCATTER SYSTEM IMPLEMENTATION PLAN

Fort Lamy - Maiduguri Route

Task	Time in Months From Start of Project
Path and Site Survey, System Engineering and Preparation of Specifications	0 - 3
Evaluation of Proposals and Contract Negotiations	3 - 6
Land Acquisition *	--
Equipment Fabrication and Delivery	6 - 12
Preparation of Building Floor-Plan	6 - 8
Tropo Antenna Construction	8 - 12
Installation of Equipment	12 - 17
Testing	17 - 18
Operation	19

* It is assumed that existing facilities of both the Chad and Nigerian PTTs will be used for the proposed tropo terminals.

to take over the continuing training required in Fort Lamy of local personnel and graduates of the PTT technical school. At the Maiduguri terminal, there will be an existing Nigerian training program designed to handle the new microwave network which is being extended from Lagos and other cities in the West and South of Nigeria. The low level 2000 MHz radio equipment proposed for the troposcatter system is basically the same as equipment proposed for the microwave alternative, and will not differ greatly from the 2000 MHz light route system being installed by the Nigerian PTT from Bauchi to Maiduguri. Therefore, the only radically different element in the tropo terminal radio equipment will be the 1 kw Klystron Power Amplifier. The period of construction and testing should provide ample time for training of local personnel by contractor personnel in the operation and maintenance of the power amplifier.

The problem of training for the microwave system alternative would be different, depending on how the system were to be operated and administered. Since two of the repeater stations would be located in Cameroon, responsibility for their operation could be placed in the hands of the Cameroon PTT organization that will be set up to run the new microwave system extending to Fort Foureau from Yaoundé. Training facilities are included in the Operational Plans for this new system. The microwave terminal in Fort Lamy would be operated by the Chad PTT and, hence, the provision and training of personnel for that terminal would be their

responsibility. Similarly, the two remaining repeaters and the terminal in Nigeria would be the responsibility of the Nigerian PTT and the required training of personnel could be handled as part of the continuing training program for the new and expanding Nigerian microwave network.

An alternative plan for consolidation of responsibility of both training and operation of the proposed microwave system would be to locate the proposed Fort Lamy terminal in Fort Foureau. Chad could then be interconnected with both the Cameroon and Nigerian networks by means of the cable proposed for connecting Fort Lamy and Fort Foureau.

APPENDIX

A

HIGH FREQUENCY SYSTEM PERFORMANCE PREDICTIONS

1. Description of Tabulated System Performance Predictions

A description of the circuit parameters used in the calculations of the system performance predictions is shown in the heading of each page of data. Starting at the top of the page after the page number, this heading is as follows:

The first line contains the month and year and the solar activity level as indicated by the 12-month running average Zurich sunspot number. The second and third lines contain the name and coordinates of the transmitter and receiver location, the azimuthal bearings in degrees of the receiver from the transmitter and vice versa, and the length of the circuit in statute miles and kilometers. The fourth and fifth lines describe the physical parameters of the antenna system for each terminal and the orientation of the antenna's main beam relative to the great-circle path. The minimum angle indicates the lowest vertical angle considered in the mode selection process.

The sixth line contains the power output of the transmitter, the man-made noise level assumed for the receiver location, in decibels relative to 1 watt in a 1 Hz bandwidth at a frequency of 3 MHz, and the hourly median signal-to-noise ratio required to provide the type of service requested. The seventh and eighth lines contain the list of frequencies to be considered in the hourly calculations.

The first line of each time block gives the Greenwich mean time (GMT) in hours, and the maximum usable frequency (MUF), the frequency which has a 50 percent probability of having a sky-wave path. This is followed by an estimate of the change in the MUF due to magnetic activity, specifically, the MUF for a local magnetic K-index of 0 and 5. The expected MUF for other values of the K-index can be

found by a linear interpolation or extrapolation. For each frequency in the list, the body of the tabulation contains: (a) the mode having the greatest reliability (MODE), (b) the vertical angle in degrees associated with this mode (ANGLE), (c) the time delay in milliseconds (DELAY), (d) the virtual height of reflection in kilometers (VIRT HT), (e) the fraction of days that any sky-wave mode is expected to exist (F. DAYS), (f) the lowest transmission loss in decibels (LOSS DB), (g) the median incident field strength for the above mode available at the receiving antenna, in decibels relative to 1 microvolt per meter (DBU), (h) the median signal power available at the terminals of the receiver in decibels relative to 1 watt (SIG. DBW), (i) the median value of the controlling noise at the receiving site in decibels relative to 1 watt (NOI. DBW), (j) the median signal-to-noise ratio in decibels for the days the sky-wave exists (S/N DB), (k) the fraction of days that the required signal-to-noise ratio will be attained (F. S/N), and (l) the fraction of days within the month that the sky-wave will be present and the required signal-to-noise ratio will be attained (REL.).

The symbols used to denote the propagation modes are as follows: E layer (E); F2 layer (F); E-F2 layers (X), i.e., 3X describes one hop by the E layer and two hops by the F2 layer; Es layer (S); and Es-F2 layers (Y), i.e., 4Y describes one hop by Es and 3 hops by the F2 layer.

2. Description of Graphical Representation

On the graph associated with the tabulations are plotted the maximum usable frequency (MUF), the frequency which has a 50 percent probability of having a sky-wave path, as an asterisk; the optimum traffic frequency (FOT), the frequency which has a 90 percent probability of having a sky-wave path, as a plus sign; and the lowest useful

frequency (LUF), the lowest frequency which has a reliability of 90 percent or greater, as a dot. When no frequency is predicted to attain a 90 percent reliability, an "X" is shown at the bottom of the graph. The MUF and FOT values are plotted for every hour of the day and the LUF values for every other hour of the day. Any values greater than or equal to 30 MHz are plotted on the top line of the graph. All plotted values are tabulated on the right-hand side of the graph. A dash in the tabulations correspond to an "X" on the graph.

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FT LAMY	TO DOUALA	AZIMUTHS	MILES	KM.
12.10N - 15.00E	4.00N - 9.70E	213.35 32.61	666.7	1072.9
RHOMBIC 17.5H 82.0L 65.0		RHOMBIC 17.5H 80.0L 63.0		

OFF AZIMUTH= 0.0DEG. MINIMUM ANGLE= 0.0DEG. OFF AZIMUTH= 0.0DEG.
POWER= 6.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DB

FREQUENCIES IN MHZ

UT	MUF	2.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	22.0	26.0	30.0	
02	11.6	K(0)MUF=(11.6)				K(5)MUF=(11.6)							
	1F	2F	2F	1F	1F	1F	1F	1F	-	-	-	-	MODE
	29.0	43.3	43.5	24.0	24.4	25.1	29.0	29.0	-	-	-	-	ANGLE
	4.3	5.1	5.1	4.1	4.1	4.1	4.3	4.3	-	-	-	-	DELAY
	336	268	270	271	277	286	336	336	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.91	.42	.03	-	-	-	-	F. DAYS
	103	126	113	103	94	91	106	144	-	-	-	-	LOSS DB
	52	30	37	48	55	57	51	35	-	-	-	-	DBU
	-66	-88	-76	-65	-56	-53	-68	-106	-	-	-	-	SIG.DBW
	-175	-158	-161	-162	-165	-169	-175	-178	-	-	-	-	NOI.DBW
	109	70	85	97	109	116	107	72	-	-	-	-	S/N DB
	.99	.39	.87	.98	.99	.99	.99	.46	-	-	-	-	F. S/N
	.50	.38	.87	.97	.98	.91	.42	.01	-	-	-	-	REL.
04	8.0	K(0)MUF=(8.0)				K(5)MUF=(8.0)							
	1F	2F	2F	1F	1F	1F	-	-	-	-	-	-	MODE
	27.8	42.7	42.6	23.4	24.6	27.8	-	-	-	-	-	-	ANGLE
	4.2	5.1	5.1	4.1	4.1	4.2	-	-	-	-	-	-	DELAY
	319	254	259	262	279	319	-	-	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.78	.23	-	-	-	-	-	-	F. DAYS
	92	126	114	103	94	92	-	-	-	-	-	-	LOSS DB
	56	30	37	48	55	57	-	-	-	-	-	-	DBU
	-54	-89	-76	-66	-56	-54	-	-	-	-	-	-	SIG.DBW
	-165	-158	-161	-162	-164	-167	-	-	-	-	-	-	NOI.DBW
	111	69	85	96	108	113	-	-	-	-	-	-	S/N DB
	.99	.37	.86	.98	.99	.99	-	-	-	-	-	-	F. S/N
	.50	.37	.85	.97	.78	.23	-	-	-	-	-	-	REL.
06	14.8	K(0)MUF=(14.8)				K(5)MUF=(14.8)							
	1F	1E	3F	2F	1F	1F	1F	1F	-	-	-	-	MODE
	28.6	7.1	56.9	43.1	24.0	23.7	24.6	28.6	-	-	-	-	ANGLE
	4.3	3.7	6.8	5.1	4.1	4.1	4.1	4.3	-	-	-	-	DELAY
	329	91	253	257	256	261	276	329	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.99	.95	.44	-	-	-	-	F. DAYS
	137	172	143	116	99	94	97	142	-	-	-	-	LOSS DB
	37	-11	6	32	49	54	55	35	-	-	-	-	DBU
	-99	-135	-105	-79	-61	-56	-59	-104	-	-	-	-	SIG.DBW
	-177	-159	-165	-166	-166	-168	-173	-178	-	-	-	-	NOI.DBW
	78	24	60	87	105	112	114	74	-	-	-	-	S/N DB
	.71	.00	.08	.90	.99	.99	.99	.54	-	-	-	-	F. S/N
	.35	.00	.08	.89	.99	.99	.95	.23	-	-	-	-	REL.

AUGUST 1969 SUNSPOT NUMBER 102.7

FT LAMY	TO DOUALA	AZIMUTHS	MILES	KM.
12.10N - 15.00E	4.00N - 9.70E	213.35 32.61	666.7	1072.9
RHOMBIC 17.5H 82.0L 65.0		RHOMBIC 17.5H 80.0L 63.0		

OFF AZIMUTH= 0.0DEG. MINIMUM ANGLE= 0.0DEG. OFF AZIMUTH= 0.0DEG.

POWER= 6.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DB

FREQUENCIES IN MHZ

UT	MUF	2.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	22.0	26.0	30.0	
08	16.7	K(0)MUF=(16.7)			K(5)MUF=(16.7)								
	1F	1E	1E	3F	2E	1F	1E	1F	1F	-	-	-	MODE
	33.2	7.1	7.1	55.2	19.6	24.0	8.5	26.8	33.2	-	-	-	ANGLE
	4.5	3.7	3.7	6.5	3.9	4.1	3.7	4.2	4.5	-	-	-	DELAY
	394	90	91	248	103	254	104	303	394	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.99	.99	.83	.23	-	-	-	F. DAYS
	137	215	195	152	126	97	99	127	133	-	-	-	LOSS DB
	29	-54	-30	1	23	51	49	41	37	-	-	-	DBU
	-99	-177	-157	-114	-89	-60	-61	-89	-95	-	-	-	SIG.DBW
	-178	-160	-166	-174	-175	-175	-175	-178	-178	-	-	-	NOI.DBW
	78	-17	9	59	86	115	114	89	82	-	-	-	S/N DB
	.73	.00	.00	.06	.90	.99	.99	.95	.85	-	-	-	F. S/N
	.36	.00	.00	.06	.90	.99	.99	.79	.20	-	-	-	REL.
10	14.8	K(0)MUF=(14.8)			K(5)MUF=(14.8)								
	1F	1E	1E	3F	2F	1F	1F	1F	1F	-	-	-	MODE
	36.4	7.1	7.1	54.8	43.0	24.0	24.8	36.4	36.4	-	-	-	ANGLE
	4.8	3.7	3.7	6.4	5.1	4.1	4.1	4.8	4.8	-	-	-	DELAY
	444	90	91	237	250	244	271	444	444	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.99	.99	.46	.06	-	-	-	F. DAYS
	143	240	213	160	130	99	101	144	116	-	-	-	LOSS DB
	28	-79	-48	-7	23	48	51	28	46	-	-	-	DBU
	-105	-202	-175	-122	-92	-62	-63	-107	-79	-	-	-	SIG.DBW
	-179	-160	-166	-175	-178	-178	-176	-178	-178	-	-	-	NOI.DBW
	74	-42	-10	53	86	116	113	72	99	-	-	-	S/N DB
	.54	.00	.00	.01	.89	.99	.99	.44	.99	-	-	-	F. S/N
	.27	.00	.00	.01	.89	.99	.99	.20	.06	-	-	-	REL.
12	14.9	K(0)MUF=(13.7)			K(5)MUF=(13.7)								
	1E	1E	1E	3F	2F	1F	1E	-	-	-	-	-	MODE
	10.3	7.1	7.1	55.1	43.5	24.2	8.1	-	-	-	-	-	ANGLE
	3.7	3.7	3.7	6.5	5.1	4.1	3.7	-	-	-	-	-	DELAY
	122	90	90	236	255	245	101	-	-	-	-	-	VIRT HT
	.99	.99	.99	.99	.99	.99	.99	-	-	-	-	-	F. DAYS
	95	242	215	161	131	100	103	-	-	-	-	-	LOSS DB
	55	-81	-50	-7	22	48	46	-	-	-	-	-	DBU
	-57	-204	-177	-123	-94	-62	-65	-	-	-	-	-	SIG.DBW
	-177	-160	-166	-175	-177	-176	-175	-	-	-	-	-	NOI.DBW
	120	-44	-11	52	83	115	109	-	-	-	-	-	S/N DB
	.99	.00	.00	.00	.83	.99	.99	-	-	-	-	-	F. S/N
	.99	.00	.00	.00	.83	.99	.99	-	-	-	-	-	REL.

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FT LAMY	TO DOUALA	AZIMUTHS	MILES	KM.
12.10N - 15.00E	4.00N - 9.70E	213.35	32.61	666.7 1072.9
RHOMBIC 17.5H 82.0L 65.0		RHOMBIC	17.5H 80.0L 63.0	
OFF AZIMUTH= 0.0DEG.	MINIMUM ANGLE= 0.0DEG.		OFF AZIMUTH= 0.0DEG.	

POWER= 6.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DB

FREQUENCIES IN MHZ

UT	MUF:	2.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	22.0	26.0	30.0	
14	14.3	K(0)MUF=(13.2)				K(5)MUF=(13.2)							
		1E	1E	1E	3F	2E	1F	1E	1F	1F	-	-	- MODE
		10.3	7.1	7.1	56.2	19.3	25.5	8.3	39.4	39.4	-	-	- ANGLE
		3.7	3.7	3.7	6.7	3.9	4.1	3.7	5.0	5.0	-	-	- DELAY
		122	90	91	255	101	271	102	496	496	-	-	- VIRT HT
		.99	.99	.99	.99	.99	.99	.99	.20	.02	-	-	- F. DAYS
		94	221	199	156	129	98	103	136	111	-	-	- LOSS DB
		55	-60	-35	-1	21	50	48	35	49	-	-	- DBU
		-57	-183	-161	-118	-91	-60	-65	-98	-73	-	-	- SIG.DBW
		-175	-160	-166	-173	-173	-173	-173	-175	-177	-	-	- NOI.DBW
		118	-23	4	55	82	112	108	77	104	-	-	- S/N DB
		.99	.00	.00	.02	.79	.99	.99	.67	.99	-	-	- F. S/N
		.99	.00	.00	.02	.79	.99	.99	.13	.02	-	-	- REL.
16	13.9	K(0)MUF=(13.9)				K(5)MUF=(13.9)							
		2F	1E	1E	2F	1F	1F	1F	1F	1F	-	-	- MODE
		67.6	7.1	7.1	45.3	25.7	26.1	29.7	40.5	40.5	-	-	- ANGLE
		10.5	3.7	3.7	5.3	4.1	4.2	4.3	5.1	5.1	-	-	- DELAY
		730	90	91	275	274	290	343	518	518	-	-	- VIRT HT
		.50	.99	.99	.99	.99	.99	.87	.30	.05	-	-	- F. DAYS
		137	181	170	119	99	95	111	129	111	-	-	- LOSS DB
		27	-20	-6	30	49	53	48	39	49	-	-	- DBU
		-99	-143	-132	-81	-62	-57	-73	-91	-73	-	-	- SIG.DBW
		-171	-156	-161	-166	-166	-166	-168	-173	-177	-	-	- NOI.DBW
		72	13	29	84	104	109	95	82	104	-	-	- S/N DB
		.43	.00	.00	.82	.99	.99	.97	.82	.99	-	-	- F. S/N
		.22	.00	.00	.82	.98	.99	.85	.25	.05	-	-	- REL.
18	14.5	K(0)MUF=(14.5)				K(5)MUF=(14.5)							
		2F	2F	2F	1F	1F	1F	1F	1F	1F	-	-	- MODE
		61.9	48.7	47.9	27.6	28.0	28.8	31.1	38.5	38.5	-	-	- ANGLE
		8.3	5.7	5.6	4.2	4.3	4.3	4.4	4.9	4.9	-	-	- DELAY
		553	308	311	313	321	333	365	483	483	-	-	- VIRT HT
		.50	.99	.99	.99	.99	.99	.84	.41	.09	-	-	- F. DAYS
		142	125	113	101	93	93	115	136	110	-	-	- LOSS DB
		27	29	36	49	55	56	47	33	50	-	-	- DBU
		-105	-87	-76	-63	-55	-55	-77	-99	-72	-	-	- SIG.DBW
		-171	-153	-157	-160	-161	-163	-167	-172	-177	-	-	- NOI.DBW
		67	66	81	97	106	107	90	74	105	-	-	- S/N DB
		.19	.29	.75	.97	.99	.99	.94	.53	.99	-	-	- F. S/N
		.10	.29	.75	.97	.99	.98	.79	.22	.09	-	-	- REL.

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FT LAMY	TO DOUALA	AZIMUTHS	MILES	KM.
12.10N - 15.00E	4.00N - 9.70E	213.35 32.61	666.7	1072.9
RHOMBIC 17.5H 82.0L 65.0		RHOMBIC 17.5H 80.0L 63.0		

OFF AZIMUTH= 0.0DEG. MINIMUM ANGLE= 0.0DEG. OFF AZIMUTH= 0.0DEG.
POWER= 6.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DB

FREQUENCIES IN MHZ

UT	MUF	2.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	22.0	26.0	30.0	
20	13.7	K(0)MUF=(13.7)				K(5)MUF=(13.7)							
	1F	2F	2F	1F	1F	1F	1F	1F	1F	-	-	-	MODE
	36.5	48.9	49.0	28.7	29.2	29.9	31.9	36.5	36.5	-	-	-	ANGLE
	4.8	5.7	5.7	4.3	4.3	4.3	4.5	4.8	4.8	-	-	-	DELAY
	448	328	330	332	338	348	377	448	448	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.98	.75	.28	.04	-	-	-	F. DAYS
	145	123	112	100	93	94	119	148	114	-	-	-	LOSS DB
	30	30	37	50	55	56	45	30	48	-	-	-	DBU
	-107	-86	-75	-62	-55	-56	-81	-110	-76	-	-	-	SIG.DBW
	-175	-157	-161	-162	-164	-166	-171	-175	-178	-	-	-	NOI.DBW
	68	72	86	100	108	110	90	65	101	-	-	-	S/N DB
	.20	.44	.89	.99	.99	.99	.96	.07	.99	-	-	-	F. S/N
	.10	.43	.89	.99	.99	.97	.73	.02	.04	-	-	-	REL.
22	13.6	K(0)MUF=(13.6)				K(5)MUF=(13.6)							
	1F	2F	2F	1F	1F	1F	1F	1F	1F	-	-	-	MODE
	34.4	48.4	48.5	28.2	28.6	29.1	30.7	34.4	34.4	-	-	-	ANGLE
	4.6	5.7	5.7	4.3	4.3	4.3	4.4	4.6	4.6	-	-	-	DELAY
	416	322	324	325	330	338	361	416	416	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.99	.76	.29	.05	-	-	-	F. DAYS
	145	124	112	100	93	93	113	148	123	-	-	-	LOSS DB
	31	30	37	50	55	56	48	31	43	-	-	-	DBU
	-107	-86	-75	-62	-55	-56	-75	-110	-85	-	-	-	SIG.DBW
	-177	-159	-162	-163	-165	-168	-174	-177	-178	-	-	-	NOI.DBW
	70	74	87	101	110	113	99	67	92	-	-	-	S/N DB
	.31	.52	.91	.99	.99	.99	.99	.19	.96	-	-	-	F. S/N
	.16	.52	.91	.98	.99	.99	.75	.06	.05	-	-	-	REL.
24	13.1	K(0)MUF=(13.1)				K(5)MUF=(13.1)							
	1F	2F	2F	1F	1F	1F	1F	1F	-	-	-	-	MODE
	31.1	46.0	46.0	26.0	26.3	26.8	28.4	31.1	-	-	-	-	ANGLE
	4.4	5.4	5.4	4.2	4.2	4.2	4.3	4.4	-	-	-	-	DELAY
	365	294	295	296	301	307	328	365	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.98	.70	.22	-	-	-	-	F. DAYS
	129	125	113	101	93	91	104	143	-	-	-	-	LOSS DB
	41	30	37	49	55	57	52	31	-	-	-	-	DBU
	-92	-87	-75	-64	-55	-54	-66	-105	-	-	-	-	SIG.DBW
	-178	-159	-161	-163	-165	-169	-175	-179	-	-	-	-	NOI.DBW
	86	72	86	99	110	116	109	74	-	-	-	-	S/N DB
	.91	.46	.89	.99	.99	.99	.99	.54	-	-	-	-	F. S/N
	.45	.46	.88	.98	.99	.98	.69	.12	-	-	-	-	REL.

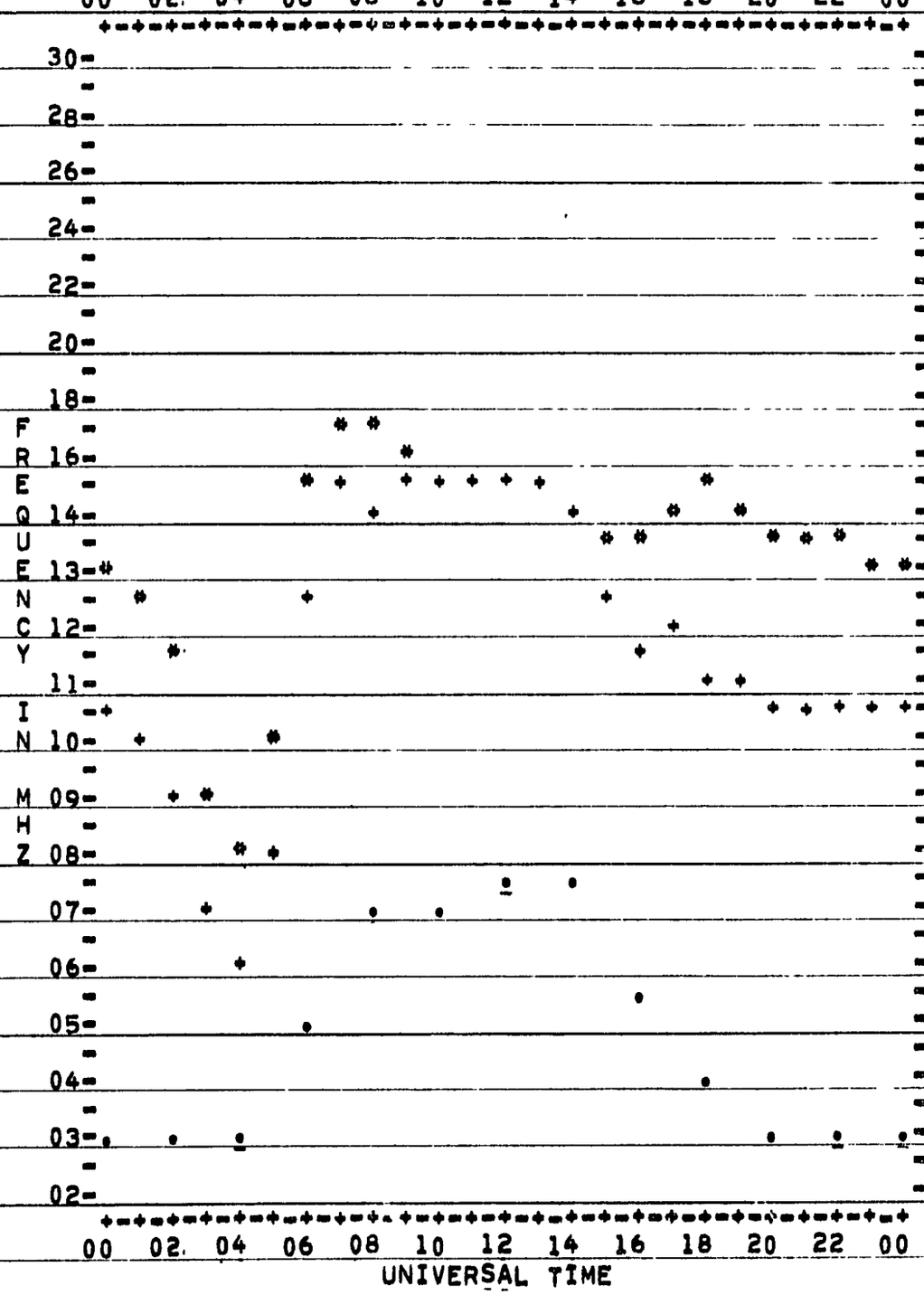
AUGUST 1969 SUNSPOT NUMBER 102.7

FT LAMY	TO DOUALA	AZIMUTHS	MILES	KM.
12.10N - 15.00E	4.00N - 9.70E	213.35 32.61	666.7	1072.9
RHOMBIC 17.5H 82.0L 65.0		RHOMBIC 17.5H 80.0L 63.0		

OFF AZIMUTH= 0.0DEG. MINIMUM ANGLE= 0.0DEG. OFF AZIMUTH= 0.0DEG.

POWER= 6.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DB

MUF(****) - FOT(++++) - LUF(....)



UT	MUF	FOT	LUF
01	12.8	10.2	
02	11.6	9.2	3.3
03	9.3	7.4	
04	8.0	6.3	3.4
05	10.3	8.1	
06	14.8	12.7	5.1
07	17.2	14.8	
08	16.7	14.4	7.1
09	15.5	14.5	
10	14.8	14.7	7.4
11	14.8	14.8	
12	14.9	14.9	7.7
13	14.9	14.9	
14	14.3	14.3	7.6
15	13.6	12.8	
16	13.9	11.8	5.6
17	14.2	12.1	
18	14.5	11.3	4.1
19	14.2	11.1	
20	13.7	10.6	3.1
21	13.5	10.5	
22	13.6	10.9	3.0
23	13.4	10.8	
24	13.1	10.5	3.1

AUGUST 1969 SUNSPOT NUMBER 102.7

FT LAMY	TO LAGOS	AZIMUTHS	MILES	KM.
12.10N - 15.00E	6.60N - 3.30E	245.57 63.66	883.3	1421.4
RHOMBIC 19.0H 86.0L 70.0		RHOMBIC 19.0H 86.0L 70.0		

OFF AZIMUTH= 0.0DEG. MINIMUM ANGLE= 0.0DEG. OFF AZIMUTH= 0.0DEG.
POWER= 6.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DB

FREQUENCIES IN MHZ

UT	MUF	2.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	22.0	26.0	30.0	
02	13.8	K(0)MUF=(13.8)				K(5)MUF=(13.8)							
	1F	1F	2F	2F	1F	1F	1F	1F	1F	-	-	-	MODE
	21.7	17.8	35.4	36.0	17.7	18.1	19.1	21.7	21.7	-	-	-	ANGLE
	5.4	5.2	6.1	6.1	5.2	5.2	5.2	5.4	5.4	-	-	-	DELAY
	339	271	273	279	277	283	298	339	339	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.98	.79	.31	.03	-	-	-	F. DAYS
	96	132	123	109	105	98	92	99	115	-	-	-	LOSS DB
	55	29	32	41	48	53	57	54	47	-	-	-	DBU
	-58	-94	-85	-72	-67	-60	-55	-62	-77	-	-	-	SIG.DBW
	-177	-148	-152	-156	-160	-165	-174	-178	-178	-	-	-	NOI.DBW
	118	54	67	84	92	105	119	117	101	-	-	-	S/N DB
	.99	.00	.25	.86	.96	.99	.99	.99	.99	-	-	-	F. S/N
	.50	.00	.24	.86	.96	.97	.79	.31	.03	-	-	-	REL.
04	9.2	K(0)MUF=(9.2)				K(5)MUF=(9.2)							
	1F	1E	3F	2F	1F	1F	1F	-	-	-	-	-	MODE
	20.5	4.3	46.6	35.9	17.4	19.4	20.5	-	-	-	-	-	ANGLE
	5.3	4.8	7.2	6.1	5.2	5.3	5.3	-	-	-	-	-	DELAY
	320	94	263	278	271	303	320	-	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.92	.54	.02	-	-	-	-	-	F. DAYS
	96	132	123	109	106	97	93	-	-	-	-	-	LOSS DB
	54	29	28	41	48	53	57	-	-	-	-	-	DBU
	-58	-94	-85	-72	-68	-59	-55	-	-	-	-	-	SIG.DBW
	-165	-149	-153	-156	-160	-164	-172	-	-	-	-	-	NOI.DBW
	107	55	68	85	92	106	117	-	-	-	-	-	S/N DB
	.99	.02	.30	.88	.97	.99	.99	-	-	-	-	-	F. S/N
	.50	.02	.29	.87	.89	.54	.02	-	-	-	-	-	REL.
06	15.8	K(0)MUF=(15.8)				K(5)MUF=(15.8)							
	1F	1E	3F	2F	1F	1F	1F	1F	1F	-	-	-	MODE
	21.1	4.0	49.9	34.9	17.7	17.3	17.5	19.0	21.1	-	-	-	ANGLE
	5.3	4.8	7.6	6.0	5.2	5.2	5.2	5.2	5.3	-	-	-	DELAY
	327	90	251	254	254	257	268	294	327	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.99	.98	.69	.08	-	-	-	F. DAYS
	102	176	147	121	111	102	95	95	112	-	-	-	LOSS DB
	53	-15	4	29	42	49	54	56	48	-	-	-	DBU
	-64	-139	-109	-83	-74	-65	-57	-57	-74	-	-	-	SIG.DBW
	-177	-152	-156	-158	-161	-164	-171	-176	-178	-	-	-	NOI.DBW
	114	13	47	75	87	100	114	119	104	-	-	-	S/N DB
	.99	.00	.00	.58	.92	.99	.99	.99	.99	-	-	-	F. S/N
	.50	.00	.00	.57	.91	.99	.98	.68	.08	-	-	-	REL.

AUGUST 1969 SUNSPOT NUMBER 102.7

FT LAMY	TO LAGOS	AZIMUTHS		MILES	KM.
12.10N - 15.00E	6.60N - 3.30E	245.57	63.66	883.3	1421.4
RHOMBIC 19.0H 86.0L 70.0		RHOMBIC 19.0H 86.0L 70.0			

OFF AZIMUTH= 0.0DEG. MINIMUM ANGLE= 0.0DEG. OFF AZIMUTH= 0.0DEG.
POWER= 6.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DE

FREQUENCIES IN MHZ

UT	MUF	2.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	22.0	26.0	30.0	
08	19.0	K(0)MUF=(19.0)				K(5)MUF=(19.0)							
	1F	1E	1E	3F	2F	2E	1F	1E	1F	-	-	-	MODE
	24.7	4.0	4.0	47.7	35.2	14.9	17.7	5.5	20.8	-	-	-	ANGLE
	5.5	4.8	4.8	7.3	6.0	5.0	5.2	4.8	5.3	-	-	-	DELAY
	384	90	90	248	252	106	258	110	320	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.99	.99	.99	.69	-	-	-	F. DAYS
	153	226	204	150	122	125	97	96	112	-	-	-	LOSS DB
	27	-65	-39	1	28	27	52	48	48	-	-	-	DBU
	-115	-188	-166	-112	-85	-87	-60	-58	-74	-	-	-	SIG.DBW
	-177	-159	-164	-169	-170	-170	-174	-177	-178	-	-	-	NOI.DBW
	61	-30	-2	57	85	83	114	119	104	-	-	-	S/N DB
	.03	.00	.00	.00	.88	.86	.99	.99	.99	-	-	-	F. S/N
	.02	.00	.00	.00	.88	.85	.99	.99	.69	-	-	-	REL.
10	17.6	K(0)MUF=(16.5)				K(5)MUF=(16.5)							
	1E	1E	1E	4F	2F	2F	1F	1E	-	-	-	-	MODE
	6.7	4.0	4.0	55.3	35.1	36.8	18.3	5.1	-	-	-	-	ANGLE
	4.9	4.8	4.8	8.6	6.0	6.2	5.2	4.8	-	-	-	-	DELAY
	125	90	90	241	249	277	268	104	-	-	-	-	VIRT HT
	.99	.99	.99	.99	.99	.99	.99	.99	-	-	-	-	F. DAYS
	99	257	226	186	127	131	99	100	-	-	-	-	LOSS DB
	53	-96	-62	-30	23	25	50	45	-	-	-	-	DBU
	-61	-219	-189	-148	-90	-94	-61	-62	-	-	-	-	SIG.DBW
	-177	-160	-166	-174	-176	-176	-175	-177	-	-	-	-	NOI.DBW
	116	-60	-23	26	86	82	114	115	-	-	-	-	S/N DB
	.99	.00	.00	.00	.91	.85	.99	.99	-	-	-	-	F. S/N
	.99	.00	.00	.00	.90	.84	.99	.99	-	-	-	-	REL.
12	17.9	K(0)MUF=(15.5)				K(5)MUF=(15.5)							
	1E	1E	1E	4F	2F	2F	1F	1E	-	-	-	-	MODE
	6.7	4.0	4.0	55.2	35.0	37.5	18.6	5.0	-	-	-	-	ANGLE
	4.9	4.8	4.8	8.6	6.0	6.2	5.2	4.8	-	-	-	-	DELAY
	125	90	90	235	246	285	272	103	-	-	-	-	VIRT HT
	.99	.99	.99	.99	.99	.99	.99	.99	-	-	-	-	F. DAYS
	99	262	230	188	128	134	99	104	-	-	-	-	LOSS DB
	53	-101	-66	-32	22	23	50	45	-	-	-	-	DBU
	-61	-225	-193	-150	-90	-96	-62	-66	-	-	-	-	SIG.DBW
	-177	-160	-166	-173	-174	-174	-174	-175	-	-	-	-	NOI.DBW
	116	-65	-27	23	83	77	112	109	-	-	-	-	S/N DB
	.99	.00	.00	.00	.84	.69	.99	.99	-	-	-	-	F. S/N
	.99	.00	.00	.00	.84	.69	.99	.99	-	-	-	-	REL.

AUGUST 1969 SUNSPOT NUMBER 102.7

FT LAMY	TO LAGOS	AZIMUTHS	MILES	KM.
12.10N - 15.00E	6.60N - 3.30E	245.57 63.66	883.3	1421.4
RHOMBIC 19.0H 86.0L 70.0		RHOMBIC 19.0H 86.0L 70.0		

OFF AZIMUTH= 0.0DEG. MINIMUM ANGLE= 0.0DEG. OFF AZIMUTH= 0.0DEG.
POWER= 6.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DB

FREQUENCIES IN MHZ

UT	MUF	2.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	22.0	26.0	30.0	
14	17.4	K(0)MUF=(15.3)				K(5)MUF=(15.3)							
	1E	1E	1E	4F	2F	2E	1F	1E	-	-	-	-	MODE
	6.7	4.0	4.0	56.2	36.4	14.2	19.9	5.1	-	-	-	-	ANGLE
	4.9	4.8	4.8	8.9	6.1	5.0	5.3	4.8	-	-	-	-	DELAY
	125	90	90	252	266	102	297	104	-	-	-	-	VIRT HT
	.99	.99	.99	.99	.99	.99	.99	.99	-	-	-	-	F. DAYS
	99	241	215	181	125	129	98	109	-	-	-	-	LOSS DB
	53	-80	-50	-25	25	23	51	46	-	-	-	-	DBU
	-61	-203	-177	-143	-88	-92	-60	-71	-	-	-	-	SIG.DBW
	-176	-158	-164	-170	-172	-171	-171	-174	-	-	-	-	NOI.DBW
	115	-45	-13	27	84	79	111	103	-	-	-	-	S/N DB
	.99	.00	.00	.00	.84	.74	.99	.99	-	-	-	-	F. S/N
	.99	.00	.00	.00	.83	.74	.99	.99	-	-	-	-	REL.
16	16.2	K(0)MUF=(16.2)				K(5)MUF=(16.2)							
	1F	1E	1E	2F	2F	1F	1F	1F	-	-	-	-	MODE
	29.5	4.0	4.0	37.1	37.2	18.9	19.5	23.0	-	-	-	-	ANGLE
	5.8	4.8	4.8	6.2	6.2	5.2	5.3	5.4	-	-	-	-	DELAY
	471	90	91	266	283	275	296	356	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.99	.99	.71	-	-	-	-	F. DAYS
	151	198	183	126	119	103	96	105	-	-	-	-	LOSS DB
	27	-37	-18	24	32	48	53	50	-	-	-	-	DBU
	-113	-160	-145	-88	-81	-65	-58	-68	-	-	-	-	SIG.DBW
	-173	-152	-157	-163	-164	-165	-167	-171	-	-	-	-	NOI.DBW
	60	-8	12	75	82	100	109	103	-	-	-	-	S/N DB
	.02	.00	.00	.56	.80	.98	.99	.99	-	-	-	-	F. S/N
	.01	.00	.00	.56	.80	.98	.99	.70	-	-	-	-	REL.
18	16.8	K(0)MUF=(16.8)				K(5)MUF=(16.8)							
	1F	3F	2F	2F	1F	1F	1F	1F	-	-	-	-	MODE
	29.1	52.3	39.3	39.2	20.2	20.5	21.6	23.9	-	-	-	-	ANGLE
	5.8	8.1	6.4	6.4	5.3	5.3	5.4	5.5	-	-	-	-	DELAY
	466	302	303	312	310	317	336	374	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.99	.95	.72	-	-	-	-	F. DAYS
	151	139	125	112	104	97	94	107	-	-	-	-	LOSS DB
	28	16	29	38	48	53	56	50	-	-	-	-	DBU
	-113	-101	-87	-74	-66	-59	-56	-69	-	-	-	-	SIG.DBW
	-171	-145	-150	-155	-157	-160	-164	-169	-	-	-	-	NOI.DBW
	57	44	63	81	91	100	107	100	-	-	-	-	S/N DB
	.00	.00	.20	.75	.94	.99	.99	.99	-	-	-	-	F. S/N
	.00	.00	.20	.74	.93	.98	.95	.71	-	-	-	-	REL.

AUGUST 1969 SUNSPOT NUMBER 102.7

FT LAMY	TO LAGOS	AZIMUTHS	MILES	KM.
12.10N - 15.00E	6.60N - 3.30E	245.57 63.66	883.3	1421.4
RHOMBIC 19.0H 86.0L 70.0		RHOMBIC 19.0H 86.0L 70.0		

OFF AZIMUTH= 0.0DEG. MINIMUM ANGLE= 0.0DEG. OFF AZIMUTH= 0.0DEG.
POWER= 6.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DB

FREQUENCIES IN MHZ

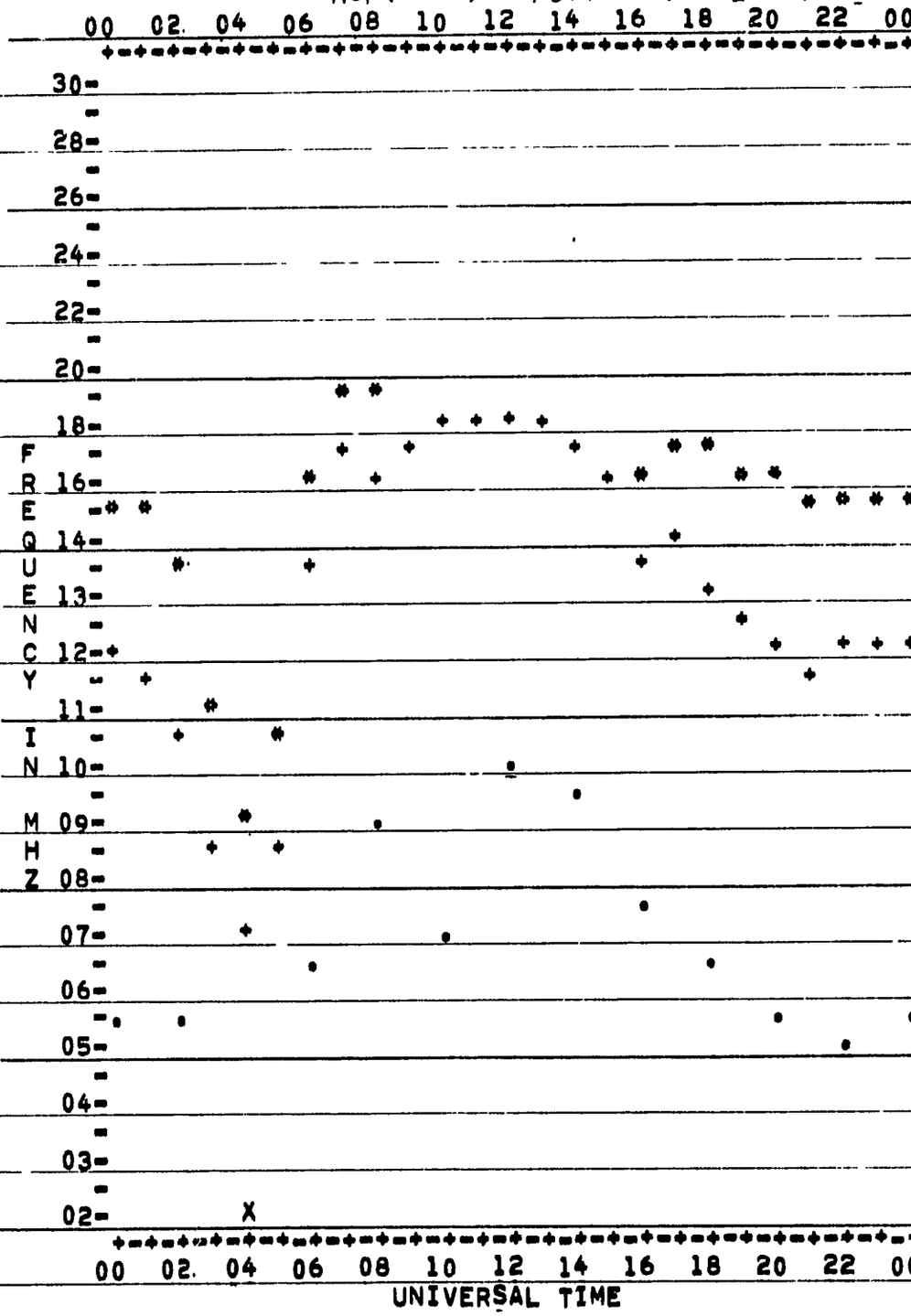
UT	MUF	2.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	22.0	26.0	30.0	
20	15.5	K(0)MUF=(15.5)				K(5)MUF=(15.5)							
	1F	3F	2F	2F	1F	1F	1F	1F	-	-	-	-	MODE
	28.2	53.1	41.2	41.7	21.9	22.3	23.4	25.9	-	-	-	-	ANGLE
	5.7	8.3	6.6	6.7	5.4	5.4	5.5	5.6	-	-	-	-	DELAY
	450	335	337	343	342	349	366	409	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.99	.91	.57	-	-	-	-	F. DAYS
	143	131	119	110	101	95	95	117	-	-	-	-	LOSS DB
	32	23	33	40	50	54	55	45	-	-	-	-	DBU
	-105	-94	-82	-72	-63	-58	-58	-79	-	-	-	-	SIG.DBW
	-174	-149	-152	-156	-159	-162	-167	-174	-	-	-	-	NOI.DBW
	69	55	71	84	95	104	110	95	-	-	-	-	S/N DB
	.29	.01	.40	.86	.98	.99	.99	.98	-	-	-	-	F. S/N
	.14	.01	.40	.86	.98	.99	.90	.56	-	-	-	-	REL.
22	15.2	K(0)MUF=(15.2)				K(5)MUF=(15.2)							
	1F	3F	2F	2F	1F	1F	1F	1F	-	-	-	-	MODE
	26.8	53.0	41.1	41.5	21.8	22.1	23.0	25.5	-	-	-	-	ANGLE
	5.7	8.3	6.6	6.7	5.4	5.4	5.4	5.6	-	-	-	-	DELAY
	424	335	336	341	340	346	360	401	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.99	.91	.53	-	-	-	-	F. DAYS
	125	132	119	110	101	95	95	114	-	-	-	-	LOSS DB
	41	23	33	40	50	54	55	47	-	-	-	-	DBU
	-87	-94	-82	-72	-63	-58	-57	-76	-	-	-	-	SIG.DBW
	-177	-152	-154	-157	-160	-164	-171	-177	-	-	-	-	NOI.DBW
	90	58	73	85	97	106	114	101	-	-	-	-	S/N DB
	.95	.00	.48	.89	.98	.99	.99	.99	-	-	-	-	F. S/N
	.47	.00	.48	.89	.98	.99	.91	.53	-	-	-	-	REL.
24	15.1	K(0)MUF=(15.1)				K(5)MUF=(15.1)							
	1F	3F	2F	2F	1F	1F	1F	1F	1F	-	-	-	MODE
	23.8	50.4	38.3	38.7	19.7	19.9	20.7	23.0	23.8	-	-	-	ANGLE
	5.5	7.8	6.3	6.4	5.3	5.3	5.3	5.4	5.5	-	-	-	DELAY
	372	302	303	308	306	311	322	360	372	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.99	.90	.51	.15	-	-	-	F. DAYS
	107	132	121	109	103	96	93	103	133	-	-	-	LOSS DB
	51	23	33	40	49	54	57	52	38	-	-	-	DBU
	-69	-94	-83	-72	-65	-59	-55	-66	-96	-	-	-	SIG.DBW
	-178	-149	-153	-156	-160	-165	-173	-178	-178	-	-	-	NOI.DBW
	109	55	70	85	95	106	117	113	82	-	-	-	S/N DB
	.99	.00	.36	.88	.97	.99	.99	.99	.82	-	-	-	F. S/N
	.50	.00	.36	.88	.97	.99	.90	.51	.13	-	-	-	REL.

AUGUST 1969 SUNSPOT NUMBER 102.7

FT LAMY	TO LAGOS	AZIMUTHS	MILES	KM.
12.10N - 15.00E	6.60N - 3.30E	245.57 63.66	883.3	1421.4
RHOMBIC 19.0H 86.0L 70.0		RHOMBIC 19.0H 86.0L 70.0		

OFF AZIMUTH= 0.0DEG. MINIMUM ANGLE= 0.0DEG. OFF AZIMUTH= 0.0DEG.
POWER= 6.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DB

MUF(****) - FOT(++++) - LUF(....)



UT	MUF	FOT	LUF
01	14.8	11.9	
02	13.8	10.9	5.6
03	11.3	8.9	
04	9.2	7.2	-
05	10.9	8.6	
06	15.8	13.6	6.9
07	19.2	16.5	
08	19.0	16.3	9.3
09	17.4	17.2	
10	17.6	17.6	7.0
11	17.7	17.7	
12	17.9	17.9	10.0
13	17.9	17.9	
14	17.4	17.4	9.9
15	15.9	15.9	
16	16.2	13.7	7.5
17	16.5	14.1	
18	16.8	13.1	6.6
19	16.4	12.8	
20	15.5	12.1	5.6
21	15.1	11.8	
22	15.2	12.2	5.4
23	15.3	12.2	
24	15.1	12.1	5.5

AUGUST 1969 SUNSPOT NUMBER 102.7

FT LAMY	TO MAIDUGURI	AZIMUTHS		MILES	KM.
12.10N - 15.00E	11.80N - 13.20E	260.52	80.15	123.4	198.6

HORIZ HW DIPOLE 12.0H -0.5L -0.0 HORIZ HW DIPOLE 12.0H -0.5L -0.0

OFF AZIMUTH= 0.0DEG. MINIMUM ANGLE= 0.0DEG. OFF AZIMUTH= 0.0DEG.

POWER= 1.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DB

FREQUENCIES IN MHZ

UT	MUF	2.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	22.0	26.0	30.0	
02	6.5	K(0)MUF=(6.5)				K(5)MUF=(6.5)							
	1F	1F	1F	1F	1F	-	-	-	-	-	-	-	MODE
	75.0	69.2	69.5	70.6	75.0	-	-	-	-	-	-	-	ANGLE
	2.7	1.9	2.0	2.1	2.7	-	-	-	-	-	-	-	DELAY
	393	273	277	295	393	-	-	-	-	-	-	-	VIRT HT
	.50	.99	.99	.92	.31	-	-	-	-	-	-	-	F. DAYS
	104	90	93	98	105	-	-	-	-	-	-	-	LOSS DB
	44	47	47	47	43	-	-	-	-	-	-	-	DBU
	-74	-60	-63	-68	-75	-	-	-	-	-	-	-	SIG.DBW
	-157	-148	-150	-154	-158	-	-	-	-	-	-	-	NOI.DBW
	83	88	88	86	83	-	-	-	-	-	-	-	S/N DB
	.84	.90	.90	.89	.84	-	-	-	-	-	-	-	F. S/N
	.42	.89	.90	.81	.26	-	-	-	-	-	-	-	REL.
04	4.7	K(0)MUF=(4.7)				K(5)MUF=(4.7)							
	1F	1F	1F	1F	-	-	-	-	-	-	-	-	MODE
	74.3	68.4	68.8	74.3	-	-	-	-	-	-	-	-	ANGLE
	2.6	1.9	1.9	2.6	-	-	-	-	-	-	-	-	DELAY
	373	256	266	373	-	-	-	-	-	-	-	-	VIRT HT
	.50	.99	.98	.34	-	-	-	-	-	-	-	-	F. DAYS
	99	90	93	100	-	-	-	-	-	-	-	-	LOSS DB
	45	47	47	45	-	-	-	-	-	-	-	-	DBU
	-69	-60	-63	-70	-	-	-	-	-	-	-	-	SIG.DBW
	-155	-150	-152	-155	-	-	-	-	-	-	-	-	NOI.DBW
	86	90	90	85	-	-	-	-	-	-	-	-	S/N DB
	.88	.91	.92	.88	-	-	-	-	-	-	-	-	F. S/N
	.44	.91	.90	.30	-	-	-	-	-	-	-	-	REL.
06	8.4	K(0)MUF=(8.4)				K(5)MUF=(8.4)							
	1F	1E	1E	1F	1F	1F	-	-	-	-	-	-	MODE
	76.3	43.5	48.3	68.9	70.6	76.3	-	-	-	-	-	-	ANGLE
	3.0	0.9	1.0	1.9	2.1	3.0	-	-	-	-	-	-	DELAY
	436	97	114	264	294	436	-	-	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.93	.24	-	-	-	-	-	-	F. DAYS
	112	103	100	102	105	115	-	-	-	-	-	-	LOSS DB
	39	36	41	43	43	38	-	-	-	-	-	-	DBU
	-82	-73	-70	-72	-75	-85	-	-	-	-	-	-	SIG.DBW
	-164	-155	-159	-161	-162	-165	-	-	-	-	-	-	NOI.DBW
	81	82	89	89	87	80	-	-	-	-	-	-	S/N DB
	.81	.76	.89	.92	.91	.78	-	-	-	-	-	-	F. S/N
	.41	.76	.89	.91	.85	.18	-	-	-	-	-	-	REL.

AUGUST 1969 SUNSPOT NUMBER 102.7

FT LAMY TO MAIDUGURI AZIMUTHS MILES KM.

12.10N - 15.00E 11.80N - 13.20E 260.52 80.15 123.4 198.6

HORIZ HW DIPOLE 12.0H -0.5L -0.0 HORIZ HW DIPOLE 12.0H -0.5L -0.0

OFF AZIMUTH= 0.0DEG. MINIMUM ANGLE= 0.0DEG. OFF AZIMUTH= 0.0DEG.

POWER= 1.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DB

FREQUENCIES IN MHZ

UT	MUF	2.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	22.0	26.0	30.0	
08	10.5	K(0)MUF=(10.5)			K(5)MUF=(10.5)								
	1F	1E	1E	1F	1F	1F	-	-	-	-	-	-	MODE
	81.8	42.4	43.8	69.2	71.1	74.6	-	-	-	-	-	-	ANGLE
	5.2	0.9	0.9	1.9	2.1	2.6	-	-	-	-	-	-	DELAY
	774	93	97	259	299	379	-	-	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.90	-	-	-	-	-	-	F. DAYS
	130	117	111	106	108	115	-	-	-	-	-	-	LOSS DB
	28	22	31	38	40	38	-	-	-	-	-	-	DBU
	-100	-87	-81	-76	-78	-85	-	-	-	-	-	-	SIG.DBW
	-170	-160	-166	-170	-171	-171	-	-	-	-	-	-	NOI.DBW
	70	73	85	94	93	86	-	-	-	-	-	-	S/N DB
	.36	.49	.86	.96	.96	.90	-	-	-	-	-	-	F. S/N
	.18	.48	.86	.96	.96	.81	-	-	-	-	-	-	REL.
10	10.3	K(0)MUF=(10.3)			K(5)MUF=(10.3)								
	1F	1E	1E	1F	1F	1F	-	-	-	-	-	-	MODE
	85.1	42.3	43.5	69.1	72.6	77.6	-	-	-	-	-	-	ANGLE
	9.4	0.9	0.9	1.9	2.3	3.3	-	-	-	-	-	-	DELAY
	1402	93	96	253	328	484	-	-	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.93	-	-	-	-	-	-	F. DAYS
	135	124	116	108	110	118	-	-	-	-	-	-	LOSS DB
	23	15	26	36	38	35	-	-	-	-	-	-	DBU
	-105	-94	-86	-78	-80	-88	-	-	-	-	-	-	SIG.DBW
	-172	-160	-166	-172	-174	-173	-	-	-	-	-	-	NOI.DBW
	67	65	79	94	94	85	-	-	-	-	-	-	S/N DB
	.18	.19	.74	.98	.97	.90	-	-	-	-	-	-	F. S/N
	.09	.19	.74	.97	.96	.84	-	-	-	-	-	-	REL.
12	10.4	K(0)MUF=(10.4)			K(5)MUF=(10.4)								
	1F	1E	1E	1F	1F	1F	-	-	-	-	-	-	MODE
	85.3	42.3	43.4	68.4	72.2	77.5	-	-	-	-	-	-	ANGLE
	10.0	0.9	0.9	1.9	2.3	3.3	-	-	-	-	-	-	DELAY
	1485	92	96	242	320	481	-	-	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.95	-	-	-	-	-	-	F. DAYS
	136	125	116	108	110	118	-	-	-	-	-	-	LOSS DB
	22	14	25	36	38	35	-	-	-	-	-	-	DBU
	-106	-95	-86	-78	-80	-88	-	-	-	-	-	-	SIG.DBW
	-170	-160	-166	-171	-172	-171	-	-	-	-	-	-	NOI.DBW
	64	65	79	93	92	83	-	-	-	-	-	-	S/N DB
	.07	.18	.73	.97	.94	.85	-	-	-	-	-	-	F. S/N
	.04	.18	.73	.97	.94	.81	-	-	-	-	-	-	REL.

AUGUST 1969 SUNSPOT NUMBER 102.7

FT LAMY	TO MAIDUGURI	AZIMUTHS		MILES	KM.
12.10N - 15.00E	11.80N - 13.20E	260.52	80.15	123.4	198.6

HORIZ HW DIPOLE 12.0H -0.5L -0.0 HORIZ HW DIPOLE 12.0H -0.5L -0.0

OFF AZIMUTH= 0.0DEG. MINIMUM ANGLE= 0.0DEG. OFF AZIMUTH= 0.0DEG.

POWER= 1.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DB

FREQUENCIES IN MHZ

UT	MUF	2.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	22.0	26.0	30.0	
14	10.6	K(0)MUF=(10.6)				K(5)MUF=(10.6)							
	1F	1E	1E	1F	1F	1F	-	-	-	-	-	-	MODE
	84.9	42.4	43.6	69.4	72.5	76.9	-	-	-	-	-	-	ANGLE
	9.1	0.9	0.9	2.0	2.3	3.1	-	-	-	-	-	-	DELAY
	1354	93	97	260	326	455	-	-	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.90	-	-	-	-	-	-	F. DAYS
	136	118	111	106	109	117	-	-	-	-	-	-	LOSS DB
	23	22	31	38	39	36	-	-	-	-	-	-	DBU
	-106	-88	-81	-76	-79	-87	-	-	-	-	-	-	SIG.DBW
	-168	-158	-163	-167	-168	-168	-	-	-	-	-	-	NOI.DBW
	61	70	82	90	89	81	-	-	-	-	-	-	S/N DB
	.03	.41	.74	.91	.91	.78	-	-	-	-	-	-	F. S/N
	.01	.41	.74	.91	.91	.70	-	-	-	-	-	-	REL.
16	11.0	K(0)MUF=(11.0)				K(5)MUF=(11.0)							
	1F	1E	1E	1F	1F	1F	-	-	-	-	-	-	MODE
	82.9	43.3	46.7	70.5	72.5	75.5	-	-	-	-	-	-	ANGLE
	6.1	0.9	1.0	2.1	2.3	2.8	-	-	-	-	-	-	DELAY
	909	96	108	288	330	407	-	-	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.99	.95	-	-	-	-	-	-	F. DAYS
	135	104	101	103	107	114	-	-	-	-	-	-	LOSS DB
	26	35	40	42	42	39	-	-	-	-	-	-	DBU
	-105	-74	-71	-73	-77	-84	-	-	-	-	-	-	SIG.DBW
	-163	-148	-153	-157	-159	-161	-	-	-	-	-	-	NOI.DBW
	57	73	82	85	83	77	-	-	-	-	-	-	S/N DB
	.00	.51	.74	.83	.81	.64	-	-	-	-	-	-	F. S/N
	.00	.51	.74	.82	.80	.61	-	-	-	-	-	-	REL.
18	10.4	K(0)MUF=(10.4)				K(5)MUF=(10.4)							
	1F	1F	1F	1F	1F	1F	-	-	-	-	-	-	MODE
	80.3	71.5	71.5	72.1	73.3	75.3	-	-	-	-	-	-	ANGLE
	4.3	2.2	2.2	2.3	2.4	2.8	-	-	-	-	-	-	DELAY
	638	305	309	323	350	402	-	-	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.97	.77	-	-	-	-	-	-	F. DAYS
	125	91	94	99	104	112	-	-	-	-	-	-	LOSS DB
	33	45	46	46	44	41	-	-	-	-	-	-	DBU
	-95	-61	-64	-69	-74	-82	-	-	-	-	-	-	SIG.DBW
	-160	-143	-148	-152	-155	-158	-	-	-	-	-	-	NOI.DBW
	65	82	84	83	81	76	-	-	-	-	-	-	S/N DB
	.14	.75	.81	.83	.79	.63	-	-	-	-	-	-	F. S/N
	.07	.74	.80	.82	.77	.49	-	-	-	-	-	-	REL.

AUGUST 1969 SUNSPOT NUMBER 102.7

FT LAMY	TO MAIDUGURI	AZIMUTHS		MILES	KM.
12.10N - 15.00E	11.80N - 13.20E	260.52	80.15	123.4	198.6

HORIZ HW DIPOLE 12.0H -0.5L -0.0 HORIZ HW DIPOLE 12.0H -0.5L -0.0

OFF AZIMUTH= 0.0DEG. MINIMUM ANGLE= 0.0DEG. OFF AZIMUTH= 0.0DEG.

POWER= 1.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DB

FREQUENCIES IN MHZ

UT	MUF	2.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	22.0	26.0	30.0	
20	8.9	K(0)MUF=(8.9)				K(5)MUF=(8.9)							
	1F	1F	1F	1F	1F	1F	-	-	-	-	-	-	MODE
	78.4	72.9	73.1	73.6	74.5	78.4	-	-	-	-	-	-	ANGLE
	3.6	2.4	2.4	2.5	2.6	3.6	-	-	-	-	-	-	DELAY
	526	341	344	356	380	526	-	-	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.89	.46	-	-	-	-	-	-	F. DAYS
	114	91	94	99	105	115	-	-	-	-	-	-	LOSS DB
	39	45	45	45	44	38	-	-	-	-	-	-	DBU
	-84	-61	-64	-69	-75	-85	-	-	-	-	-	-	SIG.DBW
	-160	-146	-150	-154	-157	-160	-	-	-	-	-	-	NOI.DBW
	76	85	86	84	82	76	-	-	-	-	-	-	S/N DB
	.65	.88	.90	.89	.85	.64	-	-	-	-	-	-	F. S/N
	.33	.87	.89	.88	.76	.30	-	-	-	-	-	-	REL.
22	8.6	K(0)MUF=(8.6)				K(5)MUF=(8.6)							
	1F	1F	1F	1F	1F	1F	-	-	-	-	-	-	MODE
	77.0	72.8	72.9	73.2	74.0	77.0	-	-	-	-	-	-	ANGLE
	3.2	2.4	2.4	2.4	2.5	3.2	-	-	-	-	-	-	DELAY
	462	337	339	348	366	462	-	-	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.88	.39	-	-	-	-	-	-	F. DAYS
	112	91	94	99	104	113	-	-	-	-	-	-	LOSS DB
	40	45	46	45	44	40	-	-	-	-	-	-	DBU
	-82	-61	-64	-69	-74	-83	-	-	-	-	-	-	SIG.DBW
	-161	-148	-151	-154	-158	-162	-	-	-	-	-	-	NOI.DBW
	79	87	87	85	83	79	-	-	-	-	-	-	S/N DB
	.77	.90	.91	.89	.86	.75	-	-	-	-	-	-	F. S/N
	.39	.90	.90	.89	.76	.29	-	-	-	-	-	-	REL.
24	7.8	K(0)MUF=(7.8)				K(5)MUF=(7.8)							
	1F	1F	1F	1F	1F	1F	-	-	-	-	-	-	MODE
	75.8	70.7	70.9	71.4	72.8	75.8	-	-	-	-	-	-	ANGLE
	2.9	2.1	2.1	2.2	2.4	2.9	-	-	-	-	-	-	DELAY
	419	297	300	311	338	419	-	-	-	-	-	-	VIRT HT
	.50	.99	.99	.99	.73	.20	-	-	-	-	-	-	F. DAYS
	108	90	93	98	104	112	-	-	-	-	-	-	LOSS DB
	42	46	46	46	45	40	-	-	-	-	-	-	DBU
	-78	-60	-63	-68	-74	-82	-	-	-	-	-	-	SIG.DBW
	-160	-148	-150	-154	-158	-163	-	-	-	-	-	-	NOI.DBW
	82	87	87	85	84	80	-	-	-	-	-	-	S/N DB
	.82	.90	.90	.89	.87	.79	-	-	-	-	-	-	F. S/N
	.41	.90	.90	.88	.63	.16	-	-	-	-	-	-	REL.

AUGUST 1969 SUNSPOT NUMBER 102.7

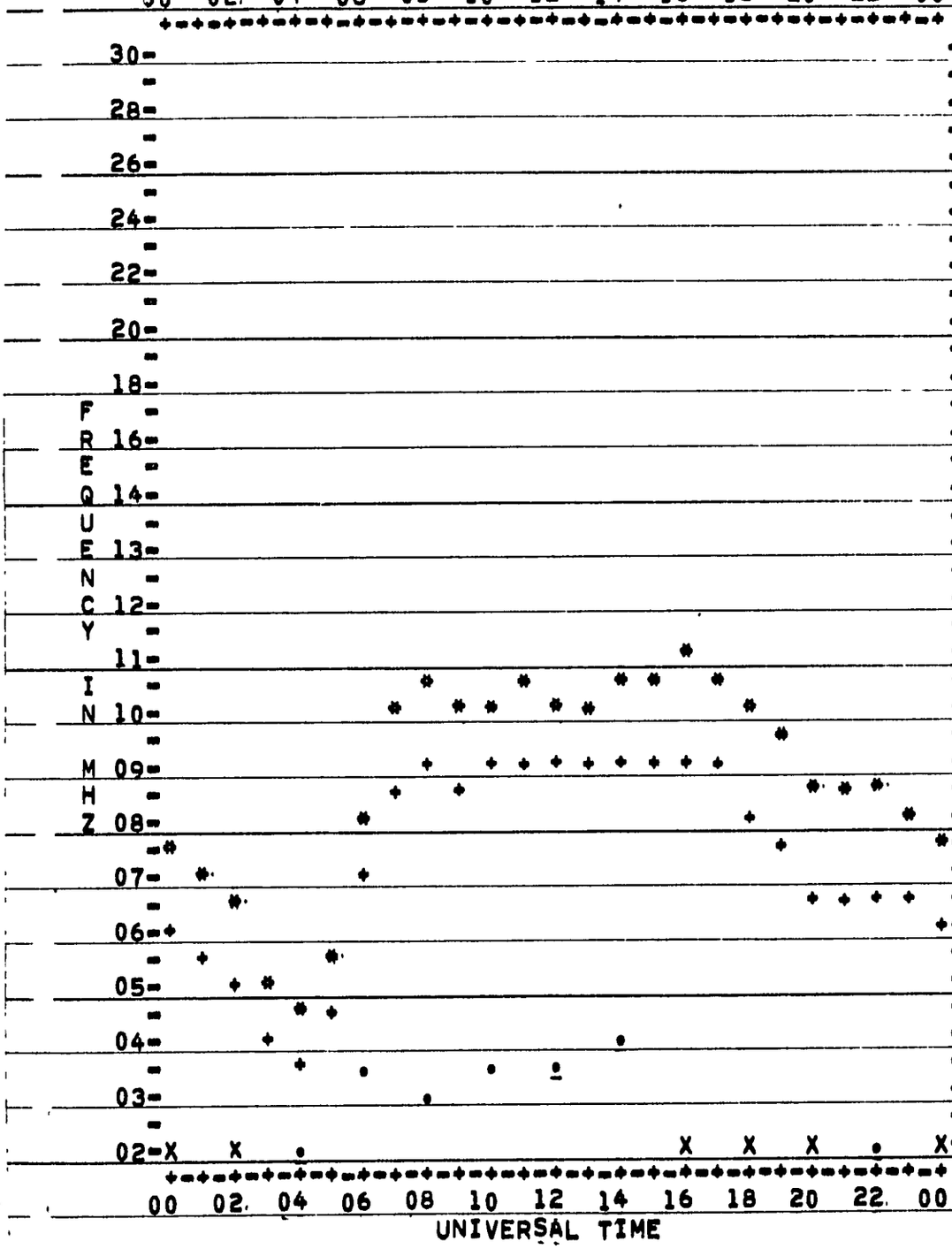
FT LAMY	TO MAIDUGURI	AZIMUTHS		MILES	KM.
12.10N - 15.00E	11.80N - 13.20E	260.52	80.15	123.4	198.6

HORIZ HW DIPOLE 12.0H -0.5L -0.0 HORIZ HW DIPOLE 12.0H -0.5L -0.0

OFF AZIMUTH= 0.0DEG. MINIMUM ANGLE= 0.0DEG. OFF AZIMUTH= 0.0DEG.

POWER= 1.00KW 3 MHZ NOISE=-165.6DBW TIME= 90 PERCENT REQ.S/N=73.0DB

MUF(****) - FOT(++++) - LUF(....)



UT	MUF	FOT	LUF
01	7.3	5.8	
02	6.5	5.1	-
03	5.2	4.1	
04	4.7	3.7	-2.0
05	5.9	4.7	
06	8.4	7.2	3.7
07	10.1	8.7	
08	10.5	9.0	3.4
09	10.2	8.8	
10	10.3	9.1	3.7
11	10.5	9.3	
12	10.4	9.3	3.8
13	10.4	9.2	
14	10.6	9.0	4.3
15	10.9	9.3	
16	11.0	9.3	-
17	10.8	9.2	
18	10.4	8.1	-
19	9.6	7.5	
20	8.9	6.9	-
21	8.6	6.7	
22	8.6	6.9	2.1
23	8.3	6.6	
24	7.8	6.2	-

APPENDIX

B

ESTIMATE OF PERFORMANCE

OF PROPOSED FORT LAMY-MAIDUGURI

TROPO LINK WITH RESPECT TO RADIO PROPAGATION

APPENDIX B

ESTIMATE OF PERFORMANCE OF PROPOSED FORT LAMY - MAIDUGURI TROPO LINK WITH RESPECT TO RADIO PROPAGATION

Introduction

Tropospheric transmission at UHF or SHF to a receiver well beyond the horizon depends upon the scattering or reflection of energy from the radio wave by non-homogeneities in the troposphere. Some of the energy is inflected to the receiver which, otherwise, would be screened by the bulge of the earth.

The course of the rays depends upon the distribution of the refractive index in the significant region of the troposphere. Since the refractive index n at any point depends in turn upon the temperature, pressure, water vapor content, etc., of the atmosphere at that point, it is not surprising that the performance of a tropo circuit is influenced strongly by climatological and meteorological factors. The troposphere is that part of the atmosphere, extending up to the stratosphere, which is responsible for weather. Terrain irregularities may affect the transmission also. So, too, do ducts and layers.

Tropo systems have been developed over the years to the point where they are widely used to provide reliable voice and teletype circuits for distances of from about 100 miles to 500 miles or more, in a single link. For example, they play an important role in spanning natural barriers or regions where it would be difficult or costly or impracticable to provide and maintain other kinds of systems. Typically, tropo links carry a moderate number of telephone channels, as contrasted to the

hundreds or thousands common on microwave relay systems.

Tropo links, depending upon environments and requirements, tend to use large antennas, often 30 to 60 feet in diameter, transmitter powers up to 10 kw or more, together with dual or quadruple diversity.

Propagation Loss; Background:

In planning a system, it is necessary to estimate the long-term median propagation loss and the long-term and short-term variations.

The short-term fading is well known to be usually of the multi-path phase-interference type, tending to follow the Rayleigh law. It is superimposed upon the slow power fading distribution whose statistics are described in terms of hourly median (or sometimes shorter interval) values as basic units.

Many theoretical and experimental studies of the long-term loss statistics have been reported. But, because of the strong dependence of the loss and its variability upon climate, season, etc., as noted above, it was usually impossible to predict performance in climates other than those in which the experiments were performed. However, an important discovery was made, which aids one in attempting to extrapolate roughly from signal strength tests made on one system, in one area, over a limited time, to predictions for another area, season, and system. The link was this: the observed correlation between signal strength and surface refractivity N_s. (In denoting the value of n, which, in the troposphere is always

slightly greater than unity, it is customary to use the quantity $N = (n-1)\ 10^6$). In a series of tests the rather good correlation was found to hold when the variables were averaged over a week to a month (Bean and Dutton, Ref. 1). The signal strength coefficient varied from 0.14 db in the afternoon hours to 0.24 db in the morning per unit change in N_s.

With respect to procedures, in Ref. 4 it is remarked that meteorological parameters such as surface refractivity and the height gradients of refractive index have been found more useful as a basis for predicting regional changes than for predicting diurnal or seasonal variations. In that report, meteorological information was used to distinguish between climatic regions, while radio data were depended on in the prediction of long-term variability about the computed long-term median value in each of these regions.

Climate Classifications:

Bean and Dutton have analyzed the annual cycle of N_s and of climatological and meteorological factors, as reported from observing stations all over the world. Based upon the annual mean of N_s and upon the annual range, and other factors, they established five climatic types. In the CCIR, Oslo 1966, some eight climatic types are tabulated, in Report 244-1, Estimation of Tropospheric Wave Transmission Loss (Ref. 2).

We quote the description of one of the CCIR types:

> "2. Continental Subtropical: Corresponds to the regions between latitudes 10° and 20°. The climate is characterized by a dry winter and a

> rainy summer. There are marked daily and annual variations of radio propagation conditions, with least attenuation in the rainy season. Where the land area is dry, radio ducts may be present for a considerable part of the year. The annual mean value of N_s is about 320 N-units and the range of variation, throughout the year, of monthly mean values of N_s is 60 to 100 units."

The Fort Lamy-Maiduguri region seems to qualify for this climatic type. The path lies at about 12° north latitude. Tabulations in the World Atlas of Atmospheric Radio Refractivity, ESSA Monograph 1 (Ref. 3) for Fort Lamy show an annual mean N_s of about 317 and monthly means extending from 360 in August to 279 in February, a range of 81 units. The region is characterized by seasonal extremes of rainfall -- about 20 inches during the middle of the summer and little or none during the rest of the year.

On the basis of the annual range of 81 units in N_s at Fort Lamy, one might as a rough estimate expect a range of as much as 0.2 x 81, about 16 db, in the monthly medians of the hourly median signal strengths, according to the relationships discussed by Bean and Dutton. (In this approximation, we have dismissed the question of the differences between monthly means and monthly medians.)
Charts in the World Atlas (3) indicate that persistent ducting or super-refractive initial gradients of N exist for more than 25 percent of the time in all seasons at Fort Lamy. This further complicates the prediction of tropo performance.

Having established what appears to be the appropriate refractive index climate, as above, we can turn to the estimation of the statistical performance of the proposed tropo link with respect to propagation.

Procedure:

It is convenient, in estimating the propagation loss, to follow generally the procedure upon which various administrations have agreed: that given in Section 2 of CCIR Report 244-1, Oslo, 1966 (Ref. 2). The method is based upon the more comprehensive and detailed treatment given in National Bureau of Standards Technical Note 101, Revised (May 1, 1966), (Ref. 5).

In the form used in Refs. 4 and 2, the long-term median transmission loss between the input to the transmitting antenna and the output of the receiving antenna is, approximately, ignoring terms negligible in our application:

$$L = 30 \log f - 20 \log d + F(\theta d) - G_p - V(d\theta) \text{ dB} \qquad (1)$$

where

f = frequency, mHz

d = distance between stations, km

θ = the "angular distance," the angle in radians between radio horizon rays in the great circle plane containing the antennae.

$F(\theta d)$ is shown by curves in Fig. 6 of Ref. 2.

G_p = path antenna gain

$$= G_t + G_r - L_{gp} \qquad (2)$$

where G_t and G_n are free-space antenna gains relative to an isotropic antenna, and L_{gp} is a coupling loss introduced primarily by the non-uniform phase fronts.

A semi - empirical estimate of for L_{gp} is

$$L_{gp} = 0.07 \exp [0.055 (G_t - G_r] \qquad (3)$$

$V(d_e)$ is a long-term adjustment for the particular type of climate. It is plotted for various climates in Fig. 7 of Ref. 2. It is to be applied to the long-term reference value of hourly median transmission loss L_{cr}, say, which is estimated for the pertinent value of N_s. For Continental Subtropical climate, $V(d_e) = 4$.

In addition to the very long-term values of $V(d_e)$, just mentioned, values for shorter periods -- seasonal, and also for diurnal time blocks in the seasons -- are given in Ref. 4, but unfortunately only for the continental temperate climate of the U.S.A. ($V(d_e)$ attains the value zero there in the winter afternoons.

As noted in the CCIR Report, no method can provide accurate predictions in all circumstances; and for specific point-to-point paths, rather large errors may occur on the tails of the distributions. But this unfortunately is characteristic of many kinds of radio systems, and not just tropo.

<u>System Assumed</u>:

Distance: 200 km, approximately, (124 miles).

Topography: Generally very level.

Vegetation: Thin bush and nearly bare regions.

Climate: Treated as CCIR Continental Sub-Tropical.

Frequency: 2,000 mHz band.

Diversity: Dual space.

Transmitter: 1 kw FM

Channels: 12 voice; one or two of these may carry FSK telegraph or telex.

Antennas: 30 foot paraboloids at height h of about seven meters.

(Some results for other combinations of transmitter power, antenna size, and order of diversity are also given.)

Loss:

The estimation will be made first on the basis of the annual average of the tabulated monthly mean values of N_s at Fort Lamy. As noted earlier, this is 317 units, from the Atlas.

The value of Θ is obtained as follows:

From Fig. 3. of Ref. 2, the effective radius a of an earth above which low-angle rays would be straight lines is taken to be about 8,750 km, when $N_s = 317$.

By simple geometry then,

$$\Theta \doteq \frac{d - 2d_1}{a} \qquad (4)$$

where d_1 is the horizon distance on an earth of radius a:

$$d_1 = \sqrt{2ah}, \text{ with } h, a, d \text{ in the same units} \qquad (5)$$

This reduces to

$$d_1 \doteq 3 \sqrt{2 h_m} \sqrt{a_{km}/8800} \quad \text{km} \tag{6}$$

giving for our present case

$d_1 = 11.1$ km

and, therefore,

$\Theta \doteq 0.0202$ radians, equal to $1.16°$.

Then $\Theta d = 4.04$, and from

CCIR Fig. 6, for $N_s = 317$, the value

$$F(\Theta d) = 153 \text{ dB} \tag{7}$$

is obtained.

The path antenna gain G_p is estimated to be 80 db, approximately, and from (1),

$$L = 99.0 - 46.0 + 153 - 80 - V(de)$$

$$= 126 - V(de) \text{ dB} \tag{7a}$$

(The median of the smoothed distribution of the monthly averages of N_s tabulated for Fort Lamy is about 305. We ignore the db or so difference in indicated loss and use (7a) for the value of L (50). The climate adjustment V(de) is a function of an "effective distance" d_e obtained as follows (Ref. 2).

Define Θ_{s1} as the angular distance where diffraction and forward scatter transmission loss are approximately equal over a smooth

earth o[illegible]e radius $a = 9000$ km, and define $d_{sl} = 9000\,\Theta_{sl}$. Then $d_{sl} = 65\,(100/f)^{1/3}$ km where f is in mHz. Next compare the path length d with the sum of d_{sl} and the smooth earth distances to the radio horizon. In our case of equal antenna heights the latter becomes $d_L = 2d_l \doteq 6\sqrt{2h_m}$ km (8)

We obtain $d_{sl} = 24$ km and $d_L = 23$ km.

The effective distance d_e is arbitrarily defined as:

$$d_e = 130 + d - (d_L + d_{sl}) \text{ km} \tag{9}$$

when as in the present case, $d > (d_L - d_{sl})$.

Then there results

$$d_e = 283 \text{ km.}$$

From a chart in the CCIR Report, $V(d_e)$ is 4 db for the climate type under consideration.

Then $L(50) = 122$ db, approximately, the long-term (yearly) median value of the hourly medians of transmission loss. The corresponding basic transmission loss L_{bsr} (that with the path antenna gain removed) is 202 db.

Variability

In predicting for a given climate the percentage of a prescribed interval, such as a year, a season, or a month, during which certain noise objectives will be met, one would like to know the distribution of the loss during the interval. One approach,

as outlined in the CCIR, is to estimate the long-term median L(50) of the hourly values by the procedure just used above -- that is, through the use of N_s and $V(d_e)$ pertaining to the interval, and then to apply curves of the distribution Y of the deviations of the hourly values from L(50), to the extent that the curves are available from radio data.

Then, using the notation of the CCIR Report, if P(q) is the value of received hourly median power P exceeded for q percent of the time and L(q) the value of loss exceeded (100-q) percent of the time,

$$P(q) = P(50) + Y(q) \quad \text{dBw} \tag{10}$$

$$L(q) = L(50) - Y(q) \quad \text{dB} \tag{11}$$

On a yearly basis, P(50) can be estimated as above; and Y(q) can be obtained from the CCIR charts, for the various climates. But for seasonal or monthly periods, there is a dearth of information on the values of the adjustment $V(d_e)$ entering into L(50), and also on the variability Y(q), quantities which have been obtained mostly from experience.

Reference 4 does, however, provide curves for the determination of the variability Y(p) in a Continental Temperate climate, for all hours of the day for summer, winter and all year for a "typical" year. An allowance for year-to-year variability is also included in the procedure. For the climate treated, there are considerable seasonal changes in Y(p), for the longer equivalent distances d_e, but very little for d_e as short as the one we are considering, about 280 km. The same Reference 4

provides curves of $V(d_e)$ for winter and summer seasons and for four time blocks. For a path having an effective length equal to the one with which we are concerned, the winter value of $V(d_e)$ is about one db and the summer value five db; all hours three db. For individual 6-hour time blocks, a value of zero db is shown as one extreme (winter) and seven db for the other (summer).

If we were to assume that the negligible seasonal trend in Y(p) reported for the Continental Temperate climate holds also for the Continental Sub-Tropical with which we are concerned, and if we assume furthermore that $V(d_e)$ also takes the value zero for the season of weakest signals, we can estimate approximately the high-loss end of the distribution for the worst season.

From the Atlas, the lowest tabulated monthly mean value of N_s at Fort Lamy is 279, in February, as noted earlier. Using this value as appropriate for the month and somewhat more conservative than the use of $N_s(50)$, and the procedure outlined above, with $V(d_e)$ taken as zero, there results for February

$$L_{bsr} = 211 \text{ db}, \tag{12}$$

$$L(50) = 131 \tag{13}$$

Comparison shows that the estimated loss L(50, February) is 9 db greater than L(50, Year) obtained above, showing the seasonal effect.

It is useful to compare the value L_{bsr} (February) of 211 db, with the result which one obtains by the application of an alternative method summarized in Section 3 of

the CCIR Report, Ref. 2. It is based upon an article by Boithias and Battesti, Les Faisceaux Hertziens Transhorizon de Haute Qualité, Annales des Telecommunications, July - August, 1965. The method was developed following professional experience acquired during the construction of a number of tropo systems. Curves are given for several climates, but here, again, the Continental Sub-Tropical is not included. However, lacking better data, if we assume on the basis of significant similarities that the weak signal end (99% point) of the CT climate can be used as an approximation for the CS, we can extrapolate from the 99% point for the "worst month" curves of Ref. 2, using the curves of variance, and obtain a "worst month" L of 213 db. This value, obtained by the "alternate" CCIR method -- admittedly with some rough assumptions in extrapolating to climate CS -- is close to the 211 db obtained above by the more comprehensive CCIR procedure. This, however, is somewhat coincidental, and should not be taken to indicate high accuracy for either result.

In estimations of radio performance, there are inevitable uncertainties in the accuracy and range of some of the parameters used. Sometimes these uncertainties are expressed in the form of the standard deviations σ_i, say, of the individual parameters, combined to provide a measure of the total uncertainty, as a function of the required reliability of service. By further statistical procedures, the probability of attaining required time availabilities can be estimated. Depending upon the particular situation -- nominal objectives, costs, etc. -- margins are sometimes provided in the designs to improve the service probability.

Estimation by Computer:

Up to now, we have included no margins. This means, roughly, that insofar as we know, the system's performance is equally likely to be better or worse than predicted. But a programmed computer estimation, independent of the discussion up to now, utilizing procedures based largely on Ref. 5 , was carried out for the Fort Lamy - Maiduguri link, on a more conservative (and more costly) basis. In it the "worst" month outage performance was estimated, with confidence limits of 90% imposed. A median long-term system transmission loss of 141 dB was used, corresponding to a long-term basic loss of about 218 dB (compared with our 211 above). To describe the variability of the hourly median loss in the worst month, a normal distribution was assumed -- an approximation often used -- with a standard deviation of 8 db (compared with our 6). The distribution of the short-term equivalent power was obtained by convolving that of the long-term power with the short-term phase interference distribution appropriate to the order of diversity operation assumed.

In addition to the prediction for the dual diversity system employing 1-kw transmitters and 30 foot antenna diameters, taken above as the basic system, additional computer estimates were made for 12, 24, and 48 voice channels, and for various combinations of 1 kw and 10 kw transmitters, 30 and 60 foot antennas, and dual and quadruple diversity. (See Table 3 of the main text.)

Collecting the basic long-term loss figures given above, the values used in the prediction of noise and outage are summarized below. Column A refers to the

approximate values on a yearly basis, Column Wo to the "worst month" approximation obtained above with no margin for prediction uncertainties, and Column Wc to the more conservative computer prediction. $L_s(50)$ refers to the system loss.

TABLE 1

Loss, dB

	Year	"Worst" Month	
	A	Wo	Wc
L_{bsr}	202	211	218
L(50)	122	131	138
$L_s(50)$	125	134	141
σ of Y(q)	6	6	8

Distribution of Instantaneous Power:

"instantaneous power" is taken here, as usual, to be the mean value, averaged over one radio-frequency cycle. In dBW it is convenient to write it (Ref. 4)

$$Pi = P_m + Yi = P_m(50) + Y - Yi \qquad \text{dBW}$$

$$= P_m(50) - [P_m - P_m(50)] - [Pi - P_m]$$

Here $P_m(50)$ is the long-term median, P_m represents the hourly median. Yi is the departure of the rapidly varying signal power from Pm. The distribution Y(q) tends to be normally distributed.

The distribution of the instantaneous power with respect to P_m can be obtained by convolving distribution Y(q) with the short term Yi(q).

In the case of diversity reception, with branch selection combining, Yi(q) is the equivalent distribution corresponding to the output of the diversity combiner. As compared to selection combining, certain other methods provide slightly greater overall improvement in practice over most of the fading range.

For our present dual diversity application, the distribution of output signal-to-noise ratio relative to a single branch median, assuming a combiner about one db better than a branch selector, was estimated by the use of a computer. The results are shown in Table 2. It is assumed that the branch fadings are Rayleigh and uncorrelated. Results are given for the two values of σ listed in Table 1.

TABLE 2

Output Signal-to-Noise Ratios Relative to a Single Branch Median, dB

Percent	Dual Diversity $\sigma = 6$	Dual Diversity $\sigma = 8$
99.99	-24	-30
99.9	-19	-24
99.0	-13	-17
95	- 8	-11
90	- 5	- 8
80	- 2.5	- 4
50	3	3

Voice-Channel Noise:

A familiar expression for the tone-to-thermal noise ratio R in a frequency division multiplex (FDM) system is

$$R = (T_o - N_{ct}) = (C - N_i) + (10 \log B_i - 10 \log 2B_c) + 20 \log DR - (P_{1c} - T_o) \quad \text{dB}$$

where T_o = test tone power at a point of zero relative level, dBm, usually, as herein, taken as OdBmO

N_{ct} = noise power in the top voice channel of nominally 3 kHz width, dBM

C = input carrier power, dBm

Bi = the IF bandwidth, Hz

B_c = voice channel bandwidth, nominally 3000 Hz

DR = deviation ratio

P_{1c} = sine wave load capacity at 0 reference level, dBm0, which for the 12 channel case is taken herein as 15 dBm0, after reference to CCIR and other sources. Application of P_{1c} produces full deviation of the FM carrier.

Requirement standards are sometimes set on (a) the small fraction of time that the carrier-to-IF noise ratio may fall below the threshold value, often taken as 10 db; (b) the small fraction of time that the noise may exceed a certain value, often set at 49 dBa0; and (c) the median noise (or in some systems the average).

The designer has some choice of options. The use of diversity transmission helps to lessen the fading range; large deviation ratios help with respect to (c) and (b), but make attainment of (a) more difficult because of the large IF bandwidths required. Threshold extension helps to offset the latter trend.

The thermal equivalent input noise is equal to -204 db + F dBW in one Hz bandwidth; where F is the noise figure of the receiver.

Curves of Predicted Performance:

Curves of calculated noise in the top voice channel as a function of the equivalent receiver input power are shown in Figure 1, for three sets of assumed equipment parameters:

TABLE 3

Curve	F db	DR	TH. EXT. db
A	8	10	0 and 5
B	5	10	0 and 5
C	3	20	0 and 8

The curves of Figure 1 show the estimated noise performance of the link, corresponding to the propagation statistics and equipment parameters discussed above. One-kw transmitters, 30 foot antenna diameters, and dual diversity are assumed, as stated earlier.

Three probability distribution scales are provided at the top of the figure. Wc applies to the "worst month" on what is believed to be a conservative basis (see earlier text); Wo is on a less conservative "worst month" basis, and A applies to a year.

Three curves are also drawn, relating to the equipment parameters of Table 3. Noise is plotted against the equivalent receiver input power.

Voice channel noise objectives for systems having the fast-fading characteristics of tropo links have not been so firmly established as the ones for essentially non-fading toll circuits. The use of diversity reception helps greatly to reduce the range of fast tropo fading; and the custom often has been to extrapolate from the usual toll objectives without much change, insofar as the quantities can be compared. Thus, the objective on average noise might be carried over to the median tropo noise, etc., pending more thorough determinations.

In the CCIR, certain reference systems 2500 km long are postulated; and on the assumption that several shorter links may be used in order to build up long circuits, certain noise objectives are pro-rated according to distance. But in the U.S.A. in the case of a short-haul microwave link (say 250 miles long) which is to be connected only occasionally to long back-bone routes, the usual underlying requirement has been that adding the short link should not degrade the noise significantly. On that basis, a value of 32 dBa0 rms noise has been used often. Allowing a nominal 3 db for other noise contributions, 29 dBa0 remains for thermal noise, a figure which is believed to be appropriate for the median noise objective in our system.

It is useful also to consider CCIR objectives for tropo systems. In Recommendation 397, Geneva 1963, conditions are given for a tropo system used where other facilities cannot be employed without excessive difficulty. A requirement is that the noise power averaged over one minute intervals (the "one-minute noise") must not exceed the equivalent of 38 dBa0 for more than 20% of any month. The diversity action and the one-minute integrations should remove much of the effect of the fast fading. If as a very rough approximation we then pro-rate on the basis of distance to 200 km, the figure becomes 27 dBa0. Our distributions have been estimated for instantaneous values for certain percentages of the hours, and direct comparison cannot be made. But in view of the smoothing implicit in the one-minute means, the use of 27 dBa0 on our scale in Figure 1 would seem to be somewhat conservative.

Turning now to the high-noise end of the curves, it was remarked that an objective of 49 dBa0 to be exceeded rarely has often been used in the U.S.A. Experience with tropo systems has shown that a good grade of voice-frequency teletype or telegraph transmission with typical equipment is obtained as long as the noise is below that value.

In considering outages, which can be taken here to occur when the noise exceeds 49 dBa0, or when the 10 - dB C/Ni is violated, as noted earlier, it may be recalled that 0.1% is about nine hours a year or 1.4 minutes a day, and that 0.01% is only eight seconds a day.

Conclusions:

The voice-channel noise distributions displayed on Figure 1 indicate that a good grade of service, with high reliability, could be realized on a Fort Lamy-Maiduguri tropo link by the use of 1-kw transmitters, 30-foot antennas, dual diversity, and an appropriate choice of equipment options.

For example, with the system utilizing Option B of Table 3 (a noise figure of 5 dB, a deviation ratio of 10, with 5 - dB of threshold extension), a median thermal noise of about 22 dBa0 is indicated for the "conservative worst month," some 7 - dB better than the 29 - db objective taken to be appropriate; and a reliability of about 99.8% for that month.

Even better performance could be obtained with Option C, with threshold extension, at a somewhat greater cost.

The system could be expanded in an orderly way to handle a greater number of channels or to provide still better performance in the future, should the need arise, as indicated for various equipment combinations in Table 3 of the main text.

Attached:
Figure 1

REFERENCES FOR APPENDIX B

1. BEAN, B.R. and E.J. DUTTON, (1966), Radio Meteorology, N.B.S. Monograph 92.

2. CCIR Report 244-1, Oslo, 1966

3. A World Atlas of Atmospheric Radio Refractivity, 1966, ESSA Monograph 1.

4. Doc. V/2 a, CCIR Study Groups 1964 - 1966, Transmission Loss Predictions for Tropospheric Communication Circuits (U.S.A.)

5. N.B.S. Technical Note 101.

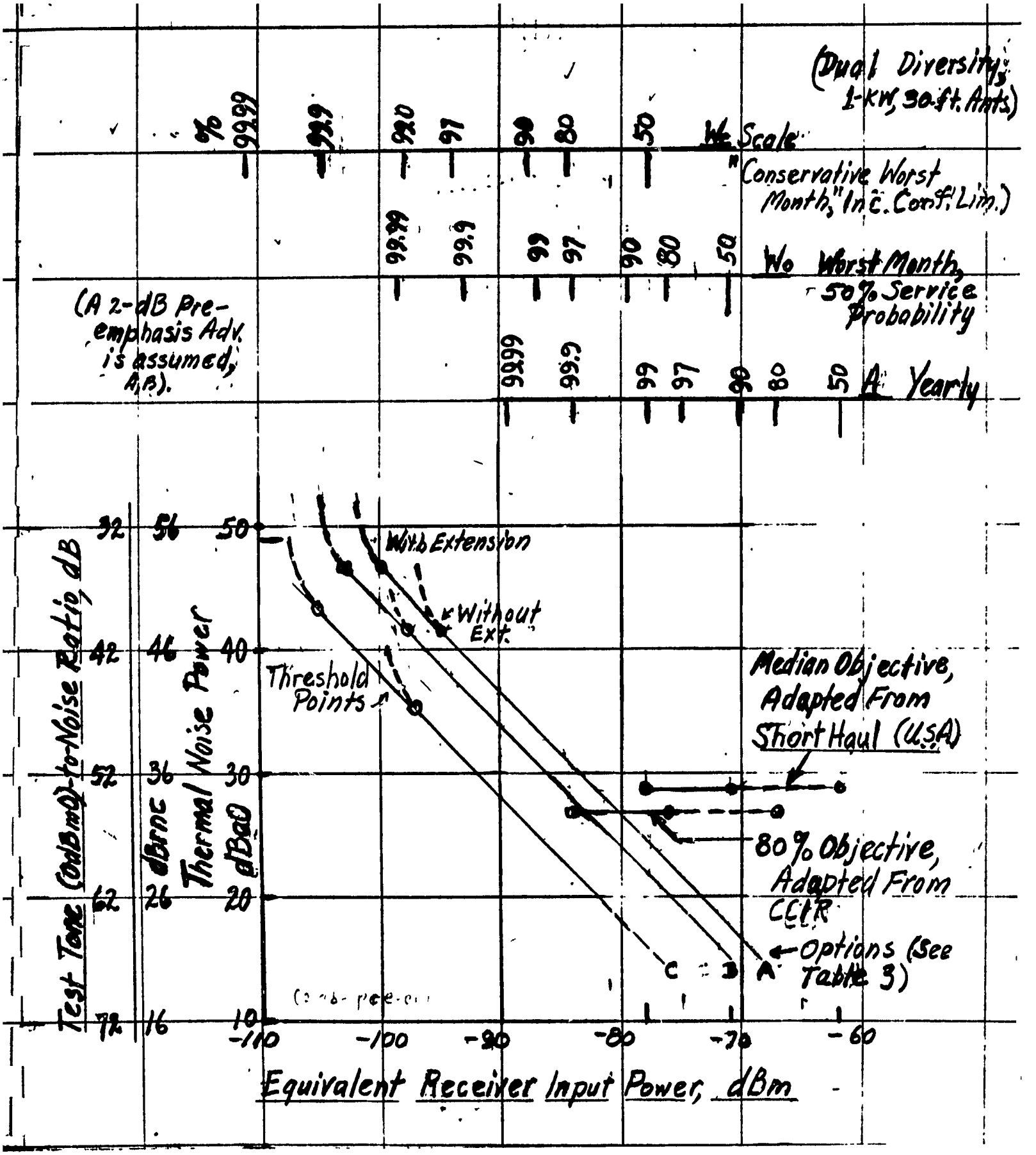


FIGURE 1

PREDICTIONS OF NOISE PERFORMANCE FOR FORT LAMY-MAIDUGIRI TROPO LINK