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TECHNICAL NOTE #1 – CARRIER CURRENT BROADCASTING THEORY

1.0 CARRIER CURRENT BROADCASTING

Broadcasting, as the word suggests, seeks maximum area coverage. *Limited Area Broadcasting* reverses this logic and seeks coverage of a defined or *limited area*. *Carrier Current* is a subset of Limited Area Broadcasting in which the convenient antenna is the existing low voltage power wiring within a building. The term *Carrier Current* has been adopted from the power utilities who have historically impressed low frequency radio signals on long high voltage transmission lines for communications and control at the far end of these lines.

This text addresses Carrier Current broadcasting in the standard AM broadcast band, as permitted and regulated in Part 15 of the Rules and Regulations of the Federal Communications Commission. See LPB Tech Note #2, CARRIER CURRENT SYSTEM DESIGN, for a description of the nuts and bolts of practical carrier current design, problems, and solutions.

The popularity of FM broadcasting raises the question of FM carrier current and other forms of limited area FM broadcasting. The use of the 88-108 MHz FM broadcast band for radiating systems is carefully regulated by the FCC because of the potential hazard to aircraft radio communications and navigation systems which utilize frequencies immediately above the FM band. Recent interference problems have caused the Commission to reaffirm this stand.

Carrier current FM broadcasting is <u>not possible</u> because at the much higher frequencies of the FM broadcast band the loss characteristics of the low voltage power wiring would consume all the FM signal before it got more than a few feet down the AC power wiring.

Recently LPB has installed successful unlicensed radiating cable stereo FM systems in colleges. These operate under Section 15.239 of the Rules as revised in 1989. Since these systems are not carrier current, they are not treated further in this document but are covered in LPB Tech Note #6, UNLICENSED FM STEREO RADIATING (LEAKY) CABLE.

2.0 THE F.C.C. RULES

2.1 Historic Background

Since 1938 Part 15 of the Rules has permitted broadcasting without either station or operator license under certain conditions designed to prevent interference to licensed broadcasters.

In 1987 the FCC opened proceedings (General Docket 87-389, issued 10/87) for the revision of Part 15, which had grown unwieldy by the necessary inclusion of sections governing the radiation from a multitude of recent-technology devices such as computers, garage door openers, and electronic game machines. In 1989 new Part 15 Rules were published (First Report and Order in the Matter of General Docket 87-389, issued 4/89). The new Part 15 dramatically reduced the permitted field strength of carrier current stations, but permitted colleges to measure at the perimeter of the campus.

A Petition for Reconsideration was filed jointly by by four interested parties, LPB Inc., LocRad Inc., Burden Associates and the Intercollegiate Broadcasting System, pointing out the unreasonable difficulties which would result for carrier current broadcasters with the application of the new 4/89 Rules. The Commission agreed, and issued a modification at the end of 1990. The result was a new set of Part 15 Rules which returns the prior permitted field strength measured outside the electric power line of each system (generally a building), and allows educational institutions optionally to measure at the perimeter of the campus with the dramatically reduced permitted field strength.

2.2 Current Part 15 Rules

The Part 15 Rules effective June 22, 1992, basically state that we may operate an unlicensed carrier current system within the standard AM broadcast band if we:

A) Choose a frequency so as to not interfere with licensed broadcasters.

B) Produce a field strength not more than 15 microvolts per meter (µV/m) at a distance in meters given by 47,715/f (where f is the frequency in kHz). The equivalent distance in feet is given by 157,000/f. The measurement is at the perimeter of the carrier current system, generally a building or group of buildings.

Optional Perimeter-of-the-Campus Measurement:
Carrier current stations at educational institutions
are permitted to produce a field strength of not more
than 24,000/f (where f is the frequency in kHz) at a
distance of 30 meters from the perimeter of the campus.

C) For new or expanded carrier current systems after June 22, 1992, measure the carrier current system for compliance with the field strength limitations, and retain the information on file at the station.

D) Utilize transmission equipment which has been shown to have specified harmonic suppression up to the 10^{th} harmonic, and has been verified for compliance with the technical requirements of Part 15.

2.3 Examination of the Rules

An examination of the Rules will provide considerable understanding of carrier current and why it works.

- **Choice of Frequency**

If broadcasting within a building is desired, the choice of a frequency (§ 2.2 A) not in use in the immediate area is obvious. It would be foolish to try to overpower a local broadcaster; it just can't be done. Exactly the opposite is true; the local broadcaster will overpower a carrier current station. This requirement seldom presents any difficulty.

- **Field Strength**

The significance of § 2.2 B is not clear at first, but is important to understand. First note that the distance at which 15 µV/m is permitted is an inverse function of frequency, therefore the low end of the AM band, where the distance at which we may have 15 µV/m is greatest (about 300 feet), is most advantageous for carrier current operation. This establishes a preference for the lower frequencies, typically those below 800 kHz, and we will see other advantages for such frequencies later.

Here's a rough but interesting guide to what 15 µV/m is like: listen to a carrier current station on a recent-model factory-installed car radio and drive away from the source. The distance at which the signal becomes noisy and difficult to understand is a fair approximation of 15 µV/m. We don't recommend this as an accurate measurement technique, but it has proven to be a reasonable guide and provides a grasp of what a 15 µV/m signal strength is like.

With the optional perimeter-of-the-campus measurement, instead of the field strength being fixed while the distance varies, the distance is fixed (30 meters, nearly 100 feet), while the permitted signal strength varies as an inverse function of frequency. At 540 kHz, for example, the calculated field strength is under 45 µV/m. This is an advantage only for buildings at least 32 meters (just over 100 feet) from the perimeter of the campus. This may be useful for suburban campuses, at least in measuring the carrier current system for compliance.

- **Measurement for Compliance**

Compliance with the field strength limitations of Part 15 has always been required by the FCC. The change requires schools to document these measurements and keep them on file, effectively so the FCC knows that bona fide compliance was achieved, and the conditions are recorded. Existing carrier current systems on June 22, 1992 are grandfathered, and need not retain information, though compliance is still required, of course.

To demonstrate compliance, first document the location and power level of all transmitters and linear amplifiers; the power input can be read directly on the internal meter in each LPB TCU-30 coupling unit.

Although an Engineer with a Field Intensity Meter could take precise measurements to demonstrate compliance, it is not absolutely necessary. A portable radio of reasonable quality with good batteries can be used to measure the distance at which the carrier current signal fades into the background. Measurements should be made at several locations around each carrier current system (or the perimeter of the campus), and recorded for the file. Naturally, if the measurements exceed the limitations, the offending transmitter or linear amplifier must be reduced in power as necessary. Changes in the carrier current system should be re-measured.

Ask for the LPB Carrier Current Compliance Form, with a compliance form (to fill out and keep on file) on the front, and instructions on the back.

- **Transmission Equipment**

Each LPB transmitter for carrier current service is tested and verified to be in compliance with the technical standards of Part 15, including the specified harmonic suppression up to the tenth harmonic. Thousands of LPB transmitters are in service under Part 15.

LPB transmitters are Type Accepted by the FCC for operation under the more stringent rules of Part 73, Radio Broadcast Service, and Part 90.242, Travelers' Information Stations, with the addition of required circuits. Hundreds of LPB transmitters currently operate in these services.

- **FCC Inspection**

The FCC has many other things to worry about, they have no interest in a carrier current operation if it does not create interference to licensed broadcasters. Good engineering is the key. The art and science of carrier current differs considerably from other forms of broadcasting. As long as a carrier current station is in compliance with the FCC Part 15 Rules listed above, in the highly unlikely event of an FCC inspection, the FCC Field Engineer will go away satisfied!

- **The Antenna**

So where do we put the antenna? There will be no usual form of antenna; it is not possible to comply with Part 15 that way.

As soon as the perimeter-of-the-campus Rule was released several suburban colleges jumped on what they saw as an opportunity to put up one antenna in the middle of the campus and cover all the residences. It won't work. Penn State and others conducted careful tests, and agreed. Consider the linear decrease of signal strength, for such a system would be working in the Radiation Field, consider the semi-shielding effect of the metal in each building, and you'll see why a single antenna won't work for any campus size.

3.0 UNDERSTANDING FIELD STRENGTH

- **The Radiation and Induction Fields**

An understanding of the nature of the field strength in the vicinity of our antenna (the power wiring) is the key to an appreciation of why and how carrier current broadcasting is successful. The Commission's choice of the distance 47,715/f meters (157,000/f feet) is logical, once understood.

A mathematical analysis of the signal strength produced by an antenna (Kraus, ANTENNAS, McGraw-Hill, 1950, ch. 5) shows 157,000/f as the distance at which the character of the field strength changes. From 157,000/f outwards is predominantly the Radiation Field (also known as the Far Field) of an antenna, wherein the signal strength decreases in direct proportion to increasing distance (1/r). All standard broadcasting and radio communications utilize the Radiation Field where the signal strength decreases linearly with distance in this manner.

In contrast, AM limited area broadcasting utilizes the Induction Field (or Near Field) which predominates from 157,000/f inwards to the antenna. In the Induction Field the signal strength increases as we approach the source at a third power of distance ($1/r^3$), i.e., the signal strength increases by $2^3 = 8$ each time we halve the distance to the source (r). Everything we deal with in this document is in the Induction Field.

- **The Induction Field at 540 kHz**

An example of what we would expect to measure at 540 kHz will dramatically show how the signal increases rapidly when moving towards the source from the 157,000/F point, which is 290 feet. The following tabulation portrays the utility of Induction Field broadcasting:

distance, in feet	field strength
290	15 µV/m
145	120 µV/m
73	960 µV/m
36	8,000 µV/m (or 8 mV/m)
18	61,000 µV/m (or 61 mV/m)
9	500,000 µV/m (or 500 mV/m)
4.5	4,000,000 µV/m (or 4 V/m)

A 500 mV/m signal will knock your socks off. It's complete receiver saturation, if not overload. Even a 5 mV/m signal is city-grade prime coverage for licensed AM broadcasters, and we have this or better at all points within about 40 feet of our source. If we can make use of the existing low voltage AC power wiring for an antenna, we should be able to provide a very strong signal to any radio in the building. Look around, it's difficult to get as far as 40 feet from the low voltage AC wiring. In addition, your receiver will probably be plugged into your AC power wiring antenna.

4.0 CARRIER CURRENT IMPLEMENTATION

Part 15 originated in 1938, to allow the operation of wireless phonograph oscillators in homes. Shortly thereafter students at Brown University started a campus radio station within the Part 15 Rules. Since then over a thousand schools in the US, and more recently also in Canada and Australia, have built carrier current radio stations to serve the specialized program interests of the student body.

Unlike Educational FM broadcasting, Part 15 has no restrictions against airing commercial advertising. Most carrier current college stations actively solicit local and national advertising accounts to offset their operating costs. Thus carrier current provides a realistic training ground for a career in commercial broadcasting.

4.1 The Economics of Coverage

Residence halls on the college campus can be covered by a carrier current broadcasting system with acceptable economics. The use of a separate transmitter and transmitter coupling unit in each residence hall can be economically feasible because a large number of residents will receive broadcast coverage in return for the equipment investment. Many campuses also include examples of uneconomical coverage because of a relatively small number of students, perhaps some fraternity and sorority houses, or small apartment buildings. Most colleges find it uneconomical to provide coverage of these except in unusual circumstances.

From this reference to a transmitter and transmitter coupling unit per residence hall, the reader might expect a large college to need a staggering number of transmitters. Our worst known case is Southern Methodist University in Dallas which once used 36 transmitters, each housed in a dorm or Greek house remote from the broadcast studio and fed audio via leased telephone lines. Now such a large number of transmitters is seldom necessary; there are ways described in the following by which two or more buildings can often be served from one transmitter. What is best and most economical depends on details of the particular campus buildings and layout.

4.2 Equipment Operation

Good sense suggests that transmitters be turned OFF during long inoperative periods, such as summer vacation. They should also be inspected on a scheduled basis, perhaps at the beginning of each semester. This is a minor maintenance burden. Solid state transmitters, pioneered by LPB in 1977, have proven outstandingly reliable. They are designed for unattended continuous operation, and, when properly installed, generally deliver flawless service for many years.

Be cautious of any claims of wondrous alternatives to low voltage carrier current. Many attempts at simplification, such as feeding RF into the high voltage lines, have repeatedly proven unsafe, impractical and unsatisfactory.

4.3 Professional Assistance

College carrier current stations have been a major user of Part 15 techniques for many years. Several transmitters may be needed in many applications, and routine maintenance of the equipment is necessary. Carrier current is a unique technology. Many colleges are unwilling to invest in outside engineering assistance having a background in this unique technology. They are willing to buy hardware (always from the lowest bidder!), but not willing to invest in its proper application and maintenance. The unfortunate direct result is that many college stations do not provide their listeners acceptable signal strength and/or quality. The erroneous presumption often follows that carrier current cannot provide good broadcast quality. This is true of an improperly designed or maintained system; however, LPB has proven to hundreds of colleges that a properly designed, installed and maintained carrier current system CAN and DOES provide listeners a signal which is easily the equal of any local commercial AM broadcaster. There are solid technical grounds for arguing that carrier current can sound BETTER.

4.4 AM Stereo

Carrier current broadcasting on your campus can be done in AM stereo. Recently the price of AM stereo generators has decreased, making it more attractive.

Motorola, and Delta Electronics, have always demonstrated their C-QUAM AM stereo systems at the National Association of Broadcasters National Conventions using LPB transmitters. Would they have chosen them if they didn't offer the best possible demonstration of their system? To be economically feasible (that again!) AM stereo carrier current does require a special approach to the transmission system design.

4.5 Other Applications

We have used the college application to make several points. The reader can readily generalize to other applications with the same characteristic of a concentrated special-interest listenership group. For example, a carrier current system on a military base differs little from a college campus. Many bases in the US and overseas operate carrier current stations. Carrier current stations are also found in hospitals, sports stadiums, convention halls, mental and penal institutions, mobile home parks, summer camps, apartment offices, office and legislative buildings, etc.

We have limited this Tech Note to a discussion of carrier current. There are, however, situations where low voltage AC wiring is not present, but where limited area broadcasting is desired. In such cases other types of wiring networks may also be used. For example, drive-in theater operators are plagued with ever-rising costs of maintaining post-mounted speakers.

An attractive alternate is the use of the existing buried audio wires as the antenna for a limited area AM transmitter. Patrons use their car radios, which afford much better sound quality. We installed hundreds of these when drive-in theaters were popular; they still are in southern California!

Continuing, there are many applications for limited area broadcasting where no network of suitable wires exists. Perhaps the drive-in theater is old and the speaker problem is complicated by broken underground audio wires. Rather than replace these, the owner may install a conductor, which is more suitable for broadcasting such as a buried leaky coaxial cable. Several of these cables have been devised to comply with Part 15. All employ some form of incomplete outer braid through which a small amount of radio signal can leak out along the length of the cable. They have been developed for applications where the standard AM car radio is the receiver.

4.6 100 mW Transmitters

A carrot-on-a-stick alternative in Part 15 we want you to know about is the 100 milliwatt rule. It allows a small AM transmitter of 100 milliwatts (0.1 watts) power input, with an antenna. Part 15 also requires the total length of the transmission line, antenna, and ground lead, shall not exceed 3 meters. A 3 meter (10 foot) antenna at AM broadcast frequencies, especially in the low end of the band, is incredibly inefficient. A conventional quarter-wave vertical antenna at 540 kHz is about 420 feet high. Granted, there are a few electrical games which can physically shorten this without serious loss of efficiency, but certainly not to 10 feet! A 100 mW system is attractively simple, but not for interior applications, even at the higher broadcast frequencies. Although they provide usable signal outside of buildings, they lack the field strength to penetrate them effectively.

LPB has done extensive work on 100 mW systems (LPB AM-2000). They do have some applications, but coverage of the college campus is not one of them. The 100 mW systems are a good choice for a commuter school, where the prime listener target is in the outdoor parking areas. Some applications may include Carrier Current for interior listeners and a 100mW system for outdoor coverage.

5.0 SELECTING A FREQUENCY

Part 15 requires that no interference be produced to the licensed services. Above we established the logic of choosing a locally unused frequency. There is no formula to predict the best frequency choice for your location and application. You will have to establish this for yourself, either by:

A) Actual listening tests, preferably repeated over a period of time, and particularly during night time to include the variable effects of sky wave signals from distant broadcasters, or,

B) Find out what has worked well for someone else in your immediate area. Don’t be afraid to copy success!

- **Frequencies Available**

The AM broadcast band in North America extends from 540 to 1700 kHz. Each 10 kHz multiple is a broadcast channel, totaling 127 channels, although many receivers will not tune the top end of the recently expanded AM band, from 1620 to 1700 kHz. 530 and 1610 kHz may be considered; receivers will tune these frequencies because Travelers’ Information Service (TIS) stations are found on 530 and 1610 kHz in some locations. In many foreign countries the channels are on 9 kHz spacing, making more channels available within their band. This was considered for adoption in the US, but has been rejected. Do not consider anything but on-channel operation. Intermediate frequencies (example: 645 kHz) will produce problems such as an annoying 5 kHz beat note and the inability of digital receivers to tune the station.

A good source of initial frequency choice possibilities is BROADCASTING AND CABLE MARKET PLACE (formerly BROADCASTING YEARBOOK), published by R. R. Bowker, 121 Chanlon Road, New Providence NJ 07974). Listings are included, by frequency, of US, Canadian, Mexican and Caribbean stations. For example, it shows that 540 kHz is not available in most of Florida because of WGTO with 50 kw on 540 kHz in Pine Hills (540 has not been a popular choice for limited area broadcasting).

- **Popular Choices**

The lower end of the AM band, below about 800 kHz, is the more likely place to find an available frequency. This 25% of the band has been 99% of LPB sales over the years. 640 kHz has been about 27% of our sales, making it by 3-to-1 the most used frequency. The popularity of 530 kHz is growing. Although 530 kHz is out-of-band, radios will tune it, including digital car radios, because of its assignment to local service TIS. The low adjacent, 520, will never have a broadcaster assigned. The only concern is avoiding a strong high adjacent on 540. There are only 17 broadcasters in the US on this frequency. (A Canadian station on 530 kHz has recently become operational!)

After initial selection of a frequency, look at the high and low first and second adjacent frequencies to see that there are no strong stations from which it would be difficult to find and identify your carrier current station. If considering 640 kHz, look at 650 and 660 as well as 630 and 620. WETS at East Tennessee State University in Johnson City should not consider 640 kHz because of WSM in Nashville, only 230 miles West, belting out 50 kw of country music on the first high adjacent, 650 kHz. WETS is on 610 kHz. For another example, Pace University’s Pleasantville campus, 25 miles North of NYC, would find tough going on 640 or 650 because of WNBC in New York City with 50 kw on 660 kHz. Pace’s WRPW manages well on 630 kHz.

- **Consider Your Harmonics**

Your harmonics are another consideration. Harmonics are multiples of the operating frequency, and are produced in all transmitters to an extent depending on design. For example, a New York City area school might consider 690 kHz, for BROADCASTING AND CABLE MARKET PLACE shows both high and low first adjacent channel clear of local broadcasters. However, the second harmonic, 1380 kHz, is the frequency of 5 kw WBNX in NYC. An NYC area school operating on 690 would probably wipe out reception of WBNX in their buildings. A limited area broadcaster with 60 dB of second harmonic suppression (second harmonic 1,000 times weaker than the carrier) meets Part 73 standards for licensed broadcast transmitters. LPB Transmitters meet this specification. In ¦ 1.3 we showed that it is possible to present a 1 to 10 V/m signal to a receiver in a carrier current system. In this situation the second harmonic would be 1,000 times weaker, at 1 to 10 mV/m which would make reception of WBNX impossible. This is another way a limited area broadcaster must protect the local licensed broadcasters.

- **Frequency Protection**

Stations become closely identified with their location on the dial. They have publications and jingles referencing their frequency. After years of quipping 64 on your dial, a new nearby station licensed on 640 kHz could suddenly appear and require you to change frequency. This happened in the greater Philadelphia area, where a construction permit was issued for 50 kw WWJZ on 640 kHz in nearby Mount Holly, NJ. In such an event, there is no alternative to moving to a new frequency, for the licensed broadcaster has the frequency protection. Part 15 requires that you cease operation immediately if you present the licensed broadcaster any interference. Interference to the licensed broadcaster created by the carrier current station would be interpreted as any difficulty in receiving the licensed station anywhere within or near its licensed 0.5 mV/m field strength contour.

6.0 Conclusion

This LPB Tech Note is a summary of what LPB personnel have learned about carrier current limited area AM broadcasting since we started building transmitters for college stations in 1960. At that time coupling into the AC power system was a nightmare, and station engineers were always running around changing transmitter tubes. We have seen and, we believe, helped the technology of carrier current grow into the reliable and effective means of broadcasting that it is today. Dozens of other interesting and related applications of this technology have grown from carrier current. We hope this information will assist you in understanding and implementing it. Call us at at LPB if we can be of help with your specific needs.

The following is a summary of the LPB Tech Notes currently available. They are available free of charge upon request:

Tech Note #1 CARRIER CURRENT BROADCASTING *(this one)*
Tech Note #2 CARRIER CURRENT SYSTEM DESIGN
Tech Note #3 PATCH PANEL WIRING AND SELECTION
Tech Note #4 ELECTRICAL CONNECTION OF A CARRIER CURRENT SYSTEM
Tech Note #6 UNLICENSED FM STEREO RADIATING (LEAKY) CABLE
Tech Note #7 CAMPUS RADIO Ñ AM OR FM?
Tech Note #8 AUDIO PROGRAM LINES
Tech Note #9 STUDIO EQUIPMENT CONSIDERATIONS
Tech Note #10 MUSIC LICENSING FOR COLLEGE RADIO