

Magnetic DC Leakage Fields From Cables

Anders Borgström takes a look at the effects of low frequency magnetic B-fields on an oscilloscope. Also a computer program that calculates the B-field from cables carrying currents is described. This is useful when estimating such fields in given electrical environments.

Electromagnetic disturbances from cables, motors, d.c.-d.c. converters, instruments, breakers, etc., is a subject that can be handled in different ways, depending on which type of problem that is to be solved. If, for example, the aim is to write a specification for procurement of system components intended to work in a system for military purposes, it may be appropriate to use the military standards MIL-STD 461-462.

These will give the requirements of susceptibility and emitted disturbance as well as the requirement for how to perform the tests. The aim is then to create a network where connected system components comply to each other with regards to disturbances, i.e. they should not affect each other in a negative way. This compatibility must also be present for the electromagnetic emitted disturbances in air.

For consumer products, in turn, the requirements on disturbance and susceptibility are different, most often less tight. There are different standards for the different countries, depending on where the product is to be sold. For example, a domestic appliance should neither deliver too much conducted disturbance to the mains network, nor should it disturb a closely located radio receiver. The manufacturer of the radio receiver can in his turn follow certain norms, combatting what kind of disturbance that may come in the air. After that, it is in his own interest to judge how much the buyer of the radio receiver will accept with regards to interference via the loudspeaker, before he decides to buy another type of radio.

Magnetic DC Fields

So far I have only mentioned relatively high frequency disturbances, they are often the most difficult ones to fight. In this article I want to highlight a special type of electromagnetic disturbance. One that is not so easy to find in issued standard specifications.

What it is all about is large magnetic fields ($>100\mu\text{T}$) with the frequency of 0 or just a few Hz. These can be found in areas containing electrical conductors carrying high levels of direct current. The magnetic fields can affect, in a negative way, closely located equipment. Examples of this can be seen by the distortion of pictures on an oscilloscope (c.r.t.) when changing of the content of magnetic storage medias (tape, discs, etc.).

The B-fields can also be created by intention, for example magnetising equipment, where you wish to give a ferromagnetic material an increased amount of magnetism, with help from current-carrying cables.

We will look at one of the mentioned examples more closely, that one concerning magnetic field effects on c.r.t.s.

It is worth mentioning that only the B-field is dealt with here, i.e. not the electrical E-field. The reason for this is the difference in difficulty to suppress disturbances from the fields respectively, using shielding. An E-field component of low frequency is rather easy to suppress with a shield of any conducting material. The only thing to keep in mind is to minimise openings in the shield. The size of these openings is related to the wavelength of the critical disturbance. The greater the wavelength, the larger openings required to let the disturbances through. The low frequencies give us long wavelengths for the electromagnetic waves which subsequently result in a small problem.

On the other hand, the magnetic field require

expensive magnetic material for shielding. It is therefore easier to handle this with other means, for example good cable-routing, enough separation, etc.

Going back to the effect from B-field on electron-beam drawn pictures, we know that the deflection of electron beams get extra components if they are located in a magnetic field. A simple test is to place a strong permanent magnet close to a computer screen. In the monochrome case this will create a movement of the picture, this movement will however be the same for the whole picture if the magnetic field is homogeneous, and no information will be lost. The colour screen which is based on several electron beams, will have a distortion of the colour as a result.

You can mostly live with the first case because of the fact that the pictures content is preserved. The colour screens suffer more though, since the colours are there to carry information. A change of the colours can result in a erroneous interpretation of the pictures.

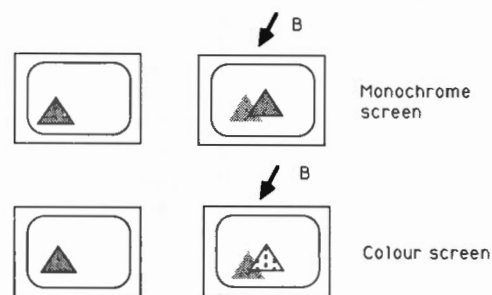


Fig. 1: B-field effects on monochrome and colour c.r.t.

The earth-magnetic field consists of one horizontal and one vertical component, varying depending on where on earth we are measuring. Provided that the screen is horizontally located, the vertical component is considered to be almost constant within large areas. The horizontal component will vary however, depending on the twisting of the screen.

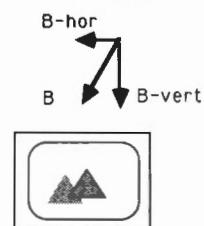


Fig. 2: Earth field related to a c.r.t.

The main problem to solve for a manufacturer of c.r.t.s will then be to suppress the horizontal component, since the vertical component can be compensated by the time of manufacturing or deliverance.

The earth field runs up to $60\mu\text{T}$. The largest vertical components are situated at the south and northern hemispheres (opposite directions), while we will find the largest horizontal by the equator (north direction). You can of course expect local variations caused by the different ground and seabottom conditions anywhere.

Consequently one should only consider other B-fields effects on c.r.t.s to be a problem, when they are increasing a level of approximately $10\mu\text{T}$ horizontally and a bit less in a vertical direction.

Theory

To illustrate the problem with c.r.t. distortion, let us look at the following picture:

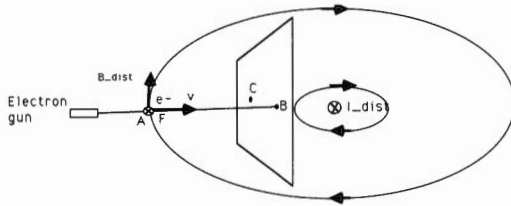


Fig. 3: Force from B-field on moving electron.

An electron in an electron-beam of a c.r.t. moves at point A with velocity v towards point B on the screen. In front of the screen there is a conductor carrying the direct current, I_{dist} . That generates a magnetic field that in A has the value B_{dist} and the direction straight up. On the electron this then acts as the force F , directed into the picture and with the value:

$$\mathbf{F} = -e * \mathbf{v} \times \mathbf{B}$$

where:

e = electron charge, '*' stands for ordinary multiplication and \times for vector multiplication. Vectors are shown in bold letters.

The energy of the electron then gets the acceleration it achieves due to the force F . Through integration we can then decide the size of the deflection on that electron when it reaches the screen, i.e. the distance between B and C. This gives us the distortion in the picture.

Computer Calculations

With the previous text as a background, we can now describe a program that can be useful when considering the disturbance rising from magnetic fields. The program calculates, from Biot Savarts rule, the total B-field in given critical points from given current carrying conductors.

The fields of application can among others be:

Cable routing.

Design of coils for magnetising equipment.

Design of compensation coils in c.r.t.s.

The conductors as well as the critical points, from which the B-field is to be calculated, are described in a perpendicular co-ordinate system. In the same co-ordinate system is the result delivered, the B-disturbance vectors.

The operators work consists of describing the conductors, the currents and the critical points in a file which will be read by the program.

Some of the trigonometrical and vectorial derivations described may be a bit comprehensive, but are easy to follow with some patience.

The Biot Savarts rule states:

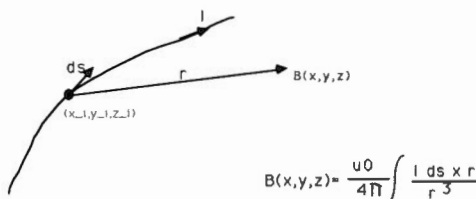


Fig. 4: Biot Savarts rule

Instead of performing an analytical integral calculation, an approximation is made by considering the conductor to be built up by straight segments. These segments can be sized arbitrarily, depending on the degree of accuracy wanted. The currents, breakpoints and B-fieldpoints are described in the infile. For every segment is calculated the vector product of $\mathbf{delta-s}$ and \mathbf{r} , as well as the \mathbf{B}_{RES} -vector resulting from this.

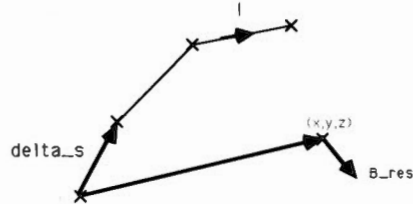


Fig. 5: B-field for approximated conductor.

After that, we sum the contribution from every segment in all conductors to all given B-fieldpoints.

The formulas needed to calculate the resulting field will shortly be derived. For this, we will only look at one conductor, Fig. 6.

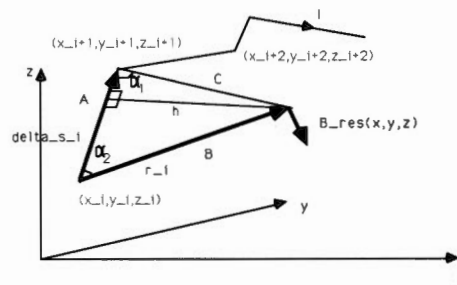


Fig. 6: Designations for conductor to be calculated.

$$A = \sqrt{((x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2 + (z_{i+1} - z_i)^2)}$$

$$B = \sqrt{((x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2)}$$

$$C = \sqrt{((x - x_{i+1})^2 + (y - y_{i+1})^2 + (z - z_{i+1})^2)}$$

$$h = c * \sqrt{1 - \cos^2(\alpha)}$$

Cosinusrule gives:

$$C^2 = B^2 + A^2 - 2 * A * B * \cos(\alpha_2); \cos(\alpha_2) = (B^2 + A^2 - C^2) / (2 * A * B)$$

$$B^2 = C^2 + A^2 - 2 * A * C * \cos(\alpha_1); \cos(\alpha_1) = (C^2 + A^2 - B^2) / (2 * A * C)$$

The value of \mathbf{B}_{RES} , which is not derived here is:

$$I \mathbf{B}_{RES} = \frac{\mu_0 I}{4 * \pi * h} * (\cos(\alpha_1) + \cos(\alpha_2))$$

The direction of \mathbf{B}_{RES} is given by $\mathbf{delta-s} \times \mathbf{r}$. This is a vector that can be calculated with help from the following formula:

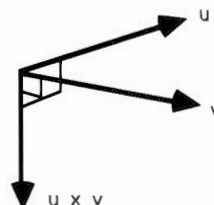


Fig. 7: Vector product

$u = (x_1, y_1, z_1)$
 $v = (x_2, y_2, z_2)$
 $uv = (y_1z_2 - z_1y_2, z_1x_2 - x_1z_2, x_1y_2 - y_1x_2)$
 Using the designations in Fig. 6, the direction of B_{RES} is the same as the vector $\Delta s_i \times r_i = (x_{i+1} - x_i, y_{i+1} - y_i, z_{i+1} - z_i) \times (x - x_i, y - y_i, z - z_i) = (s_x, s_y, s_z) \times (r_x, r_y, r_z) = (s_y r_z - s_z r_y, s_z r_x - s_x r_z, s_x r_y - s_y r_x) = (sr_x, sr_y, sr_z)$
 To make this a vector of length 1, we divide its components with the absolute value of the vector. We will then achieve the total expression of B_{RES} :

$$B_{RES} = \frac{\mu_0 I}{4 \pi h} * (\cos(\alpha_1) + \cos(\alpha_2)) * \frac{1}{\sqrt{(sr_x^2 + sr_y^2 + sr_z^2)}} (sr_x, sr_y, sr_z)$$

The expression gives the resulting field in point (x, y, z) from one segment Δs_i between the points (x_i, y_i, z_i) and $(x_{i+1}, y_{i+1}, z_{i+1})$, carrying the current I .
 The computer can now work and calculate the contribution to an arbitrary number of B-fieldpoints from an arbitrary number of conductors.

The program is developed out from the following figure:

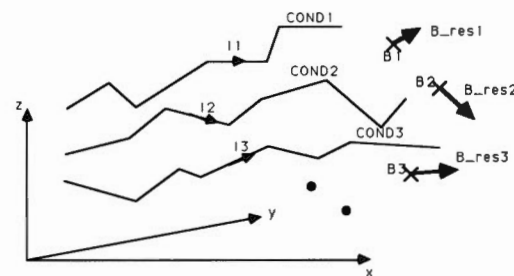


Fig. 8: Data to and from the program

The variables needed are:

NAME	TYPE	SIZE	DESCRIPTION
N_OF_COND	INTEGER	1	Number of conductors
I	REAL	50	Current in conductors
N_OF_SEGMENT	INTEGER	50	Number of segments in a conductor
BP	REAL	50x51x3	Breakpoints of the conductors
N_OF_B	INTEGER	1	Nr of fieldpoints
B_F	REAL	50x3	Fieldpoints
B_RES	REAL	50x3	Resulting field in fieldpoints
A,B,C,H	REAL	1x4	Triangles side and height
COSALFA1-2	REAL	1x2	Cos for angles in triangle
SX,SY,SZ	REAL	1x3	Coordinates for Δs_i
RX,RY,RZ	REAL	1x3	Coordinates for r_i
MY,MY0,PI	REAL	1x3	u, u_0, π
CONST, COSROOT	REAL	1	help constants
INFILE	FILE	8052	file describing the object

With this set of variables there is a capability to investigate up to 50 conductors, each consisting of 50

segments. This can of course be increased or decreased depending of computer capacity and need of calculation. As a comparison, I ran the program to calculate 99 B-fieldpoints from 798 conductors, each conductor consisting of between 6-12 segments. The calculation were performed on a VAX 780 and required approximately 1.2 minutes of CPU-time.

The program flow chart is shown in Fig. 9:

Format of the infile defining conductors, currents and fieldpoints is the following:
 NUMBER OF CONDUCTORS

```

CONDUCTOR 1:
CURRENT                               NR OF SEGMENTS
BREAKPOINT 1
BREAKPOINT 2
.
.
CONDUCTOR 2:
CURRENT                               NR OF SEGMENTS
BREAKPOINT 1
BREAKPOINT 2
.
.
NR OF FIELDPOINTS
FIELDPOINT 1
FIELDPOINT 2
.
  
```

Example of program run:

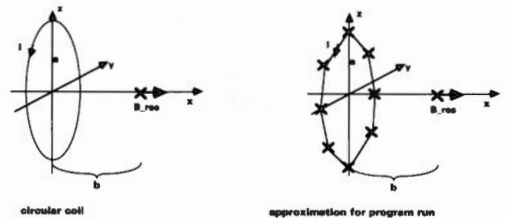


Fig. 10: Analytical and numerical calculation of field from circular coil

The theoretically calculated value of the B-field in the fieldpoint is given by the formula:

$$B_{res} = \frac{\mu_0}{2} I \frac{a^2}{(a^2 + b^2)^{1.5}}$$

With $a = 2.5m$, $b = 3.2m$ and $I = 12.7A$, we get the resulting field

B_{res} analytically calculated to **0.745 uT**.

Result from the program run:

A circular conductor approximated with 8 straight segments gives:

0.710uT.

A more accurate approximation requires smaller segments.

Space does not allow us to include the computer program listing in with the article. Readers who would like a copy of the program listing should write to;

Computer listing offer (magnetic)
PW Publishing,
The Quay,
Poole Dorset,
BH15 1PP
and enclose an A5 sized stamped s.a.e.

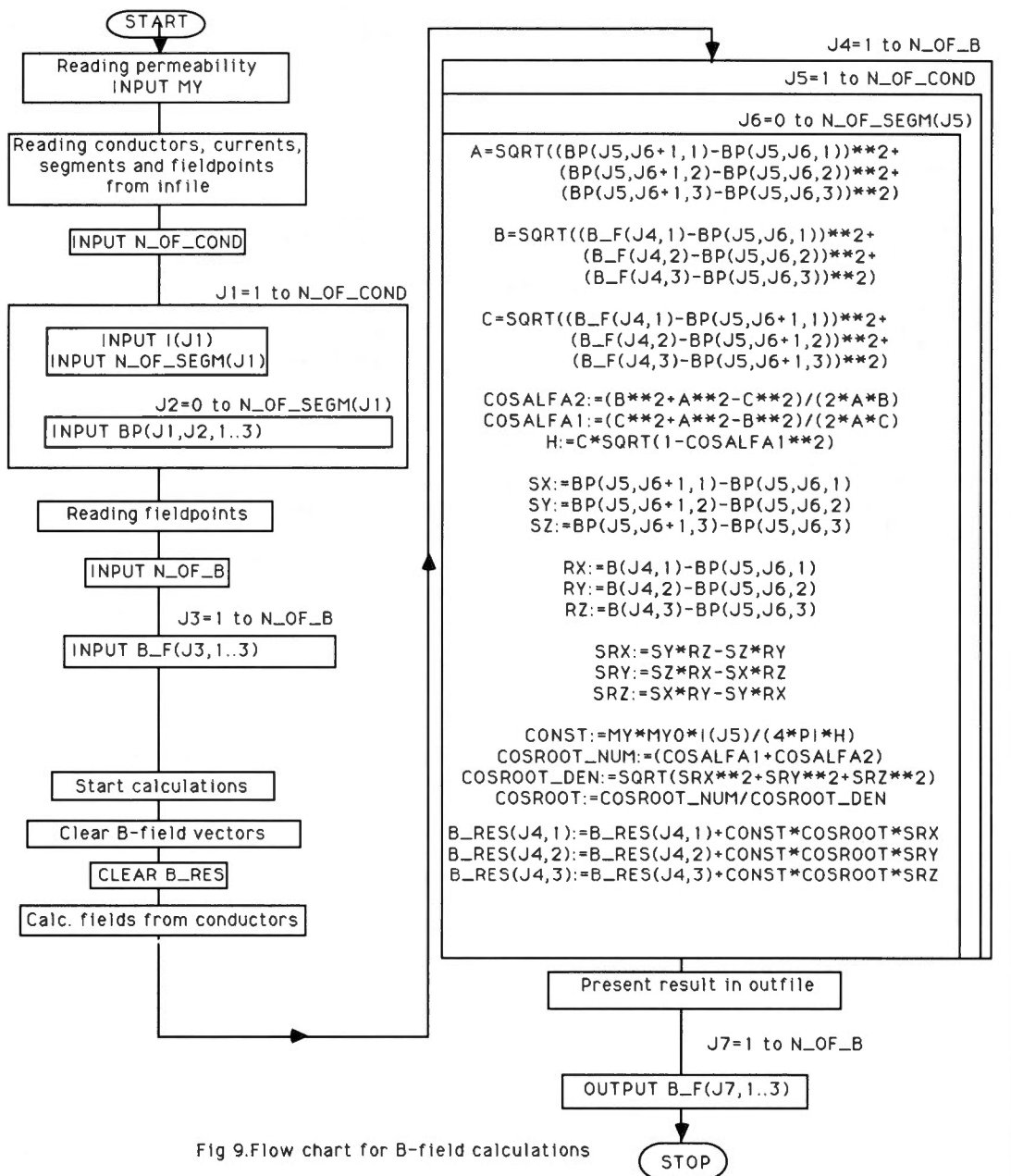


Fig 9. Flow chart for B-field calculations

Fig. 9: Flow chart for B-field calculations

Wanna Swap!

Have FT-790RII, NiCads, charger plus 3 x 5/8 collinear, little used, mint. Would exchange for h.f. linear or tribander/rotator or anything interesting for h.f./c.w. Arthur. Tel: Halifax 368021.

Have R1155, HR0, WS19. All need repair. Would exchange for any of - TCS TX, TCS RX, B46, B47, 5AH, R1475, BC348, TR101, Canadian WS19. Must be unmodified. Barker. 29 St Andrews Court, Benton, Newcastle upon Tyne NE7 7UT

Have G2DAF type h.f. linear amplifier 2 x 813 valves adn 1 spare. Power unit for 1800V h.t., weighs 50kg! amplifier weighs 15kg. Would exchange for BBC-B computer with DFS. G R B Wilson G3APV. Tel: (09467) 28449.

Have Redifon R408 commsRX, 13kHz-28MHz continuous & Trio TX599 custom special. Both good condition, both with manuals. Would exchange for 144MHz multimode. Tom. 42 Albert Road, Cleethorpes DN35 8LX. Tel: (0472) 602335.

Have Realistic PRO2004 scanner with discone, mast and coaxial cable. Would exchange for 144MHz transceiver or w.h.y? Tony GOMQG. Tel: (0603) 611764.

Have Eddystone 770R Mk2 v.h.f. receiver, range 19 to 160MHz in six bands, very large tuning dial (require space). Would exchange for mains airband

receiver, i.e. Hallicrafter or aircraft rx . F. Walker. Tel: (0221) 241088, Cambridge.

Have late '20s 4-valve 'portable' RX with built-in frame antenna and speaker, working well. Would exchange for h.f. receiver. Mann. Tel: (0223) 860150.

Have AOR2002, discone antenna and 1330MHz frequency counter and appropriate p.s.u.s and leads, second-hand value about £500. W.h.y?, cash adjustment considered. Tel: 961-748 9604.

Have Realistic PRO2004 scanner. Would exchange for good h.f. receiver. John. Tel: (0865) 774602 after 5pm.

Have ERA MkII Microreader. Would exchange for h.f. mobile equipment, w.h.y? Tel: (0283) 63667.

Have BBC computer and lots of extras, FT-902DM system, portable h.f. manpack, 40ft lattice mast, portable masts, Sony ICF-7600D, PK88, 4CX250Bs. Would exchange for PC1512/1640. Send s.a.e. for full list of bits. G4SOL, QTHR.

Have mains operated c.c.t.v. camera with video output. Would exchange for anything for an FT DX400 (i.e. outboard v.f.o.) or w.h.y. P. Mann Tel: 0572 812354 evenings.